TOWARDS IMPROVED PUBLIC TRANSPORT IN DEVELOPING CITIES: STAKEHOLDERS' PERSPECTIVES ON TRANSIT-ORIENTED DEVELOPMENT PLANNING SUPPORT TOOL IN KIGALI CITY, RWANDA.

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JULY, 2024

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ABSTRACT

This research aimed to identify potential Transit-Oriented Development (TOD) locations to enhance Public Transport (PT) in developing cities, using Kigali City, Rwanda, as a case study. The study also sought to build a Planning Support System (PSS) prototype to help prioritize Bus Rapid Transit (BRT) development along the BRT Corridors proposed by the city. Primary data were collected via Key Informant Interviews (KIIs) with stakeholders, while secondary data were used to compute Potential TOD indicators such as population density, commercial density, employment density, business density, land use diversity, land use mix, intersection density, and the total length of roads suitable for walking and cycling. These indicators underwent Spatial Multicriteria Analysis (SMCA) to create a TOD Index.

The findings revealed a mean TOD Index of 0.28495 and a median of 0.29993 across approximately 8,459 grid cells of 300300m each in the city. High TOD index values (greater than 0.5) were found in the city centre, reflecting favourable conditions for TOD due to higher densities, better transit connectivity, and diverse land uses. Conversely, peri-urban and peripheral areas exhibited low TOD index values (ranging from 0 to 0.2) due to lower population densities, limited transit connectivity, and less diverse land use patterns. Spatial statistical analysis using Global Moran's I demonstrated significant positive spatial autocorrelation and clustering of high TOD index values. The Getis-Ord Gi and Anselin Local Moran's I statistics identified significant hotspots, particularly in central urban areas, indicating areas that would benefit most from transit connectivity improvements and TOD interventions.

To test the PSS Prototype, variables for population, commercial, employment, and business densities were used in CommunityViz to derive the TOD Index at each BRT Corridor. Two scenarios were set: the Base scenario considered the current situation, while the Increased Density scenario accounted for the city's dynamic changes. In the Base scenario, BRT Corridor 2 was the most favourable with a mean TOD Index of 0.21, while BRT Corridor 4 was the least favourable. In the Increased Density scenario, BRT Corridor 2 remained the most favourable, validating its potential for TOD implementation. The PSS prototype demonstrated potential for interactive analysis to prioritize BRT development, providing urban planners and policymakers with actionable insights.

This study concluded that TOD could effectively address urban mobility challenges. However, tailored strategies that consider local contexts and involve stakeholders are essential. Policy recommendations include expanding the PT network to connect the city centre with peripheral areas, encouraging mixed-use development to create vibrant, walkable neighbourhoods, redistributing services across the city, providing economic incentives for investment in peripheral areas, prioritizing affordable housing to prevent displacement, and enhancing capacity-building initiatives for planners. Continuous data integration and user feedback are crucial for refining the PSS tool.

Limitations to this study included the unavailability of socioeconomic data and a constrained timeframe. These limitations affected the in-depth exploration of the PSS prototype. Future research should focus on integrating more datasets to enhance the tool's functionality and relevance. This integration may provide a better representation of urban conditions, enabling more precise planning and policy decisions. The City of Kigali can benefit from the tool by having more data, thus enhancing its TOD planning strategies.

Keywords: Transit-Oriented Development (TOD), Public Transport (PT), City of Kigali(CoK), Potential TOD Index, Developing Cities (DCs).

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Murakoze! Asante! Merci! Thank you! Dank u wel! Vielen Dank! Teşekkür ederim!

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LIST OF ACRONYMS

BRT: Bus Rapid Transit
CBD: Central Business District
CoK: City of Kigali
CRS: Coordinate Reference System
CTOD: California Transit-Oriented Development
DCs: Developing Countries
DSS: Decision Support System
ESRI: Environmental Systems Research Institute
GDP: Gross Domestic Product
GIS: Geographic Information System
GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit (German Development Cooperation)
HDx: Humanitarian Data Exchange
ITC: International Training Centre
ITDP: Institute for Transportation and Development Policy
JICA: Japan International Cooperation Agency
KII: Key Informant Interview
MININFRA: Ministry of Infrastructure (Rwanda)
MOOC: Massive Open Online Course
NGO: Non-Governmental Organization
NISR: National Institute of Statistics Rwanda
NLA: National Land Authority
NMT: Non-Motorized Transport
OSM: OpenStreetMap
PSS: Planning Support Systems
PT: Public Transport
QGIS: Quantum GIS
RHA: Rwanda Housing Authority
RPHC5: Rwanda Population and Housing Census 5
RTDA: Rwanda Transport and Development Agency
RUDP: Rwanda Urban Development Project
SABE: School of Architecture and Built Environment
SDF: Spatial Development Framework
SDSS: Spatial Decision Support System
SMCA: Spatial multi-criteria Analysis
SSA: Sub-Saharan African
TOD: Transit-Oriented Development
TUMI: Transformative Urban Mobility Initiative
UDM: Urban Dynamic Map
UN-Habitat: United Nations Human Settlements Programme
UR-CST: University of Rwanda, College of Science and Technology
UT: University of Twente

1. Introduction

1.1. General Introduction

Urban mobility challenges in sub-Saharan African (SSA) cities are escalating due to rapid urbanization. The lack of policies promoting sustainable transport modes has led to increased reliance on private vehicles (Sietchiping et al., 2012). According to the World Bank (2022), this dependency exacerbates issues such as traffic congestion, air pollution, accidents, and long waiting times. Effective public transport (PT) is crucial, as highlighted by Grisé et al. (2019). They argued that PT efficiency should be measured by its ability to enable users to reach their destinations conveniently. However, in SSA cities, Pojani and Stead (2015) found that limited and inefficient PT options led to prolonged commutes, disproportionately affecting the urban poor in informal settlements.

Despite the rise in motorized transport in SSA cities (Sietchiping et al., 2012), global initiatives have sought to tackle these challenges through various policies and planning approaches. These measures advocate for urban sustainability by promoting sustainable transport modes. Among these, Transit-Oriented Development (TOD) has gained prominence.

1.2. Background

TOD is a planning strategy that integrates land use and transportation planning to foster high-density mixed-use development around transit stations (Khare et al., 2020). This approach promotes sustainable transport modes such as walking, cycling, and PT (Pengjun et al., 2018). Initially introduced by Calthorpe in the 1990s as a solution to combat urban sprawl in US cities (Strong et al., 2017), TOD gained global attention, particularly in Europe, Scandinavian, and Asian cities, such as Hong Kong, Singapore, and Tokyo, where it aimed to bolster transit ridership (Knowles, 2012). In developing countries, TOD has been implemented in cities such as Curitiba (Brazil), Ahmadabad, Delhi (India), Guangzhou (China), and Johannesburg (South Africa) to mitigate motorized transport-related issues (Abdi et al., 2022).

Previous research on TOD has predominantly focused on evaluating completed projects across various scales, including the urban, regional, and station levels. These assessments often involve private sector participation (Chorus 2009; Singh 2015). Additionally, some studies have emphasized the integration of TOD with Bus Rapid Transit (BRT) systems (McKone, 2010). Despite extensive literature in this area, a significant gap persists in quantitatively assessing TOD characteristics, often referred to as "TOD-ness," across different areas, especially in locations where TOD has not yet been implemented.

