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ASSESSMENT OF THE IMPACTS OF TRANSIT-ORIENTED DEVELOPMENT ON LIGHT RAIL TRANSIT: THE CASE OF ADDIS ABABA LIGHT TRANSIT

BY: **SAHLIT GIRMA SIYUM**

OCTOBER, 2024
EIABC, AAU
ADDIS ABABA, ETHIOPIA

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ASSESSMENT OF THE IMPACTS OF TRANSIT-ORIENTED DEVELOPMENT ON LIGHT RAIL TRANSIT: THE CASE OF ADDIS ABABA LIGHT TRANSIT

A Thesis Submitted to Ethiopian Institute of Architecture Building construction and city development to the school of graduate studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Masters of Science in Urban Planning.

By: Sahlit Girma Siyum

Advisor: Dr. Dipl-Ing. Berhanu Woldetensae (Associate Professor)

OCTOBER, 2024
EIABC, AAU
ADDIS ABABA, ETHIOPIA

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This Thesis is submitted to the Graduate Program Director of the Ethiopian Institute of Architecture Building construction and city development (EiABC), Addis Ababa University, in partial fulfillment of the requirements for the degree of Masters of Science in Urban Planning

Title of thesis: **Assessment of The Impacts of Transit-Oriented Development on Light Rail Transit: The Case of Addis Ababa Light Transit**

Author Sahlit Girma

Data October 2024

Approved by boards of examiners

Dipl-Ing. Berhanu Woldetensae (Associate Professor)		
Advisor	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date
Chairperson	Signature	Date

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Declaration

I hereby declare that the contents of the thesis, “Assessment of The Impacts of Transit-Oriented Development on Light Rail Transit: The Case of Addis Ababa Light Transit”, is the outcome of my original work and no part has been copied from any published source except proper citation and due acknowledgment has been made. I further declare that this work has not been submitted for the award of any other diploma/degree.

Author Sahlit Girma (GSR/4282/13)

Signature _____________

Date _________________

Certification

Certification Here with, we state that Sahlit Girma Siyum has carried out this research work on the topic entitled “Assessment of The Impacts of Transit-Oriented Development on Light Rail Transit: The Case of Addis Ababa Light Transit” under my supervision and it is sufficient for submission for defense.

Dr. Dipl-Ing. Berhanu Woldetensae (Associate Professor)

Signature _____________

Date _________________

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Acknowledgment

First and foremost, I would like to thank the almighty God for his unending blessings and gave me the health and strength to carry out this research. I would like to express my heartfelt gratitude to my advisor, Dr. Dipl-Ing. Berhanu Woldetensae (Associate Professor), for his invaluable guidance, brilliant constructive comments, expertise, and support throughout the course of this research.

I would like to extend my sincere appreciation to Addis Ababa University for sponsoring my master's degree and making this thesis possible. I would also like to express my gratitude to all the people and organizations especially the Addis Ababa Light Rail Transit office who supported me in providing useful data and materials required for the research. Finally, I have no words to express my warm feeling of appreciation and thanks to my family and friends for their lovely encouragement and support.

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Abstract

This research aims to probe the impact of transit-oriented development (TOD) on light rail transit efficiency at selected Addis Ababa Light Rail Transit (AALRT) stations (Ayat, CMC, Megenagna, and Mexico Stations). It studied the integration of transit-oriented development principle (density, diversity, design, and destination accessibility) into the AALRT, the impact of integrating TOD into AALRT on the ridership pattern or passengers flow, and a lesson from successful implementation of TOD on other cities. Both quantitative and qualitative research approach used to conduct this research. Likewise, both primary and secondary data source was used for this particular research. Observation and spatial analysis (GIS) used to generate the existing land use and road network map for the selected stations and the TOD principles were calculated using different formulas based on the existing land use and road network maps. Counting of sold tickets at peak hours, data from AALRT transport department, and structured interview was used to determine passengers flow at peak hours, average daily passengers, and passengers flow within the TOD influence zone respectively. Through a literature review, different cities' successful TOD implementation experiences were studied. Purposive and availability sampling were used to choose an AALRT station to study and to determine passenger flow at peak hours. Spatial multi-criteria analysis and SPSS were used to analyze the TOD index and the relation between the TOD index and passenger flow. The research found that Ayat station is with better integration of TOD and Mexico station is with least TOD integration or TOD index. With high TOD index at all selected station within 800-meters TOD influence zone, the research concluded that TOD principle is more integrated within the 800-meters TOD influence zone than within 400-meters TOD influence zone. The passenger flow both daily passenger and passengers flow at peak hours has direct relation with the TOD index. Ayat station has the highest passenger flow daily and at peak hours correspondingly highest TOD index value. The passenger flow at peak hours doesn't not affect by the distance to transit as the result demonstrate that majority of the trip is generated outside of the TOD influence zone. It shows that a dearth of affordable house within the TOD influence zone.

Key words: *Addis Ababa Light Rail Transit, Transit-oriented development principles, Passengers flow, TOD index, AALRT Efficiency*

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Acronyms

AALRT – Addis Ababa Light Rail Transit

BRT – Bus Rapid Transit

ERC – Ethiopian Rail Corporation

LRT – Light Rail Transit

NRN – National Rail Network

TOD – Transit-Oriented Development

SMCA – Spatial Multi-criteria Analysis

CHAPTER ONE

1. INTRODUCTION

The capital of Ethiopia and the diplomatic hub of Africa, Addis Ababa, has a history of growth that has shaped its current socio-spatial characteristics over the course of 130 years. It is the political capital and the most important commercial and cultural center of Ethiopia, and geographically located at the heart of the nation, 9º2'N latitude and 38º45'E longitude. As the diplomatic center of Africa, Addis Ababa hosts several international organizations, such as the headquarters of the African Union (AU) and the United Nations Economic Commission for Africa (UNECA)(Gezahegn Berhe et al., 2017).

Addis Ababa is strongly linked economically and through road infrastructure with other major urban centers of Ethiopia. It is also connected with Djibouti's port, through a railway, and to Nairobi, with a recently upgraded highway(Olievschi, 2013). Ethiopian Airlines, the national airline that links locations in Ethiopia and throughout the African continent, with its primary hub at Addis Ababa Bole International Airport, as well as connects Addis Ababa to Asia, Europe, and North and South America. It helps in stimulating of the economic with investment, tourism, and foreign trades. (Ethiopian Airports Enterprise, 2017; "Logistics Capacity Assessments (LCAs)," 2024). The city acts as the center for the transportation of products and services across the nation. From an estimated 15,000 residents in 1888, Addis Ababa's population increased to almost 3.6 million in 2020. The Central Statistical Agency projects that by 2036, the population will have surpassed 5 million (Ezana Haddis Weldeghebrael, 2021).

The railway network in Africa is inadequate and does not display a density similar to that in other regions. On a global scale, the railway infrastructure is an enormous network with more than 1 million km of tracks. The total length of the railway network in Africa is lower than the railway infrastructure in individual countries like Canada, Russia, India, China or the United States. One major factor contributing to the railways' current small market share in sub-Saharan Africa (SSA) is the network's inadequate length (Olievschi, 2013).

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1.1. Background Study

1.1.1 Addis Ababa urban context

Addis Ababa, the capital of Ethiopia, is home to the African Union (AU), the Economic Commission for Africa (ECA), and several other international institutions in addition to being the seat of government. Thus, the city assumes a symbolic importance both locally and globally (Kassahun and Bishu, n.d.). After the Italian conquest in 1935, formal urban planning techniques based on Western customs were used. Mahiteme claims that in 1938, the Italians made a bold effort to assist in creating a master plan for the City of Addis Ababa. But the Master Plan has never been put into action. After that, during the Dergue government, the first official master plan was created in 1978 (Tufa, 2008). From 1986 to 2006, this master plan was in effect (Mahiteme, 2007). One of the main planning exercises in the master plan was zoning. As a result, the city was zoned based on the functional specialization of each area (Tufa, 2008).

After the regime change in 1991, the City of Addis Ababa witnessed major changes, in terms of its size and demographics, its finance and economic structure, and its physical and spatial organization. The city's economy has been increasing by double digits, additional infrastructure and housing construction have been implemented, the population has increased by more than 80%, the total built-up area has increased by at least 25%, and a healthy private sector has flourished. Reorganizing the spatial organization and productivity of economic activities has been influenced by the construction of large residential housing projects by private real estate developers, the proliferation of commercial high-rise buildings, and condominium housing across more than a hundred city sites(Addis Ababa City Road and Transport Bureau, 2016).

1.1.2 Urbanization

The City of Addis Ababa is home to 4,030,000 inhabitants (Ethiopia Statistics Service [ESA], 2024). Addis Ababa is the only city in the country that accounts for 100% urban population followed by Dire Dawa (68%) urban population and the Harari National Regional State which accounts for 58% urban population (MOUDHC, 2015 p. 4). The country's level of urbanization has been constantly growing from 6% in 1960, 11.4% in 1984, and 13.7% in 1994, and moving forward the country has been projected to have an urbanization level of 19.4% in 2014 (MUDHC, 2015, p. 14). By 2030 the it is estimated to reach an urbanization level of 30%(Kassahun and Bishu, n.d.).

The urban population growth rate is projected to increase significantly because of the transformation of the national economic strategy from an agriculture-based into an industry-based economy (MUDHC, 2015, p. 7;(Nallet C, 2018)). The fast-growing urban population and urbanization trends in the country continue to pose significant economic, social, and physical challenges to the population. With fast growing urbanization trend, which is partly generated by rural-urban migration, is exacerbating housing shortage, basic urban infrastructure (social and physical infrastructure), unemployment, and others(Kassahun and Bishu, n.d.).

1.1.3 Housing

An official report by the Ministry of Urban Development, Housing and Construction (2015) indicates that 20% of the country's population lives in urban areas, and of this 20% of urban residents 60% are estimated to live in slum dwellings with below standard housing conditions and deteriorated environments in the absent of basic service infrastructure. Un-Habitat (2011b) argues that the absence of appropriate land and housing policy in the City of Addis Ababa has given way to massive urban slums and informal settlements in the City of Addis Ababa.

According to the 2007 census, Kebele houses account for 24% of the housing stock in Addis Ababa. In inner city areas, kebele houses often form more than 70% of dwellings. The Integrated Housing Development Program (IHDP) introduced in 2005, aims to provide affordable housing for the low- and medium-income earning section of the society. The government builds and transfers multistory condominium apartments to the public through this program. The condominiums are built in small and large sizes as infill in small groups of blocks on available vacant land; as large neighborhoods on open land in expansion areas of the city and more recently as urban renewal projects by clearing inner city old neighborhoods. Kebele houses and other low-quality houses are becoming reduced as a result of inner-city renewal initiatives. Housing in Addis Ababa is also characterized by a widening gap between supply and demand. In 2004 400,000 non-home owners officially registered to be included in the government condominium housing program, this number increased to 1,000,000 in 2012. However, the IHDP has only managed to deliver less than 200,000 units in Addis Ababa since its launch in 2005. (Gezahegn Berhe et al., 2017). According to the 2017 Addis Ababa city master plan, there is a 1.2-million-unit backlog for housing.

1.1.4 Urban finance

Addis Ababa is one of the two self-ruled cities in the country along with Dire Dawa. These two cities have the autonomy to "select a rate appropriate for their circumstances and to introduce a new tax base -full autonomy" (World Bank and City Alliance, 2010, p. 196). The city of Addis Ababa's financial revenue is gathered in several ways. According to a World Bank and City

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Alliance report, the city's income comes from "own tax and non-tax revenue, foreign grants, road fund, federal ministries support directly to the respective sectors in the city and off-budget sources like NGOs."(2010).

1.1.5 Addis Ababa Light Rail Transit

The Addis Ababa Light Rail Transit (AALRT) project is a modern transportation system designed to improve mass transit transportation and reduce congestion in Ethiopia's capital. The project was launched by the Ministry of Transportation in 2008 and received 85 percent of its funding from a loan from the Export-Import Bank of China. It is Sub-Saharan Africa's only light rail system outside of South Africa(World Bank Group, 2017).

The AALRT has a total length of 34.25 km (North-South line 16.9 km and East-West line 17.35 km). The two lines (North-South and East-West lines) use common track of about 2.7 km(Yehualaeshet Jemere, 2012). The AALRT's design capacity at the fully operational level is 60,000 passengers per hour through two lines connecting the city on a north-south and east-west axis(World Bank Group, 2017; Yehualaeshet Jemere, 2012). According the data obtained from Addis Ababa light rail transit transport department (OCC), the actual performance of the AALRT is below the design capacity. Figure 1.1 shows the average daily passenger for six consecutive months (September 2023 – February 2024) through the two lines. The Figure shows that the average daily passenger each month is below 12,000 through the two lines, 13.3% of the designed capacity per hour.

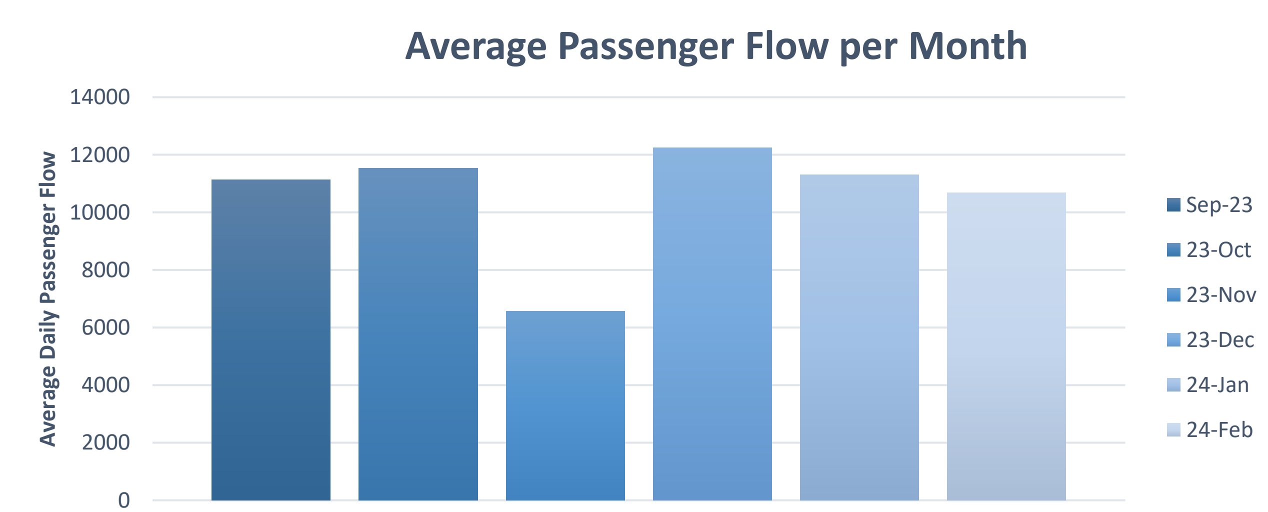

Figure 1.1 Average passenger Flow per month (from September 2023 – February 2024)

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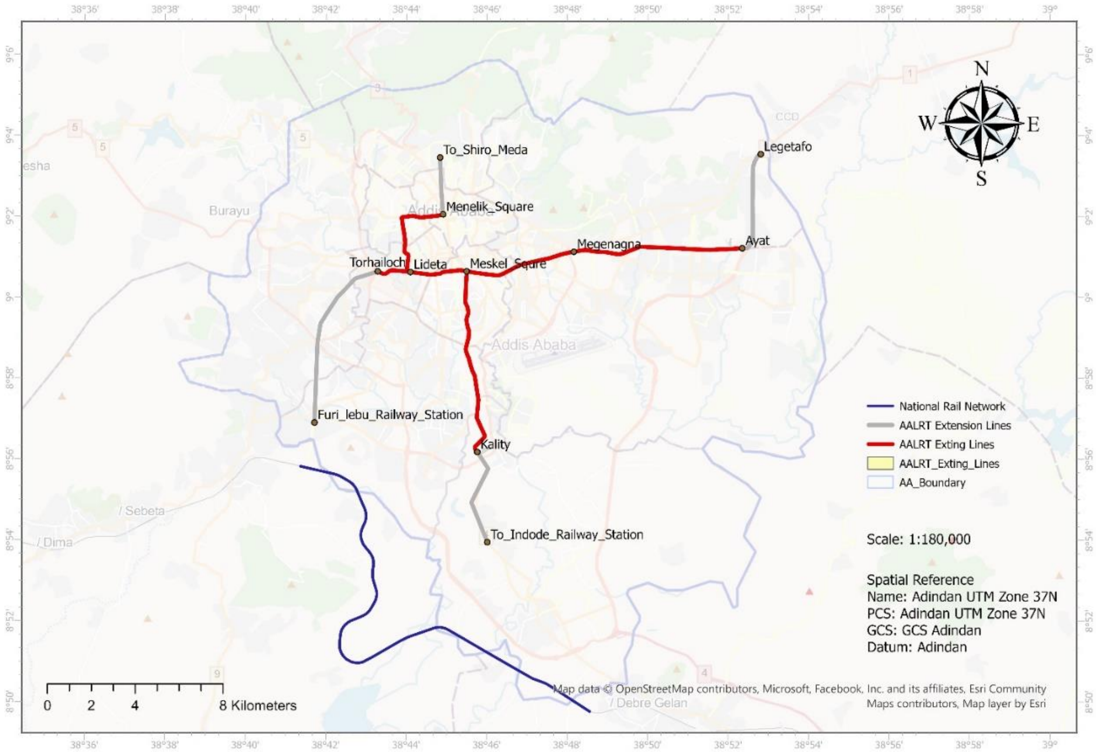

Figure 1.2 AALRT Lines Alignment with Extension

Source: (Yehualaeshet Jemere, 2012b)

1.2. Statement of the Problem

There is diverse research on Addis Ababa light rail transit mostly on the E-W line; some of these researches focused on how Addis Ababa light rail transit affects mobility in terms of traffic congestion at grade intersections and pedestrian mobility (Azmeraw, 2015; Tekletsadik, 2015). Other research focused on customer satisfaction with Addis Ababa light rail transit and service quality from riders' perspective (Debebe and Asteray, 2022a; Obsie et al., 2020). The relation between land value and light rail transit and the impact of Addis Ababa light rail transit on adjacent communities' economies was also studied (Deyas, 2019; Wubet, 2018). Despite the research mentioned above, there is a research gap in the study of the relationship between transit-oriented development and Addis Ababa light rail transit ridership.

According to Wondimu Tekolla et al. (2021) and a data from Addis Ababa light rail transit transport department (OCC) the efficiency level of AALRT is decreasing annually. The study of Wondimu Tekolla et al. (2021) indicated the modal share of AALRT in public transport is 6% which shows

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that it is working under 20% compared to its designed capacity which is 60,000 passengers per hour through the two line. The number of passengers at both LRT lines (East–West and North-South) is much lower than anticipated. The number of yearly passengers is unceasingly diminished on the contrary yearly trip cancellation is increasing.

As determined by Wondimu Tekolla et al. (2021) the number of passengers at starting stations is higher than the other stations because of the development around those stations is mostly high-density residential development. Based on this, the research indicate that transit-oriented development would help to increase transit ridership (Wondimu Tekolla et al., 2021).

Despite there are numerous reasons for the lack of efficiency of Addis Ababa LRT; lack of necessary operating skill and sufficient financial support, blackouts and driver inexperience, a

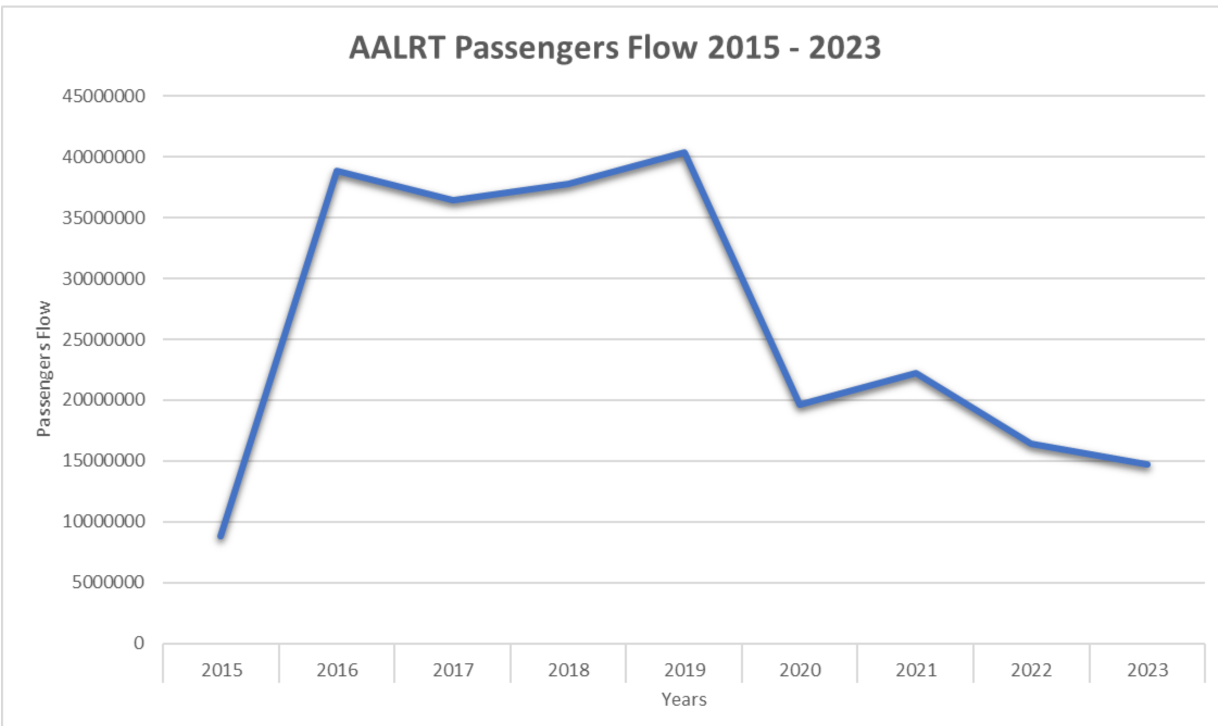

Figure 1.3 Passenger Flow

Source: Addis Ababa Light Rail Transit Transport department

lack of spare parts, absence of passenger information system (PIS) and service quality(Obsie et al., 2020; Wondimu Tekolla et al., 2021a), but the impact of transit-oriented development on the efficiency of AALRT hasn't been studied so far. Teklemariam and Shen (2020) studied transit-oriented development levels along the AALRT east–west line but failed to study the relationship between the transit-oriented development and Addis Ababa light rail transit ridership.

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Global researches studied the relation between transit-oriented development and light rail transit; Arrington and Brinckerhoff (2003) discussed how transit-oriented development enhance LRT projects viability, add rider to the system, and increase property value by increasing population density and mixed land use in areas surrounding transportation hubs, correspondingly Guo et al. (2018) mentioned TOD plan has increased the ridership and modal share of public transport in several America cities.

In sum, since there is a lack of research on the relation between transit-oriented development (TOD) and Addis Ababa light rail transit (AALRT) efficiency, this research will be carried out to bridge this gap. Few researchers tried to study AALRT focusing on the efficiency of the AALRT and Transit-oriented development along the AALRT, on the other hand, this research attempted to examine the relationship between transit-oriented development (TOD) and light rail transit (LRT) (Teklemariam and Shen, 2020; Wondimu Tekolla et al., 2021). However, more studies and research need to be conducted to have sustainable urban development. Furthermore, the research will recommend strategies to enhance transit-oriented development around Addis Ababa light rail transit stations and concurrently enhance AALRT ridership.

1.3. Objective

1.3.1 General objective

To Assess and study the impacts of transit-oriented development on light rail transit efficiency and ridership: The case of Addis Ababa light rail transit.

1.3.2 Specific objective

- To study to what extent transit-oriented development (TOD principles) is implemented or integrated with Addis Ababa light rail transit;
- To study the impact of transit-oriented development (TOD) on the usage of Addis Ababa light rail transit (AALRT) and ridership patterns;
- To study and take lesson from successful TOD implementation in other cities that can be implement to Addis Ababa light rail transit;

1.4. Research Question

1. To what extent TOD or TOD principles are implemented or integrated with Addis Ababa light rail transit?
2. How does TOD in Addis Ababa influence the ridership patterns and usage of the Addis Ababa LRT?

3. What lessons can be learned for the Addis Ababa light rail transit from successful TOD implementation in other cities?

1.5. Scope and Limitation of the Study

For this research, from the existing two AALRT lines, the east–west line was selected. This LRT line was chosen based on the following criteria: has more city centers on the line main center, Tertiary center (Megenagna and Ayer tena and Jemo on future expansion of the LRT) and Secondary center (Meri) relative to the other line, and has high-density residential development along the stations makes it preferable for this study. The research only focused on the E-W line of AALRT and the N-S line is not included. It is only on four selected AALRT stations (Ayat, CMC, Megenagna, and Mexico) along the E-W line.

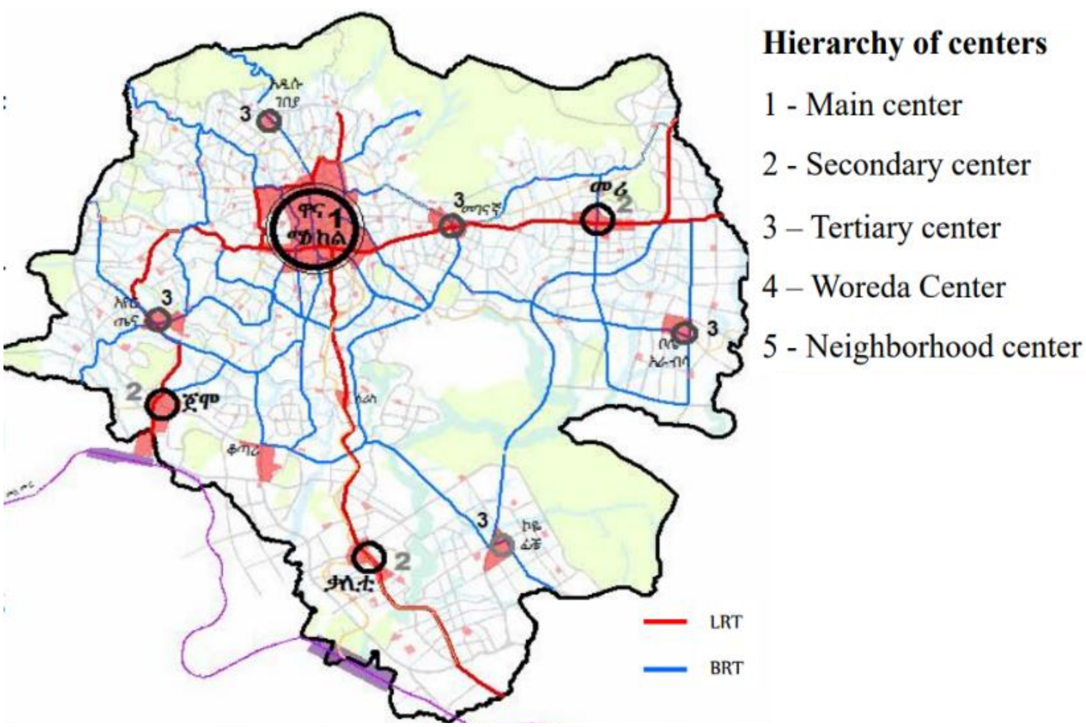

Figure 1.3 Addis Ababa City Centers

1.6. Limitation of the study

In this research, the relation between the disembarking passengers and commerce density or other trips attracting land use within the TOD influence zone of the selected stations was not studied and covered.

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1.7. Significance of the Study

As the political and economic center of Ethiopia, Addis Ababa should have a transportation and urban development plan that can mitigate the existing challenges. One of the ways is to integrate public mass transportation into a land use plan. From the launching day of the AALRT, the LRT can’t operate or be as efficient as anticipated. This research will help to identify the relationship between light rail transit and transit-oriented development, to identify the transit-oriented development level around the designated stations, and to understand how transit-oriented development around those stations will affect the efficiency of the LRT in case of transit ridership. In sum, the research will help policymakers and urban planners to develop efficient transportation plan in the aspect of public mass transportation.

1.8. Organization of the research

This research is organized in five chapters; the first chapter is the introduction part and the second chapter covers related literature review includes both theoretical and empirical reviews. The third chapter is the research methodology, The first section discusses case study of Addis Ababa in the aspect of urban context, urbanization, housing, implementation, challenges and opportunities of Addis Ababa light rail transit and challenges and opportunities of TOD in Addis Ababa. The second section of the third chapter discusses the research design, data collection and analysis methods. The fourth chapter presents the result and findings of the research and discussion of the research result comparing with previous researches finding and results. The fifth and final chapter is the conclusion and recommendation of the research.

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CHAPTER TWO

2. LITERATURE REVIEW

In this section, the review of the theoretical and empirical literature (journal, article, and books) and international case studies that are vital for this particular research is provided. It includes indicators, principles, and characteristics of transit-oriented development (TOD), how to measure TOD, previous studies on the relation between transit-oriented development and light rail transit (LRT), case studies of successful TOD implementation in different cities, and challenges and opportunities of TOD.

2.1. Theoretical Literature Review

2.1.1 Transit-Oriented Development

This sub section provides transit-oriented development (TOD) origin, principles, characteristics, and measurement methods.

2.1.1.1 What Is Transit Oriented Development (TOD)

The American architect Peter Calthorpe was the first to propose transit-oriented development/design (TOD). His original definition of TOD encouraged mixed-use development that was near a transit stop and a commercial district (Qi, 2017). Akinori Morimoto defines TOD as urban development that prioritizes public transportation over excessive dependence on personal vehicles(Akinori Morimoto, n.d.).