Limited studies, such as those conducted by Kamruzzaman et al. (2014) and Singh (2015), have attempted to address this gap by quantitatively assessing TOD characteristics. Typically, these evaluations involve dividing the study areas into zones to analyze the effectiveness and impact of TOD. Singh's (2015) study, for instance, computed both actual and potential TOD indices using specific criteria and indicators. The Potential TOD Index was designed to identify areas lacking transit connectivity and to highlight the need for improvement at the city region level of Arnhem and Nijmegen in the Netherlands. In contrast, the Actual TOD Index focuses on enhancing the transit around existing stations. Ultimately, Singh utilized the TOD Index and developed the Planning Support System(PSS) to assist the city region of Arnhem and

Nijmegen in delivering TOD. This index, along with the PSS, played a crucial role in addressing planning interventions across various land-use and transport-planning scenarios.

1.3. Justification

TOD is widely acknowledged for its potential to address pressing urban transport challenges effectively. Studies by Noland et al. (2014) and Ibraeva et al. (2020) emphasize the numerous benefits associated with TOD, including the reduction of air pollution and the promotion of sustainable urban development. Over the decades, the integration of BRT into urban master plans has shown these advantages, with Curitiba often cited as a global benchmark (Mercier et al., 2015; Joshi et al., 2017). Recognizing the uniqueness of each city, the success of Curitiba serves as a compelling example of how innovative planning approaches, such as TOD, can address complex urban issues faced by similar developing cities and ensure sustained urban development.

1.4. Research Gap

Although TOD has been extensively researched since its inception, the focus has predominantly been on cities in developed countries, leaving a noticeable gap in the literature regarding TOD in developing nations. Various studies, including Abdi et al.(2022), acknowledge the importance of tailoring TOD strategies to reflect local realities. Abdi et al. (2022) highlight the challenges hindering the successful implementation of TOD in developing countries, such as the lack of participation from concerned parties due to top-down planning approaches. Therefore, there is a critical need to understand specific factors, such as stakeholder preferences, transportation choices, and local conditions and priorities, which significantly influence the implementation and effectiveness of TOD in these contexts.

1.5. Research Problem

The complexity of TOD is widely acknowledged; however, planning institutions in developing countries often lack the necessary tools and policies to address these challenges effectively. Cities in these regions encounter various obstacles, including a mismatch between land use and transport policies, poor governance, financial constraints, and lack of expertise in TOD, all of which hinder the success of TOD initiatives. To tackle these issues, Abdi et al. (2022) advocate a participatory planning approach involving stakeholders to ensure that the needs of marginalized populations are not overlooked by the interests of wealthier or dominant transport modes.

Given these challenges, geographic information system (GIS)-based tools, such as Planning Support Systems (PSS), have emerged as essential for decision-making in planning-related endeavours. Recognizing their potential, Zefreh et al. (2023) argued that planners should be equipped with these tools to enhance public transport service provision, particularly in underserved areas. However, the potential of such systems to identify areas requiring improved public transport, particularly in Sub-Saharan African (SSA) cities where TOD has not yet been implemented, remains underexplored.

1.6. Research Objectives and Questions

This study aims to bridge the gap in TOD planning by developing a TOD Planning Support Tool(used interchangeably with PSS Prototype in the context of this study) tailored to enhance PT in developing cities. To achieve this overarching goal, the following objectives are pursued:

First, a comprehensive review of recent literature and case studies on TOD implementation in developing countries, as well as the use of PSS in similar contexts is carried out. This serves to elucidate the challenges encountered and the lessons learned in implementing TOD and PSS tools within the context of developing cities.

Second, active engagement with local stakeholders, including researchers, urban planners, transport planners, policymakers, and NGO Staff, is undertaken to gather insights into the specific challenges and priorities of TOD in the local context. This participatory approach is designed to ensure that the TOD Planning Support Tool is grounded in the diverse perspectives and needs of the local stakeholders.

Following stakeholder engagement, the Potential TOD Index values are computed using secondary data sources and inputs provided by local stakeholders.

Finally, a PSS prototype is developed based on the computed Potential TOD Index values and insights from local stakeholders. This tool is designed to help prioritize TOD, enabled by BRT, as envisioned in the city's master plan 2050's ambition.

The overarching research question guiding this study is:
How can the TOD Index and Planning Support Tool enhance PT in developing cities?

To address this central inquiry, specific research objectives and sub-questions are delineated, as outlined in Table 1.

Specific Objectives	Research Sub-Questions
Investigate and compute indicators for the Potential TOD Index.	• What is the spatial extent and resolution for the analysis?
	• What indicators are used for the Potential TOD index calculation?
	• What data is needed to compute the potential TOD index?
Use spatial analytical methods (GIS and SMCA) to derive a Potential TOD index from specified indicators.	• How is the Potential TOD Index calculated?
Apply spatial statistical methods to analyze TOD index values.	• How are the Potential TOD index values classified and interpreted?
	• What areas have significantly high and low TOD index values?
	• What areas have the potential for transit connectivity?
Develop a TOD Planning Support Tool using Potential TOD index values to prioritise PT along the main BRT Corridors.	• What components should a TOD Planning Support Tool have?
	• How can the TOD Planning Support Tool leverage the Potential TOD Index to prioritise

	BRT development along the proposed BRT Corridors?
	• What are the limitations of the proposed TOD Planning Support Tool?

Table 1: Research Objectives and Questions

1.7. Significance and Contribution of the Research

This study is valuable to academia and policymakers in SSA and other developing urban areas. It proposes improvements in TOD to address disparities in PT accessibility, which is crucial for enhancing urban life and fostering inclusive urban development.

Methodologically, this research offers insights into engaging stakeholders in urban planning, particularly for TOD. Engaging stakeholders facilitates the development of TOD projects that are responsive to local contexts and challenges.

From a practical perspective, the PSS prototype developed in this study shows promise for replication and scalability across diverse urban contexts, given the common planning constraints faced by cities in the developing world.

1.8. Conceptual Framework

This study adopts a comprehensive conceptual framework to elucidate the multifaceted nature of TOD in developing countries. Based on the study by Evans et al. (2007), Ewing and Cervero's 5Ds (2010), and insights from Fard (2013) and Singh et al. (2014), the framework emphasizes four essential criteria deemed critical for successful TOD: Density, Diversity, Design, and Economic Development. Each criterion is associated with specific indicators that collectively contribute to enhancing the TOD outcomes.

Density includes population, employment, and commercial density, all of which are crucial for increasing transit ridership. The second criterion, Diversity, is evaluated through land-use data and it is used to highlight the importance of diverse land uses in enhancing transit viability and fostering pedestrian-friendly environments. For Design, assessments are made on the mixedness index, road lengths favouring walking and cycling, and intersection density, which are all crucial for enhancing walkability and cyclability around transit stations. Economic Development includes indicators such as the number of business establishments, municipal tax earnings, and employment levels, essential for bolstering transit performance.

To enrich this framework, the TOD Planning Support Tool is integrated to leverage the potential TOD indicators as inputs for calculating the TOD index. This integration facilitates interactions among different stakeholders, enabling them to discern the most favourable outcomes from various planning interventions, thereby enhancing participatory, collaborative, and transparent decision-making.

Figure 1 below illustrates the adopted conceptual framework with all the indicators commonly used for computing the TOD index. These indicators are widely recognized for assessing the potential of TOD in the area. However, it is worth noting that decisions regarding the inclusion and exclusion of indicators were made considering context-specific challenges of data availability and the constraints of the research timeframe.

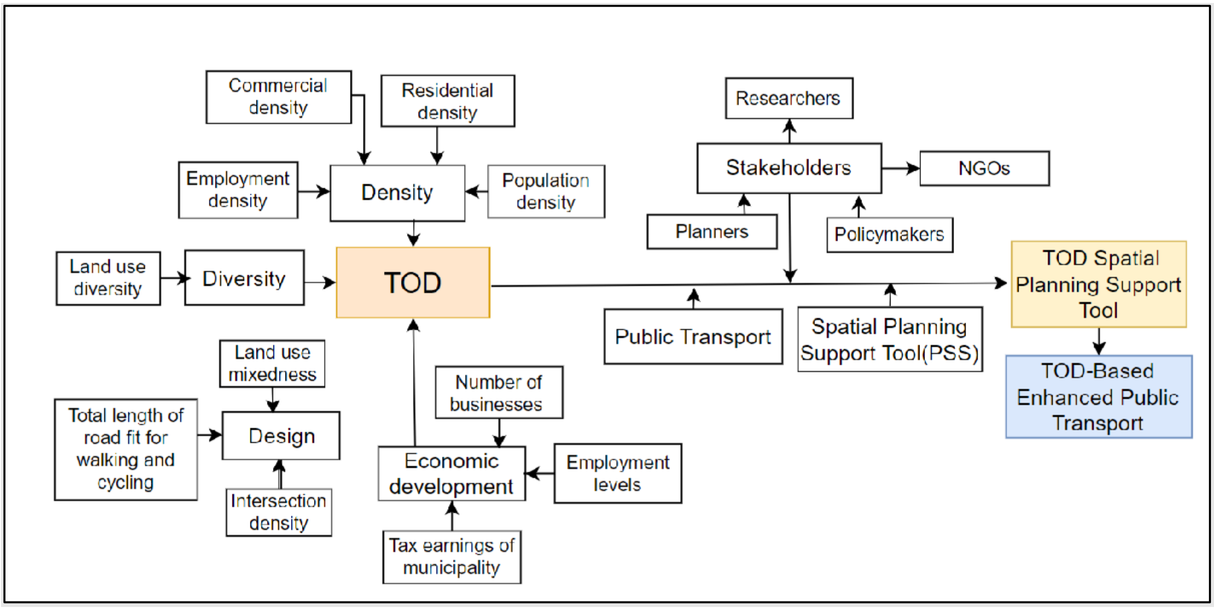


Figure 1: Adopted conceptual framework

1.9. Research Methodology Overview

The research methodology, illustrated in Figure 2, outlines the steps followed throughout the study, from the literature review to the development of the PSS.

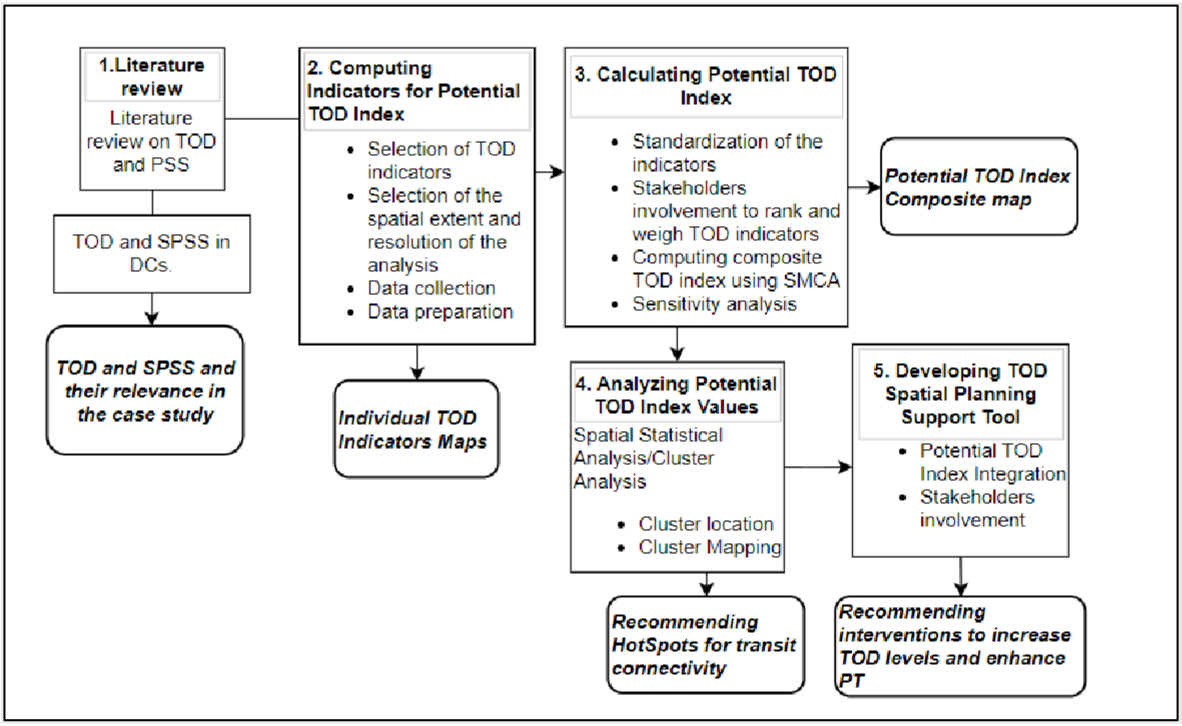


Figure 2: Overview of research methodology

First, the existing literature on TOD and PSS is explored to establish the theoretical foundation and relevance of TOD and PSS within the context of developing cities. This review aids in understanding the applicability and impact of these concepts through a case study.

In the second phase, indicators for computing the Potential TOD Index are identified and calculated. This involves selecting relevant TOD indicators, determining the spatial extent and resolution of the analysis, collecting the necessary data, and performing data processing. The result of this step is a set of maps that display individual TOD indicators.

In the third phase, the Potential TOD Index is computed. This step involves Spatial Multi-Criteria Analysis (SMCA) which includes standardizing the indicators to ensure comparability and ranking, weighing of the indicators based on inputs from stakeholders and finally computing a composite TOD index. The final output is a composite map that visualizes potential TOD areas in the selected city.

Next, the Potential TOD Index values are analyzed by performing spatial statistics and cluster analyses to identify and map clusters, allowing for the visualization of areas with high or low TOD potential. This analysis sheds light on the spatial distribution of potential TOD areas, leading to recommendations for interventions to enhance transit connectivity.

Finally, a TOD Planning Support Tool is developed. Selected variables and indicators are imported into CommunityViz, the ArcGIS extension used for the PSS prototype development. These variables are linked to their respective indicators via different formulas to derive the Potential TOD Index. This index is used to help the city prioritise the TOD along its proposed BRT corridors. The PSS prototype is made user-friendly, allowing stakeholders to interact with the tool by modifying the weights assigned to the potential TOD indicators and identifying the impact of changing these weights on the Potential TOD Index values.

1.10. Research Outlines

This study is organized into six main sections, each designed to understand and develop TOD in developing countries, notably in the City of Kigali(CoK), Rwanda.

- **Introduction:** This section sets the stage for this research. It provides a general introduction and background to the study. It outlines the justification for the research and identifies the research gap. Additionally, it states the research problem, objectives, and questions. The section also discusses the significance and contribution of the research and presents the conceptual framework and an overview of the research methodology.

- **Literature Review:** This section explores existing literature relevant to the study. It covers the definitions and principles of Transit-Oriented Development (TOD). The review also examines methods for measuring TOD and discusses the benefits and challenges of TOD planning in developing countries. It includes an examination of Planning Support Systems (PSS), their types, and roles in the planning process. Additionally, it explores the intersection of TOD and PSS and discusses the state of public transport in developing countries.

- **Methodology:** This section details the research design and the rationale for selecting Kigali City as the case study area. It provides an overview of Kigali's population dynamics, urban form, and transport system. The methodology section includes a comprehensive explanation of the data collection processes, both primary and secondary. It describes the analytical techniques used and the steps for computing the composite Potential TOD Index. Finally, it explains the development and implementation of the PSS prototype.