TOD is typically defined as an approach to transportation and land use planning that "...makes walking, cycling, and transit use convenient and desirable, and that maximizes the efficiency of existing public transit services" by concentrating development around public transit stations, stops, and exchanges.(Hrelja et al., 2020).

The term "Transit Oriented Development" (TOD) refers to the construction of concentrated, moderate-to-high density mixed land use that includes housing, employment, retail, and recreational nodes that are connected with feeder, transit, bicycle, and pedestrian networks within five to ten minutes' walking distance of mass transit stations (BMRCL, 2018).

TOD can also produce a variety of other local and regional benefits by encouraging walkable compact and **infill development**(Arrington and Brinckerhoff, 2003). It is a type of development that mostly takes place at public transportation hubs to increasing construction density and public

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transportation patronage.It is more conducive to walking, cycling, and public transportation.(Hrelja et al., 2020).

Numerous researchers (Cervero and Kockelman; Ewing and Cervero …) defined transit-oriented development relating to the 'Ds' concept density, diversity, design, distance to transit, and destination accessibility.

Density refers to having a high number of units per hectare compared to typical development densities; Design refers to creating attractive and efficient urban design and street layout that encourage walking, cycling, and public transportation; Diversity refers to having a high mix of users in a development(Hrelja et al., 2020). Distance to transit shows that the distance between home and a station or the workplace and a station plays a significant role in generating high transit ridership. Destination accessibility in which the transit station should be well connected to popular destinations, such as retail shops, movie theatres, restaurants, and activity centers(Qi, 2017).

Similar methodology can be found in Kamruzzaman et al. (2014), whose framework for calculating the level of TOD comprises the following: land use mix, intersection density, cul-de-sac density, net residential density, net employment density, and public transportation accessibility level(Hrelja et al., 2020).

To reduce the demand for transportation, TOD, as a planning and development concept initially, aims to enhance the modal shares of public transportation, cycling, and walking at the expense of driving. Second, TOD aims to produce more highly desirable, livable neighborhoods. Thirdly, TOD is recognized as a tool or even a driver of economic development (Hrelja et al., 2020).

The main objectives of TOD are encouraging transit use, improving housing opportunities, promoting walking and cycling, and facilitating neighborhood revitalization (Lund, 2006). Urban sustainability, a decrease in car-dependent expansion, well-planned and designed neighborhoods, more accessible public transit with the convenience of walking and bicycling, and a reduction in auto use, obesity, and other detrimental health effects are all benefits of TOD(Uddin et al., 2023).

2.1.1.2 TOD Typology

Peter Carlthorpe (1993) has identified two types of TODS **urban TOD** and **neighborhood TOD**. Along subway, LRT, or BRT lines, which offer increased commercial land uses, high-density job prospects, and medium-density residential land uses, is where urban TOD is typically initiated. It

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should take less than 10 minutes to get to one of the closest rail transit stations or BRT stations from the center of the "neighborhood TOD," which should be supported by bus stops.

TOD provides transit options such as subways, LRT, or BRT for residents to use to travel outside of the TOD. Within the TOD, the compact urban form, mixed land uses, and pedestrian-friendly environment encourage residents to walk or bike to different destinations(Qi, 2017).

2.1.1.3 TOD Indicators

A quantitative indicator that is frequently employed is the **walking distance to a station** (or distance to transit), but the distance differs between researchers. According to Ginn (2009), TOD is restricted to an area 400–600 meters (m) from a public transportation hub. According to Calthorpe (1993), TOD refers to popular places that are less than 600 meters (2000 feet) from a station (Hrelja et al., 2020). If the station spacing is around one kilometer, the National Transit Oriented Development (TOD) policy specifies the influence zone of TOD as 500-800m(Uddin et al., 2023).

The pedestrian shed ratio, developed by Vale (2015), is a term that is described as the percentage of walkable territory inside a 700-m buffer from a station. According to Bolleter and Ramalho (2020), TOD zones are places that are 800 meters and ten minutes walk from a public transportation hub (Hrelja et al., 2020). Based on their research including bicycle access, could increase the geographical catchment areas of public transport stations in the range of 1,6 km up to 10 km. According to Uddin et al. The National Transit Oriented Development (TOD) Policy defines the influence zone of TOD as 500–800 m if the station spacing is approximately 1 km(Uddin et al., 2023).

Density is another indicator frequently used to define TOD areas. According to Calthorpe (1993), a lower threshold of 25–62 units per hectare should be maintained for residential zones outside of the principal areas. Using floor-area ratio (FAR), Cervero and Dai (2014) promote "the wedding cake style" of planning, which places densely populated areas close to stations and gradually lowers the heights of buildings as they get farther from BRT lanes (Hrelja et al., 2020). Population, commercial, employment, job, and business density are the performance measurements that are used in previous research to study the density of the study area(Huang et al., 2018; Khare et al., 2021; Uddin et al., 2023).

Diversity is also another TOD indicator: The objective of land use diversity (LUD) is to assess the variety of land use within a given area and their geographic distribution(SINGH Ph.D. Scholar

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et al., 2015). According to Cervero (1991), areas with a diversify land uses had a higher transit share. The use of single-occupancy automobiles, public transportation, and active modes of transportation (walking), according to Frank and Pivo (1994), is influenced by mixed land use and density (Bordoloi et al., 2013).

According to Khare et al. (2021), LUD was measured with the widely used “entropy” concept. High land use diversity is indicated by a high value of entropy index. Beside Khare et al., Huang et al., 2018, Cervero and Kockelman,1997, and Uddin et al., 2023 used the entropy index to study LUD.

Cervero and Kockelman (1997) also mentioned entropy and the dissimilarity index utilized to quantify the land use diversity. The most generally used and accepted index for calculating the diversity of land uses is the entropy index. In general entropy measures the homogeneity of land use in a certain area, and the dissimilarity between grid cells was calculated using the dissimilarity index (Kockelman, 1997).

Shannon entropy is the most effective method of expressing land with three or more uses, according to Song et al. (2013), who conducted a simulation and comparison of the characteristics of various land use diversity indexes. As a result, the Shannon entropy-based index has emerged as the most prominent and widely used technique for determining the diversity of different land uses in urban areas (Chen and Song, n.d.). For instance, Shannon entropy is used in the "6Ds" study framework within the "diversity" concept measure, which has been used in numerous studies in the transportation sector (Ewing & Cevero, 2010).

The Shannon entropy-based land use mix index, however, has been under increasing scrutiny in recent years due to several serious flaws that seriously impair the construct validity of the index (Im & Choi, 2018; Hess, 2001; Manaugh & Kreider, 2013). The Shannon entropy-based land use mix index may not effectively evaluate the vision that the land use mix idea was intended to offer, as suggested by Jacob’s research using it.

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The modifiable areal unit problem (MAUP) refers to study results being influenced by both the shape and scale of the measure aggregation unit, which means that the CSE index calculated at the census block level would be highly different from that calculated at the neighborhood or county level(Chen and Song, n.d.).

Figure 2.1 Land Use Diversity at different Scale

By (1) adding geographical weight (GW) to the entropy equation, (2) adding GW and regional structural weight (RSW), and (3) using cluster methods to summarize the land use mix pattern based on GW modified land use data from alternative, Chen Y and Song Y propose three improved alternatives to the index. They discovered that the validity problems with the CSE measure for land use mix can all be fixed by the GW, RSW, and clustering multi-measure approaches. They concluded that for different projects or influence subjects, the “best” land use composition varies(Chen and Song, n.d.).

Destination accessibility: also known as land use mixedness (LUM) is considers the accessibility of nearby destinations. With enough neighboring mixed-use development, trip destinations, including business and recreational ones, are easily accessible on foot(Uddin et al., 2023). The advantages of mixed usage would shorten trip distances from a transportation perspective by bringing various sites of origin and destination closer to one another (Chen and Song, n.d.).

According to Cervero, adequately mixing residential land use with other land use encouraged people to walk or cycle to do their daily activities. Zhang and Guindon use the following Equation to calculate the land use mixedness:

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$$MI(i) = \frac{\sum_j L_o}{\sum_j L_r + L_o}$$

MI - land use mixedness, Lo - non-residential land use for each TSC j, Lr - residential land use for each TSC j. MI values may range from 0 to 1, MI value of 0.5 suggesting a 50/50 split between residential and non-residential land uses.

Design is one of the 5D indicators of TOD; different measurement variables are used in numerous research. The total length of pedestrian and bicycle lanes (Length of walkable/cyclable paths (LWC).), walkable path, intersection density, Parking utilization (PU), and Open/Green spaces(Huang et al., 2018; Khare et al., 2021; Uddin et al., 2023).

The total length of pedestrian and bicycle lanes/ Length of walkable/cyclable paths is a measure that reflects the length of accessible roads for non-motorized transport and the number of pedestrian, and cycle-accessible roads near each transit station results in determines walkable areas. **Intersection density (**ID**)** measures walkability and the street connectivity of the road network of each station area. The number of junctions per km^2 from the road network data is used to calculate the ID. For cyclists and pedestrians, more intersections are beneficial because the routes become shorter in terms of travel time (Ewing & Cervero, 2001).

According to Renne, there are ten indicators to evaluate TOD: transit ridership, density, quality of streetscape, quantity of mixed-use structure, pedestrian safety, increase in property value, increase in tax revenue, public perception, number of mode connections at transit stations, and parking (Renne, 2005). However, as discussed in the above paragraph most research used the 5D concept as the indicator of transit-oriented development.

2.1.1.4 Transit Oriented Development (TOD) VS Transit Adjacent Development (TAD)

TAD can be characterized as a development that lacks functional connectedness to the public transportation system. According to Cervero et al. (2002) and Hale (2014), TAD stands for different development types near stations, but with only a limited amount of integration between land use and transportation planning (Hrelja et al., 2020). It can be defined broadly as development in close proximity to transit, generally within one-quarter mile. TAD is development close to transit, but not oriented to transit(Arrington and Brinckerhoff, 2003).

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TOD is also closely linked to current planning ideals such as Smart growth and new urbanism (Knowles, 2012). A core idea in such ideas about urban planning is to develop walkable and livable settlements(Hrelja et al., 2020).

Calthorpe (1993) proposed that TOD should rest on the principles of a primary area (primary area includes a residential zone with high densities close to stations and then a successive decrease in densities towards the perimeter of the primary area) in the immediate proximity of the station where major commercial and employment areas should be located. Cervero and Dai (2014) also express similar ideas about vertical mixing of uses within buildings(Hrelja et al., 2020).

While a TAD is "physically near transit which fails to capitalize upon this proximity, lacks any functional connectivity to transit - whether in terms of land-use composition, means of station access, or site design," a TOD is a station-area precinct that is compact, mixed-use, and facilitates transit connectivity through urban design, according to Cervero et al. (2002) (Renne, 2009).

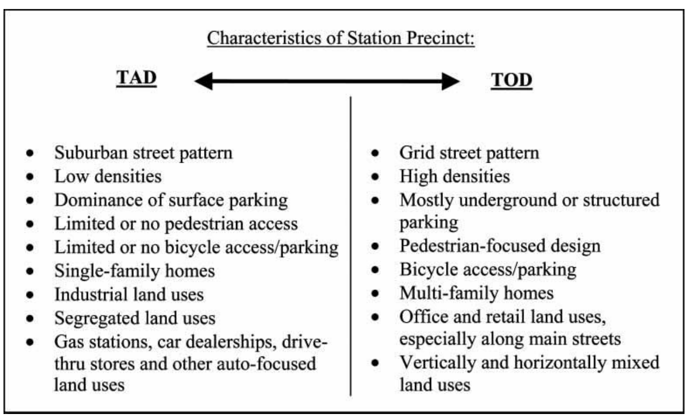

Figure 2.2 Characteristics of TAD and TOD

Source: Renne, 2009

2.1.1.5 Characteristics of Transit-Oriented Development

Studying the impacts of transit-oriented development (TOD), decompose TOD impacts into separate components which are segregated into two categories of TOD-generated amenities and TOD-generated dis-amenities (Wang, 2016).

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TOD-generated amenities contain three major components: transit accessibility effects, pedestrian-friendly network effects, and mixed-use effects. TOD-generated dis-amenities such as traffic congestion, noise, and air pollution, would likely reduce property values(Wang, 2016).

TOD draws on many of the same planning and development **principles** embraced by New Urbanism, Smart Growth, and the Livable Communities Movement(Arrington and Brinckerhoff, 2003: 90):

- Moderate to high density development in relation to the existing pattern of development;
- A mix of land uses, horizontally or vertically;
- Compact pedestrian-oriented design and streetscapes;
- Building design and orientation to street which allows easy pedestrian and transit access;
- A fine-grained connected street pattern without cul-de-sacs; and
- A system of parks and open spaces.

According to Uddin et al. (2023) the TOD **principles** include:

- Mixed and dense land use
- Accessibility
- Walking and amenities
- Compact development with pedestrian-friendly design

2.1.1.6 TOD index measurement

Singh et al. (2014) suggested the actual TOD index and the potential TOD index as two indices for measuring TOD. The actual TOD index, by definition, assesses the amount of TOD that is currently present in close proximity to transportation facilities, more specifically within 800 meters of the station's buffer. On the other hand, the prospective TOD index assesses accessibility at the regional level.

Spatial muti-criteria analysis (SMCA) has been used to calculate the TOD index in numerous researches(Khare et al., 2021; Singh et al., 2015; Uddin et al., 2023). According to Singh et al. (2015) in SMCA there are two main steps standardization and weighing of indicators. Since all TOD indicators has different unit using 'maximum' method the maximum value of all indicators is set to 1 and all other values of the indicator were reduced to a value less than 1. Ranking is the approach that is most frequently used to weigh the indicators; all criteria and their indicators are ordered according to their relative value.

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The importance of stakeholders' opinions on TOD measurement was emphasized by Renne (2016). In their research, Singh et al. (2015) used the mayors of the City regions to weigh the indicators. Following the Borda Count method's aggregation of their rankings (Reilly, 2002), the ranks were further transformed into weights in ILWIS using the rank sum approach (ITC, 2007). The final weights and the maps for each indication were then entered into ILWIS, and for each of the roughly 12,000 grid cells, a TOD index was computed.

Delaware Valley Rating System: A rating system was created by the Delaware Valley Regional Planning Commission (DVRPC) to assess a site's suitability for transit-oriented development. There are two categories in the evaluation system: potential for future TOD development and current TOD orientation. Twelve criteria are included in these two categories, with 1 being the least supportive of TOD and 4 being the most supportive. The criteria are ranked 1-4. Criteria of the "Existing TOD Orientation" include transit service quality, job access, travel time, intensity, car ownership, non-car commuters, and Walk Score. Criteria of the "Future TOD Potential" include Development Activity, Commercial Market, Residential Market, Available Land, and Planning Context(Zhang and Goodrich, 2018).

With the Indy Connect initiative, **the Indianapolis Metropolitan Planning Organization** identified 19 criteria to determine areas that are ideal for TOD. Each location is ranked in each category on a 1-5 scale and then different weight is given to different variables based on their importance to a composite score. The composite score then correlates with location. Scores of less than 80 are considered to have little potential for TOD and scores of 110 or more are considered areas with high potential for TOD(Zhang and Goodrich, 2018).

2.1.2 Light Rail Transit (LRT)

Light rail transit is a one form of mass transportation. Because it transports a lot of people in one vehicle, mass transit is economical because it uses less resources per person to meet transportation needs, it is equitable because anyone can ride for a small fare, and finally it has been shown to be effective when properly implemented(Hooker, 2023). Rail transit, including streetcar, light rail, rapid transit, and regional rail, is a type of transportation mode with a broad range of service, operational, and cost characteristics. Rail modes are classified into four categories: streetcar, light rail, rapid transit, and regional rail(Vuchic and Day, n.d.). Light rail systems have historically evolved from street railway (streetcar) systems(Vuchic, 1972).

According to Armstrong-Wright there are four main type of transit system:

- Bus transit systems, including motor buses and trolley buses normally operating on public streets, in either mixed traffic, bus only lanes or exclusive busways.
- Light rail transit, ranging from trams operating in mixed traffic along public streets to semi-metro rail systems on exclusive tracks. Passengers usually board from the road surface or from low platforms and vehicles operate in single units or in short trains at slow to moderate speeds.
- Rapid rail transit (often called metros, subways or "the underground") invariably operates on completely exclusive rights-of-way at high speeds and high capacity. In order to speed up loading, passengers board from elevated platforms. Vehicles operate in trains composed of four to ten passenger cars.
- Suburban rail transit (sometimes termed commuter rail systems) operate on tracks shared with inter-city passenger trains and freight trains. Rolling stock may be similar to heavy intercity trains or metro trains.(Armstrong-Wright, 1929: 3-24)

The phrase "light rail" describes a variety of rail systems that are powered by electricity. Trams or streetcars, which run on tracks and share the road with other vehicles, are at one extreme. Light rail systems are distinguished by the fact that passengers typically board from the road surface or low platforms, the fact that the vehicles operate in single units or short trains at slow to moderate speeds, and the possibility that some trackways may be shared with other traffic and have specific sections of exclusive rights-of-way. LRT systems typically run along streets on tracks, and they may be given segregated rights of way along all or a portion of their routes. They might receive priority signaling at crossings or grade separation.

Figure 2.3 Grade-separated LRT

Figure 2.4 At grade LRT

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Source: Wikipedia

LRT operating speeds must be significantly lowered in situations where people or animals can access the tracks. The LRT system will lose capacity if the tracks are not grade-separated at junctions because other traffic will slow it down. On the other hand, giving a high-frequency LRT system priority can cause crossing traffic to become backed up. Consideration may be given to developing an LRT system with either an elevated or underground right-of-way due to the issue of disrupting other traffic at intersections(Armstrong-Wright, 1929).

LRT has a significant impact on a city, helping to improve mobility and directly or indirectly revitalizing the city's central business district. Direct influence would be related to travel efficiency, mainly in reducing commute time and cost, increasing public transport ridership, decreasing traffic congestion, and decreasing private car dependency. Indirect influence would be associated with urban development, land value capture mechanism, agglomeration labor market and economy, improvement of the environment, and health situation in the city(Wondimu Tekolla et al., 2021a).

2.1.3 TOD and LRT

Several researchers discussed below studied the relationship between transit–oriented development and light rail transit. Urban development's most crucial element is the transportation infrastructure. The most important issue affecting the effectiveness of transportation infrastructure, from the standpoint of sustainable and integrated urban development, is the imbalance between land use and transportation systems. A viable solution to this imbalance has been suggested: transit-oriented development (TOD) (Guo et al., 2018).

TOD aims to boost the use of public transportation by increasing mixed land use and population density in areas surrounding transportation hubs and by promoting connectivity between stations and trip origins/destinations(Guo et al., 2018). Dueker and Bianco's research on the existing eastside LRT in Portland concludes that high-density development around the LRT doesn't assure the impact of LRT in increasing transit ridership unless it is reinforced with mixed-use development(Dueker and Bianco, 1998). Likewise, Nyunt and Wongchavalidkul said reducing private vehicle trips and motorized trips while boosting the percentage of public transportation and non-motorized trips is the general goal of TOD(Nyunt and Wongchavalidkul, 2020). In several American cities, the 3D-based TOD plan has increased the ridership and modal shares of public transport and has decreased vehicle mileage by 3%–5%(Guo et al., 2018).

Transit-oriented development (TOD) can be an effective measure to help cities solve the issues that arose from their former growth strategy, including traffic congestion triggered by the growing

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population and the increase in private vehicle ownership. The goal of transit-oriented development (TOD) is to increase the amount of business, residential, and recreational space that is accessible by foot from public transportation. It builds mixed-use, compact, walkable, and pedestrian-focused communities that are based around outstanding train lines. TOD contributes to increasing transit ridership and housing choice, relieving traffic congestion, reducing pollution, and creating a diverse and lively community(ITF, 2023).

TOD provides numerous advantages, such as facilitating polycentric cities and regions, mitigating urban sprawl, boosting public transport ridership, increasing bike usage and walkability, accommodating economic growth, and creating sustainable neighborhoods(Papa and Bertolini, 2015).

The advantages of TOD include enhanced access to jobs, healthy lives, low air pollution and greenhouse gas emissions, higher transit ridership, walkable environments, and increased access to public transportation (Teklemariam and Shen, 2020). According to Cervero and Murakami (2009), TOD is a good option for funding railway infrastructure, particularly in situations with high densities by bringing potential riders closer to transit facilities. They also show how the investment in TOD might be recouped through an increase in transit usage and the profit from rising real estate values.

Correspondingly, Arrington and Brinckerhoff mentioned TOD can enhance LRT project viability TOD can add riders to the system, increase property values, enhance the prospects for federal funding, and leverage additional local government support for LRT(Arrington and Brinckerhoff, 2003).

2.1.4 Detailed Station Area Plans

Detailed station area plans are a one way of integrating transit-oriented development and transit. The neighborhoods and the development community can benefit from the certainty and predictability that station area plans can provide. A thorough evaluation of the region up to.25 to.50 mi around each station area is usually part of a detailed station area-planning effort, producing the following results (Arrington and Brinckerhoff, 2003: 193-194):

- The preparation and local adoption of a station area plan including a vision;
- A land use plan map of future land uses;
- A description of zoning to accompany the land use map; and
- An urban design plan and a schedule for TOD and economic development projects and programs.

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The core objectives of station area planning:

- Reinforcing the public’s investment in light rail by assuring that only transit friendly development occurs near the stations;
- Seizing the opportunity afforded by light rail to promote transit-oriented development as part of a broader strategy;
- Rezoning the influence area around stations to allow only transit supportive uses;
- Targeting public agency efforts at stations with the greatest development opportunity;

2.1.5 Addis Ababa light rail transit

Among many of Africa's fast-expanding metropolises, Addis Ababa is confronted with the difficulty of providing efficient public transportation while adhering to modern urban mobility systems. Before the opening of the AALRT, the city was challenged by poor transportation infrastructure characterized by emissions, accidents, and congestion (Yehualaeshet Jemere, 2012). The idea of developing a mass transit project for Addis Ababa began to emerge in the 2000s with the decentralization movement of the Ethiopian political system. Public transport had an important role in the arranging of the 2003 city development plan. The city's east-west and north-south axes were then determined to be the top targets for improving the transportation system (Nallet C, 2018). A bus rapid transit (BRT) network was considered for a long time to form the backbone until the central government finally introduced a light rail transit system in 2008.

Since urban light railway infrastructure serves as a mainstay of urban mobility in conurbations, due to its benefits such as mass transit capacity, comfortability, fast speed, safety reliability, better environmental congestion, and mitigation impacts, Addis Ababa responded by implementing an urban LRT through the city and its suburbs(Sekasi and Martens, 2021). The Ethiopian Railways Corporation (ERC) was set up in 2007 to construct railway infrastructure and provide passenger and freight rail transport services in Ethiopia. The envisaged infrastructure consists of two railway

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project components: the Addis Ababa Light Rail Transit (LRT) and the National Railway Network (NRN) (NS-167, Pt.1). s

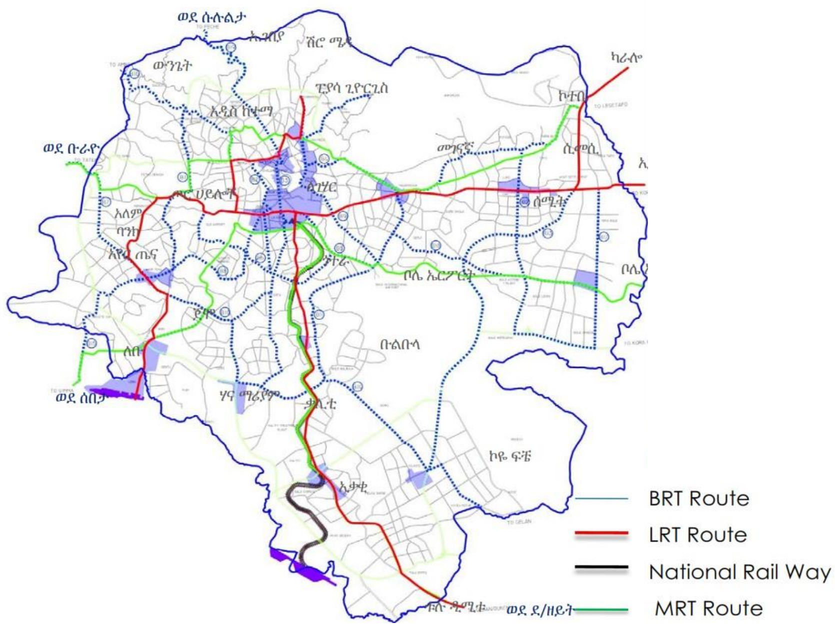

Figure 3.1 Addis Ababa LRT and BRT Lines with extension

Source: (*Addis Ababa City Plan & Development Commission, 2023*)

The aim of the Addis Ababa Light Rail Transit (LRT) project is to improve mass transit options and lessen traffic in the capital of Ethiopia and it is a modern transportation system. In Eastern and Sub-Saharan Africa, it is the first light rail and rapid transit system. Ethiopia Railways Cooperation officially opened the $475 million AA-LRT infrastructure development project on September 21, 2015, after a three-year development period. 60,000 passengers per hour will be able to be transported by the LRT system when it is fully operational, with two lines connecting the city on an east-west and north-south axis (ERC) (Debebe and Asteray, 2022; GDI, 2017; Kassahun and Bishu, n.d.). It is an electrified light rail transit with 41 stations and a total length of 34.25 km of rail lines. It used 23km on ground level, 0.9km through underground tunnel, and 7.33km of bridge construction. The 23km ground-level line is fenced on the two sides of the rail tracks(Kassahun and Bishu, n.d.; Obsie et al., 2020). It has two lines, one running north-south from Menelik Square to Kality (16.9 km) serving 23 stations and the other running east-west from Ayat to Tor Hailoch 17.35 (km) with the two lines sharing a 2.7 km(Debebe and Asteray, 2022).

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2.1.5.1 Challenges of AALRT

After construction, the LRT project caused heavy traffic at all roundabouts with ground-level LRT lines and in close proximity to all train stations. It ignored the safety of pedestrians crossing at and from train stations. LRT caused a significant financial loss for individual business owners whose businesses face fenced roads (Deyas, 2019; Kassahun and Bishu, n.d.).
During Construction, besides, the construction of LRT lines induced an enormous number of economic wastages on the part of the government. A total of nearly $42 million was wasted that could have been used for other infrastructure or urban service provision on a demolished 40-meter-wide road that cost exceeding 283.6-million-birr, relocation of an 8km main water pipeline, and electric lines(Kassahun and Bishu, n.d.).

Implementation challenges, a challenge during the planning and building of the LRT system was the government's ability to successfully operate and manage the system, stakeholder engagement, and Inter- and intragovernmental relations. Addis Ababa lacked an urbanization plan to integrate various transportation systems to improve road and pedestrian safety, even if the LRT system proved successful. Moreover, approximately 65 percent of the road network in Addis Ababa lacks pedestrian walkways or sidewalks (World Bank 2016). These conditions hamper the project's development goals and limit the effectiveness of the LRT system(GDI, 2017).

The implementation challenge is addressed by, five-year skills transfer agreement between Shenzhen Metro Group and the Ethiopia Railways Corporation. The Shenzhen Metro Group has trained 250 Ethiopians. Integrate the new LRT system with existing transportation options; the project coordinated with Anbessa and the public bus operator in Addis Ababa to align routes; incorporate private taxi operators into the new LRT network and build more official taxi stands near stations. A $300 million financing agreement was negotiated by the World Bank and the Ethiopian government to enhance transportation safety (GDI, 2017).

2.1.5.2 Opportunities of AALRT

Certainly, railroads are essential in the developing a safer, more environmentally friendly, and sustainable transportation system. Because they offer economical, efficient transportation with minimal negative environmental effects, light rails can significantly mitigate the environmental impact of any city (Sekasi and Martens, 2021).

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2.1.5.3 Efficiency of Addis Ababa Light Rail Transit

Challenges facing the Addis Ababa LRT, according to Wondimu Tekolla et al., include a lack of sufficient financial support and the necessary operating skills, blackouts and driver inexperience, a lack of spare parts, the absence of a passenger information system (PIS), and a lack of integration with other modes of public transportation. The analysis's findings showed that the AALRT is not operating as efficiently as it should be in all areas of performance indicators, evaluating mode share, assessing station efficiency regarding the number of passengers boarding at every station, and general operational performance. The research by Wondimu Tekolla et al., (2021) revealed that Addis Ababa LRT had no significant influence on the public transport system in Addis Ababa; its mode share is only 6% and diminishing daily at an arming rate. According to the data from the Addis Ababa Light Rail Transit Transport Department on yearly passenger flow data, it shows the number of passengers is reducing every year. The researchers concluded that successful TOD plays a vital role in the efficiency of LRT correspondingly LRT also has a vital impact on creating successful transit-oriented development(Wondimu Tekolla et al., 2021).

2.1.6 TOD In Addis Ababa

AALRT has faced challenges that would ultimately bring its operation to an end. These challenges have also been emboldened by so many reasons, however, the main one is the lack of funding to sustain operations. The Addis Ababa City Administration is considering implementing Transit Oriented Development (TOD) around selected stations along the routes of AA-LRT as a remedial measure to overcome the challenges (Wondimu Tekolla et al., 2021). Though Addis Ababa didn't have stated TOD policies until recent years, the proposal of the 10th structural plan of Addis Ababa incorporated TOD in different aspects. TOD in Land use proposal, TOD in Transport, and Road Network, and TOD in Centers proposal are TOD plans that are incorporated into the 10th structural plan of Addis Ababa (Addis Ababa City Plan & Development Commission, 2023). TOD in land use proposal includes high-density mixed residences along the mass transport routes, at least 40% residence share with a minimum of 150hu/ha, and a greater mix of uses. TOD in centers proposal includes integrating the centers with mass transport and providing pedestrian-only streets.