- **Results:** This section presents the findings from the data analyses. It includes the results of primary data analysis from Key Informant Interviews (KIIs) with stakeholders. Additionally, it covers the secondary data analysis, which involves computing TOD indicators such as population density, commercial density, employment density, land use diversity, intersection density, and road length suitable for walking and cycling. The section also presents spatial statistical and cluster analysis results and the outcomes from testing the PSS prototype.

- **Discussion**: This section interprets the results obtained from the analyses. It discusses the findings from the KIIs and the Potential TOD Index results. The discussion also includes the interpretation of spatial and cluster analysis results. Furthermore, it interprets the PSS results, highlighting the practical implications of the findings for TOD planning and public transport improvements in Kigali.

- **Conclusion:** The final part of the study summarizes the key findings and presents policy recommendations based on the research results. It addresses the limitations encountered during the study and suggests directions for future research.

References and supplementary materials are included, with appendices providing additional information.

2. Literature Review

2.1. Transit-Oriented Development (TOD)

2.1.1. Definition and Principles

TOD is an urban planning approach that aims to integrate land use and transportation planning. By doing so, it fosters sustainable environments favourable for pedestrian and cycling activities. Various definitions of TOD exist within the scholarly discourse, as shown in Table 2. For instance, the Center for Transit-Oriented Development(2009) defined TOD as a concept that emphasizes the creation of pedestrian- and cycling-friendly environments to reduce reliance on individual vehicles for long commutes. Other authors, such as Calthorpe (1993) and Hale and Charles (2006), have also described TOD as high-density urban areas with mixed-use developments located within easily walkable distances from transit stops.

Author	Definition
Calthorpe (1993)	A mixed-use community within a 2000-ft walking distance of a transit stop and core commercial area, promoting convenience for residents and employees to use transit, bicycle, walk, or drive.
Bernick and Cervero (1997)	A compact, mixed-use community centred on a transit station, designed to reduce car usage and promote mass transit.
Still (2002)	A mixed-use community encouraging residents to live near transit services and reduce car dependence.
Cervero et al. (2004)	TOD serves as a tool for smart growth, economic development, and meeting changing housing market demands and lifestyle preferences.

Transit-Oriented Development Institute	A combination of regional planning, city revitalization, suburban renewal, and walkable neighbourhoods addressing climate change and energy security by creating dense, walkable communities.
World Resources Institute	A sustainable urban development solution creating mixed-use, dense, walkable communities with access to high-quality transport.
US Department of Transportation	TOD involves commercial, residential, office, and entertainment spaces near transit stations, promoting dense, walkable, mixed-use development.
Centre for Transit-Oriented Development	Defined as high-density, mixed-use developments within walking distance of a transit station, fostering increased transit ridership and reduced regional congestion.
Maryland Department of Transportation	TOD consists of higher-density developments incorporating residential, employment, shopping, and civic uses within easy walking distance of a transit centre.

Table 2: Various definitions of TOD

Effective TOD planning extends beyond merely enhancing transit ridership and involves extending transit connectivity to areas exhibiting TOD characteristics. As argued by Singh(2015), TOD Planning seeks to adapt urban development to be more transit-oriented while improving transit services in areas with TOD potential, but lacking connectivity. This would lead to achieving the key objectives of TOD, namely, reducing dependence on private cars, enhancing public transportation access through efficient land use planning, improving connectivity, and promoting non-motorized transport modes (Ghosh, 2020).

The conceptualization of TOD by Peter Calthorpe in the late 1980s laid the groundwork for subsequent research and development in this field. Calthorpe's seminal work, "The New American Metropolis" (1993), established a basic framework for TOD that has since evolved to address contemporary urban challenges such as congestion, pollution, and the imperative for sustainable living (Carlton, 2017). As argued by Austin et al.(2010), these definitions collectively emphasize TOD's role of TOD in creating sustainable urban environments by reducing car dependency and promoting PT use.

2.1.2. Measurement

The evaluation typically employs a 3D framework consisting of Density, Diversity, and Design. Galelo (2014) measured density from the perspective of residential and job densities, diversity from land use, and design based on street connectivity ideal for cycling and walking. Later, Ewing and Cervero (2001) expanded this framework to the 5D framework by incorporating Destination Accessibility, which measures the ease of reaching destinations, and Distance to Transit, which assesses the proximity to transit nodes. Building on this, Kamruzzaman et al. (2014) further refined the approach by including indicators such as PT accessibility, net residential and employment densities, land-use mix, intersection density, and cul-de-sac density.

These indicators are crucial for evaluating the success and effectiveness of TOD projects. As reported by Ibrahim et al. (2022), TOD indicators can help identify areas with high TOD potential. This can further guide stakeholders, governments, and investors to effectively plan and prioritize investments in identified areas.

2.1.3. Benefits and Challenges of TOD Planning in Developing Countries (DCs)

The World Bank defines "Developing Countries" (DCs) as nations with low to middle-income, young populations, rapidly urbanizing cities, and growing economies. However, in the realm of transport and urban development, cities in DCs present both challenges and opportunities for implementing TOD.

They often face mobility and transport challenges owing to inadequate PT systems, leading to a reliance on informal modes of transport, such as walking and cycling. Unlike developed nations that have successfully integrated safe bicycling facilities, DCs often lack such infrastructure, impacting accessibility and mobility and contributing to increased private car ownership. This situation further exacerbates environmental degradation and climate change(UN-Habitat 2013).

Conversely, urban development in DCs is characterized by dense urban cores, sprawling informal settlements, and poor road infrastructure, which significantly affect access to employment opportunities (Cervero, 2013). Various challenges in implementing successful TOD have been identified. These include the 60 challenges identified by Abdi et al. (2022), which they categorized into contextual, policy and planning, implementation, and actor challenges.

Despite these obstacles, Pojani and Stead (2017) suggested that trends in active transport modes and bus ridership in DCs may not decrease, as observed in North America. This underscores the potential benefits of TOD in DCs, as it can help alleviate pressing urban development and transport issues by promoting compact, mixed-use development that enhances accessibility and reduces car dependency.

2.2. Planning Support Systems (PSS)

2.2.1. Overview and Types

PSS, as described by Geertman and Stillwell (2009), are advanced data-driven tools that leverage Geographic Information Systems (GIS) and decision support capabilities to translate data into actionable insights for planning-related decision-making processes. Initially designed for short-term decision-making, PSS evolved in the late 1980s to support planners in various planning activities, including analysis, visualization, and prediction (Pelzer et al., 2008; Pelzer et al., 2014). Geertman (2014) identifies three main types of PSS: (1) Information PSS, which delivers data through interactive maps and visualizations, commonly observed in web-based platforms for regions like Brabant and Utrecht in the Netherlands, (2) Communication PSS, exemplified by platforms like www.verbeterdebuurt.nl, facilitating multiple user interactions to identify and discuss area improvements, and (3) Analysis PSS, used by researchers to enhance planning outputs.

2.2.2. Role of PSS in the Planning Process

PSS play an important role in enhancing the effectiveness of urban planning processes. When integrated with spatial data, analytical models, and expert insights, PSS offer valuable support in decision-making processes, such as validating anticipated impacts and guiding policy decisions (Barmentlo, 2012).
In addition, PSS contribute to structuring knowledge within collaborative planning efforts. It incorporates both explicit knowledge (such as datasets and information) and tacit knowledge (expressed through discussions) to facilitate richer exchanges among stakeholders, leading to improved outcomes for urban planning initiatives (Barmentlo, 2012; Te Brömmelstoet & Bertolini, 2008).

Furthermore, GIS-based PSS provides a powerful tool for visualizing policy impacts on maps, aiding in the identification of affected areas, and offering clear insights to non-GIS experts (Esri, 2012). This visualization capability is particularly valuable in contexts with limited data availability, such as developing countries. In these settings, the PSS capitalizes on datasets to support informed decision-making processes (Barmentlo, 2012).