2.1.6.1 Opportunities for transit-oriented development in Addis Ababa

High-density urban development around the LRT will boost ticket sales (better ridership) and

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property/lease values, which will support the LRT's long-term viability. Simultaneously TOD will directly (through avoidance of transport needs as commercial and social activities are grouped within the TOD) and indirectly (increased LRT ridership as TOD residents will use LRT when transport is required) reduce GHG emissions in Addis Ababa (NS-167, Pt.1).

2.1.6.2 Challenges of implementing transit-oriented development in developing countries

Inconsistencies in the co-ordination between land-use planning and transport planning, future visions and plans tend to be poorly coordinated between stakeholders, lack of pre-existing networks and infrastructure, such as public transport networks and sufficient roads, compared to developed countries, and Paratransit is a common part of the transport systems in such cities. While helpful in providing low-income populations with essential transport services, it can weaken the public transport systems, hindering the implementation of TOD (ITF, 2023).

2.1.6.3 Challenges for integrating Land Use and transport in Addis Ababa

Knowledge (lack of practical knowledge, technical design issues, and experience), access to finance, and gaps in the regulatory framework are the typical barriers to TOD implementation in developing countries, correspondingly these are also barriers to the implementation of TOD in Addis Ababa. Regulatory barrier: Establishing the TOD may also take place through public-private partnership (PPP). Such co-development structures are without precedent in Ethiopia (NS-167, Pt.1). Lack of coordination between agencies in the same sector and between the different transport and housing programs. World Bank report demonstrates that land use and transport development are poorly coordinated. Housing and land use decisions are based on the location of available land, with almost no assessment of transport impacts while road transport investment decisions are based on criteria often unrelated to land use patterns. For instance, brand-new condominiums have been built without consulting transportation agencies on the periphery of the metropolitan area(Nallet C, 2018).

2.1.7 Implementation of Successful TOD In Different Cities

Successful Transit-Oriented Development (TOD) strategies implemented in several cities including Curitiba, Singapore, Japan, Hong Kong, and St. Paul Central Corridor in Minnesota is presented in the following section.

2.1.7.1 Curitiba, Brazil

In contrast to other Latin American towns, Curitiba, in the state of Parana, Brazil, realized early on the necessity of a transportation strategy. Curitiba established its first BRT line in 1974 and

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had a transportation master plan in place by the 1960s. Curitiba's progressive plan aims to increase ridership by integrating land use surrounding the transit system, rather than only providing it for commuters. This will appeal to all social classes in the city (Joshi and Joseph, 2017).

Curitiba has integrated public transportation planning into the overall city plan, promoting the trinary system since the 1970s, which sought to integrate mass transit, access roads, and dense land uses together. Unable to afford a light rail system, the city gave priority to buses, allowing them to move faster and be more efficient. Urban growth was structured along key urban transport axes radiating out from the center. These corridors were zoned to accommodate high density residential and commercial development (*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3,* 2018).

Curitiba's Success Factors

Curitiba's success factors include, Innovative initiatives and strategies that put in place regardless of budgetary constraints; Right to Build, tax relief, and other innovative incentives: FAR bonuses for provision of extra open space within the plot, property tax % reduction when planting local species, land-swap and property right swap, are among many initiatives implemented to aid regeneration and development within the corridor and the city. Curitiba focused largely in the concession of fiscal incentives to attract foreign investment. It was put at the investor's disposal fiscal incentives, such as exemption from VAT and property tax.

The successful BRT Mass Transit model is used as one of the tools to shape the city, the system currently contains stops approximately every 500 meters with 390 bus routes and 2,000 vehicles that are used for approximately 2.1 million passenger trips daily, nearly 50 times the amount of travelers 20 years ago. The BRT gained an annual ridership of 2.3% of the population for over 20 years after its construction in 1974. The ridership has now reached 46%, reducing traffic congestion and fuel consumption, while enhancing air quality (Curitiba has now the lowest rate of air pollution in Brazil). Nearly 90% of the city is served by bus, and everyone can access public transit within 500 meters of their location (*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3,* 2018).

The city implemented a detailed regulation zoning plan based on the public transport network. Institute for Research and Urban Planning of Curitiba (IPPUC), has adopted several policies that have bettered the quality of the city and ensured a rich mix of functions, from the pedestrianizing of central streets (Curitiba's car-free zone) to the construction of low-income housing in the

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proximity of the structural axes. By strategically placing high-traffic locations adjacent to public transportation hubs, such as shopping malls and high-rise apartment complexes in a land-use mix, car dependence is decreased (*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3*, 2018).

There is very little parking in central Curitiba, Curitiba controls the use of private vehicles by expensive off-street parking around the main corridors and limited on-street parking in location and duration(Joshi and Joseph, 2017).

Structural Axis focused on urban density and investment along the BRT corridors: the core of density was focused along BRT routes. The typical 'Structural Axis' includes two side blocks and three roadways called a 'Trinary System'. Land within two blocks of the transit arteries, the buildings facing the transit corridors need to be high rise with mixed building use, since it generates more transit ridership per unit area. Beyond the two blocks, zoned residential densities taper in proportion to the distance from transit ways (*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3*, 2018; Joshi and Joseph, 2017).

Institutional capacity and innovative initiatives: Independent, technical body (Research and Urban Planning of Curitiba (IPPUC)) leading planning and implementation of the TOD strategies along the corridor and the wider city. It handles not only research and planning but also the implementation and supervision of urban plans. BRT & Bus Network supported the economic transformation of the city: BRT connectivity was applied across the city, also to some of the low-density employment hubs. This supported economic growth and responded to the employment profile of the city(*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3*, 2018).

2.1.7.2 Singapore

Overview

Singapore has a transit-oriented city model that is accessible to all through a strong network of public transport routes and high-density development built around transport interchanges, key nodes, and transit corridors.

Singapore, one of the most successful growth models, features effective public transportation and some sensible policies for the adoption of TOD. The city has a ring radial structure with circumferential MRT rail networks and LRT feeder networks with a densely built urban center, It has major and minor sub-center nodes with high densities at the intersection of MRT lines. (Joshi and Joseph, 2017).

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Today Singapore offers its citizens and tourists fast connections through a highly penetrative integrated public transport system. About 5.3 million trips are made daily via public transport network and at least half of its population uses it daily. The Mass Rapid Transit (MRT), provides speed and efficiency, especially during peak hours. The MRT is publicly owned, while buses and taxis are privately owned.

The urban planning policy relies on effective public transport to link each new community to each other and the city center. 20 town centers, all served by MRT, are mixed-use and connected by the extensive pedestrian-cycling network. High-density housing, retail shops, community facilities, and open spaces are typically found in all hubs(*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3,* 2018).

Singapore's Success Factors

Factors contributing to the success of Singapore are: Perseverance and long-term planning (50-year strategy); Focused, dense development along transport nodes, the urban structure of Singapore focused on 'new towns' integrated and located around MRT stops with diverse activities of local shopping, other commercial and community services with residential populations envisaged to be about 60,000 to 120,000people in these new towns (Joshi and Joseph, 2017). One critique of the new towns was the balance between employment centers and housing where 80% of the employed residents in new towns traveled to the industrial estates located on the western part of the island near the port or in other new towns (Barter and Dotson 2013).

Inter-ministerial committee to promote integrated approach: Since 1959, Singapore has actively expropriated land for public facilities to promote city redevelopment, and catalyze new development. Today, about 90% of the land is owned by the city-state. Urban Redevelopment Authority within the Ministry of National Development is in charge of urban planning and promotes Singapore's policy of high-density development.

Encouragement of usage of public transport through the implementation of Certificate of Entitlement: Fares are adjusted frequently to aim for a certain traffic flow. To reduce vehicle usage, a Certificate of Entitlement (COE), costing more than $80,000 to successful bidders, is required before a car owner can drive a vehicle in Singapore which is only useful for 5 or 10 years (*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3,* 2018). Singapore also has a Vehicle Quota Scheme (VQS) that limits annual vehicle registrations through an electronic open bidding system with additional supplemental charges for vehicle registration (Joshi and Joseph, 2017).

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Walkability: the Walk2Ride program significantly extended the sheltered walkway network to connect MRT stations to trip-generating hubs, such as schools, healthcare facilities, public amenities, offices, and residential developments within 400m of the stations. Quality of life delivered through environmental improvements: Singapore's high-density, built-up areas have enabled the preservation of open spaces, natural parks, and greenery(*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3,* 2018).

2.1.7.3 Japan

Historically, the concept of TOD is recognized as an essential theory of urban development in Japan. From 1910 to 1930 two railroad companies were established, Hankyu Railroad and Tokyo railroad company. Private transit operators in Tokyo built high-density areas along their transit lines to boost ridership. Each station is within walking distance of most daily services. The different high-density regions are interconnected by an efficient rail and bus system. Feeder buses also service TOD stations, and direct connections between the rail lines and subways provide easy access to the city center.

The high-density areas are fully navigable by foot, bus or subway. In many cases, the vast railway system allows to residents in TOD zones to access most leisure activities by mass transit. Relatively high gas prices, expensive and limited parking, and narrow roads further reduce the impulse to drive and make the cheaper mass transit option even more attractive. Japan allows private industry and transit operators to develop denser, mixed-use areas around transit stations.

Tokyo's reconstruction of Shibuya Station is one of the most recent examples of TOD. There are eight train lines that go through the heart of Shibuya, and the station is used by large numbers of passengers every day. The Urban Renaissance Emergency Development Area was established in December 2005 for Shibuya Station and the surrounding area (Reggiani, 2021). The Shibuya Station redevelopment encompasses the Shibuya area, and almost all services are set up around the transport hub. In these redevelopment projects, all new facilities and areas within and around stations are integrated with the pedestrian system, which makes the stations very accessible. The stations function not just as transport hubs but also as integrated city spaces(ITF, 2023).

2.1.7.4 Hong Kong SAR, China

Hong Kong has an advanced public transportation system that includes multiple ferry services, buses, trams, trains, and a metro network. Over 90% of daily journeys (11 million) are by public transport. Railways account for about 41% of daily public transport passenger travel to the

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mainland. A sizeable proportion of living quarters and commercial/office floor space are within 500m - walkable catchment of transit stations. Carefully planned open spaces and parks are integrated with the transit stations.
Mass Transit Rail Corporation (MTRC) is a 75% government-owned corporation responsible for Hong Kong's underground and railway networks. By provision of new infrastructure, the value of assets increases hence tax revenue increases and the corporation uses it for further development in transport infrastructure.

The government gave comprehensive land development rights of the sites to the MTRC on a new railway and the MTRC had to pay dividends and business tax to the government. MTR as a Master Developer pays special attention to the development parameters such as area size, building densities, floor uses and site designs, working closely with the developer, community, and urban planning authorities(*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3*, 2018).

Hong Gong had successful transit-oriented development implementation because of the following factors:

A Dense Development Hong Kong is one of the most densely inhabited places on earth. Its population density over the city averages almost 7,000 people per square kilometer, this varies greatly and includes some peaks of over 50,000 people per square kilometer, in the case of Kwun Tong district. An Innovative implementation and financing model Hong Kong adopted innovative and unconventional models of implementing and financing mass transit at city scale, through its R+P model. Unique Rail + Property Model (R+P) development is a core part of MTR Corporation's business model, capturing real estate income to finance the capital and running costs of new railways through public-private partnerships.

A Focused design model based on the "3Ds" Hong Kong case also demonstrates how high-density liveable communities could be created by capitalizing on transit stations and focusing on designing stations as places through 3Ds: Density, Diversity, and Design. A Continuous review of the typologies and approaches: The constant evolution and effort in planning TOD is also evident. In the last decade, MTR has evolved from developing stand-alone stations and adjacent development to more comprehensive models and produced specific station typologies that promote TOD growth. A Healthy lifestyle supported by planning and TOD policies Special policies: station focused public realm design encouraging walking and cycling(*DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3*, 2018).

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2.1.7.5 St. Paul Central Corridor St. Paul Minnesota

The METRO Green Line is an 11-mile light rail line that connects downtown Minneapolis and downtown Saint Paul via the University of Minnesota. It was known as the Central Corridor LRT (Light Rail Transit), was a project with 18 new stations built for the Green Line, ST. PAUL CENTRAL CORRIDOR which also shares five stations with the METRO Blue Line in downtown Minneapolis. Service began on the Green Line in June 2014.

Characteristics of Central Corridor LRT before the implementation metro green line by auto-oriented uses like strip malls, drive-throughs, and surface parking, along with some small-scale retail, housing, current industrial uses, and industrial redevelopment. The neighborhoods along the corridor contain low-income areas, immigrant communities, and communities of color.

The city collaborated with the Central Corridor Funder's Collaborative, a collection of nonprofit development and service groups whose goals were to prevent the displacement of small and immigrant companies along the Corridor and to preserve and construct affordable housing. Two stages of TOD zoning implementation were suggested by the Development Strategy. The first, a zoning overlay, was put into place in 2008 and was set to expire in 2011.
The land use regulation was related to auto use, parking, and density which includes: No new or expanded auto-oriented uses, a minimum 1.0 FAR within 1/4 mi of the station, a minimum 0.5 FAR elsewhere in the district, a minimum 2-story building height, and Parking behind or to the side of buildings, not in front of the building.

The final ordinance used rezoning and new zoning categories to shift the corridor towards more transit-friendly uses and to allow buildings from the streetcar era to come into conformance. Rezoning allowed more intense mixed uses, density, pedestrian-friendly design, and reduced or eliminated parking requirements. Along the entire corridor, minimum parking requirements were eliminated within a quarter mile of stations. Planners opted not to include any park-and-rides, along the corridor.

The planners in Saint Paul found it valuable to delineate areas where mass redevelopment would be targeted, and others where change would be slower and planning would focus on infill and rehabilitation of existing buildings. Collaboration was essential to meet the community goals for the central corridor project. In partnership with the city and non-profit partners, the project team went beyond the usually narrow engagement scope of construction mitigation.

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2.1.8 Challenges and Opportunities of TOD

2.1.8.1 Challenges of TOD implementation

Hooker J in his research on Barriers to Transit-Oriented Development in Portland, OR, stated four categories of barriers in TOD implementation. Cost of development (The cost of construction and development is a huge barrier to making TOD happen and lack of proven development incentive programs); Ineffective planning and misaligned suburban development regulations (Commonly identified code barriers were height maximums and density requirements.); inadequate community communication and involvement (Lack of community involvement during the planning stage.); and stakeholder relationships(Hooker, 2023). Land use acquisition, economics, and planning approaches are also the main barriers to the implementation of TOD mentioned by numerous researchers. (Hooker, 2023).

2.1.8.2 Stakeholder Relationships

some researchers found that positive relations are important in the implementation of TOD and others found that poor relations between the stakeholders lead to barriers in the implementation process. A lack of balance between the government, private, and community sectors was noted by Dorsey and Mulder (2013) in their study of an ongoing TOD project in Ogden, Utah, which resulted in significant division in the planning process.

Despite formal policies in place, Hrelja et al. (2022) found that government officials' disagreements over crucial development aspects served to slow down the process. These issues were further exacerbated by the officials' failure to include the community members living in the prospective TOD site, which ultimately rendered development impossible. Tan et al. (2014) found that government stakeholders held mismatched views on TOD and oftentimes perceived other stakeholders as indifferent or purposefully sabotaging policy implementation.

Mu and de Jong (2016) also found successful stakeholder collaboration led to policy implementation in Urumqi, China. Thomas and Bertolini (2014) found that the success of implementing TOD policies was enhanced by positive relationships between actors, such as multidisciplinary implementation teams, visionary officials, public participation in the planning process, and strong communication and goal and vision overlap. According to Hrelja (2015), the new TOD planning approaches in Sweden were successfully facilitated by consensus between politicians and governmental officials.

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2.1.8.3 Land Use and Acquisition

Feldman et al. (2012), in their study of TOD implementation in Montreal, Quebec, found an increasing insufficiency of buildable TOD. Sites are a major barrier to development and other related barriers are demographic growth, lack of good sites near transit, and the perception that undeveloped land on the outskirts of the metro area would require too much additional infrastructural development to be worth investment.

Searle et al. (2014), in their study of TOD creation in Melbourne, Brisbane, and Sydney identified the biggest barriers to TOD as site context and ownership. The authors found that prospective TOD sites built in locations with non-residential uses led to less public opposition and were also more likely to have only one or two owners to buy from. Other locations with fragmented ownership in more residential areas served as a contrast to this.

Apart from the ownership barrier land use pattern is another hindrance for implantation of TOD. Yang and Pojani (2017) examined the land use features and population densities surrounding TODs in Brisbane and discovered that despite the existence of planning regulations aimed at encouraging TOD in Brisbane, residential land use was still denser in non-TOD areas while commercial use was denser in TOD areas.

2.1.8.4 Economics

In Montreal, Quebec, Maulat et al. (2021) found a major barrier to TOD was the transit authority's limited financial resources, thereby restricting the supply of public transit. Mu and de Jong (2016) found it was crucial to TOD and transit system success to attract private-sector investors with supportive policies and regulations to align government and private sector goals and increase financial viability, resulting in circumventing financial barriers.

2.1.8.5 Planning Approaches

Van Lierop et al. (2017), interviewed planners in North America and the Netherlands on planning practices essential for post-development TOD success, identifying the importance of physical design, transportation, natural environment, community composition, economy, stakeholder collaboration, and accessibility.

Hrelja et al. (2020), identify in many cases land use planning and transport planning are done by different agencies at different levels of government, which serves to complicate collaboration between actors and integration of planning modes to design and implement successful TODs, especially in urban areas.

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According to Randhawa, challenges of TOD implementation in Indian cities are urban development challenges (unplanned urban development, lack of proactive planning and funding i.e. planning and provision of transportation plans don't keep with the pace of population growth), master plans, Development control regulations, institutional issues, and financing(Randhawa, 2021).

In Australia community barriers, development feasibility barriers, governance barriers, and emerging barriers are barriers to TOD implementation. Community obstacles include the fact that current inhabitants frequently oppose urban density increases and that potential people frequently have no desire to live in Activity Centers. Development feasibility barriers: Train station surroundings often have heritage building stock, are typically complex "knots" of intersecting road and rail infrastructure, and have fragmented land ownership, and the active city centers lack service infrastructure and the cost to upgrade can affect the feasibility of a development. The governance barrier includes the local government's failure to create community awareness and the lack of professionals in the government.(Bolleter and Ramalho, 2020)

2.1.9 Opportunities of TOD implementation

The main state and regional benefits identified by guidelines of TOD implementation generally involve increased transit ridership, increased property values, and health and environmental benefits that are seen as deriving from a more pedestrian- and cyclist-oriented environment dependent less on personal vehicle ownership. Undoubtedly, an increase in transit ridership can result in a decrease in vehicle miles traveled (VMT), an important root of the perceived environmental benefits of TOD and lowered regional congestion, air pollution, and greenhouse gas emissions. As the guidelines of California discuss, TOD can promote public safety by creating places that are busy during the day and at night, placing eyes on public spaces even during off-peak times. Many TOD guidelines also note TOD's potential boost for economic development and propensity to increase property values. TOD also has the potential to result in a revitalization of depressed activity centers and neighborhoods (Zhang and Goodrich, 2018).

Goals of TOD from the perspective of transit agencies: increase ridership, promote economic development, raise revenues, enhance livability, widen housing choices, private development opportunities, improve safety, share construction costs, reduce parking, increase intermodal integration, enhance pedestrian access, and improve air quality(Zhang and Goodrich, 2018). According to Hale and Charles implementation of TOD has the following opportunities: (1) Boosting Patronage and Ticket Revenue: a mixed-use character contributes to a more balanced and consistent passenger throughput at various times of day and on different days of the week

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and throughout the year. The increased and varied passenger market can contribute revenue and hopefully lead to better utilization of transit capacity and more efficient employment of expensive transit infrastructure. (2) Concentration of Passengers and Activity at Key Stations (3) Metropolitan Structure: Bannister (2002, p239) supports the idea that coordinated land use and transport planning can achieve a great deal for urban structure over the long run. (Hale and Charles, n.d.)

2.1.10 Strategies for implementation of TOD

2.1.10.1 Zoning

Zoning ordinances also help to incentivize TOD in areas that are considered strong candidates for this type of development. Overlay zoning, or a zone that is placed on top of existing zoning, can modify current zoning to create regulations that support TOD without changing current zoning(Zhang and Goodrich, 2018).

2.1.10.2 TOD incentives

Offering different incentives for developers or any other organizations to building development that promote or fulfill transit-oriented development guidelines. The incentives include funding, expediting administrative and environmental review, and other…(Zhang and Goodrich, 2018).

2.1.10.3 Smart Growth Maps

Smart growth-designated areas often have similar characteristics as those determined to be strong candidates for transit-oriented development. This area is a considered development near transit, traditional neighborhood development, and conservation subdivisions. The areas that are considered development near transit have some of the attributes of TOD but not all attributes that would apply to TOD development(Zhang and Goodrich, 2018).

2.1.10.4 Joint Development of TOD

In the past, joint-development was done by leasing the land to a private developer for a project that would be mutually beneficial to the developer and transit. Later these policies on joint development changed and allowed transit authorities to sell the land and keep the proceeds, with the requirement that the proceeds be used on transit service. Other forms of joint development include sharing operating and construction costs, which is a cost-saving strategy for both station and development projects Another component of successful TOD is coordinated joint planning. The transit agency must work with land owners, municipalities, and developers as well as

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stakeholders to collaborate on the best method to carry out a station plan(Zhang and Goodrich, 2018).

2.2. Empirical Literature Review

Previous research ((Khare et al., 2021; Teklemariam and Shen, 2020a; Uddin et al., 2023)) researched the measurement of transit-oriented development. Khare et al. (2021) did research on the measurement of station-level TOD on a quantitative scale in the case of Bhopal, India. Based on selected parameters, the study employed a multi-criteria evaluation to determine Bhopal's TOD level. The objective of the research was to evaluate how BRT stations TOD-ness is affected by the surrounding land use. Seven criteria and respective performance measures were used to measure the TOD level. The two steps of the multi-criterial evaluation method after the selection of criteria are standardization and determination of weight for each factor. The maximum method used to standardize each performance measure. Based on stakeholders' perspective the performance measure was ranked and the rank sum method was used to weight. The result of the research shows that in stations with high TOD index values, there is high-density development around the station. On the other hand stations near low-density, development have low scores on the TOD index.

Uddin et al. (2023) The primary objectives of this paper are to measure the nodal TOD index by developing a framework for emerging cities and to plan for TOD improvements within walking distance of the station areas based on the results in the case of mass rapid transit system Dhakar. Based on the four criteria (4Ds), the TOD index was measured spatially in the geographic information system (GIS) using nine indicators: population density, commercial density, employment density, land use mix, length of walkable/cyclable, intersection density, parking utilization, and open/green space. Following the calculation of the indicators, the spatial multi-criteria analysis (SMCA) was used to determine the TOD index for the 800-meter buffer between each station. Following standardization, the adopted indicators have been balanced. Then each criterion was weighted by academicians from different universities in Dhaka and personnel from DMTCL based on the criterion's importance for the TOD. The significant finding of this research is that the transit stations that serve many transportation modalities and have high commercial density have high TOD index ratings. Stations with low land use diversity have low TOD index values.

Teklemariam and Shen (2020) researched "Determining transit nodes for potential transit-oriented development: Along the LRT corridor in Addis Ababa, Ethiopia." The research proposes a

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methodology to quantitatively measure the existing TOD in terms of a TOD index within the walkable distance of transit nodes by measuring the criteria that define TOD levels. The research determines which stations have high and low potential for TOD. To measure TOD levels GIS and spatial multiple criteria analysis (SMCA) are used. The TOD index was measured by using eight indicators (population density, commercial density, land use mix, land use mixedness, pedestrian path, intersection density, parking utilization, and open/green space). The maximum standardization method used and how the weighting of the indicators was done are not mentioned. The results show, that stations that accommodate transits to different transportation modes, have a high land use diversity and density, have high TOD index scores, and vice versa. The research indicates the need to improve on land-use diversity; balance the relationship between residential land use and other land uses; and improve parking, pedestrian-friendliness, and access to transport modes.

In sum, previous research discussed above on measuring the TOD index and identifying the potential of TOD around transit stations used spatial multicriteria analysis (SMCA). Likewise, the other researchers ((Huang et al., 2018; Ibrahim et al., 2021)) regarding TOD measurement also used SMCA. Spatial multicriteria analysis has the advantage of being comprehensiveness, it combines spatial data with multiple criteria (non-spatial), making it ideal for capturing the complexity of urban environments. The method allows for a spatially explicit TOD index, making it useful for detailed location-based comparisons and urban planning across regions. It allows stakeholders to assign different importance (weights) to different criteria based on policy goals. However, this could also be a disadvantage since the choice of indicators and weights can be subjective, leading to potential biases. Furthermore, SMCA relies profoundly on accurate spatial data, which may not always be available in developing regions. This research tried to address the weakness of the methodology by using widely accepted TOD indicators (5D), an equal weighting method to avoid the subjective perspective of stakeholders, and generating the necessary spatial data (land use and road network map) by using GIS.

2.3. Conceptual Framework

This conceptual framework examines how Transit-Oriented Development (TOD) influences Light Rail Transit (LRT) ridership. Based on relevant theories and literature discussed in the above sections, the framework identifies key variables and illustrates their interrelationships.

1. Independent Variable: Transit-Oriented Development (TOD) indicators

Land Use Density: Residencial and commercial land use density around LRT stations.

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Diversity: Integration of residential, commercial, recreational spaces, and other land uses.

Destination accessibility: the integration of residential land use with other land use.

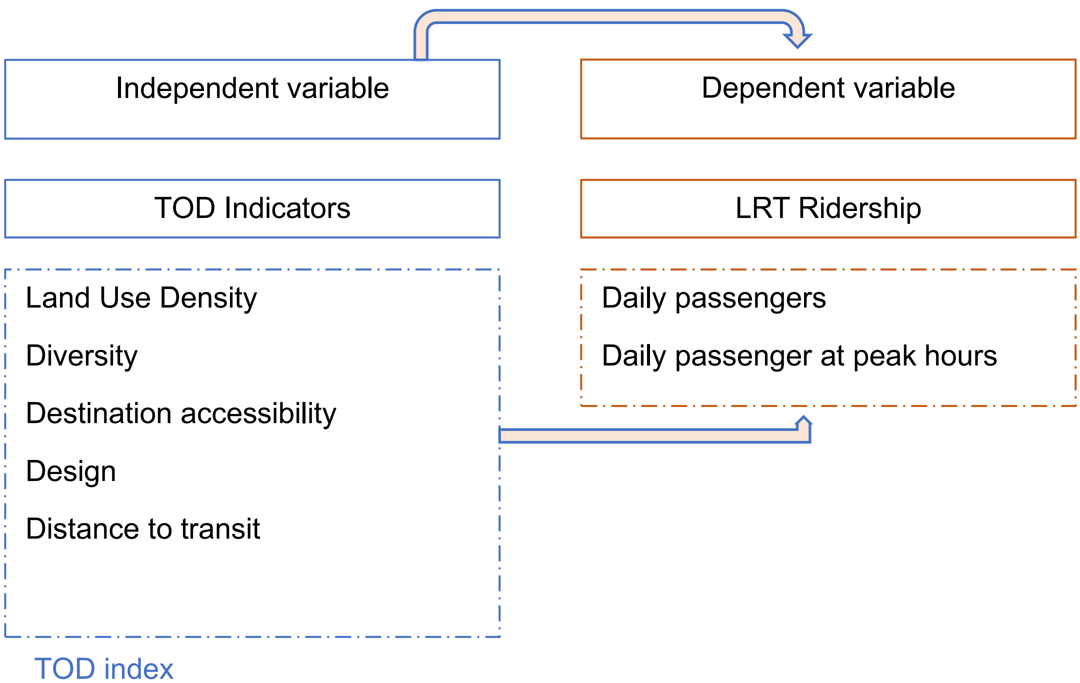
Design: Distance from developments to LRT stations.

Distance to transit: Distance from developments to LRT stations.

2. Dependent variable

Daily passenger

Daily passenger at peak hours



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CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Research Design

A quantitative research method was used for this particular research. The research design described in Figure 3.1 indicates the measurable variable, data collection, and analysis method for each research question and overall research design framework. To study the integration of TOD principles into AALRT observation and spatial analysis by GIS was used. To identify AALRT ridership flow interviews of passengers and data from the Addis Ababa light rail transit transport department were used.

3.2. Sampling

3.2.1 Target Population

For research question two the target population are the daily passengers and passengers at peak hours.

3.2.2 Sampling Technique

For Research question one, the research focuses on the East-West AALRT line from the two existing lines (East-West and North-South lines). The reason for choosing the E-W line already discussed previously in the scope of the research section. The East-West line has twenty-four stations. From those stations, four stations are selected for this research based on a different rationale, using purposive sampling method. Based on observation and previous research (Teklemariam E and Shen Z), the selection criteria for the chosen stations of this research are set. The criteria for the selection of those stations are presented on the below tables. Ayat, CMC, Megenagna, and Mixco stations are chosen based on those criteria.

For Research question two, Convenience /volunteer sampling was used to identify transit ridership from the TOD influence zone and the transit ridership's travel purpose using structured interviews. The number of the LRT passengers at peak hours was studied by counting the number of tickets sold at peak hour (from starting time until 3 o'clock LT). For the research question three, no specific sampling was required as the study relied on a literature review of cities with successful TOD implementations.

3.2.3 Sample Size

For the research question one, as indicated in the "Literature Review" section, different researchers had different definitions of distance to transit (influence zone of TOD). Some

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. MEGEAGNA STATION
One of the centers of the city
Existence of different transportation mode
Designated as development with a high TOD level(Teklemariam and Shen, 2020b) .

Table 3.1 Criteria for choosing Megenagna

CMC STATION
High density residential district
Emerging of new development both commercial and residential development.
Designated as development with a low TOD level(Teklemariam and Shen, 2020b).

Table 3.2 Criteria for choosing CMC Station

MEXICO STATION
Main center of the city (CBD)
Relatively high number of organizations around this station.
Designated as development with a high TOD level(Teklemariam and Shen, 2020b).

Table 3.3 Criteria for choosing Mexico Station

AYAT STATION
High density residential district
High density of population
Designated as development with a low TOD Level(Teklemariam and Shen, 2020b).

Table 3.4 Criteria for choosing Ayat Station

researchers defined TOD as restricted to an area of 400 to 600 meters from LRT stations, and others defined TOD as an area of 700 and 800 meters from the LRT station ((Ginn, 2009), (Calthorpe, 1993), (Vale, 2015), and (Hrelja et al., 2020)). This research studied the transit-oriented development based on two different catchment areas, the first is the development within 400 meters distance from the station, and the second is the development within 800 meters distance from the station. For the research question two, a twenty-percent sample size was used relative to daily passengers. According to Bartlett (2001) if the target population is lower than 1000 a sampling percentage of 20% to 50% is necessary to ensure representativeness (Bartlett et al., 2001).

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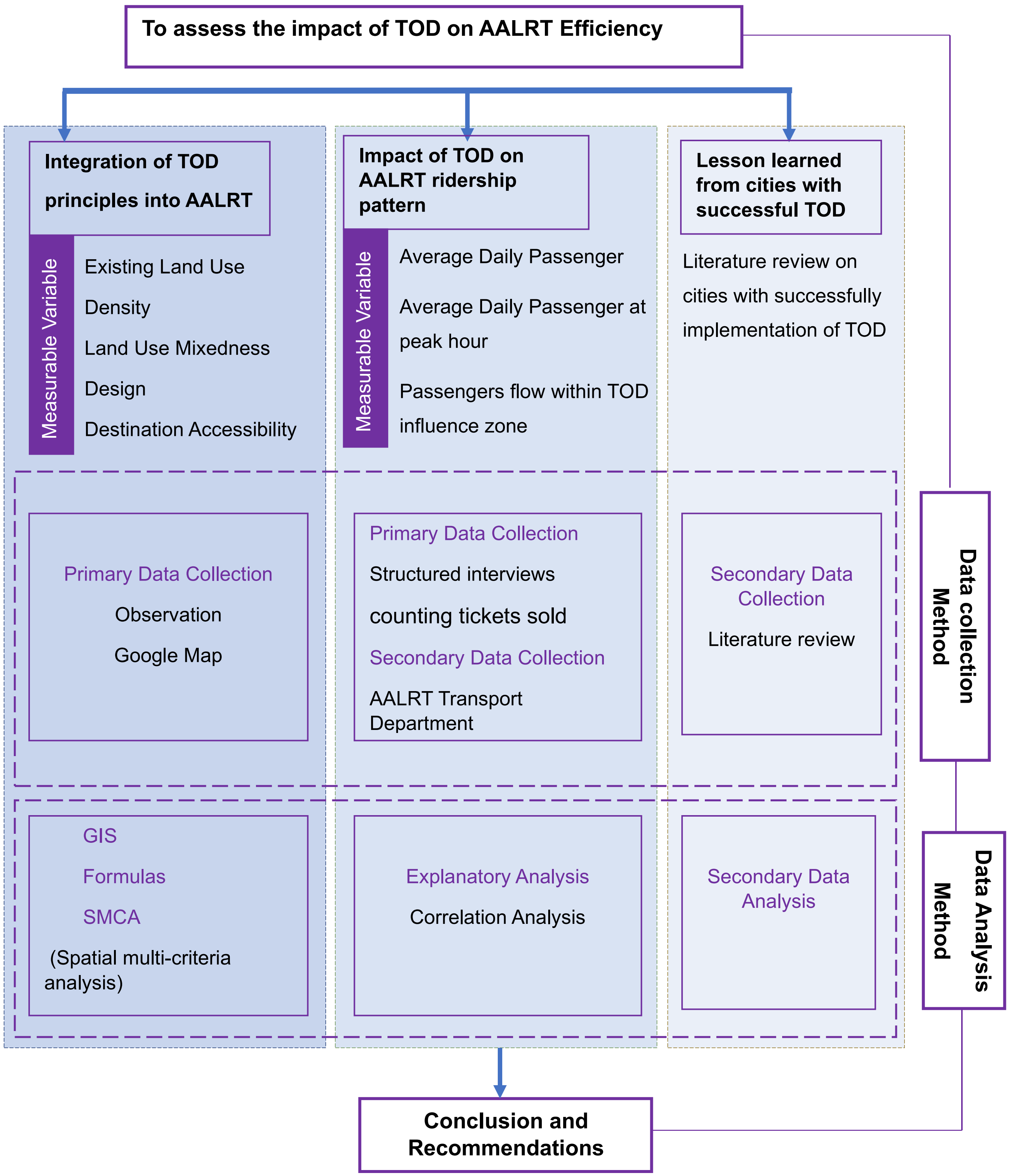

Figure 3.3 Research Design

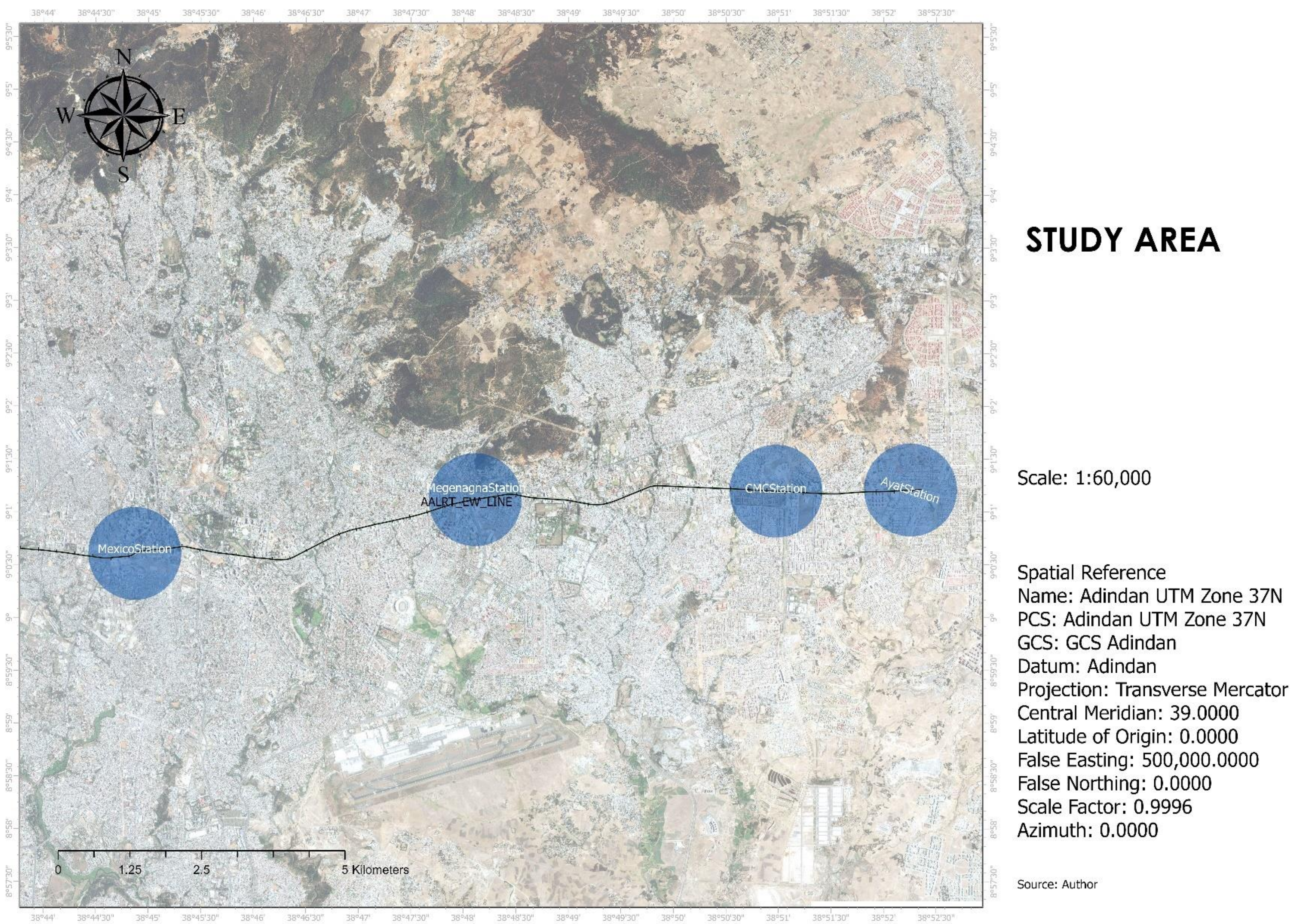

Figure 3.2 Study Area

3.3. Measurable Variables

For research question one, Density (residential, and commercial density), diversity, design (street amenity, intersection density, length of walkable or cyclable path, and parking utilization (on-street parking and off-street parking)), and destination accessibility. For research question two, average daily passenger, average daily passenger at peak hour, and passenger flow within TOD influence zone (within 800 meters).

3.4. Data Collection Method

This research used both primary and secondary data collection methods based on the measurable variables (dependent and independent variable) that are discussed on the previous sub section (conceptual framework).

Primary data collection, observation and google map used together to generate exiting land use which is a data source for the independent variables (density, diversity, design, and destination accessibility). Interviews: Structured interviews with passengers to understand ridership patterns and travel purposes. Ticket Sales Data, counting tickets sold at peak hours to determine average daily ridership at peak hours.

Secondary Data Collection, from AALRT Transport Department Data: Six months of daily passenger data were collected to calculate average daily ridership. Literature Review: Secondary data from cities with successful TOD implementations were reviewed to draw lessons for Addis Ababa light rail transit.

3.5. Data Analysis Method

For Research Question one, ArcGIS was used for spatial analysis, including calculating commercial and residential land use density, land use diversity, destination accessibility intersection density, and walkable/cyclable path lengths.

1. Density

The density of residence and commercial land use were studied for each site (Ayat, CMC, Megenagna, and Mexico LRT station) selected. Commercial Land Use Density: according to Haylie M, there are two types of density, gross density and net density. After subtracting necessary infrastructure and vital areas from the gross area, leaving only the space devoted to the commercial lots, the number of units per acre of land is referred to as the net density. Gross density refers to the number of commercial unit acres of land. The calculation is made by dividing the total lot area by the number of units(Haylie Miller, 2020).

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Gross density and ArcGIS were used to study commercial land use density for two rationales. First, Since the aim of the research is to understand how the density of commercial units in a specified area impacts the LRT ridership, identifying the net residential unit is insignificant. Second, if the net density is used, it will lead to every selected site to having a different study area.

The updated exiting land use created in the previous stage was used as a data source to calculate the density and the data was analyzed using ArcGIS.

$$Commercial\ Land\ Use\ Density = \frac{\text{Number of commercial unit}}{\text{Total lot area}}$$

$$Residential\ Land\ Use\ Density = \frac{\text{Number of Residential unit}}{\text{Total lot area}}$$

2 Diversity

To study the land use diversity of the selected sites existing land use plan was used. To calculate and analyze the land use diversity Shannon entropy index was used.

$$\text{Entropy} = \frac{\sum \mathrm{j}\mathrm{P}_j \times \ln{(P_j)}}{\ln{(J)}}$$

P_j = the proportion of total land area of jth land-use category found in the tract being analyzed

J = total land uses considered in the study area

Since, the entropy is normalized using natural logarithm of the number land uses, its value lies between 0 and 1 where 0 represents homogenous land use and 1 represent high diversity of land use.

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3.Design

The research used the existing land use plan as a data source. Intersection density, and length of walkable/ cyclable path are measurement variables to study the design aspect of TOD. The study of the design is focused on the walkability of the street.

Intersection density is also used to measure walkability of the streets and street block. It calculates the number of junctions per km^2 from the road network data (plan). High intersection density indicates shortest walking distance.

Length of walkable/ cyclable path (cycling and walking friendly design) measures the number of pedestrian, and cycle-accessible roads near each designated transit station. The road network plan and observation were used as data gathering method.

4. Destination accessibility

Or land use mixedness measures the land use mixedness of residential land use with other land use of the selected sites. The existing land use plan from previous section used as data source to study destination accessibility. Zhang and Guindon's land use mixedness equation was used.

$$MI(i) = \frac{\sum_j L_o}{\sum_j L_r + \ L_o}$$

MI - land use mixedness, Lo - non-residential land use for each TSC j, Lr - residential land use for each TSC j. MI values may range from 0 to 1, MI value of 0.5 suggesting a 50/50 split between residential and non-residential land uses.

A spatial multi-criteria analysis (SMCA) was used as an analysis method to calculate and analyze the TOD index. Since all indicators have different units, maximum method was used to standardize the indicator with equal weight.

For research question two, the data gathered from semi-structured interview analyzed and interpreted using Microsoft excel and a correlation analysis method was used to identify the relation exist between transit-oriented development (indicators) and Addis Ababa light rail transit ridership using SPSS. TOD Index vs total passenger (Average daily passenger) Density vs boarding passenger (Average daily passenger at peak hour) and distance to transit vs boarding passenger at peak hours at peak hours. For Research Question three, Secondary data analysis of successful TOD implementations in other cities used to derive lessons for Addis Ababa.

CHAPTER FOUR

4. RESULT AND DISCUSSION

In this section the data collected from both primary and secondary source is presented and analyzed in accordance with the research questions.

4.1. The integration of TOD principles with AALRT

To study to what extent TOD principles are integrated with AALRT (with the designated AALRT stations), the existing land use and road network were studied priorly. The existing land use and road network map was used to evaluate the implementation of TOD principles; density, diversity, design, destination accessibility, and distance to transit to the selected LRT stations (Ayat, CMC, Megenagna, and Mexico stations). The existing land use of the selected station is presented in the following maps:

1. Mexico Station

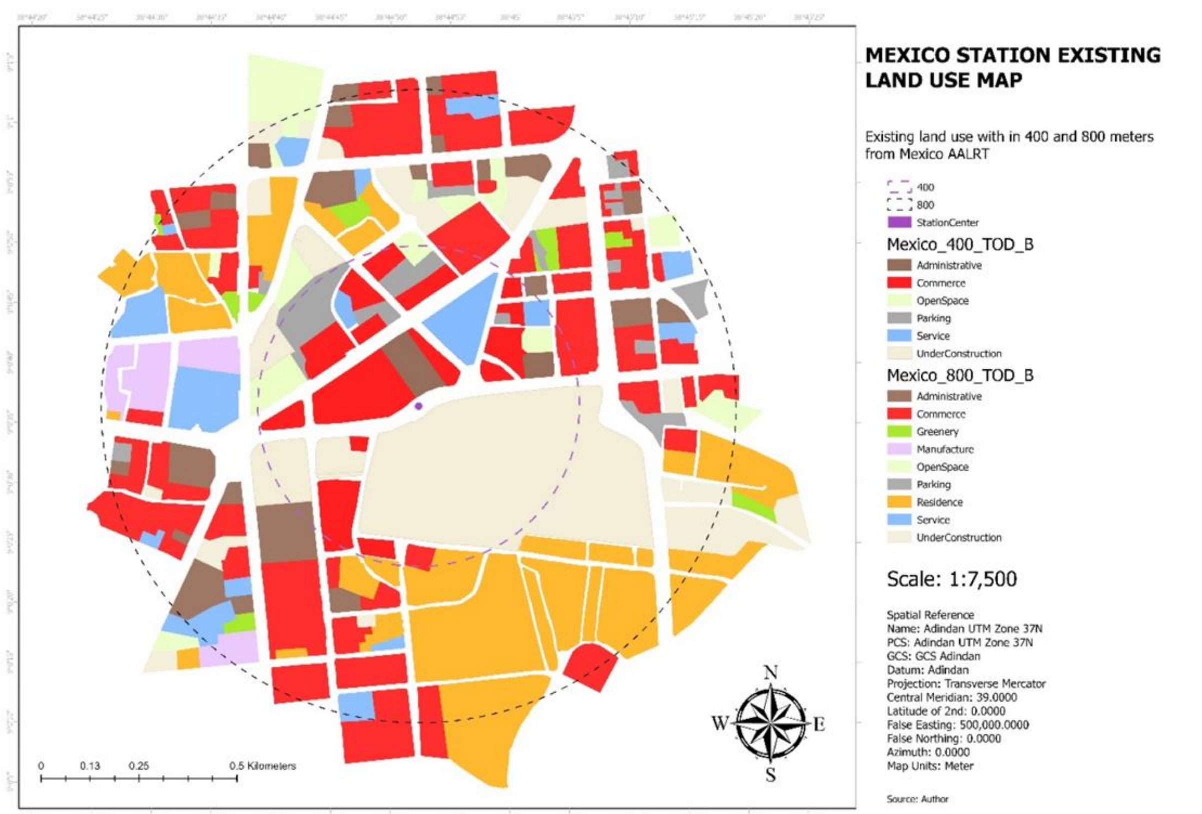

Figure 4.1 Mexico Station existing land use within distance 400 and 800 meters from the station center

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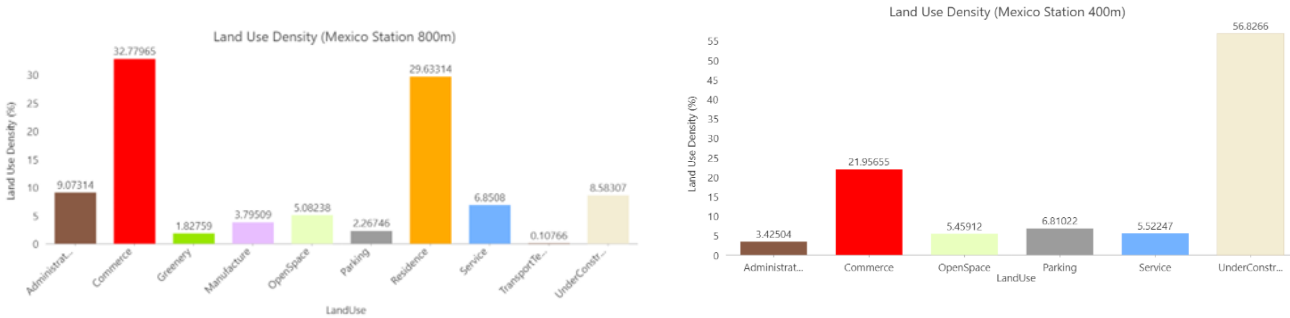

Figure 4.2 Mexico Station Land Use Density with in 400 and 800m from the station center

The figures 4.1 and 4.2 present an analysis of land use distribution around Mexico Station within 400 meters and 800 meters TOD influence zone. The 400m TOD influence zone has a high concentration of commerce and administrative land use with zero percent of residence land use indicating that the area serves as a commercial and business hub. The 800m TOD influence zone shows a mix of commercial, residential, and open spaces, suggesting a transition from a business-dominant 400m TOD influence zone to more diverse land uses. The high percentage of under-construction land in both zones suggests ongoing urban development and expansion around Mexico Station.

2. Megenagna Station

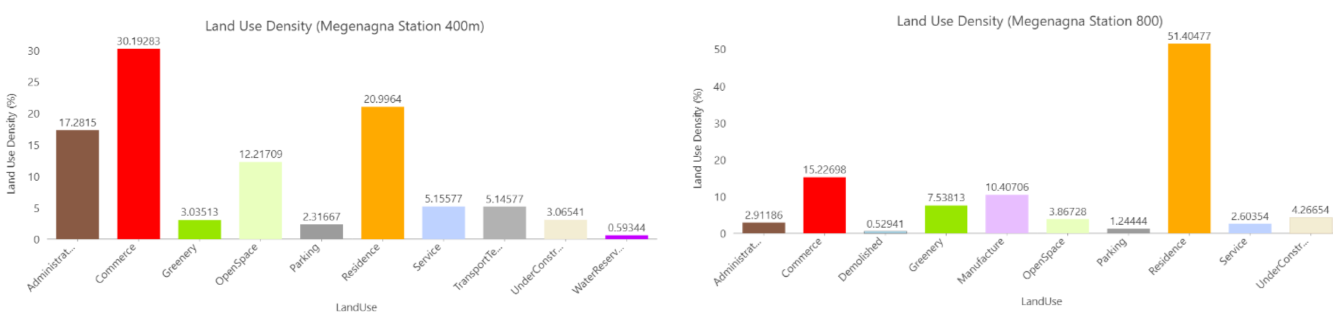

Figure 4.3 Megenagna Station Land Use Density with in 400 and 800m from the station center

The figures 4.3 and 4.4 analyze the land use distribution around Megenagna Station within 400 meters and 800 meters TOD influence zone. The land use density analysis reveals diversity in land utilization intensity within 400m and 800m zones. Within 400 meters TOD influence Commerce land use with 30.79% dominates the area, indicating that Megenagna serves as a major commercial hub. Open space (12.22%) and residential areas (20.39%) show a balanced mix of business and living spaces. Administrative buildings, parking, and service areas exist but

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have lower density, suggesting that business and housing functions take precedence over institutional land use. Within 800 meters TOD influence zone the residence land use is the dominant with 51.4 % and commerce land use (15.2) with the second dominant land use in the area. Demolished and manufacturing areas exist but are not dominant, suggesting redevelopment projects in progress.

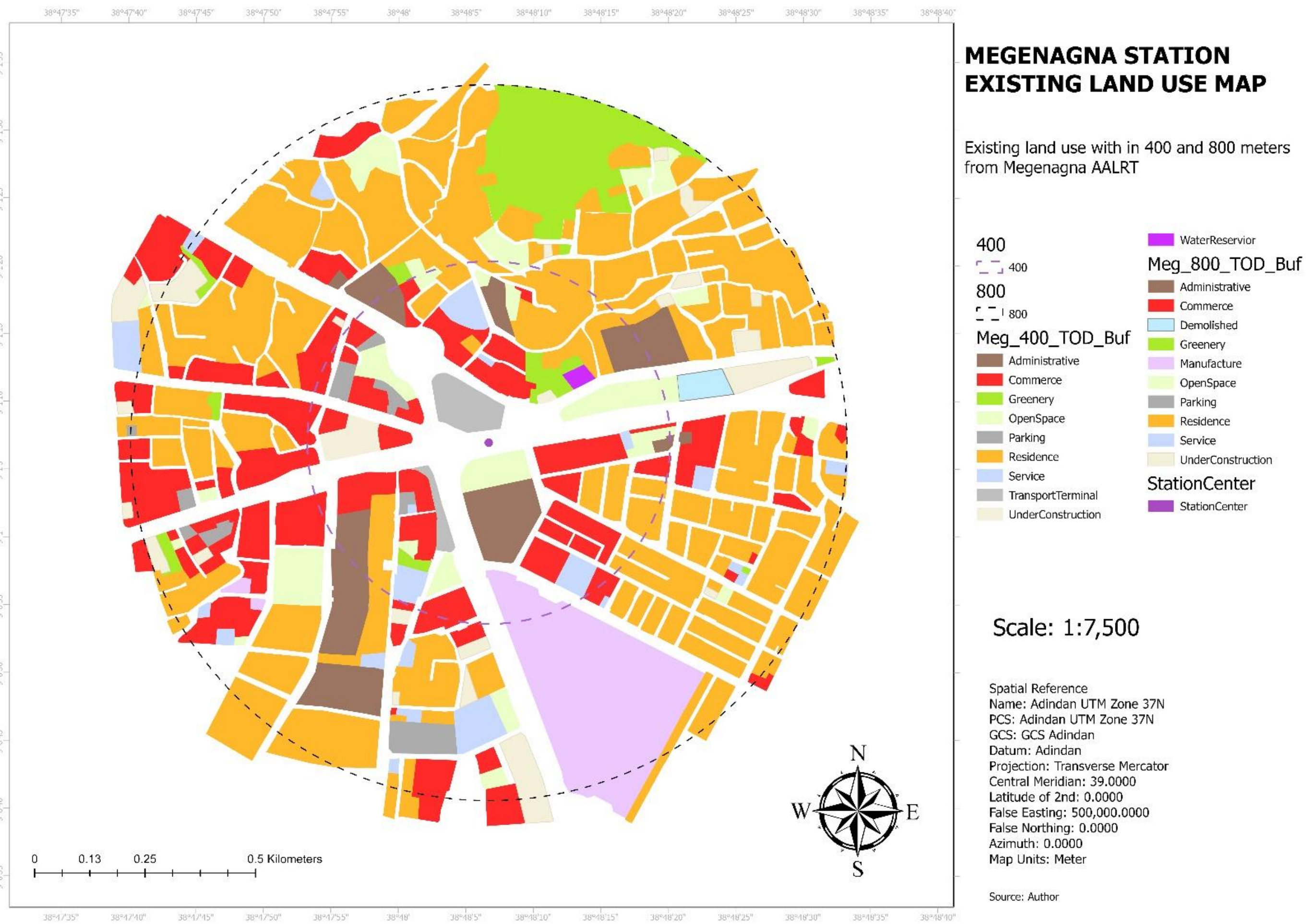

Figure 4.4 Megenagna Station existing land use within distance 400 and 800 meters from the station center

3. CMC Station

The figures 4.5 and 4.6 illustrate land use distribution in the CMC Station area, analyzing how different land types are utilized within 400 meters and 800 meters TOD influence zone. The 400 meters TOD influence zone is heavily residential with smaller commercial and service areas scattered around. Residence land use with 56.00% is the dominant land use, suggesting that CMC primarily serves as a residential area near the station. Commerce (1.79%) is also present but

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significantly lower than residential use, indicating some commercial activity but not a business-dominated hub. Greenery (4.62%) and open spaces (3.95%) contribute to a more balanced urban environment. Service-related land (1.72%) suggests the presence of essential urban amenities such as schools, or public services. Within the 800 meters TOD influence zone the residence (48.22%) remains the dominant land use, confirming that the area is primarily residential at a wider radius. Commerce (6.44%) shows that commercial functions exist but do not define the land use pattern. Manufacturing and under-construction areas exist but play a minor role in the station's overall land use.

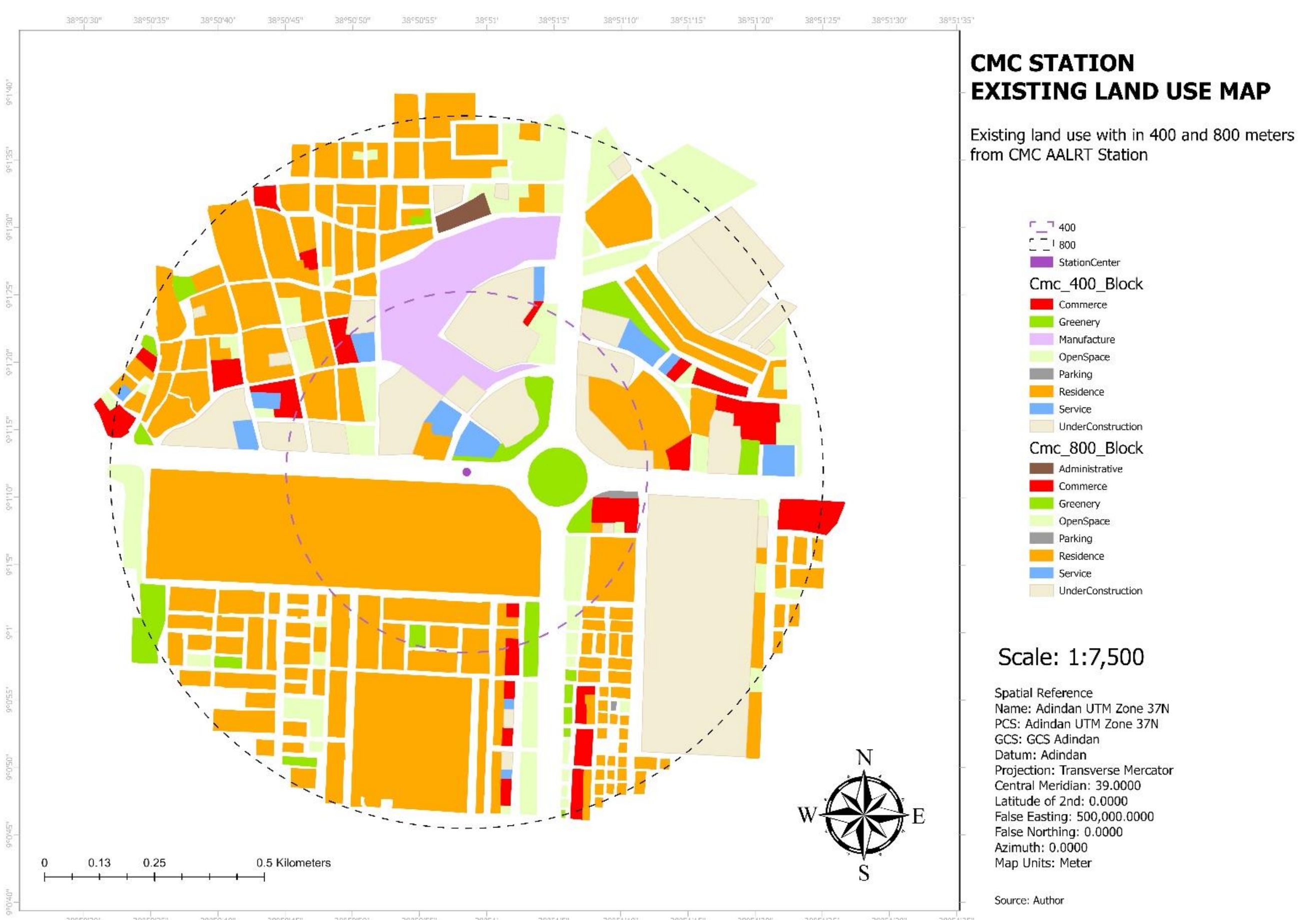

Figure 4.5 CMC Station existing land use within distance 400 and 800 meters from the station center

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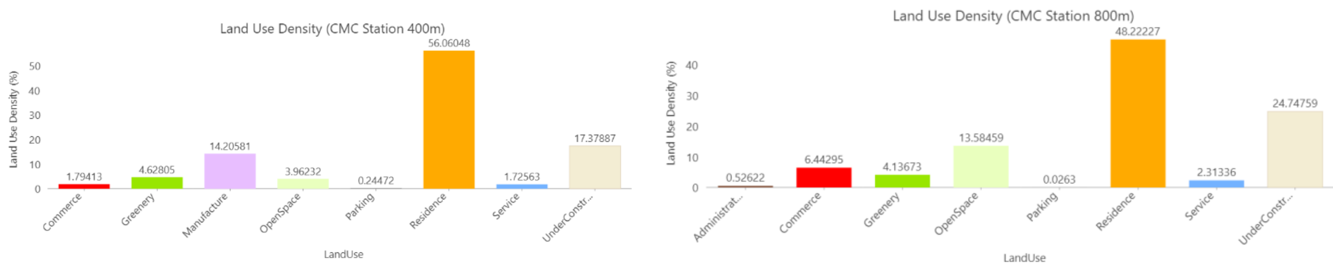

Figure 4.6 CMC Station Land Use Density with in 400 and 800m from the station center

4. Ayat Station

Figure 4.7 and 4.8 illustrate the existing land use and land use density within 400- and 800-meters TOD influence zone of Ayat Station. In both TOD influence zones 400 and 800 meters the residence is the dominant land use with 53.3% and 53.7 land use coverage respectively. Green space and open areas, while present, they are relatively low in percentage. Commerce land use relatively has the same coverage of land use in both TOD influence zones.