2.2.3. TOD and PSS

Recent trends in PSS have showcased a concerted effort towards enhancing planning processes and outcomes (Pelzer et al., 2014). A notable example is illustrated by Singh (2015), who demonstrated the potential of PSS in evaluating TOD at local and regional levels within the Arnhem and Nijmegen city regions in the Netherlands. Singh's research stresses the capabilities of PSS in analyzing, visualizing, and predicting land-use scenarios. This best practice offers valuable insights into planning practices, serving as a model for other regions, particularly developing countries, to adopt similar tools and enhance their planning strategies.

2.2.4. Public Transport(PT) in Developing Countries(DCs)

PT encompasses various collective transport services accessible to the public, including buses, trams, trains, and ferries, facilitating shared travel experiences. According to UN-HABITAT(2018), achieving accessibility to urban mobility is crucial for sustainable development, requiring high-capacity PT integrated within a multimodal framework. This entails creating more compact and walkable cities through improved urban planning and the integration of land-use and transportation-planning strategies. Additionally, as pointed out by Barmentlo(2012), PT can be evaluated based on (1) affordability, (2) availability, (3) accessibility, and (4) acceptability, which have a direct impact on PT quality and inclusivity.

According to UN-Habitat (2018), accessibility can be enhanced by promoting PT and active transport modes with good intermodal connectivity, helping reduce car-centric travel, and fostering inclusive urban environments. However, existing studies reveal challenges in PT planning, particularly in developing countries (DCs), where formal PT systems often struggle with mismanagement and lack profitability, leading to low quality and safety standards (Sohail et al., 2006; Barmentlo, 2012). Despite these issues, informal PT or paratransit plays a crucial role in meeting transportation needs, especially for lower-income populations (Barmentlo, 2012).

Addressing these challenges requires assessing the needs of various stakeholders, including passengers, operators, and government agencies in PT planning. Passenger-centric planning is essential, particularly in ensuring PT is affordable, available, accessible, and acceptable for low-income groups that are heavily reliant on PT, as concurred by Gomide et al.(2007). Transit operators typically prioritize profitability and passenger satisfaction, whereas governments aim to create efficient and sustainable transit systems that cater to diverse societal needs, such as reducing pollution and congestion (Vuchic, 2005; Barmentlo, 2012). Thus, effective coordination is essential to minimise potential conflicts of interest between transit operators and the government.

3. Methodology

3.1. Research Design

This study is designed to develop a TOD Spatial Planning Support Tool to enhance public transport (PT) in Kigali City, Rwanda. The approach integrates qualitative and quantitative methodologies to address the research questions and objectives comprehensively. The approach adopted allows for an in-depth understanding of the unique contextual factors influencing TOD.

3.1.1. Rationale for Case Study Selection

Kigali stands out as one of Africa's cleanest and most rapidly developing cities. Despite the challenges posed by rapid urbanization in the cities of developing countries, the city has witnessed significant economic growth and infrastructure development over the past few decades, resulting in improved residents' socioeconomic well-being, education, and health standards (Baffoe et al., 2020). This transformation is largely attributed to the strategic urbanization policies implemented by the Rwandan government, which aimed to transition the nation from a rural, impoverished state to a thriving, modern economy.

In pursuit of sustainable transport and urban excellence, Kigali has revised its master plan to address current challenges and capitalize on new opportunities (Nkurunziza et al., 2021). Notably, the Kigali Master Plan 2050 envisions TOD enabled by BRT and zoning regulations to promote high-density mixed-use developments along transport corridors. This plan prioritizes pedestrian-friendly designs, aiming to provide 80% of Kigali's population with access to reliable public transport within a 500-meter radius (ITDP, 2022).

The Master Plan also projects substantial growth in employment and population, with jobs expected to increase from 0.58 million in 2018 to 1.7 million by 2050, and the population from 1.3 million to 3.8 million in the same period. These ambitious plans highlight TOD as a crucial planning approach to help Kigali address its unique challenges and support its sustainable urban development.

3.1.2. City of Kigali: Overview

Kigali is the capital and largest city of Rwanda. It spans an area of 730 km² and is located at a latitude of 10°58' S and longitude of 30°07' E. The city is divided into three administrative districts: Gasabo, Kicukiro, and Nyarugenge. Gasabo is the largest, covering 429.3 km², followed by Kicukiro (166.7 km²) and Nyarugenge (134 km²), and is further divided into 35 sectors, 161 cells, and 1,155 villages (Kigali City, n.d.).