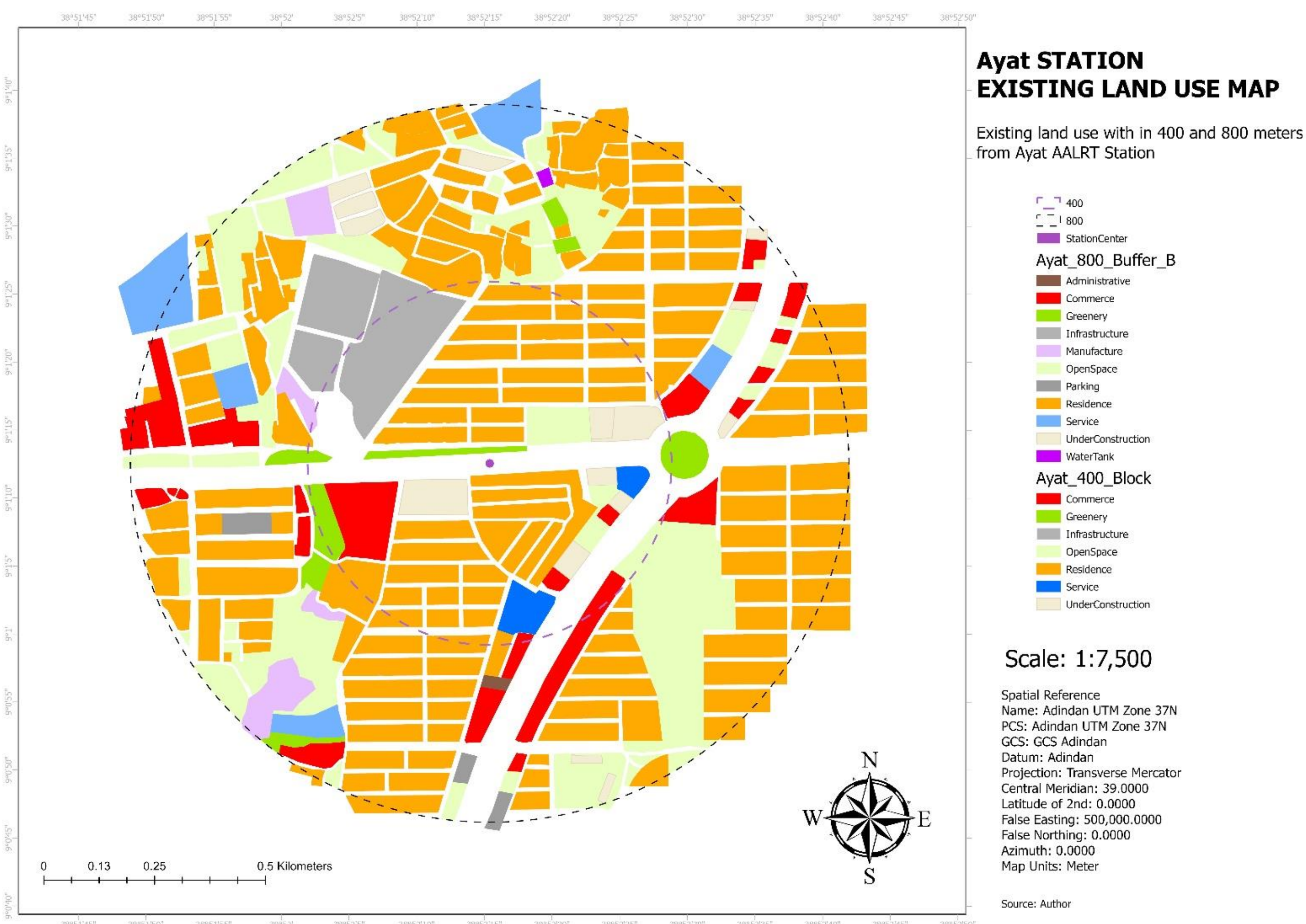

Figure 4.7 Ayat Station existing land use within distance 400 and 800 meters from the station center

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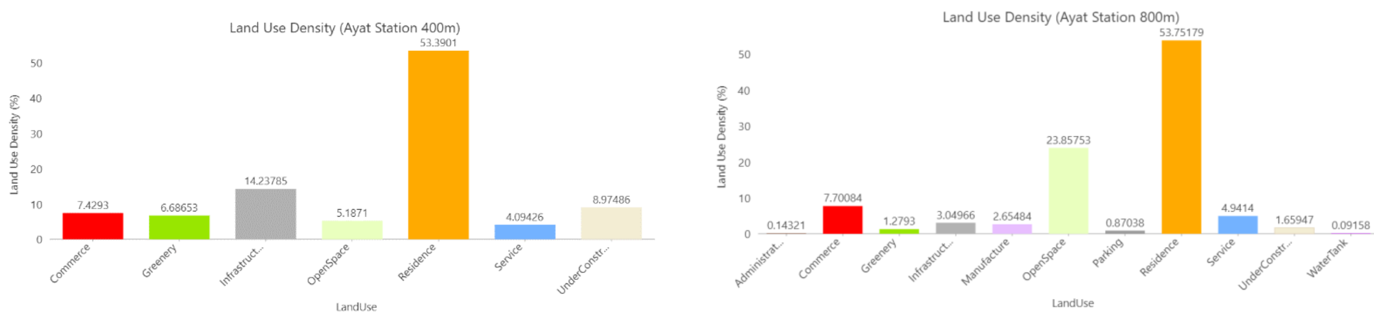

Figure 4.8 Ayat Station Land Use Density with in 400 and 800m from the station center

4.1.1 Residential and Commercial Land Use Density

Gross density used to calculate the density of commercial and residential land use with in the TOD influence zones. (400 and 800m) The commercial and residential land use density for each station is presented in the following table and maps.

Name of Station	Residence Density %		Commerce Density %	
TOD Influence Zone	400m	800m	400m	800m
Mexico Station	0	29.63	21.95	32.78
Megenagna Station	21	51.4	30.19	15.22
CMC Station	56.06	48.22	1.79	6.44
Ayat Station	53.39	53.75	7.43	7.7

Table 4.1 Residential and commercial density

Table 4.1 indicates a high density of residences at Ayat station, and the density gets lower at CMC, Megenagna, and Mexico station, respectively.

In the 400m TOD influence zone Ayat station and CMC station have the highest residence density and Mexico station has the lowest. In the 800m TOD influence zone Megenagna and Ayat station has the highest residence density. On the contrary, Mexico station has the highest commerce density within the 800m TOD influence zone and Megenagna station has the highest commerce density within 400m TOD zone.

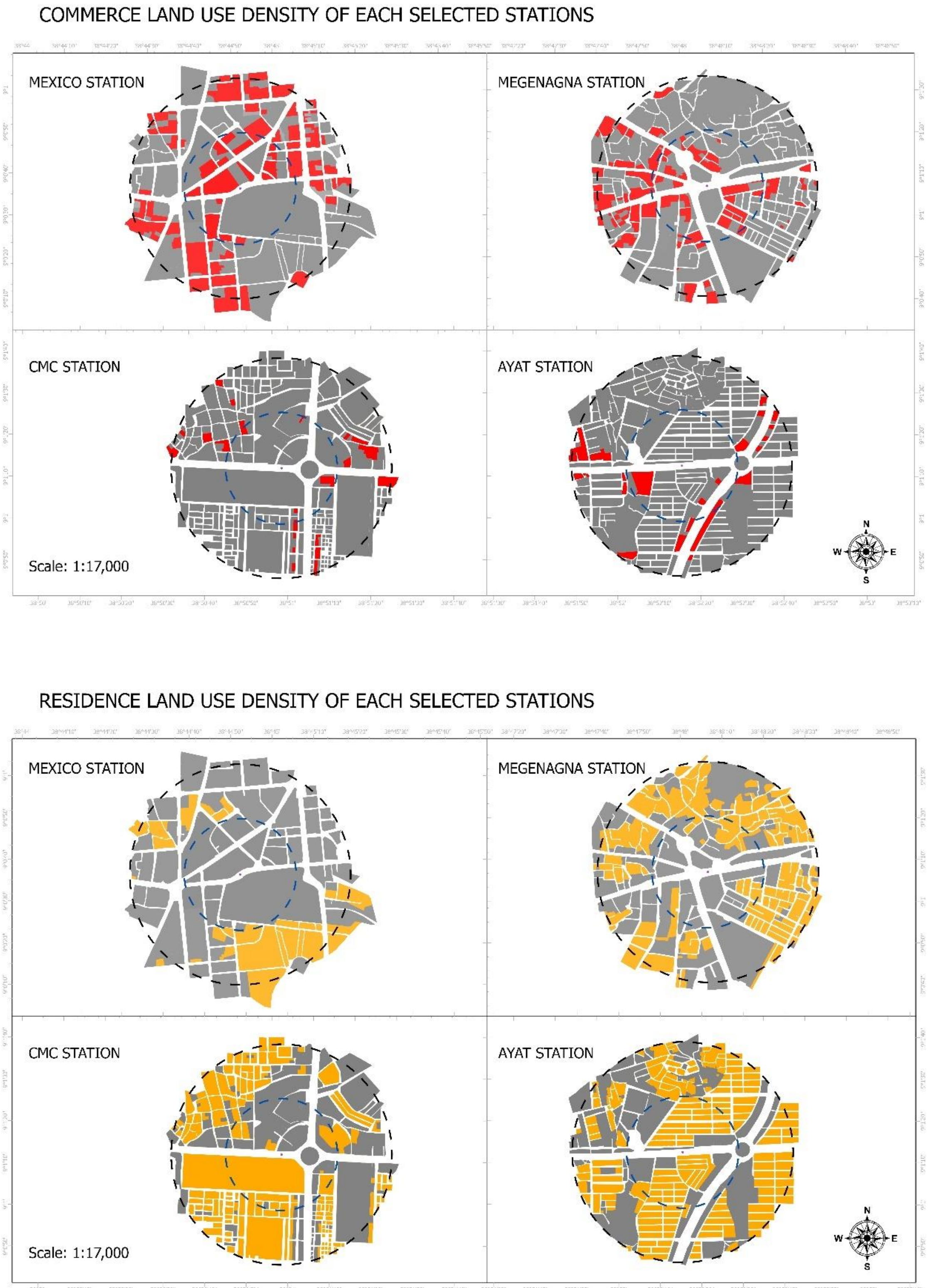

Figure 4.9 Commerce and residence density

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4.1.2 Land Use Diversity

The land use diversity of the study area was studied using the Shannon Entropy index. If the value of the index is equal to 0 it shows homogeneity and if it is equal to 1 it shows diversified land use within the area. To study the diversity six land uses are included administrative, commerce, residence, greenery, service, and manufacture. As Table 4.2 shows from the 400-meter TOD influence zone Megenagna has the most diversified land use and Mexico has the most diversified land use within 800-meters TOD influence zone.

Land Use Diversity Index		
TOD Influence Zone	400m	800m
Mexico Station	0.43	0.78
Megenagna Station	0.76	0.73
CMC Station	0.48	0.45
Ayat Station	0.46	0.48

Table 4.2 Land Use Diversity Index

4.1.3 Design

1. Intersection Density

Number and density of intersection with in the TOD influence area (400m and 800m) is calculated for each designated station. High intersection density indicates more walkable street. CMC and

Station Name	**Number of Intersection**		**Intersection Density per km^2**	
	TOD Influence Zone			
	400m	800m	400m	800m
Mexico Station	35	50	70	33.3
Megenagna Station	77	146	154	97.3
CMC Station	35	223	70	148.6
Ayat Station	64	168	128	112

Table 4.3 Number or intersection and intersection density

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Megenagna station have highest number of intersection and intersection density, it shows a walkable street.

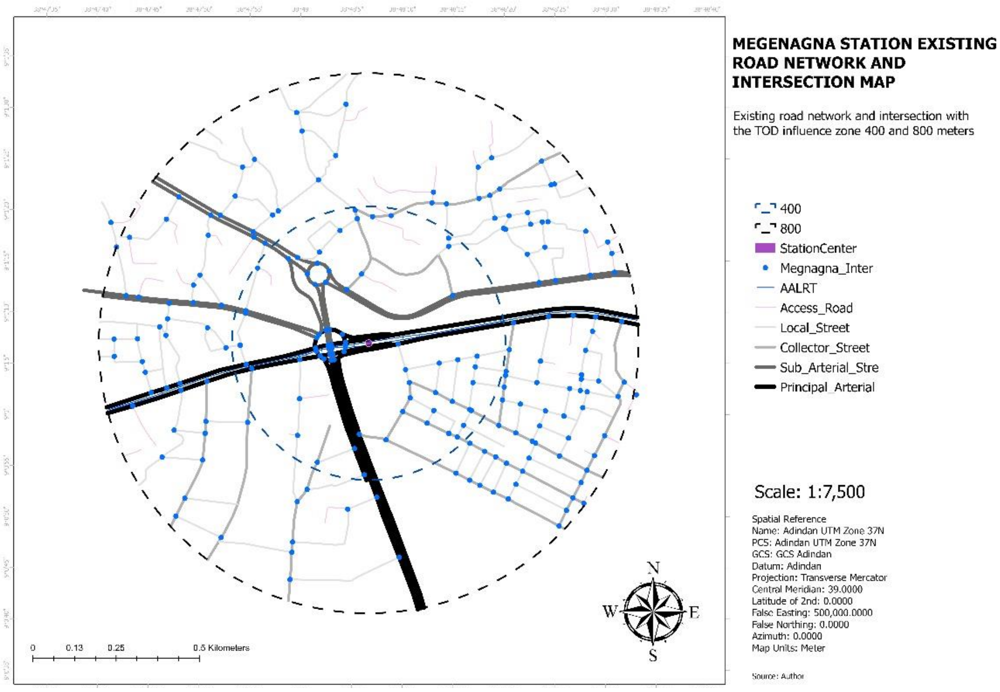

Figure 4.10 Megenagna existing road network and intersection with in 400 and 800 meters from the station

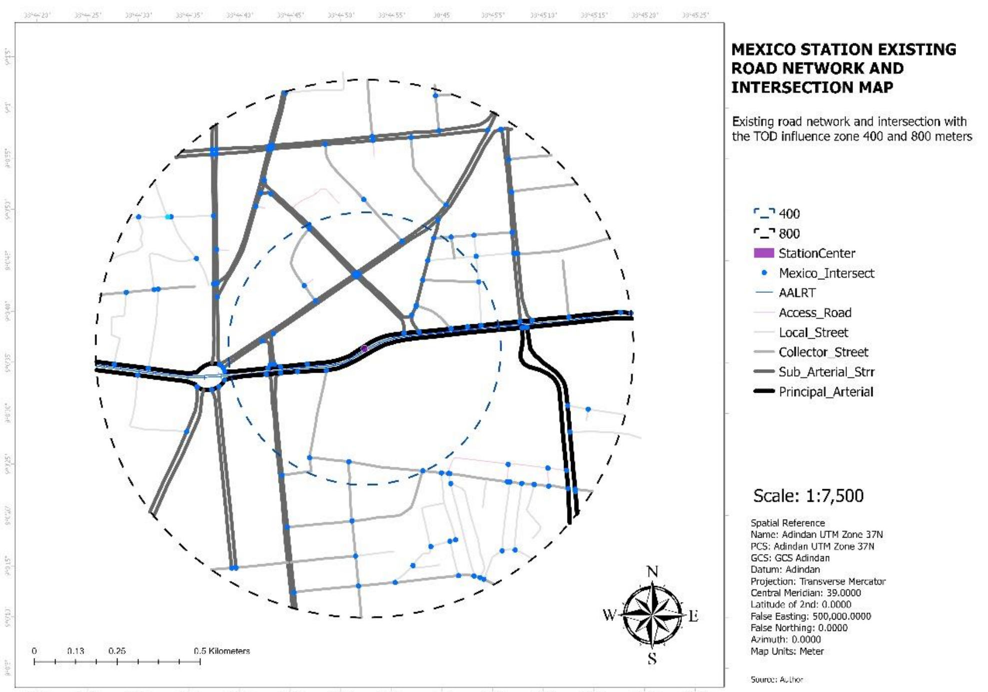

Figure 4.11 Mexico existing road network and intersection with in 400 and 800 meters from the station

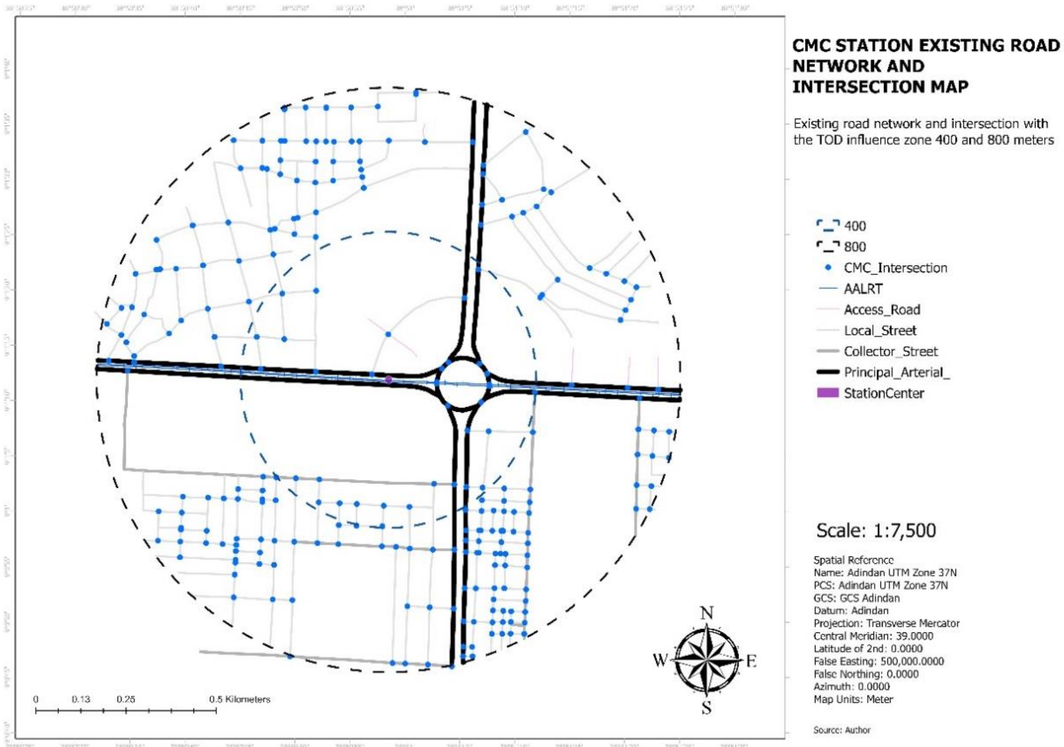

Figure 4.12 CMC existing road network and intersection with in 400 and 800 meters from the station

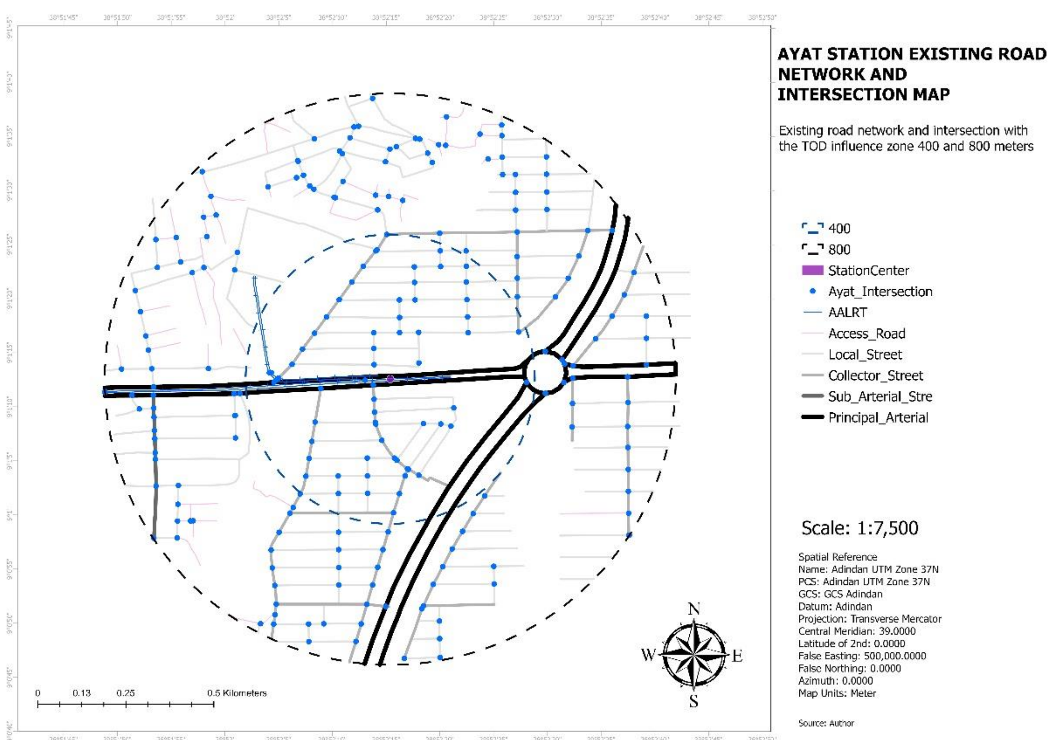

Figure 4.13 Ayat existing road network and intersection with in 400 and 800 meters from the station

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2. Total length of walkable/ cyclable path

Total length and number of streets that are comfortable for pedestrian was calculated within the TOD influence zone excluding major road with high traffic speed.

Station Name	Total length of walkable path	
	400	800
Mexico	3.17KM	11.53KM
Megenagna	5.31KM	18.99KM
CMC	3.25KM	24.32KM
Ayat	8.22KM	24.59KM

Table 4.4 Total length of walkable path

Stations with highest total length of walkable path are considered as walkable areas and vice versa. Ayat station is containing more walkable streets than other station.

4.1.4 Destination Accessibility

Residence land use mixedness with six other land use (Commerce, Administrative, manufacture, Greenery, Service, and Open space) was studied. A value equal to 0.5 or close to 0.5 indicates 50 50 mixedness of residential with non-residential land use. CMC and Megenagna stations have highest mixedness in 400m and 800m TOD influence zone respectively.

Land Use Mixedness Index		
TOD Influence Zone	**400**	**800**
Mexico Station	1	0.8
Megenagna Station	0.84	0.45
CMC Station	0.58	0.4
Ayat Station	0.28	0.39

Table 4.5 Land use mixedness index

TOD Index of area within 400 meters								Rank
Weight	1/6	1/6	1/6	1/6	1/6	1/6		
Station Name	Commerce Density	Residence Density	Land Use Diversity	Intersection Density	Total Walkable Path	Land Use Mixedness	TOD Index	
Mexico	0.72	0	0.56	0.45	0.38	0.28	0.41	4
Megenagna	1	0.37	1	1	0.64	0.33	0.74	2
CMC	0.05	1	0.63	0.45	0.39	0.48	0.51	3
Ayat	0.24	0.95	0.59	0.83	1	1	0.78	1

Table 4.6 TOD index of stations within 400-meters

TOD Index of area within 800 meters								Rank
Weight	1/6	1/6	1/6	1/6	1/6	1/6		
Station Name	Commerce Density	Residence Density	Land Use Diversity	Intersection Density	Total Walkable Path	Land Use Mixedness	TOD Index	
Mexico	1.00	0.55	1.00	0.22	0.46	0.48	0.63	4
Megenagna	0.46	0.96	0.94	0.65	0.77	0.86	0.79	1
CMC	0.20	0.90	0.58	1.00	0.96	0.97	0.78	2
Ayat	0.23	1.00	0.62	0.75	1.00	1	0.78	2

Table 4.7 TOD index of stations within 800-meters

Table 4.6 and 4.7 presenting the TOD (Transit-Oriented Development) Index for the selected stations within 400 meters and 800 meters. Using spatial multiple criteria evaluation all TOD indicators are standardized using the maximum method and equally weighted (1/6). The lowest TOD index value shows less integration of indicators and the highest value indicates more integration of indicators with AALRT. In 400m TOD influence zone Ayat station has the highest TOD index and in 800m TOD influence zone Megenagna has the highest TOD index. In both TOD influence zones Mexico station has the lowest index. As shown in the tables TOD index of areas with 400 meters from the stations is lower than to areas with 800 meters from the stations. It can be concluded that the TOD indicators (density, diversity, design, and destination accessibility) are more integrated or implemented within 800-meter TOD influence zone.

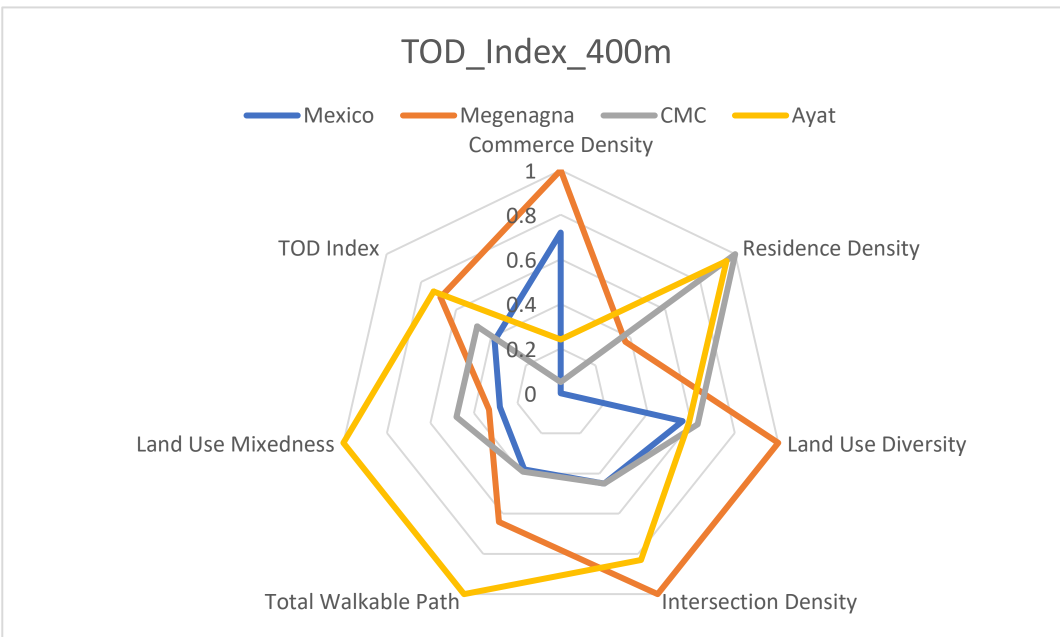

Figure 4.14 Web diagram for TOD Index 800m influence zone

Figure 4.8 illustrate the web diagram representation of the TOD indicator (residence and commerce land use density, land use diversity, land use mixedness, total walkable path, and intersection density) index with 400 meters TOD influence zone for each selected station. In this influence zone CMC Station has the highest residence density index, Megenagna station has the highest commerce density, land use diversity, and intersection density index. Ayat station has the highest land use mixedness and highest total walkable path relative to other stations.

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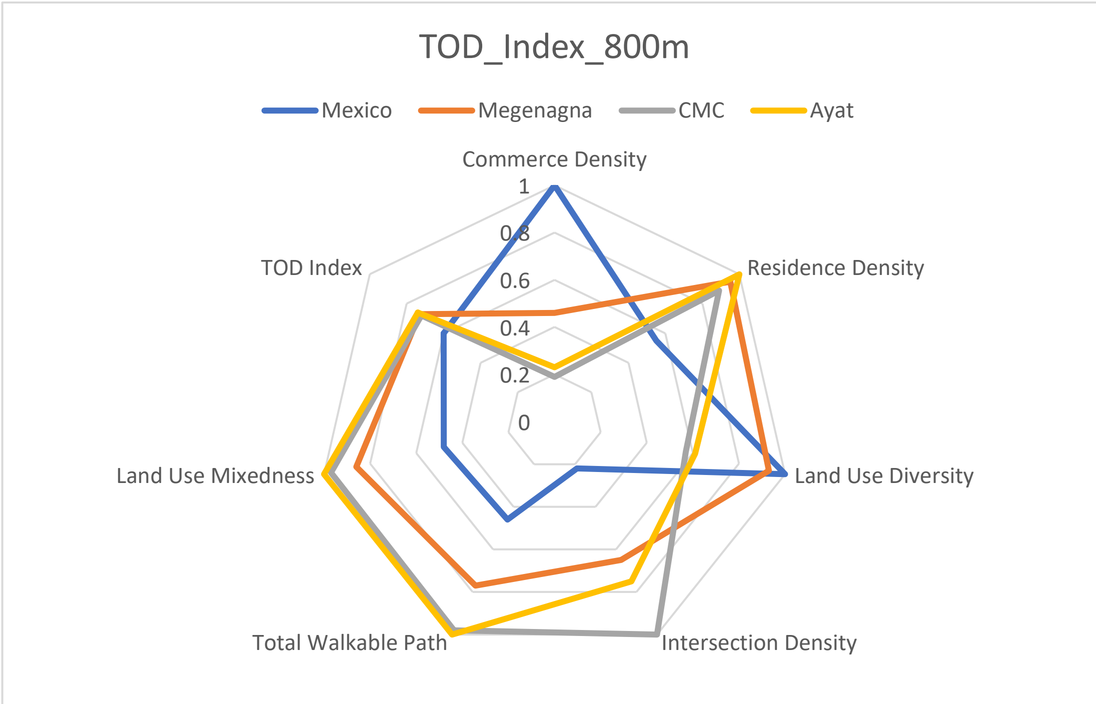

Figure 4.15 Web diagram for TOD Index 400m influence zone

Figure 4.9 illustrate the web diagram representation of the TOD indicator (residence and commerce land use density, land use diversity, land use mixedness, total walkable path, and intersection density) index with 800 meters TOD influence zone for each selected station. In this influence zone Ayat Station (1) has the highest residence density index followed by Megenagna (0.96) and. CMC (0.9) station. Ayas station also has the highest land use mixedness and total walkable path. CMC station has the highest intersection density and Mexico station has the highest commerce density and land use diversity relative to other station.

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4.1.5 Validation

A sensitivity analysis was used to measure the robustness of the results. This research used equal weighting for the TOD indicators to calculate the TOD index. To check the robustness of the result (TOD index value) each criterion's weight was adjusted by 10%, and the weights of others were accordingly changed because the sum of the weights never exceeded 1. Accordingly, four scenarios were produced, in the first scenario weight of density (residence and commerce density) was increased by 10 %, in the second scenario the weight of diversity was increased by 10%, in the third scenario the weight of design (intersection density and Total walkable path) was increased by 10%, and the last scenario the weight of destination accessibility (land use mixedness) was increased by 10%. The average error percentage in 400 and 800 TOD influence zones is 1.78% and 1.98% respectively. In all four scenarios, the maximum and the minimum TOD index remain the same. Consequently, it shows that the TOD index value presented by this research is robust.

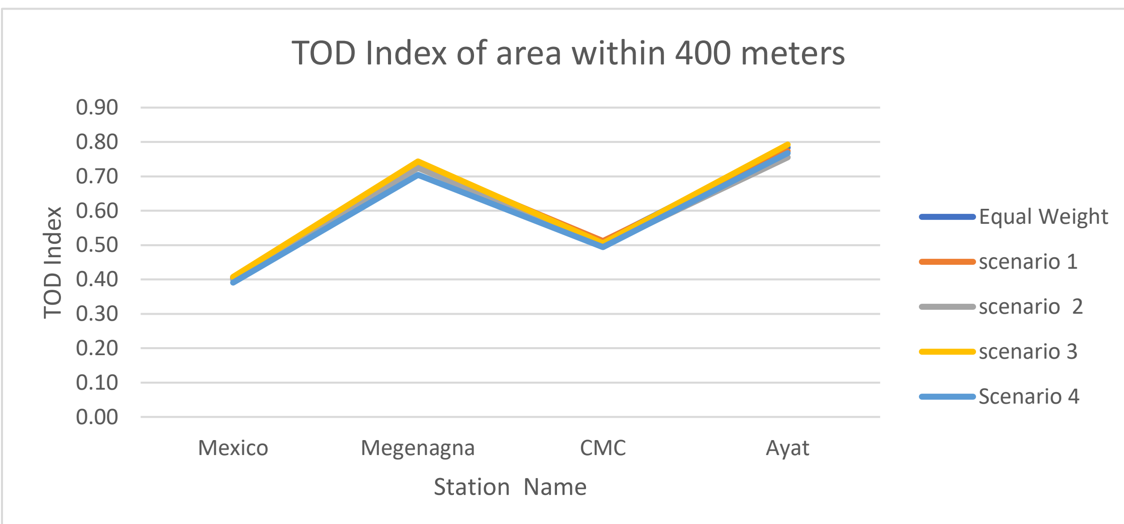

Figure 4.16 The TOD index value in four scenarios with 400 meters TOD influence zone

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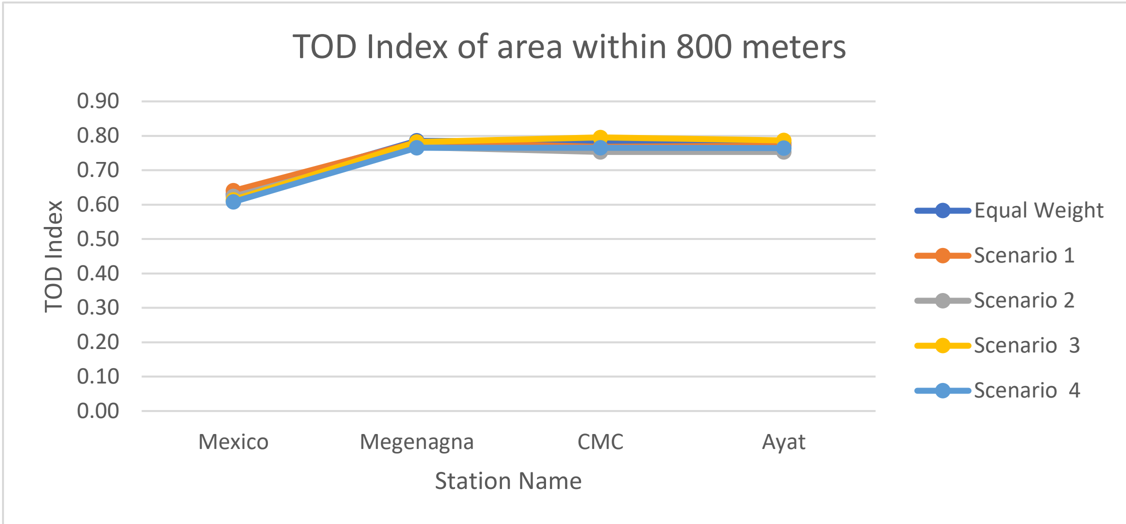

Figure 4.17 The TOD index value in four scenarios with 800 meters TOD influence zone

4.2. AALRT Ridership at Designated Stations

4.2.1 Average daily ridership and ridership at peak hour

The average daily ridership at Mexico, Megenagna, CMC, and Ayat station obtained from AALRT transport department and the average daily passenger at peak hour (6:30AM – 9:00AM EAT) was counted at the stations.

Station Name	Average Daily Passengers	Average Daily Passenger at Peak Hour
Mexico	380	102
Megenagna	1408	285
CMC	557	165
Ayat	3074	1280

Table 4.8 Average daily passenger and average daily passengers at peak hour

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According to the data presented on Table 4.9 the correlation between passenger flow and average TOD index shows high and significant correlation. Passenger flow increase as TOD index value increases. Ayat station has the highest index correspondingly highest daily passenger. On Contrary Mexico Station has the lowest TOD index congruently lowest passenger flow.

Station Name	TOD Index			Average Daily Passenger
	400m TOD Influence Zone	800m TOD Influence Zone	Average	
Mexico	0.41	0.63	0.52	380
Megenagna	0.74	0.79	0.77	1408
CMC	0.51	0.78	0.65	557
Ayat	0.78	0.78	0.78	3074

Table 4.9 TOD index vs Average daily passenger

As table 4.10 point out the correlation between residence density index and passenger flow at peak hour shows moderate correlation. In the case of Ayat station and Mexico station as residence density increases as passenger flow at peak hour increases and as residence density decreases as passenger flow at peak hour decreases respectively. In the case of Megenagna station though has a lower residence density than CMC station, has more passenger flow at peak hours than CMC station. This indicates that residence density is not the only factor to impact passenger flow at peak hours.

Name of Station	Residence Density %			Average Daily Passenger at Peak Hour
TOD Influence Zone	400m	800m	Average	
Mexico Station	0	0.09	0.05	102
Megenagna Station	0.06	0.16	0.11	285
CMC Station	0.17	0.15	0.16	165
Ayat Station	0.16	0.17	0.17	1280

Table 4.10 Residence density vs average daily passenger at peak hour

4.2.2 Ridership Flow Within and Outside of TOD Influence Zone

This sub-section aims to understand the impact of distance to transit on the utilization of the LRT. From the passengers who utilized the AALRT at peak hours the number of passengers within the TOD influence area was determined using a structured interview (see Appendix 2). The purpose of the trip and transportation mode used to access the LRT station was also studied. The interview was done with ten percent of the average daily passengers at peak hours. The following chart shows the number of passengers who utilized the AALRT from and outside of the TOD influence zone. Passengers within the TOD influence zone and outside the TOD zone are represented as residents and visitors respectively.

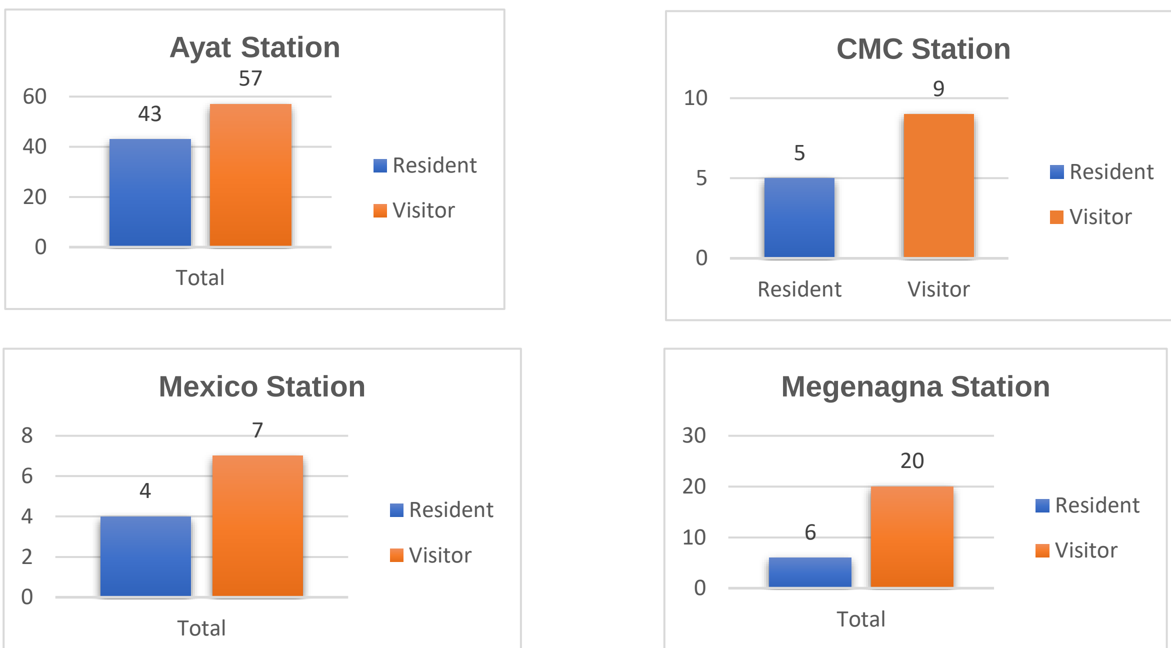

Figure 4.18 Passengers flow within and outside TOD influence zone

As the above diagram points out the passenger flow outside of the TOD influence zone is higher than the passenger flow within the TOD zone. Ayat station has 43%, CMC station has 35.7%, Megenagna station has 23.1%, and Mexico has 36.4% of passengers flow within the TOD influence zone at peak hours.

According to the interviewee responses, the visitor passengers at Ayat station are from Tafo condominium, Arabesa condominium, Ayat 49, Summit 72, and Yeka condominium; at CMC station are mostly from Summit condominium and some are from Feyel Bet and Koteb, at

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Megenagna station are mostly from Goro, Gergi, Koteb, Kara and some are from 4 kilos, Addis Gebeya, Semien hotel and Francaye; and at Mexico Station from Jemo, St. Lideta, Tor Hiloch, Kera, and kore. According to the result of the interview, Passengers of the AALRT at peak hours use different transport modes to access the LRT station (see Appendix 3). 41%, 36%, 16%, and 27% of passengers at Ayat, CMC, Megenagna, and Mexico stations respectively at peak hours walks to access the LRT station.

The daily passengers at peak hours are not merely affected by the residence density within the TOD influence zone and distance to transit but also the connectivity of the station with other potential trip-generating (high-density residence) areas.

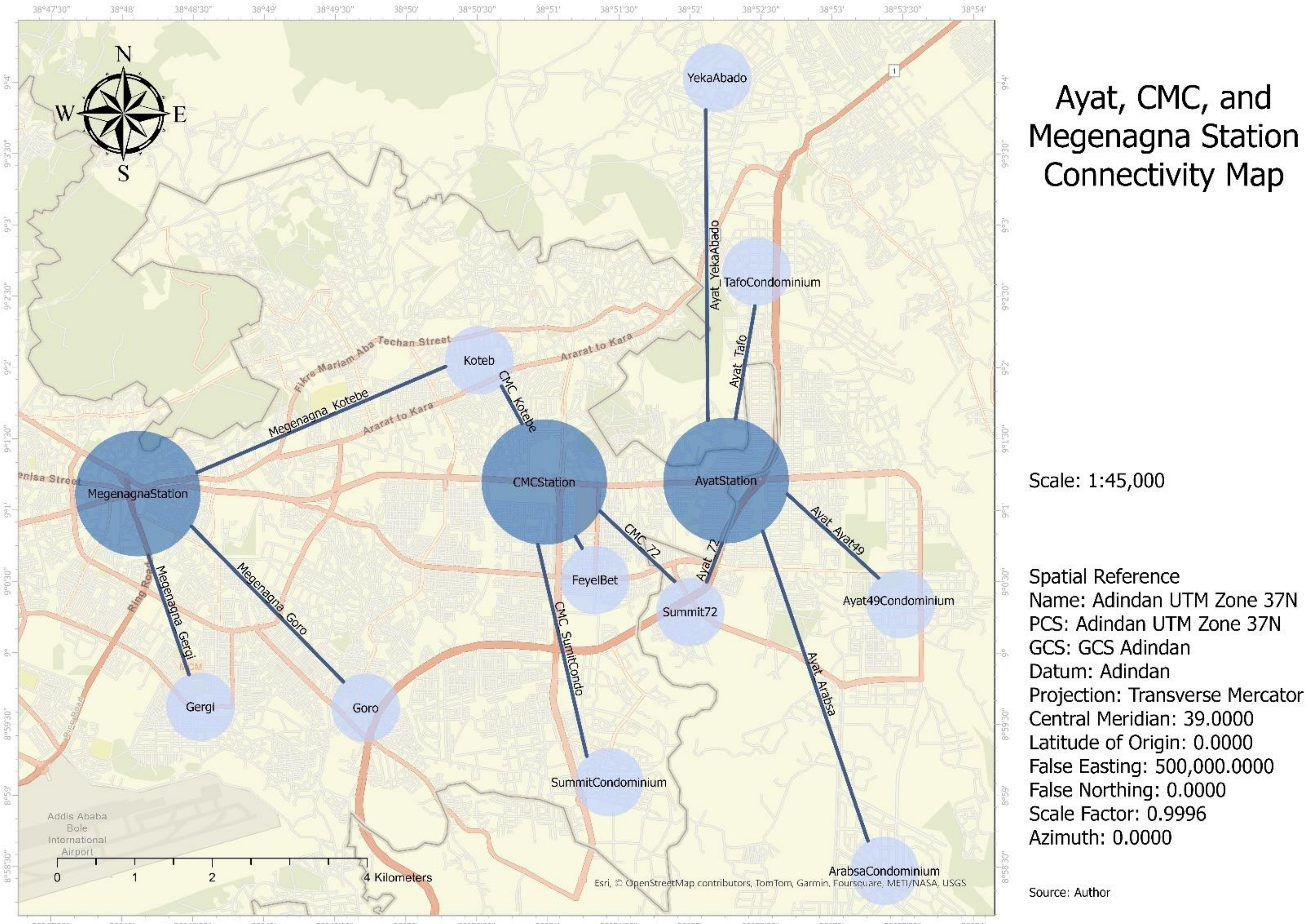

Figure 4.19 Connectivity Map

4.3. Lesson learned from successful TOD implementation in other cities.

Curitiba, Singapore, Japan, and Hong Kong each offer unique approaches to transit-oriented development (TOD), emphasizing density, mixed-use development, and public transport accessibility.

Curitiba: Used TOD to increase annual ridership (from 2.3% to 46%.) by zoning land for mixed-use near public transport stations, implementing structural axes with high-density development along BRT corridors, very little parking, and offering innovative incentives for regeneration and development. They also focused on attracting foreign investment through tax incentives (exemption from VAT and property tax). To dedicate an institution responsible for research, planning, implementation, and supervision was another factor for its success. The city allows for additional development only through the purchase of development certificates which were used to raise revenue for the development of BRT.

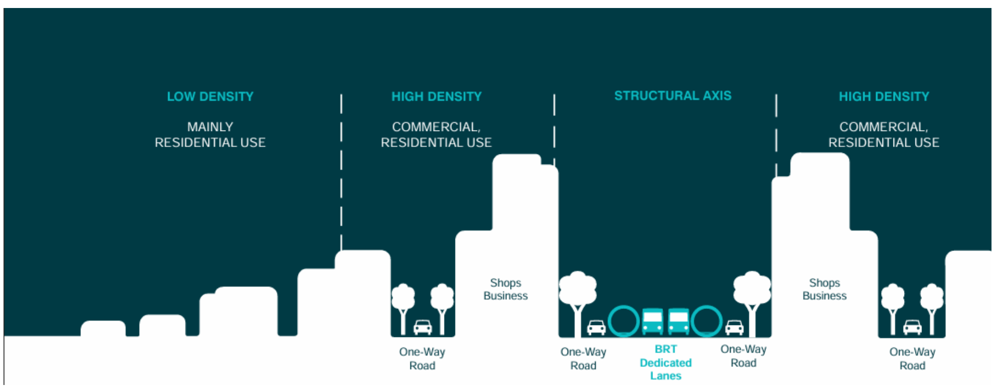

Figure 4.20 Curitiba Section through transport corridor

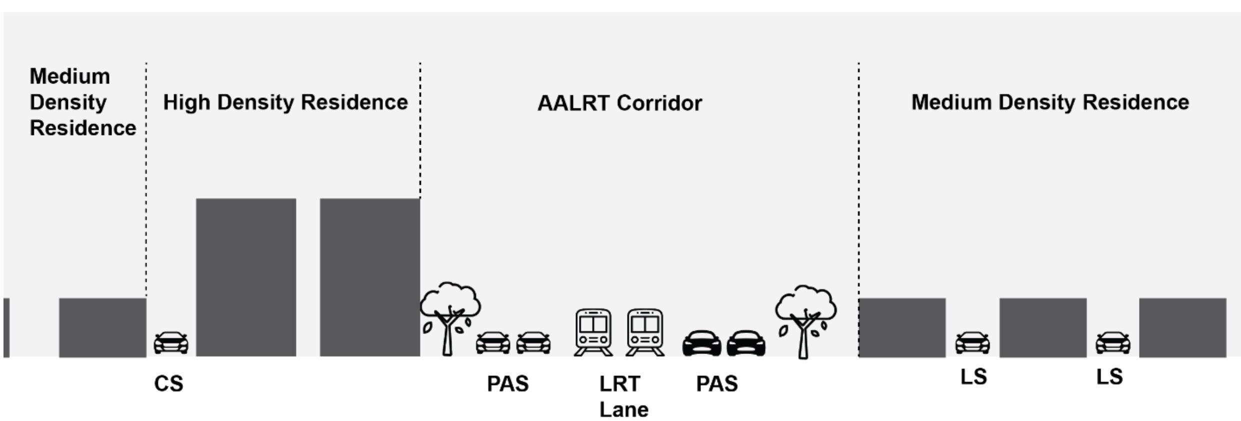

Figure 4.21 Section through transport Corridor at Ayat station

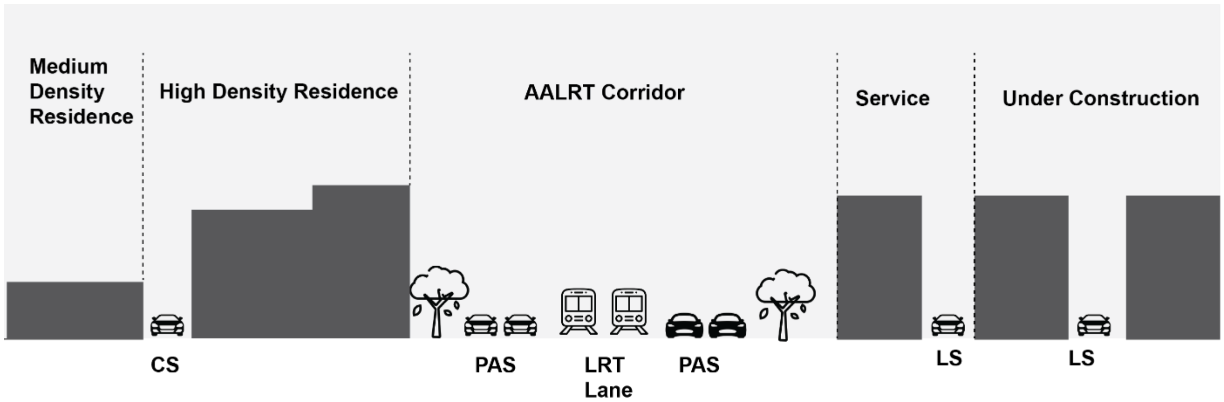

Figure 4.22 Section through transport Corridor at CMC station

In the above figure show section through transport corridor at Ayat and CMC station, comparing with Curitiba it can be learned that the integration commercial density adjacent to the transport corridor is essential in boosting ridership.

Singapore: Depends on a vast public transportation system and densely populated areas surrounding transit corridors, town centers, and transportation interchanges. Walkability is emphasized through the Walk2Ride program, and open spaces are preserved within built-up areas. The city used an innovative method to encourage the usage of public transport through the implementation of a certificate of entitlement which costs $80,000 before a car owner can drive a vehicle in Singapore and is only useful for 5 or 10 years.

Japan: Private transit operators in Tokyo developed high-density areas around transit lines, making stations accessible by foot, bus, or subway. High gas prices, limited parking, and narrow roads discourage private vehicle use, making mass transit more attractive.

Hong Kong boasts a highly efficient public transportation system, with ferry services, buses, trams, trains, and a metro network facilitating over 90% of daily journeys, totaling 11 million. Notably, railways account for 41% of daily public transport travel to the mainland. Living and commercial spaces are strategically located within 500 meters of transit stations, integrating carefully planned open spaces and parks.

Institutionally, the Mass Transit Rail Corporation (MTRC), largely government-owned, manages the underground and railway networks. Through innovative financing models, such as the Rail + Property (R+P) model, MTRC captures real estate income to fund transit infrastructure. This approach emphasizes development density and focuses on designing stations as hubs for diverse, densely populated communities, guided by the principles of Density, Diversity, and

Design (3Ds). Continuous review and evolution of transit-oriented development (TOD) typologies ensure Hong Kong's transit system remains adaptable and supports a healthy lifestyle through station-focused public realm designs that encourage walking and cycling.

St. Paul Central Corridor: Implemented TOD zoning and regulations to shift towards more transit-friendly land uses, including mixed-use developments and reduced parking requirements. Collaboration with non-profit partners was crucial in preserving affordable housing and supporting small businesses along the corridor.

To conclude each city's success is attributed to factors, density, mixed-use development, innovative financing models, institutionalizing certain corporations responsible for planning and implementation development around public transport corridors, focused design around transit stations, and continuous review and adaptation of TOD policies to meet community goals.

4.4. Discussion

There is a research gap in studying the impact of transit-oriented development on Addis Ababa light rail transit efficiency. The efficiency of the Addis Ababa light rail transit is decreasing in the aspect of ridership annually. Though efficiency is affected by different reasons operational efficiency, service quality, and lack of financial support, the impact of transit-oriented development hasn't been studied. The research uses a quantitative research method and different data-gathering methods with respect to the research questions. The research was carried out on four selected Addis Ababa light rail transit (AALRT) stations and with 400-meter and 800-meter transit-oriented development (TOD) influence zones.

According to the 10th structural plan of Addis Ababa (Addis Ababa City Plan & Development Commission, 2023) on the integration of transit-oriented development into a land use plan, high-density mixed residences along the mass transport routes were proposed with 40% residence share. Comparing both CMC and Ayat stations with more than 40% residence density in both TOD influence zones (400 and 800 meters) and Megenagna station with 56% residence density within the 800-meter TOD influence zone Corresponds with the proposal.

The research demonstrates the daily passenger flow and passenger flow at peak hours (6:30 AM – 9:00 AM EAT) has a direct relation with the TOD index. It concludes the integration of transit-oriented development into Addis Ababa light rail transit (AALRT) contributes to boosting the AALRT ridership. Considering previous global research ((Guo et al., 2018; ITF, 2023; papa and Bertolini,2015)) and the global case studies of cities with successful implementation of transit-oriented development, it was expected that the TOD index and AALRT ridership have a direct relation. The research demonstrates unexpected results on the number of passengers who utilized the AALRT stations at peak hours. As Figure 4.16 demonstrates the number of passengers outside of the TOD zone is greater than the number of passengers within the TOD zone at all selected stations. As Nallet C (2018) discussed riders with different socio-economic profiles utilize the Addis Ababa light rail transit (AALRT), and the majority of riders are part of the lower and middle segments of Addis Ababa's middle class (middle-income civil servant-employees, small traders, low wage-earners, and small business owners). Therefore, the result indicates a shortage of affordable housing development within the TOD influence zone of the selected stations. As the connectivity map demonstrates in Figure 4.17 the majority of trips are generated from the high-density condominiums outside of the TOD zone.

Dueker and Bianco (Dueker and Bianco, 1998) indicate the flow of passengers at peak hours does not always increase with the residence density moreover the land use diversity concerns. In line with Dueker and Bianco's, the CMC station has higher residence density than Megenagna station though Megenagna station has a higher passenger flow at the peak hour. In contrast to Dueker and Bianco's, though in land use diversity Megenagna station has more diversified land use than CMC station, as discussed in the above paragraph shortage of affordable houses inside the TOD zone also affects the passenger flow.

In the research of the Challenge of Urban Mobility, A case study of Addis Ababa Light Rail, Nallet C (2018) discusses Transit that only 25% of the passengers surveyed walk to get to the LRT station and leave it. Likewise, this research found that the percentage of passengers who walk (on foot) to reach the perspective stations at peak hours is lower than other transportation mode. As discussed in the above paragraphs this result occurs due to the majority of the passenger flow at peak hours is from outside of the TOD influence zone.

The research acknowledges the following limitations, this research doesn't consider the impact of street amenities and pedestrian lane quality which might affect the street walkability from the riders' perspective who utilized the LRT.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

This section includes the conclusion of the study, recommendations to enhance the transit-oriented development at studied stations, recommendation for future studies.

5.1. Conclusion

The research aimed to delve the impact of transit-oriented development on the efficiency of Addis Ababa light rail transit. The research presents an in-depth assessment of various aspects related to transit-oriented development (TOD) principles and their integration with Addis Ababa Light Rail Transit (AALRT) and its impact on transit ridership. Lessons learned from successful TOD implementation are also included. The third section of the paper explained the approach to data collection and analysis in alignment with the research questions. The fourth section presents a comprehensive analysis of TOD integration with AALRT and TOD impact on ridership patterns, backed by data and insights from both primary and secondary sources, along with valuable lessons from successful TOD implementations globally. The conclusion drawn is presented in the following paragraphs.

Global case studies analysis draws insight from successful TOD implementation in cities like Curitiba, Singapore, Japan, Hong Kong, and St. Paul Central Corridor. It emphasizes key strategies such as density, mixed-use development, innovative financing models, and institutional framework that contribute to effective TOD planning and implementation, and using the successful implementation of TOD they managed to boost their transit ridership.