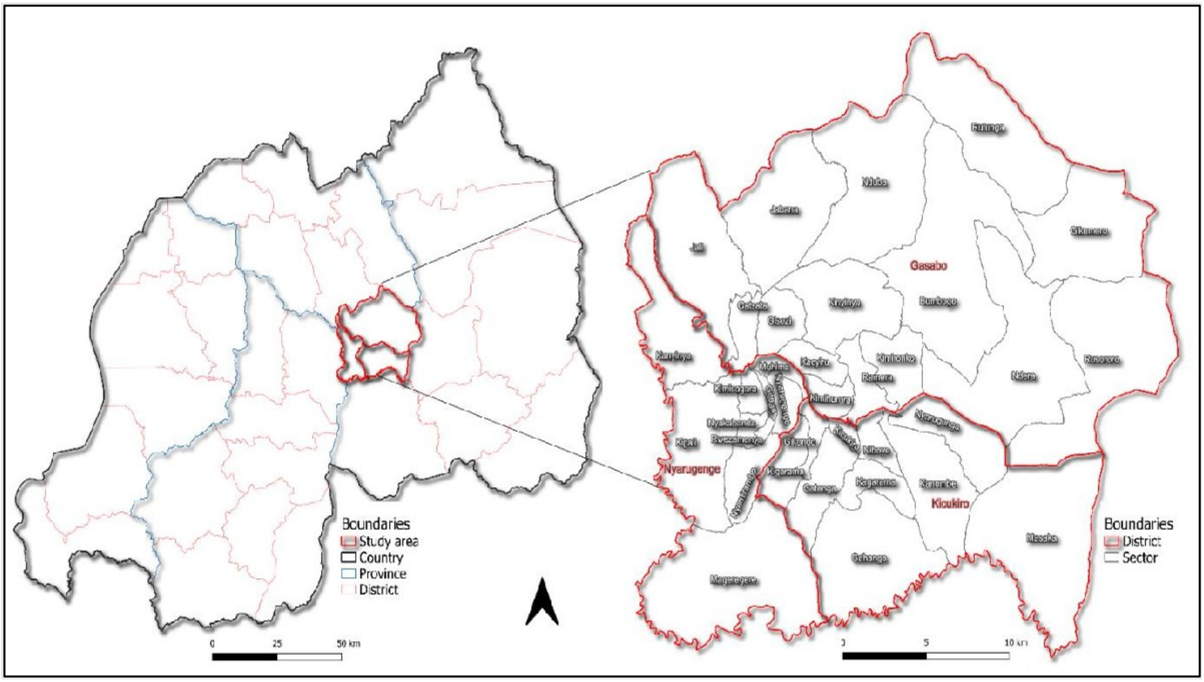


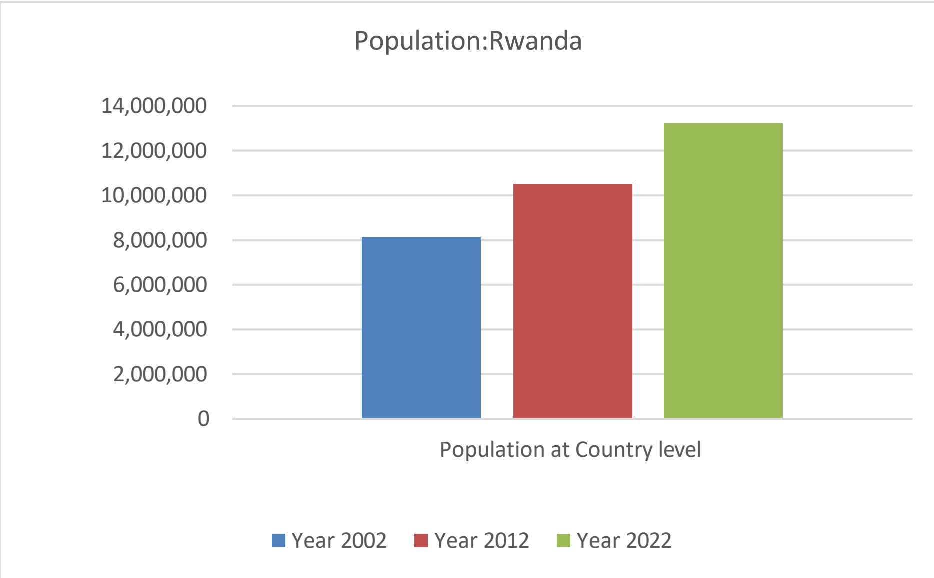
Figure 3: Map of the City of Kigali

Kigali is bordered by the Gicumbi and Rulindo Districts to the north, Bugesera and Rwamagana Districts to the east, and Kamonyi District to the south. The city has a mean annual precipitation of 1,189.18 mm and an average annual temperature of 19.20°C.

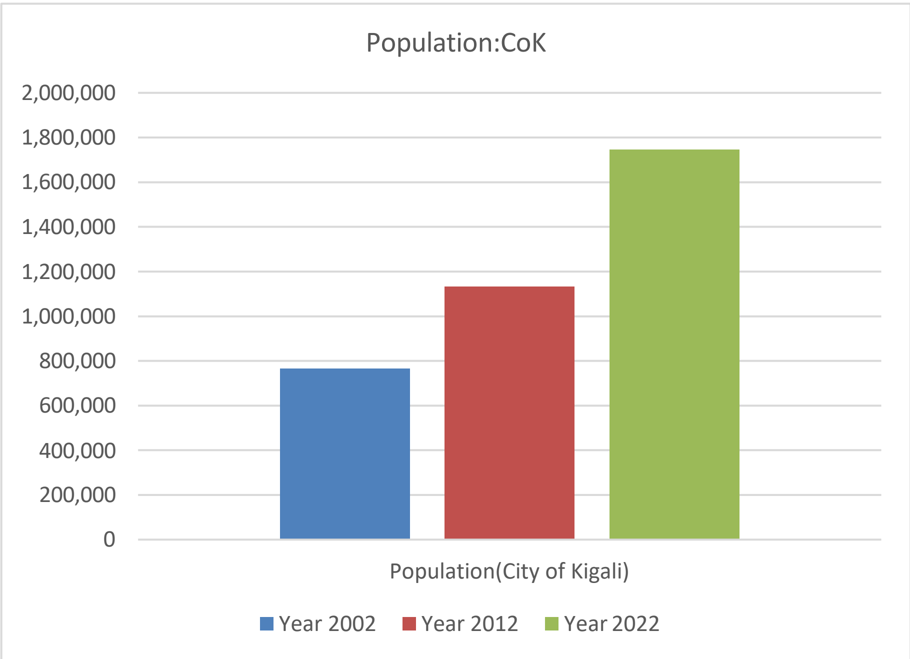
Over the last two and a half decades, Kigali has experienced rapid growth, making it one of the fastest-growing cities in Africa with an annual urbanization growth rate of 4%. The city contributes over 41% of the national GDP, showcasing its significance to the Rwandan economy.

3.1.2.1. Population and Population Density

According to the Fifth Rwanda Population and Housing Census (RPHC5) of 2022, Kigali's population was 1,745,555, reflecting a 35% increase from 1,132,686 in 2012 and a 56% increase from 765,325 in 2002. In comparison, Rwanda's population grew from 10,515,973 in 2012 to 13,246,394 in 2022, a 26% increase, and a 63% increase from 2002 to 2022 (City Population, 2024).

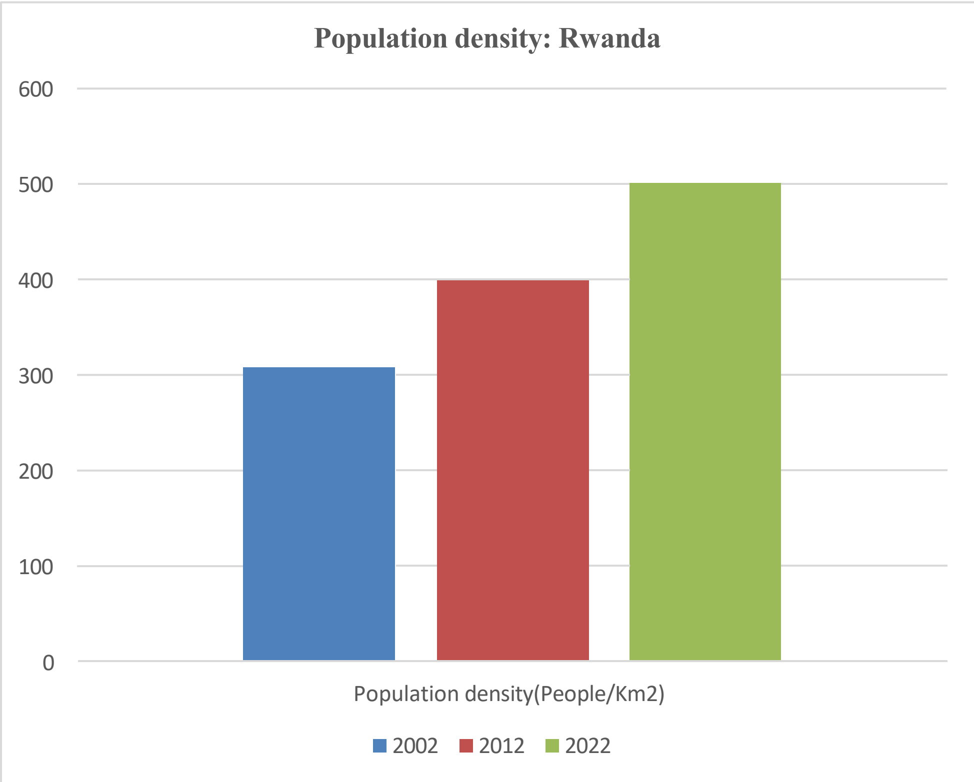


Graph 1: Rwanda population dynamics for 2000, 2012 and 2022

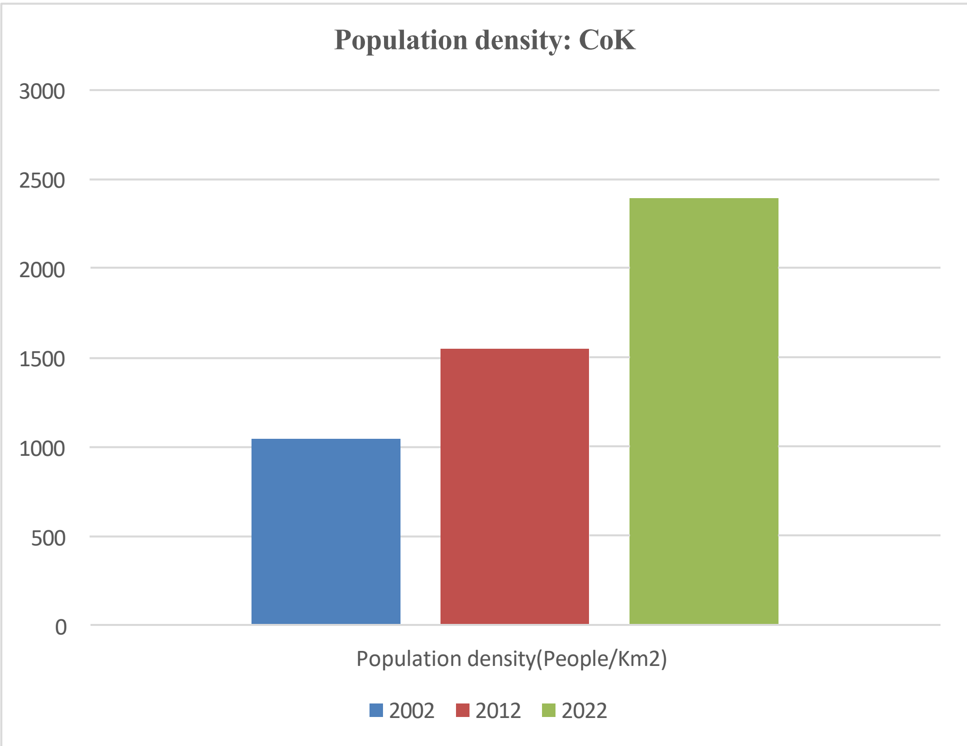


Graph 2: The CoK population dynamics for 2000, 2012 and 2022

Kigali's population density has also significantly changed, increasing from 1,048 people/km² in 2002 to 2,391 people/km² in 2022. This dynamic is primarily driven by rural-urban migration, with many people moving to the city in search of job opportunities.



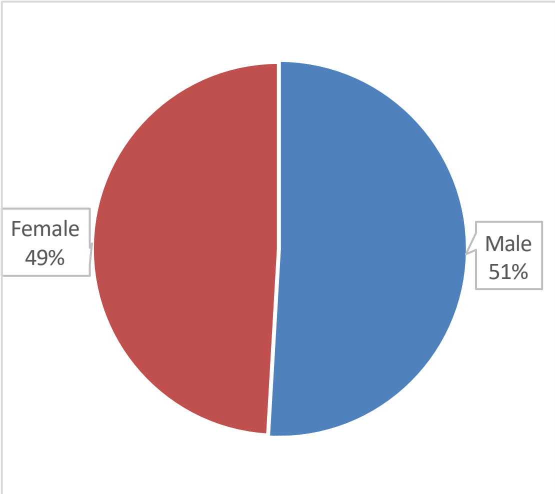
Graph 3: Rwanda Population density changes for 2000, 2012 and 2022



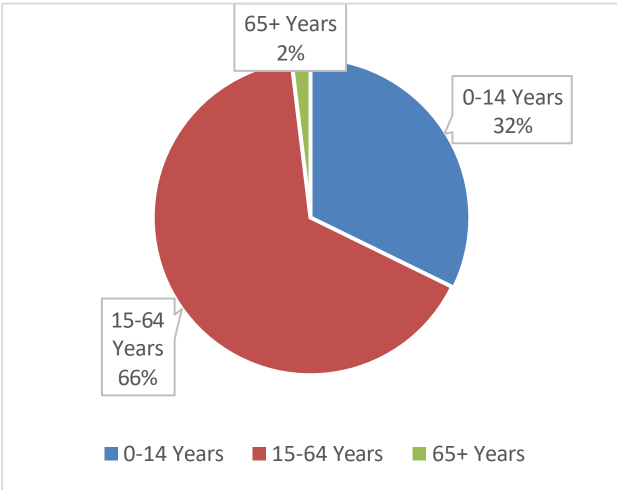
Graph 4: Kigali Population density changes for 2000, 2012 and 2022

3.1.2.2. Gender Composition and age structure

Kigali City exhibits a nearly balanced gender distribution, with males constituting 49.1% (888,882 people) and females 50.9% (856,673 people) of the population (City Population, 2024). The population is predominantly youthful, with 32.2% (562,888 persons) under 15 years of age. The working-age group (15-64 years) comprises 65.8% (1,149,188 persons), indicating a potentially strong labour force(City Population, 2024).



Graph 5: Population distribution by gender

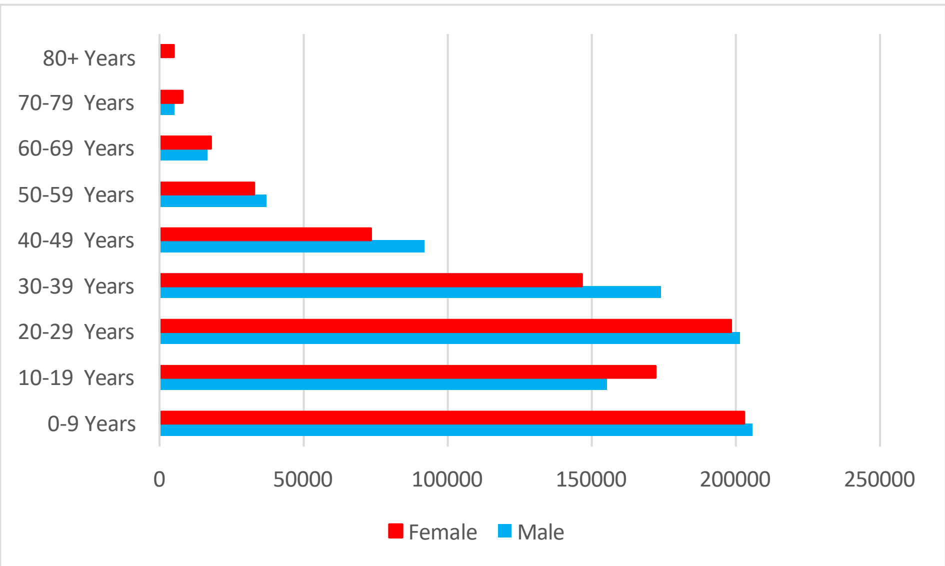


Graph 6: Population distribution by age groups

Only a small proportion, 2% (33,479 people), are aged 65 years and above.

3.1.2.3. Age distribution by gender

Examining age by sex reveals disparities in older age groups. In the 60+ age bracket, females outnumber males, indicating a higher female life expectancy (City Population, 2024).



Graph 7: Age distribution by gender

3.1.2.4. Land use

The city has a diverse range of land uses, with agriculture occupying the largest portion at 457,710 hectares, accounting for 62.7% of the total area. Nature areas are the second-largest land use type, covering 125,441 hectares or 17.18%. Residential zones comprise 80,300 hectares, representing 11% of the land use. Infrastructure spans 27,740 hectares, representing 3.8% of the area, while public administrative, institutional, and service areas cover 14,600 hectares (2%). Special use areas occupy 9,490 hectares (1.3%), commercial areas cover 3,285 hectares (0.45%), and industrial areas have 4,380 hectares (0.6%). Open spaces account for 1,825 hectares (0.25%), water bodies for 5,110 hectares (0.7%), and mixed-use areas are the smallest wth 219 hectares (0.03%).