Integration of TOD principles with AALRT on designated stations was studied. The research evaluates indicators such as land use density, diversity, design, and destination accessibility, providing detailed analysis and mapping for each station. According to the TOD index on both TOD influence zones (400m and 800m), TOD indicators are more integrated to Ayat station relative to other selected stations.

The ridership pattern, daily average passenger flow, and peak hour passenger flow at selected stations were studied. The analysis correlates the passenger flow with the residence density and TOD index and found out that there is a positive relation between ridership pattern and TOD index conversely peak how passenger flow increases not only affected by residence density. The impact of distance to transit on AALRT utilization was explored. The analysis highlights distance to transit doesn't significantly affect the ridership pattern at peak hours, it identifies residential areas outside of the TOD and the connectivity of the station with other transport mode contribute to the ridership.

5.2. Recommendation

5.2.1 General recommendation

Based on the research findings, it is recommended that integrating TOD principles into the existing AALRT stations or on the expansion line of the AALRT is crucial to enhance the ridership flow.

- Provision of new residence development in the TOD influence zone should consider affordable houses for the low-income community houses within walking distance from the LRT station. As the research demonstrates most of the trips are generated from condominiums outside of the TOD influence zone.
- Innovative initiatives and strategies are recommended to attract private investors for instance FAR and density bonus, tax relief, and property tax reduction.
- Integration of Addis Ababa Light Rail stations with other transport modes, as the research demonstrates the connectivity and integration of stations with other transport modes increases the AALRT ridership at the selected stations. For instance, more than 80 percent of passengers who utilize the Megenagna station at peak hours use another transport mode to access the station (Appendix 2).
- Implementation of a detailed regulation zoning plan around Addis Ababa Light Rail stations which includes land use mix, low-income housing, high-rise apartments, and high-quality open space or public realm.
- Reducing or avoiding parking areas within the TOD influence zone is crucial to boost ridership since it encourages public transport usage, as indicated in the case studies of cities with successful Transit-oriented development.

5.2.2 Recommendation for each selected station

1. Ayat Station

Though Ayat station has the highest index and ridership flow relative to other selected stations, the ridership flow can be improved. In both TOD influence zones, it is found that commerce density is low. High Commercial density development within 400 and 800 meters of the station is recommended.

2. CMC Station

CMC station is the second lowest station with low ridership flow and TOD index value beside Mexico station. The commerce density within the 400m TOD influence zone is negligible and the total walkable path is also low as a result high commerce density development and reduction of block size are recommended. In the 800m TOD influence zone high commerce density development is recommended.

3. Megenagna Station

Megenagna station is the second station with the highest TOD index and ridership flow next to Ayat station. Since Megenagna station has a low residence density within the 400-meter TOD influence zone, it is recommended to increase the residence density. Conversely, high commerce development is recommended in the 800- meter TOD influence zone since it has low commerce density.

4. Mexico Station

Mexico station has the lowest index value and ridership flow relative to other selected stations. Since there is no residence within the 400-meter and large block sizes hence low intersection density, it is recommended high residence density development and minimizing of block size. The same recommendation is for the 800-meter TOD influence zone too.

5.2.3 Recommendation for further study

Further study is recommended on the uncovered station along the E-W AALRT line stations to understand their transit-oriented development level and impact on the respective ridership. There is limited research on the N-S line of the AALRT regarding TOD and the efficiency of the LRT. It is recommended to study the integration TOD and ridership pattern along the N-S line to boost the overall LRT efficiency. Further study on the relation between commerce density and disembarking passengers is also recommended.

REFERENCE

Addis Ababa City Plan & Development Commission, 2023. TOD Elements of the Addis Ababa city Structure Plan 2017-27.

Addis Ababa City Road and Transport Bureau, 2016. Addis Ababa City Road and Transport Bureau ENVIRONMENTAL AND SOCIAL MANAGEMENT FRAMEWORK ETHIOPIA TRANSPORT SYSTEMS IMPROVEMENT PROJECT-TRANSIP (Final Draft).

Akinori Morimoto, n.d. Chapter 2: Transportation and land use | 23.

Armstrong-Wright, A., 1929. W TP-52 Urban Transit Systems Guidelines for Examining Options.

Arrington, G.B., Brinckerhoff, P., 2003. Light Rail and the American City State-of-the-Practice for Transit-Oriented Development.

Azmeraw, E., 2015. ADDIS ABABA INSTITUTE OF TECHNOLOGY School of Civil and Environmental Engineering Effects of Light Rail Transit System on Pedestrians and Public Transport Users' Mobility Addis Ababa, Ethiopia.

Bolleter, J., Ramalho, C.E., 2020. Transit-Oriented Development (TOD) and Its Problems. pp. 13–39. https://doi.org/10.1007/978-3-030-29601-8_2

Chen, Y., Song, Y., n.d. From Measuring Land Use Mix to Measuring Land Use Pattern-New Methods for Assessing Land Use.

DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3, 2018.

Debebe, G., Asteray, B., 2022a. Assessment on the Current and Future Performance of Addis Ababa Light Rail Transit Service Using Mathematical Modeling. Advances in Civil Engineering 2022. https://doi.org/10.1155/2022/5097929

Debebe, G., Asteray, B., 2022b. Assessment on the Current and Future Performance of Addis Ababa Light Rail Transit Service Using Mathematical Modeling. Advances in Civil Engineering 2022. https://doi.org/10.1155/2022/5097929

Deyas, G.T., 2019. THE SOCIAL AND ECONOMIC IMPACTS OF PUBLIC TRANSPORTATION ON ADJACENT COMMUNITIES: THE CASE OF EAST-WEST ROUTE OF THE ADDIS ABABA LIGHT RAIL TRANSIT ADDIS ABABA, ETHIOPIA.

Dueker, K.J., Bianco, M.J., 1998. Effects of Light Rail Transit in Portland: Implications for Transit-Oriented Development Design Concepts.

Ethiopian Airports Enterprise, 2017. An Integrated Investment Incentives and Cargo Hub Airports to Stimulate Air Cargo Demand.

Ezana Haddis Weldeghebrael, B., 2021. ADDIS ABABA: CITY SCOPING STUDY.

GDI, 2017. GDI Delivery Note Ethiopia Light Rail.

Gezahegn Berhe, A., Erena, B., Hassen, M., Mamaru, T.L., Soressa, Y.A., 2017. CITY PROFILE ADDIS ABABA SES Social Inclusion and Energy Managment for Informal Urban Settlements.

Guo, J., Nakamura, F., Li, Q., Zhou, Y., 2018. Efficiency Assessment of Transit-Oriented Development by Data Envelopment Analysis: Case Study on the Den-en Toshi Line in Japan. J Adv Transp 2018. https://doi.org/10.1155/2018/6701484

Hale, C., Charles, P., n.d. Making the Most of Transit Oriented Development Opportunities.

Haylie Miller, 2020. PRESENTATION: NET DENSITY & GROSS DENSITY.

Hooker, J., 2023. Barriers to Transit-Oriented Development in Portland, OR.

Hrelja, Robert., Olsson, Lina., Pettersson-Löfstedt, Fredrik., Rye, Tom., 2020. Transit oriented development (TOD) : a literature review.

Huang, R., Grigolon, A., Madureira, M., Brussel, M., 2018. Measuring transit-oriented development (TOD) network complementarity based on tod node typology. J Transp Land Use 11, 304–324. https://doi.org/10.5198/jtlu.2018.1110

Ibrahim, S.M., Ayad, H.M., Saadallah, D.M., 2021. Measuring transit-oriented development levels: A methodological framework to incorporate the user into modelling, in: WIT Transactions on the Built Environment. WITPress, pp. 157–166. https://doi.org/10.2495/UT210131

ITF, 2023. Transit-Oriented Development and Accessibility Case studies from Southeast Asian cities, International Transport Forum Policy Papers, No. 124, OECD Publishing, Paris.

Joshi, R., Joseph, Y., 2017. Transit-Oriented Development: Lessons from International Experiences.

Kassahun, M., Bishu, S.G., n.d. The Governance of Addis Ababa City Turn Around Projects: Addis Ababa Light Rail Transit and Housing.

Khare, R., Villuri, V.G.K., Chaurasia, D., Kumari, S., 2021. Measurement of transit-oriented development (TOD) using GIS technique: a case study. Arabian Journal of Geosciences 14. https://doi.org/10.1007/s12517-021-07142-y

Logistics Capacity Assessments (LCAs), 2024.

Nallet C, 2018. The Challenge of Urban Mobility A Case Study of Addis Ababa Light Rail, Ethiopia Notes de l'Ifri Clélie NALLET.

Nyunt, K.T.K., Wongchavalidkul, N., 2020. Evaluation of Relationships Between Ridership Demand and Transit-Oriented Development (TOD) Indicators Focused on Land Use Density, Diversity, and Accessibility: A Case Study of Existing Metro Stations in Bangkok. Urban Rail Transit 6, 56–70. https://doi.org/10.1007/s40864-019-00122-2

Obsie, A., Woldeamanuel, M., Woldetensae, B., 2020. Service Quality of Addis Ababa Light Rail Transit: Passengers' Views and Perspectives. Urban Rail Transit 6, 231–243. https://doi.org/10.1007/s40864-020-00135-2

Olievschi, V.N., 2013. Framework for Improving Railway Sector Performance in Sub-Saharan Africa.

Papa, E., Bertolini, L., 2015. Accessibility and Transit-Oriented Development in European metropolitan areas. J Transp Geogr 47, 70–83. https://doi.org/10.1016/j.jtrangeo.2015.07.003

Qi, N.J., 2017. Impacts of Transit-Oriented Development (TOD) on the Travel Behavior of its Residents in Shenzhen, China.

Randhawa, A., 2021. Challenges of Transit Oriented Development (TOD) in Indian Cities. https://doi.org/10.13140/RG.2.2.35660.13444

Renne, J.L., 2009. From transit-adjacent to transit-oriented development. Local Environ 14, 1–15. https://doi.org/10.1080/13549830802522376

Sekasi, J., Martens, M.L., 2021. Assessing the contributions of urban light rail transit to the sustainable development of addis ababa. Sustainability (Switzerland) 13. https://doi.org/10.3390/su13105667

SINGH Ph D Scholar, Y.J., Flacke, J., A M Van Maarseveen, M.F., 2015. MEASURING TOD OVER A REGION USING GIS BASED MULTIPLE CRITERIA ASSESSMENT TOOLS PENGWEI HE, The SPA Journal of Planning and Architecture.

Singh, Y.J., Flacke, J., A M Van Maarseveen, M.F., 2015. MEASURING TOD OVER A REGION USING GIS BASED MULTIPLE CRITERIA ASSESSMENT TOOLS PENGWEI HE, The SPA Journal of Planning and Architecture.

Teklemariam, E.A., Shen, Z., 2020a. Determining transit nodes for potential transit-oriented development: Along the LRT corridor in Addis Ababa, Ethiopia. Frontiers of Architectural Research 9, 606–622. https://doi.org/10.1016/j.foar.2020.03.005

Teklemariam, E.A., Shen, Z., 2020b. Determining transit nodes for potential transit-oriented development: Along the LRT corridor in Addis Ababa, Ethiopia. Frontiers of Architectural Research 9, 606–622. https://doi.org/10.1016/j.foar.2020.03.005

Tekletsadik, A.G., 2015. ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAIT) School of Civil and Environmental Engineering Evaluation of the Feasibility of At-Grade Crossings and Traffic Management Strategies for The Addis Ababa Light Rail Transit Corridor.

Uddin, M.A., Hoque, M.S., Tamanna, T., Adiba, S., Muniruzzaman, S.M., Parvez, M.S., 2023. A framework to measure transit-oriented development around transit nodes: Case study of a mass rapid transit system in Dhaka, Bangladesh. PLoS One 18. https://doi.org/10.1371/journal.pone.0280275

Vuchic, V.R., 1972. Light Rail Transit Systems: A Definition and Evaluation.

Vuchic, V.R., Day, F.B., n.d. RAIL TRANSIT-CHARACTERISTICS, INNOVATIONS, AND TRENDS.

Wang, Z., 2016. The Impact of Light Rail Transit-Oriented Development on Residential Property Value in Seattle, WA.

Wondimu Tekolla, A., Segni Tulu, G., Gebre Tarekegn, A., 2021a. Evaluating the Impact of Addis Ababa Light Rail Transit on Public Transit System, Its Efficiency and Eligibility for Transit Oriented Development (TOD). American Journal of Traffic and Transportation Engineering 6, 160. https://doi.org/10.11648/j.ajtte.20210606.13

Wondimu Tekolla, A., Segni Tulu, G., Gebre Tarekegn, A., 2021b. Evaluating the Impact of Addis Ababa Light Rail Transit on Public Transit System, Its Efficiency and Eligibility for Transit

Oriented Development (TOD). American Journal of Traffic and Transportation Engineering 6, 160. https://doi.org/10.11648/j.ajtte.20210606.13

World Bank Group, 2017. Light Rail Transportation Systems Are Built in Ethiopia.

Wubet, M., 2018. The Impact of Light Rail Transit on Commercial Property Value: A case of Addis Ababa.

Yehualaeshet Jemere, 2012. Ethiopian Railways Corporation (ERC) Addis Ababa Light Rail Transit Project Yehualaeshet Jemere (MSc. CEng) Chief Officer, Construction and Project Execution Department.

Zhang, M., Goodrich, B., 2018. Regional Opportunities and Challenges for Transit-Oriented Development: The Case of the Texas Triangle.

Appendix 1

The Impacts of Transit-Oriented Development on Light Rail Transit Ridership Pattern: The Case of Addis Ababa Light Transit

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Abstract This research aims to probe the impact of transit-oriented development (TOD) on light rail transit efficiency at selected Addis Ababa Light Rail Transit (AALRT) stations (Ayat, CMC, Megenagna, and Mexico Stations). It studied the integration of transit-oriented development principle into AALRT, and the impact of integrating TOD into AALRT on ridership pattern or passenger flow. Observation and spatial analysis (GIS) used to generate the existing land use and road network map for the selected stations. Multi criteria analysis is used to quantify the TOD index. Counting of sold tickets at the stations at peak hours, AALRT transport department, and structured interview was used to determine passengers flow at peak hours, average daily passengers, and passengers flow within the TOD influence zone respectively. The research found that Ayat station is with better integration of TOD and Mexico station is with least TOD integration or TOD index within both TOD influence zone (400 and 800m). The passenger flow both daily passenger and passengers flow at peak hours has direct relation with the TOD index. The passenger flow at peak hours doesn't not affect by the distance to transit as the result demonstrate that majority of the trip is generated outside of the TOD influence zone.

1.Introduction

The Addis Ababa Light Rail Transit (AALRT) project is a cutting-edge transit system intended to enhance mass transit and lessen traffic in the capital of Ethiopia. The project was launched by the Ministry of Transportation in 2008(World Bank Group, 2017). Though, there are diverse researches on Addis Ababa light rail transit mostly on E-W line(Azmeraw, 2015; Debebe and Asteray, 2022b; Deyas, 2019; Obsie et al., 2020; Tekletsadik, 2015; Wubet, 2018), there is a research gap on study of relation between transit-oriented development and Addis Ababa light rail transit ridership. According to Wondimu Tekolla et al. (2021) and a data from Addis Ababa light rail transit transport department (OCC) the efficiency level of AALRT is decreasing annually. As determined by Wondimu Tekolla et al. (2021) the number of passengers at starting stations is higher than the other stations because of the development around those stations is mostly high-density residential development and indicate that transit-oriented development would help to increase transit ridership. This research paper aimed to determine the relationship between transit-oriented development and light rail transit in the case of transit ridership. More specifically the research aimed to accomplish the following specific objectives: to study to what extent transit-oriented development (TOD principles) is implemented or integrated with Addis Ababa light rail transit and to study the impact of transit-oriented development (TOD) on the usage of Addis Ababa light rail transit (AALRT) and ridership patterns. For this research, from the existing two Addis Ababa light rail transit lines, the east – west line is selected. This light rail transit (LRT) line is chosen based on the following criteria: more city centers on the line (main center, Tertiary center, and Secondary center) relative to the other line, and has high-density residential development along the stations makes it preferable for this study. The research will help policymakers and urban planners to develop efficient transportation plan in the aspect of public mass transportation.

The paper has four parts, first literature review on transit-oriented development (TOD), TOD indicators, index measurement, characteristics, light rail transit, and previous research on the relation between TOD and LRT. This is followed by a description of the research methods used in the study. Then result and discussion and finally conclusion and recommendation are presented.

2. Literature Review

The American architect Peter Calthorpe was the first to propose transit-oriented development/design (TOD). He defined TOD as development that encouraged mixed-use development near to a transit stop. TOD is characterized by concentrated, mixed-density development around public transit systems (stations), encourage walkability, cycling, and efficient transit usage. It also encourages compact and infill development around transit stations(Arrington and Brinckerhoff, n.d.; Hrelja et al., 2020; Qi, 2017; BMRCL, 2018). Some researchers (Cervero and Kockelman; Ewing and Cervero) defined transit-oriented development relating to the 'Ds' concept density, diversity, design, distance to transit, and destination accessibility also considered as TOD indicators. The main objectives of TOD are encouraging transit use, improving housing opportunities, promoting walking and cycling, and facilitating neighborhood revitalization (Lund, 2006). Urban sustainability, a decrease in car-dependent expansion, well-planned and designed neighborhoods, more accessible public transit with the convenience of walking and bicycling, and a reduction in auto use, obesity, and other detrimental health effects are all benefits of TOD(Uddin et al., 2023). Density is one of the TOD indicators refers to having a high number of units per hectare compared to typical development densities. Population, commercial, employment, job, and business density are the performance measurements that are used in previous research to study the density of the study area (Huang et al., 2018; Khare et al., 2021; Qi, 2017; Uddin et al., 2023). Diversity (land use diversity (LUD)) is the second TOD indicator refers to having a high mix of users in a development (Hrelja et al., 2020). LUD objective is to assess the variety of land use within a given area and their geographic distribution(SINGH Ph D Scholar et al., 2015). Khare et al., Huang et al., 2018, Cervero and Kockelman (1997), and Uddin et al. (2023) used the entropy index to study LUD. High land use diversity is indicated by a high value of entropy index. Design is the third TOD indicator, refers to creating attractive and efficient urban design and street layout that encourage walking, cycling, and public transportation (Hrelja et al., 2020). Different measurement variables are used in numerous research. The total length of pedestrian and bicycle lanes, walkable path, intersection density, Parking utilization (PU), and Open/Green spaces were used to measure design (Huang et al., 2018; Khare et al., 2021; Uddin et al., 2023). Distance to transit is the fourth TOD indicator, shows that the distance between home and a station or the workplace. Different researchers had different definitions of distance to transit (influence zone of TOD). Some researchers defined TOD as restricted to an area of 400 to 600 meters from LRT stations, and others defined TOD as an area of 700 and 800 meters from the LRT station ((Ginn, 2009), (Calthorpe, 1993), (Vale, 2015), and (Hrelja et al., 2020)). According to Uddin et al. (2023) and Bolleter and Ramalho (2020) TOD influence zone specifies as 500-800 meters(Bolleter and Ramalho, 2020). Destination accessibility is the last TOD indicator also known as land use mixedness (LUM). It refers to mixing of residential land use with other land use. Transit-oriented development is characterized by: moderate to high density development in relation to the existing pattern of development; a mix of land uses, horizontally or vertically; compact pedestrian-oriented design and streetscapes; a fine-grained connected street pattern without cul-de-sacs; and a system of parks and open spaces (Arrington and Brinckerhoff, 2003).

Spatial muti-criteria analysis (SMCA) has been used to calculate the TOD index in numerous researches (Khare et al., 2021; Singh et al., 2015; Uddin et al., 2023). According to Singh et al. (2015) in SMCA there are two main steps standardization and weighing of indicators. Since all TOD indicators has different unit using 'maximum' method the maximum value of all indicators is set to 1 and all other values of the indicator were reduced to a value less than 1. The most commonly used method to weigh the indicators is ranking, where all criteria and their indicators are ranked in terms of their importance(Singh et al., 2015). Light rail transit (LRT) is a one form of mass transportation. Rail transit, including streetcar, light rail, rapid transit, and regional rail. LRT run on tracks and share the road with other vehicles. It typically run along streets on tracks, and they may be given segregated rights of way along all or a portion of their routes (Armstrong-Wright, 1929; Hooker, 2023; Vuchic, 1972). LRT has a significant impact on a city, helping to improve mobility and directly or indirectly revitalizing the city's central business district. Directly it increases public transport ridership, decreases traffic congestion, and decreases private car dependency. Indirect influence would be associated with urban development, land value capture mechanism, agglomeration labor market and economy, improvement of the environment, and health situation in the city(Wondimu Tekolla et al., 2021a). Global studies found that TOD encourage the use of public transportation and increases transit ridership ((Arrington and Brinckerhoff, 2003; Dueker and Bianco, 1998; Guo et al., 2018; ITF, 2023; Papa and Bertolini, 2015; Teklemariam and Shen, 2020b)).

3. Methods

3.1 Case Study - Addis Ababa

Ethiopia's capital, Addis Ababa, is home to important regional and international organizations like the Economic Commission for Africa and the African Union ((Kassahun and Bishu, n.d.)). Its urban development traces back to Italian colonial planning in the 1930s, with subsequent master plans evolving over time (Mahiteme, 2007). Since 1991, Addis Ababa has experienced rapid growth, witnessing a growth in population, economic activity, and infrastructure development(Addis Ababa City Road and Transport Bureau, 2016). Urbanization in Addis Ababa has accelerated, with projections indicating a continued rise in the urban population. The city faces challenges such as housing shortages, inadequate infrastructure, and unemployment, exacerbated by rural-urban migration (Kassahun and Bishu, n.d.). A significant portion of the urban population resides in slum dwellings, highlighting the need for improved housing policies and infrastructure development (Ministry of Urban Development, Housing and Construction, 2011).

The Addis Ababa Light Rail Transit (AALRT) project, inaugurated in 2015, aimed to address transportation challenges and improve urban mobility (Debebe and Asteray, 2022b). It is an electrified light rail transit with 41 stations and a total length of 34.25 km of rail lines. It has two lines, one running north-south from Menelik Square to Kality (16.9 km) the other running east-west from Ayat to Tor Hailoch 17.35 (km) with the two lines sharing a 2.7 km(Debebe and Asteray, 2022; Kassahun and Bishu, n.d.; Obsie et al., 2020). Challenges facing the Addis Ababa LRT, according to Wondimu Tekolla et al. (2021) include a lack of sufficient financial support and the necessary operating skills, blackouts and driver inexperience, a lack of spare parts, the absence of a passenger information system (PIS), and a lack of integration with other modes of public transportation. However, the main one is the lack of funding to sustain

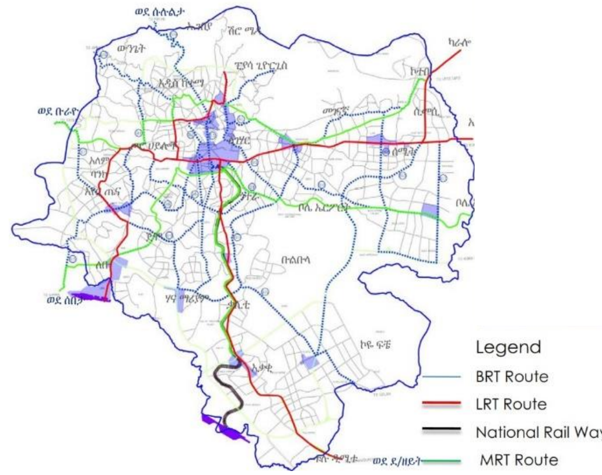


Fig. 1 Addis Ababa LRT and BRT Lines

operations. Transit-Oriented Development (TOD) has emerged as a potential solution to the challenges faced by the AALRT. The city administration is considering implementing TOD around selected stations to overcome operational challenges and improve efficiency. The 10th structural plan of Addis Ababa incorporates TOD in various aspects, including land use, transport, and urban centers (Addis Ababa City Plan & Development Commission, 2023).

3.2 Sampling and Data Collection Method: The research focuses on the East-West line of AALRT which has twenty-four stations. From those stations, four stations (Mexico, Megenagna, CMC, and Ayat station) are selected for this research based on their location (Megenagna and Mexico are located at the city centers), connectivity with another transport system, high-density development around the stations (Ayat and CMC stations), and according to Teklemariam and Shen (2020) research on TOD along the AALRT E-W line, station with designated as high and low TOD index. The four TOD indicator (density, diversity, design and destination accessibility) discussed on the literature review were measured and TOD index was calculated for the selected stations. Based on previous researches on TOD influence zone that discussed on the literature review, this research used 400 and 800m TOD influence zone. Using spatial analysis (GIS) and observation the exiting road network and land use map was generated (fig 2). The existing land use and road network map was used to evaluate the integration of TOD principles to the selected LRT stations.

Density: Gross density and ArcGIS were used to study commercial and residential land use density.

$$Commercial\ Land\ Use\ Density = \frac{\text{Number of commercial unit}}{\text{Total lot area}}$$

$$Residential\ Land\ Use\ Density = \frac{\text{Number of Residential unit}}{\text{Total lot area}}$$

Diversity: To study the land use diversity of the selected sites existing land use plan was used to determine the area for each land uses within the TOD influence zone. To calculate and analyze the land use diversity Shannon entropy index was used.

$$\text{Entropy} = \frac{\sum j P_j \times \ln(P_j)}{\ln(J)}$$

Pj = the proportion of total land area of jth land-use category found in the tract being analyzed, J = total land uses considered in the study area

Design: The research used the existing land use plan as a data source to measure the intersection density and total length of walkable/cyclable path. Intersection density calculates the number of junctions per km2 from the road network data and total length of walkable/cyclable path measures the number of pedestrian, and cycle-accessible roads within TOD influence zone of the designated transit station.

Destination accessibility: using the existing land use map, it measures the land use mixedness of residential land use with other land use. Zhang

$$MI(i) = \frac{\sum_j L_o}{\sum_j L_r + L_o}$$

and Guindon's land use mixedness equation was used.

MI - land use mixedness, Lo - non-residential land use for each TSC j, Lr - residential land use for each TSC j. MI values may range from 0 to 1, MI value of 0.5 suggesting a 50/50 split between residential and non-residential land uses.

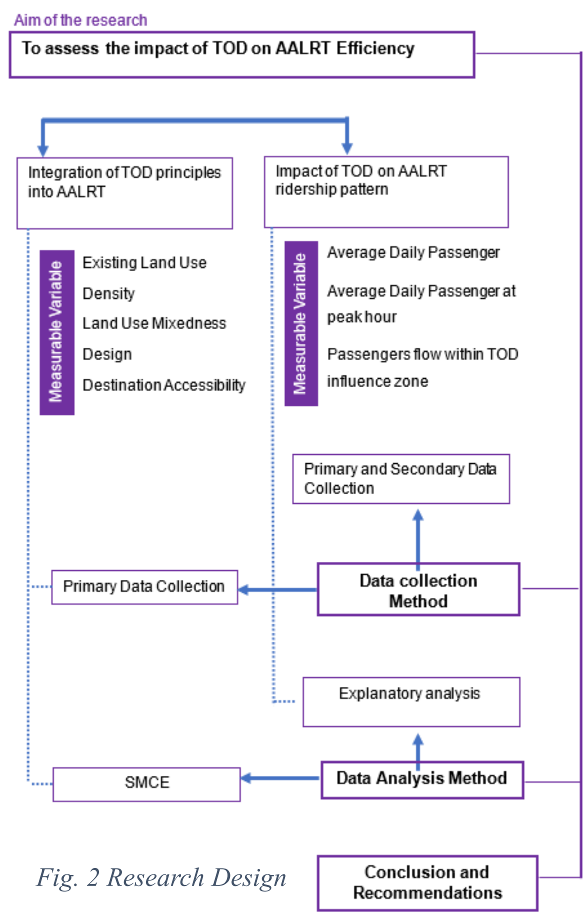


Fig. 2 Research Design

A spatial multi criteria analysis (SMCA) was used as an analysis method to calculate and analyze the TOD index. Since all indicators has different unit maximum method was used to standardized the indicator with equal weight.

Primary data (interview) used to determine the average daily passenger (Counting of sold tickets) and the passenger flow within the TOD influence zone (Structured Interview) at peak hours. The interview was done with ten percent of the average daily passengers at peak hours. Secondary data was used to determine the average daily passenger at the designated stations. Explanatory and comparison analysis was used to analyze the relation between TOD and transit ridership pattern.

4. Result and Discussion

Result of TOD indicators and index: Gross density was used to calculate the density of commercial and residential land use within the TOD influence zones. In the 400m TOD influence zone, Ayat station and CMC station have the highest residence density, and Mexico station has the lowest. In the 800m TOD influence, zone Megenagna and Ayat station have the highest residence density. On the contrary, Mexico station has the highest commerce density within the 800m TOD influence zone, and Megenagna station has the highest commerce density within the 400m TOD zone. Land use diversity: the land use diversity of the study area was studied using the Shannon Entropy index. If the value of the index is equal to 0, it shows homogeneity, and if it is equal to 1, it shows diversified land use within the area. To study the diversity six land uses are included administrative, commerce, residence, greenery, service, and manufacture. The result found that from the 400-meter TOD influence zone, Megenagna has the most diversified land use and Mexico has the most diversified land use within the 800-meter TOD influence zone. The number and density of intersections within the TOD influence area (400m and 800m) is calculated for each designated station. High intersection density indicates a more walkable street. CMC and Megenagna station have the highest number of intersections and intersection density it shows a walkable street. The total length of a walkable/ cyclable path was calculated using the total length and number of streets that are comfortable for pedestrians by excluding major roads with high traffic speed. Stations with the highest total length of walkable paths are considered walkable areas and vice versa. Ayat station contains more walkable streets than other stations as shown in table 3.

Name of Station	Residence Density %		Commerce Density %	
TOD Influence Zone	400m	800m	400m	800m
Mexico Station	0	29.63	21.95	32.78
Megenagna Station	21	51.4	30.19	15.22
CMC Station	56.06	48.22	1.79	6.44
Ayat Station	53.39	53.75	7.43	7.7

Table 1 residence and Commerce Density

Land Use Diversity Index		
TOD Influence Zone	400m	800m
Mexico Station	0.43	0.78
Megenagna Station	0.76	0.73
CMC Station	0.48	0.45
Ayat Station	0.46	0.48

Table 2 Land use diversity index

Station Name	Number of Intersection		Intersection Density per km^2	
	TOD Influence Zone			
	400m	800m	400m	800m
Mexico Station	35	50	70	33.3
Megenagna Station	77	146	154	97.3
CMC Station	35	223	70	148.6
Ayat Station	64	168	128	112

Table 3 Number of intersection and intersection density

Residence land use mixed with six other land uses (Commerce, Administrative, manufacture, Greenery, Service, and Open Space) was studied. CMC and Megenagna stations have the highest mixedness in the 400m and 800m TOD influence zone respectively.

Land Use Mixedness Index		
TOD Influence Zone	400	800
Mexico Station	1	0.8
Megenagna Station	0.84	0.45
CMC Station	0.58	0.4
Ayat Station	0.28	0.39

Table 4 Land use mixedness index

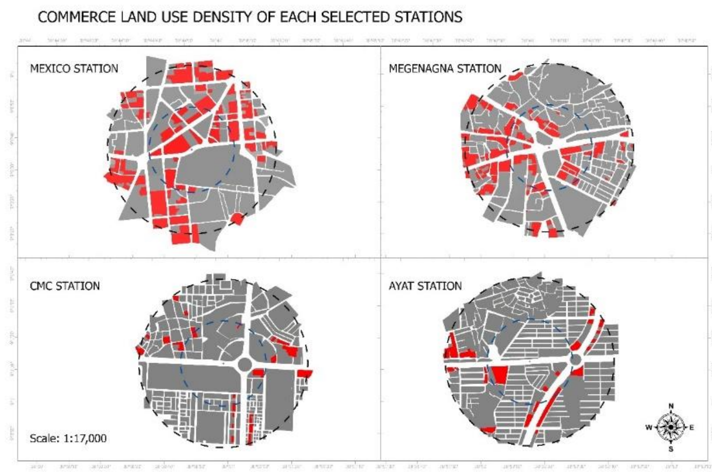


Fig. 3 Commerce land use density

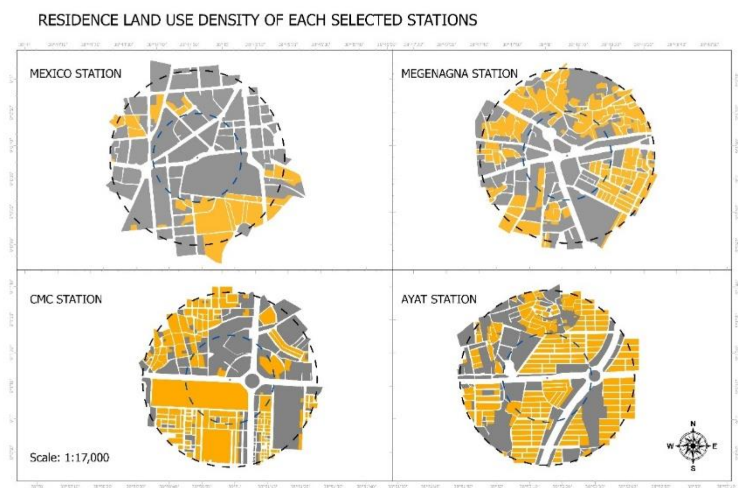
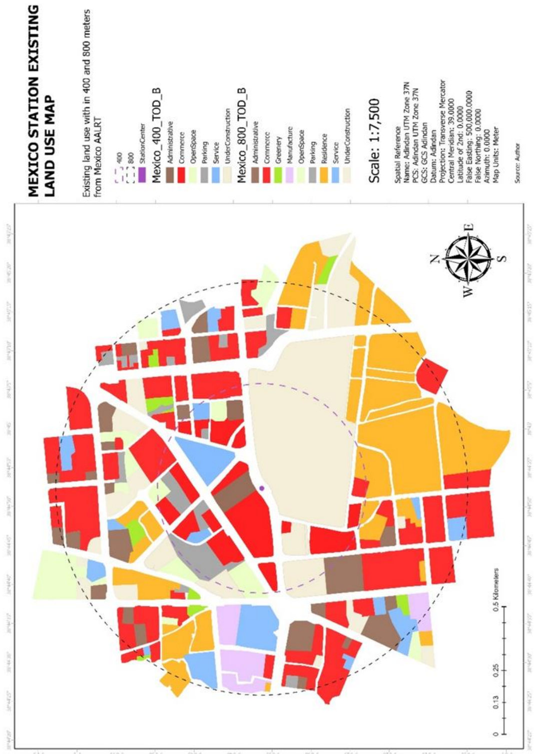
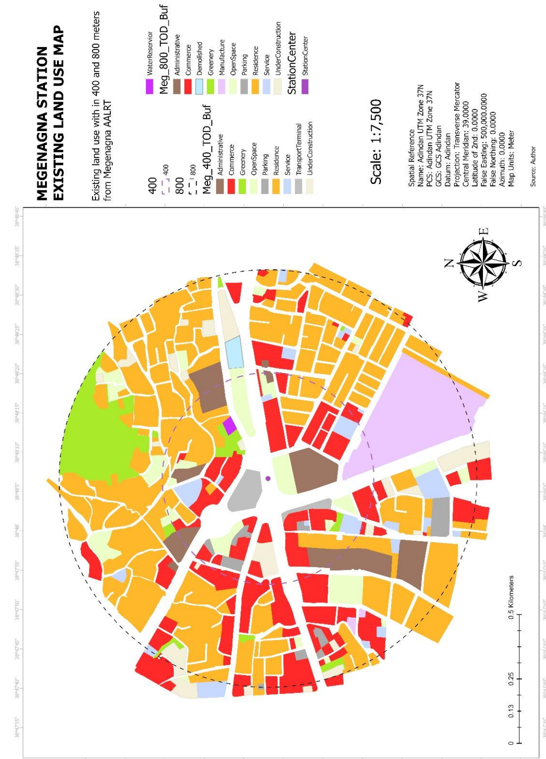
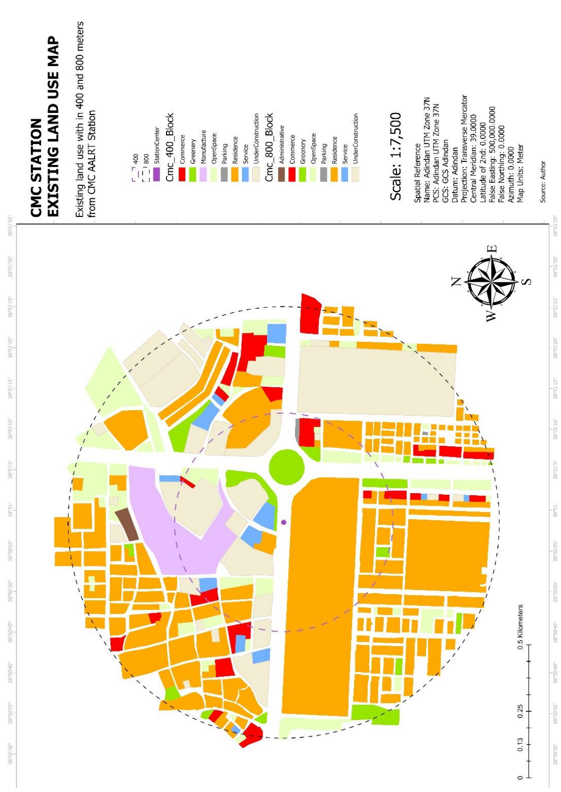


Fig.4 Residence land use density

All TOD indicators are uniformly weighted (1/6) and standardized using the maximum approach in spatial multiple criteria evaluation. Less indicator integration is indicated by the lowest TOD index value, and greater indicator integration with AALRT is indicated by the greatest value.







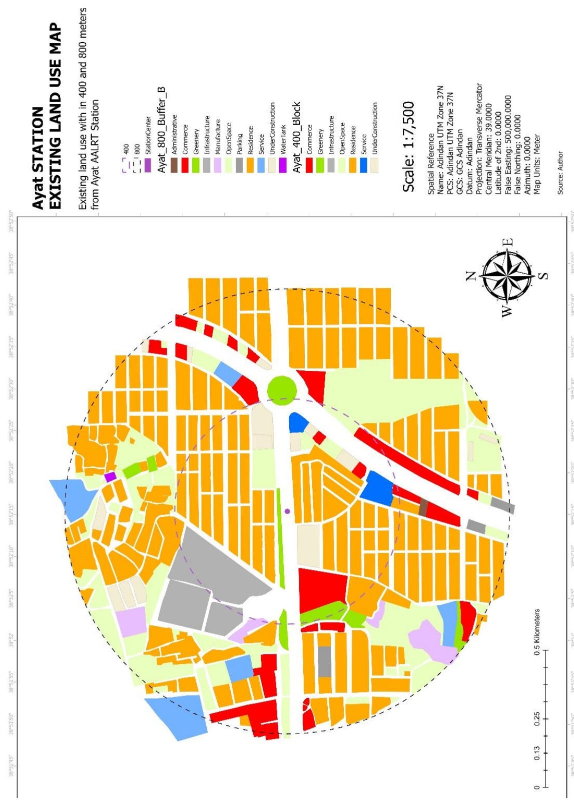


Fig.5 Mexico, Megenagna, CMC, and Ayat exiting land use map

TOD Index of area within 400 meters								Rank
Weight	1/6	1/6	1/6	1/6	1/6	1/6		
Station Name	Commerce Density	Residence Density	Land Use Diversity	Intersection Density	Total Walkable Path	Land Use Mixedness	TOD Index	
Mexico	0.72	0	0.56	0.45	0.38	0.28	0.41	4
Megenagna	1	0.37	1	1	0.64	0.33	0.74	2
CMC	0.05	1	0.63	0.45	0.39	0.48	0.51	3
Ayat	0.24	0.95	0.59	0.83	1	1	0.78	1

Table 5 TOD Index of area within 400 meters

TOD Index of area within 800 meters								Rank
Weight	1/6	1/6	1/6	1/6	1/6	1/6		
Station Name	Commerce Density	Residence Density	Land Use Diversity	Intersection Density	Total Walkable Path	Land Use Mixedness	TOD Index	
Mexico	1	0.55	1	0.22	0.46	0.48	0.63	4
Megenagna	0.46	0.95	0.93	0.65	0.77	0.86	0.79	1
CMC	0.19	0.89	0.57	1	0.98	0.97	0.78	2
Ayat	0.23	1	0.61	0.75	1	1	0.78	2

Table 6 TOD Index of area within 800 meters

Ayat station has the greatest TOD index in the 400-meter TOD influence zone, whereas Mexico station has the lowest level in both TOD influence Zone. Tables 5 and 6 demonstrate that the TOD index of areas within 400 meters of stations is lower than that of areas within 800 meters of the stations.

Result of Average Daily Passenger Vs TOD Index: The result found that average daily passengers increase as the TOD index increases. In both TOD influence zones Ayat station has the highest TOD index concurrently highest daily passengers. Conversely, Mexico station has the lowest index in both TOD influence zones and simultaneously the lowest daily passengers. Passenger flow at peak hours increases with residence density at all selected stations except CMC station. Megenagna station though has a lower residence density than CMC station and has more passenger flow at peak hours than CMC station. The result of ridership flow within and outside of TOD influence zone shows the passenger flow outside of the TOD influence zone is higher than the passenger flow within the TOD zone. Ayat station has 43%, CMC station has 35.7%, Megenagna station has 23.1%, and Mexico has 36.4% passengers flow within the TOD influence zone at peak hours.

Discussion The research found the following major findings, a high density of residences at Ayat station, and the density gets lower at CMC, Megenagna, and Mexico station, respectively. The commerce density is opposite to the residence density, with the highest commerce density at the Mexico station, and the density gets lower at

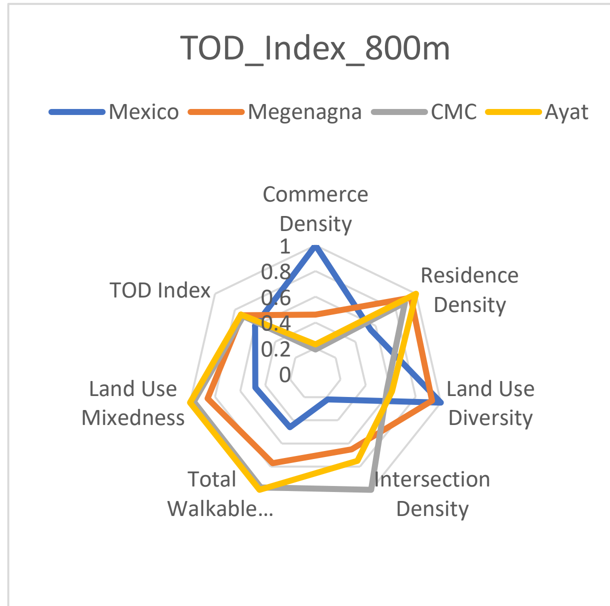


Fig 7 Web diagram for TOD Index 800m influence zone

Megenagna, CMC, and Ayat station,

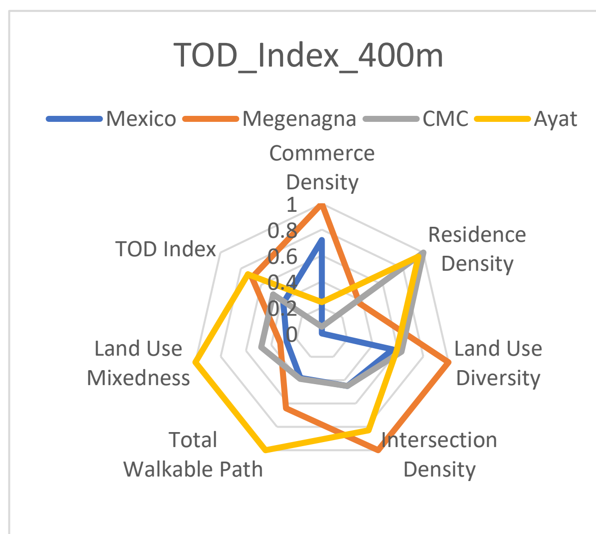


Fig. 6 Web diagram for TOD Index 400m influence zone

respectively. As the results demonstrate Megenagna and Mexico stations have highly diversified land use, and CMC and Ayat stations have low land use diversity with

similar value. Megenagna and Ayat station has the highest intersection density followed by CMC station, and Mexico station has the lowest intersection density. Ayat and CMC station has the highest total length of walkable paths. Megenagna and CMC stations have the highest mixedness of land use with the residence, and Mexico and Ayat stations with low mixedness. The TOD indicators calculated into TOD index, indicates TOD principles or indicators are more integrated with Ayat station relative to other selected stations within 400-meter TOD influence zone. With in the 800-meter TOD influence
zone, the TOD index doesn't vary too much but Ayat and Megenagna Stations has the highest index. It shows that within 800-meter TOD influence zone there is a better integration of the TOD principles at all selected station than within 400-meters TOD influence zone.

The research discovered the integration of transit-oriented development (TOD) into the Addis Ababa light rail transit (AALRT) system, focusing on passenger flow and its relation to TOD index. The 10th structural plan of Addis Ababa proposed high-density mixed residences along mass transport routes, aiming for a 40% residence share (Addis Ababa City Plan & Development Commission, 2023). Stations like CMC and Ayat have achieved this target, with Megenagna station with 56% residence density within 800-meter TOD influence zone Corresponds with the proposal.

In line with previous global research (Guo et al., 2018; ITF, 2023; papa and Bertolini,2015), the study finds a direct relation between TOD index and AALRT ridership, suggesting that TOD integration enhances AALRT usage. However, it also reveals unexpected results regarding passenger distribution at peak hours. More passengers originate from areas outside the TOD zone and it indicates a lack of affordable housing within the TOD influence zone. As Nallet C (2018) discussed riders with different socio-economic profiles utilize the Addis Ababa light rail transit (AALRT), and majority of riders are part of the lower and middle segments of Addis Ababa's middle class. Therefore, the result indicates shortage of affordable housing development within the TOD influence zone of the selected stations.

Dueker and Bianco's (1998) indicate the flow of passengers at peak hours not always increases with the residence density moreover the land use diversity concerns. In line with Dueker and Bianco's, the CMC station has higher residence density than Megenagna station though Megenagna station has the higher passenger flow at the peak hour. In contrast to Dueker and Bianco's, though in land use diversity Megenagna station has more diversified land use than CMC station, as discussed on the above paragraph shortage of affordable houses inside the TOD zone also affects the passenger flow.

On the research of the Challenge of Urban mobility A case study of Addis Ababa Light Rail, Nallet C (2018) discuss Transit that only 25% of the passengers surveyed walk to get the LRT station and leave it. Likewise, this research highlighted the low percentage of passengers walking to reach stations during peak hours, reflecting a reliance on other transportation modes to access the LRT stations. This phenomenon is linked to the majority of passengers originating from areas outside the TOD influence zone as discussed on the above paragraphs.

The research acknowledges the following limitations, particularly the lack of consideration for street amenities and pedestrian lane quality, which could influence street walkability and affect riders' perspectives on utilizing the AALRT.

5. Conclusion and Recommendation

The research aimed to delve the impact of transit-oriented development on the efficiency of Addis Ababa light rail transit. The research presents an in-depth assessment of various aspects related to transit-oriented development (TOD) principles and their integration with Addis Ababa Light Rail Transit (AALRT) and its impact on transit ridership. The research evaluates indicators such as land use density, diversity, design, and destination accessibility, providing detailed analysis and mapping for each station. According to the TOD index on both TOD influence zones (400m and 800m), TOD indicators are more integrated into Ayat station relative to other selected stations.

The ridership pattern, daily average passenger flow, and peak hour passenger flow at selected stations were studied. The analysis relates the passenger flow with the residence density and TOD index and found out that there is a positive relation between ridership pattern and TOD index conversely peak how passenger flow increases not only affected by residence density. The research concluded that distance to transit doesn't significantly affect the ridership pattern at peak hours, it identifies residential areas outside of the TOD and the connectivity of the station with other transport modes contribute to the ridership.

Based on the research findings considering affordable housing in the provision of new residence development in the TOD influence zone is recommended. Innovative initiatives and strategies (tax relief, and property tax reduction) are recommended to attract private investors. Integration of Addis Ababa Light Rail stations with other transport modes is recommended, as the research demonstrates the connectivity and integration of stations with other transport modes increases the AALRT ridership at the selected stations. Reducing or avoiding parking areas within the TOD influence zone is crucial to boost ridership since it encourages public transport usage, as indicated in the case studies of cities with successful Transit-oriented development. Further study is recommended on the uncovered station along the E-W AALRT line stations and in addition to that study on the relation between commerce density and disembarking passengers is also recommended.

Reference

Addis Ababa City Plan & Development Commission, 2023. TOD Elements of the Addis Ababa city Structure Plan 2017-27.

Addis Ababa City Road and Transport Bureau, 2016. Addis Ababa City Road and Transport Bureau ENVIRONMENTAL AND SOCIAL MANAGEMENT FRAMEWORK ETHIOPIA TRANSPORT SYSTEMS IMPROVEMENT PROJECT-TRANSIP (Final Draft).

Akinori Morimoto, n.d. Chapter 2: Transportation and land use | 23.

Armstrong-Wright, A., 1929. W TP-52 Urban Transit Systems Guidelines for Examining Options.

Arrington, G.B., Brinckerhoff, P., 2003. Light Rail and the American City State-of-the-Practice for Transit-Oriented Development.

Azmeraw, E., 2015. ADDIS ABABA INSTITUTE OF TECHNOLOGY School of Civil and Environmental Engineering Effects of Light Rail Transit System on Pedestrians and Public Transport Users' Mobility Addis Ababa, Ethiopia.

Bolleter, J., Ramalho, C.E., 2020. Transit-Oriented Development (TOD) and Its Problems. pp. 13–39. https://doi.org/10.1007/978-3-030-29601-8_2

Chen, Y., Song, Y., n.d. From Measuring Land Use Mix to Measuring Land Use Pattern-New Methods for Assessing Land Use.

DAR ES SALAAM METROPOLITAN DEVELOPMENT PROJECT VOLUME 3, 2018.

Debebe, G., Asteray, B., 2022a. Assessment on the Current and Future Performance of Addis Ababa Light Rail Transit Service Using Mathematical Modeling. Advances in Civil Engineering 2022. https://doi.org/10.1155/2022/5097929

Debebe, G., Asteray, B., 2022b. Assessment on the Current and Future Performance of Addis Ababa Light Rail Transit Service Using Mathematical Modeling. Advances in Civil Engineering 2022. https://doi.org/10.1155/2022/5097929

Deyas, G.T., 2019. THE SOCIAL AND ECONOMIC IMPACTS OF PUBLIC TRANSPORTATION ON ADJACENT COMMUNITIES: THE CASE OF EAST-WEST ROUTE OF THE ADDIS ABABA LIGHT RAIL TRANSIT ADDIS ABABA, ETHIOPIA.

Dueker, K.J., Bianco, M.J., 1998. Effects of Light Rail Transit in Portland: Implications for Transit-Oriented Development Design Concepts.

Ethiopian Airports Enterprise, 2017. An Integrated Investment Incentives and Cargo Hub Airports to Stimulate Air Cargo Demand.

Ezana Haddis Weldeghebrael, B., 2021. ADDIS ABABA: CITY SCOPING STUDY.

GDI, 2017. GDI Delivery Note Ethiopia Light Rail.

Gezahegn Berhe, A., Erena, B., Hassen, M., Mamaru, T.L., Soressa, Y.A., 2017. CITY PROFILE ADDIS ABABA SES Social Inclusion and Energy Managment for Informal Urban Settlements.

Guo, J., Nakamura, F., Li, Q., Zhou, Y., 2018. Efficiency Assessment of Transit-Oriented Development by Data Envelopment Analysis: Case Study on the Den-en Toshi Line in Japan. J Adv Transp 2018. https://doi.org/10.1155/2018/6701484

Hale, C., Charles, P., n.d. Making the Most of Transit Oriented Development Opportunities.

Haylie Miller, 2020. PRESENTATION: NET DENSITY & GROSS DENSITY.

Hooker, J., 2023. Barriers to Transit-Oriented Development in Portland, OR.

Hrelja, Robert., Olsson, Lina., Pettersson-Löfstedt, Fredrik., Rye, Tom., 2020. Transit oriented development (TOD) : a literature review.

Huang, R., Grigolon, A., Madureira, M., Brussel, M., 2018. Measuring transit-oriented development (TOD) network complementarity based on tod node typology. J Transp Land Use 11, 304–324. https://doi.org/10.5198/jtlu.2018.1110

Ibrahim, S.M., Ayad, H.M., Saadallah, D.M., 2021. Measuring transit-oriented development levels: A methodological framework to incorporate the user into modelling, in: WIT Transactions on the Built Environment. WITPress, pp. 157–166. https://doi.org/10.2495/UT210131

ITF, 2023. Transit-Oriented Development and Accessibility Case studies from Southeast Asian cities, International Transport Forum Policy Papers, No. 124, OECD Publishing, Paris.

Joshi, R., Joseph, Y., 2017. Transit-Oriented Development: Lessons from International Experiences.

Kassahun, M., Bishu, S.G., n.d. The Governance of Addis Ababa City Turn Around Projects: Addis Ababa Light Rail Transit and Housing.

Khare, R., Villuri, V.G.K., Chaurasia, D., Kumari, S., 2021. Measurement of transit-oriented development (TOD) using GIS technique: a case study. Arabian Journal of Geosciences 14. https://doi.org/10.1007/s12517-021-07142-y

Logistics Capacity Assessments (LCAs), 2024.

Nallet C, 2018. The Challenge of Urban Mobility A Case Study of Addis Ababa Light Rail, Ethiopia Notes de l'Ifri Clélie NALLET.

Nyunt, K.T.K., Wongchavalidkul, N., 2020. Evaluation of Relationships Between Ridership Demand and Transit-Oriented Development (TOD) Indicators Focused on Land Use Density, Diversity, and Accessibility: A Case Study of Existing Metro Stations in Bangkok. Urban Rail Transit 6, 56–70. https://doi.org/10.1007/s40864-019-00122-2

Obsie, A., Woldeamanuel, M., Woldetensae, B., 2020. Service Quality of Addis Ababa Light Rail Transit: Passengers' Views and Perspectives. Urban Rail Transit 6, 231–243. https://doi.org/10.1007/s40864-020-00135-2

Olievschi, V.N., 2013. Framework for Improving Railway Sector Performance in Sub-Saharan Africa.

Papa, E., Bertolini, L., 2015. Accessibility and Transit-Oriented Development in European metropolitan areas. J Transp Geogr 47, 70–83. https://doi.org/10.1016/j.jtrangeo.2015.07.003

Qi, N.J., 2017. Impacts of Transit-Oriented Development (TOD) on the Travel Behavior of its Residents in Shenzhen, China.

Randhawa, A., 2021. Challenges of Transit Oriented Development (TOD) in Indian Cities. https://doi.org/10.13140/RG.2.2.35660.13444

Renne, J.L., 2009. From transit-adjacent to transit-oriented development. Local Environ 14, 1–15. https://doi.org/10.1080/13549830802522376

Sekasi, J., Martens, M.L., 2021. Assessing the contributions of urban light rail transit to the sustainable development of addis ababa. Sustainability (Switzerland) 13. https://doi.org/10.3390/su13105667

SINGH Ph D Scholar, Y.J., Flacke, J., A M Van Maarseveen, M.F., 2015. MEASURING TOD OVER A REGION USING GIS BASED MULTIPLE CRITERIA ASSESSMENT TOOLS PENGWEI HE, The SPA Journal of Planning and Architecture.

Singh, Y.J., Flacke, J., A M Van Maarseveen, M.F., 2015. MEASURING TOD OVER A REGION USING GIS BASED MULTIPLE CRITERIA

ASSESSMENT TOOLS PENGWEI HE, The SPA Journal of Planning and Architecture.

Teklemariam, E.A., Shen, Z., 2020a. Determining transit nodes for potential transit-oriented development: Along the LRT corridor in Addis Ababa, Ethiopia. Frontiers of Architectural Research 9, 606–622. https://doi.org/10.1016/j.foar.2020.03.005

Teklemariam, E.A., Shen, Z., 2020b. Determining transit nodes for potential transit-oriented development: Along the LRT corridor in Addis Ababa, Ethiopia. Frontiers of Architectural Research 9, 606–622. https://doi.org/10.1016/j.foar.2020.03.005

Tekletsadik, A.G., 2015. ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAIT) School of Civil and Environmental Engineering Evaluation of the Feasibility of At-Grade Crossings and Traffic Management Strategies for The Addis Ababa Light Rail Transit Corridor.

Uddin, M.A., Hoque, M.S., Tamanna, T., Adiba, S., Muniruzzaman, S.M., Parvez, M.S., 2023. A framework to measure transit-oriented development around transit nodes: Case study of a mass rapid transit system in Dhaka, Bangladesh. PLoS One 18. https://doi.org/10.1371/journal.pone.0280275

Vuchic, V.R., 1972. Light Rail Transit Systems: A Definition and Evaluation.

Vuchic, V.R., Day, F.B., n.d. RAIL TRANSIT-CHARACTERISTICS, INNOVATIONS, AND TRENDS.

Wang, Z., 2016. The Impact of Light Rail Transit-Oriented Development on Residential Property Value in Seattle, WA.

Wondimu Tekolla, A., Segni Tulu, G., Gebre Tarekegn, A., 2021a. Evaluating the Impact of Addis Ababa Light Rail Transit on Public Transit System, Its Efficiency and Eligibility for Transit Oriented Development (TOD). American Journal of Traffic and Transportation Engineering 6, 160. https://doi.org/10.11648/j.ajtte.20210606.13

Wondimu Tekolla, A., Segni Tulu, G., Gebre Tarekegn, A., 2021b. Evaluating the Impact of Addis Ababa Light Rail Transit on Public Transit System, Its Efficiency and Eligibility for Transit Oriented Development (TOD). American Journal of Traffic and Transportation Engineering 6, 160. https://doi.org/10.11648/j.ajtte.20210606.13

World Bank Group, 2017. Light Rail Transportation Systems Are Built in Ethiopia.

Wubet, M., 2018. The Impact of Light Rail Transit on Commercial Property Value: A case of Addis Ababa.

Yehualaeshet Jemere, 2012. Ethiopian Railways Corporation (ERC) Addis Ababa Light Rail Transit Project Yehualaeshet Jemere (MSc. CEng) Chief Officer, Construction and Project Execution Department.

Zhang, M., Goodrich, B., 2018. Regional Opportunities and Challenges for Transit-Oriented Development: The Case of the Texas Triangle.

Appendix 2

Structured Interview Questions

1. *What transport did you use to reach the train station?*

   Taxi

   Bus

   On foot

   Personal vehicle

   Other

2. *Are you resident of the area or a visitor?*

   ____

3. *If you are a resident from which district you came?*

   ____

4. *On average, how many days per week do you use public transit?*

5. *What is your travel purpose?*

Appendix 3

Transport mode passenger uses at peak hours to access the LRT station.