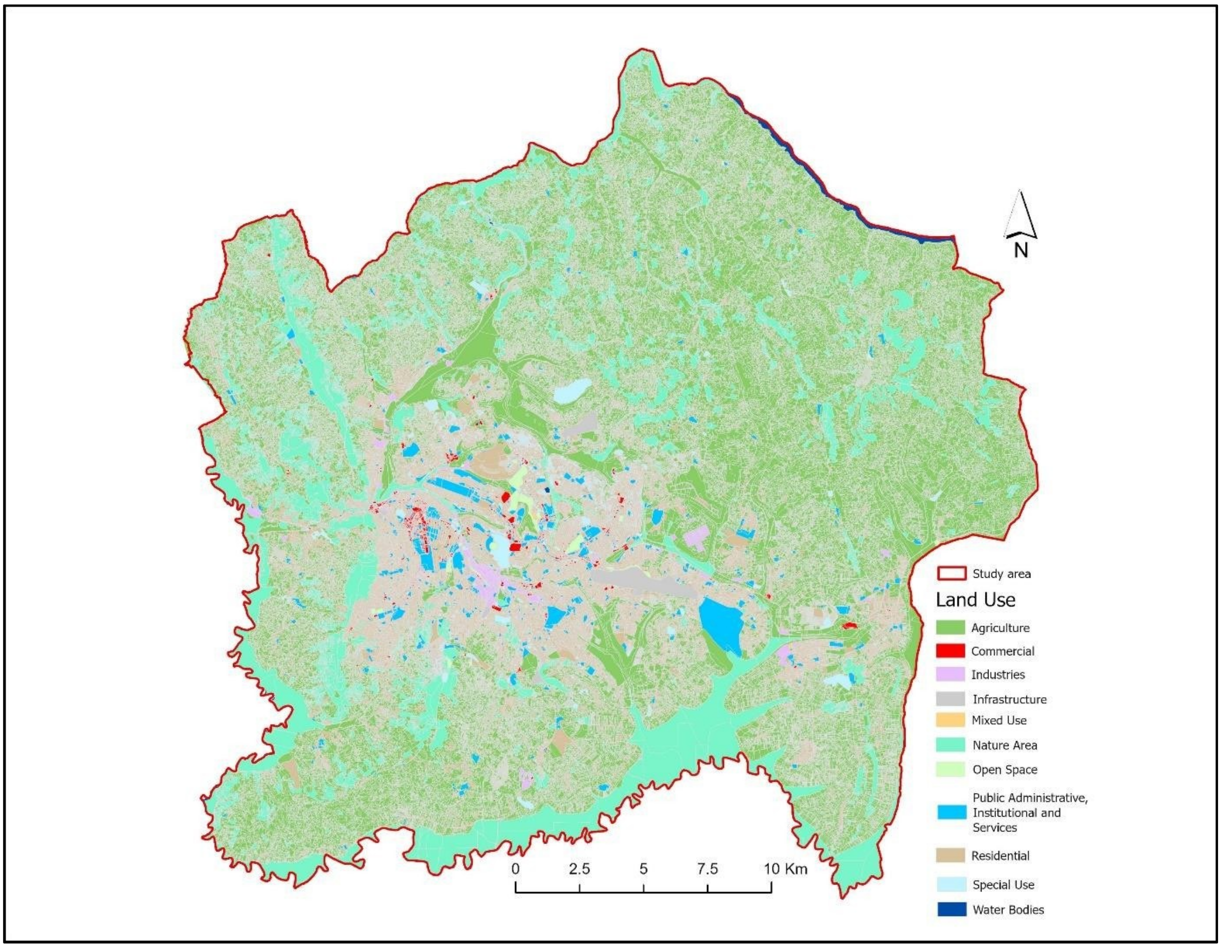


Figure 4: Land Use map of Kigali

A significant majority of the city's population, 86.9% (1,517,168 people), resides in urban areas, while the remaining 13.1% live in rural areas (City Population, 2024).

3.1.2.5. Urban Form and Road Network

Kigali's elevation ranges from 1,333 meters to over 2,069 meters above sea level, with lower elevations predominantly in the central and southern parts of the city, and higher elevations towards the periphery, especially in the northern and western regions. The transport network is marked by a dense concentration of bus routes and stops in the central areas. This reflects the urban core's quite good accessibility and connectivity to PT.

In the city's higher elevation zones, PT coverage is less prevalent due to the challenging terrain. This is further corroborated by a report of the Japan International Cooperation Agency(n.d.) stressing this issue as hindering transport infrastructure development due to the limited availability of areas for new road construction.

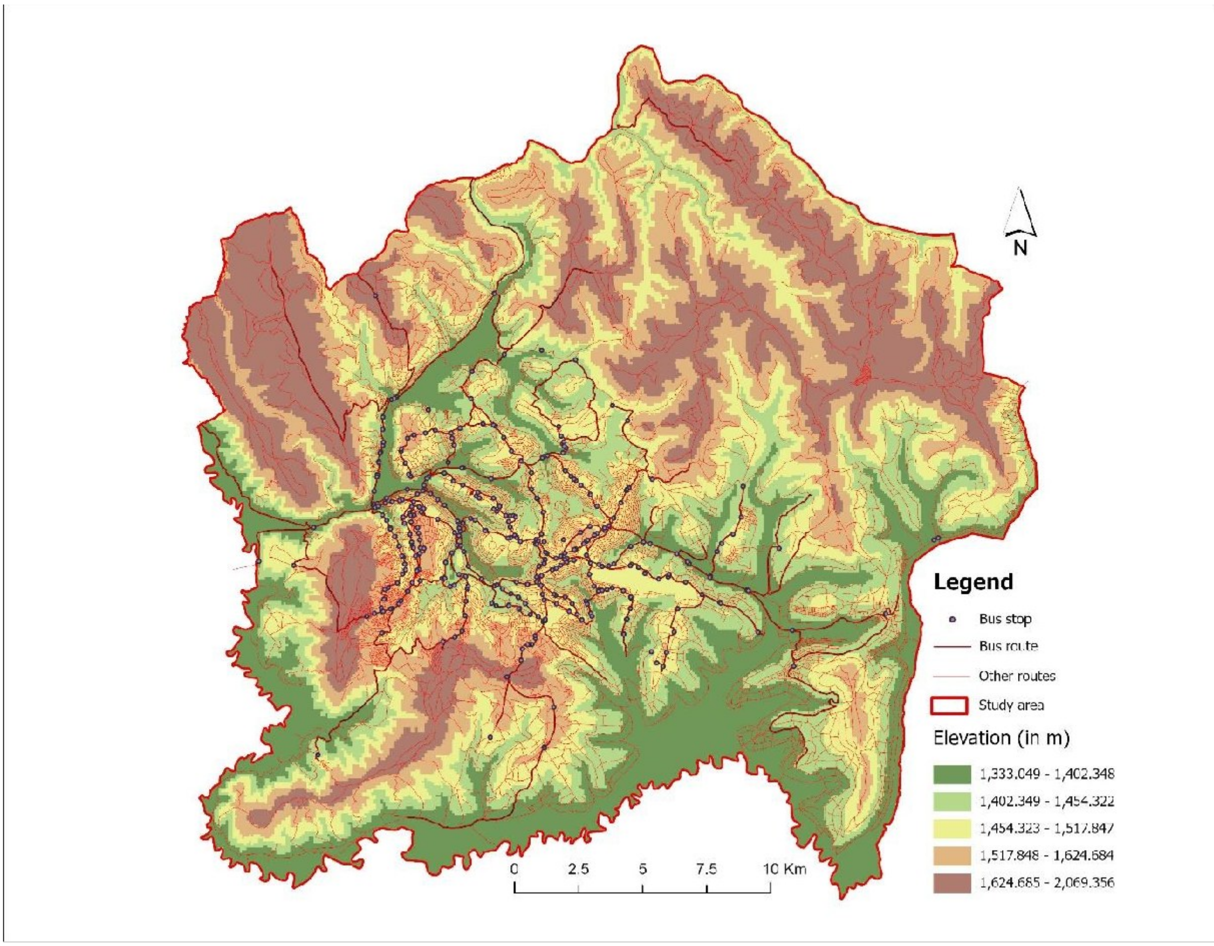


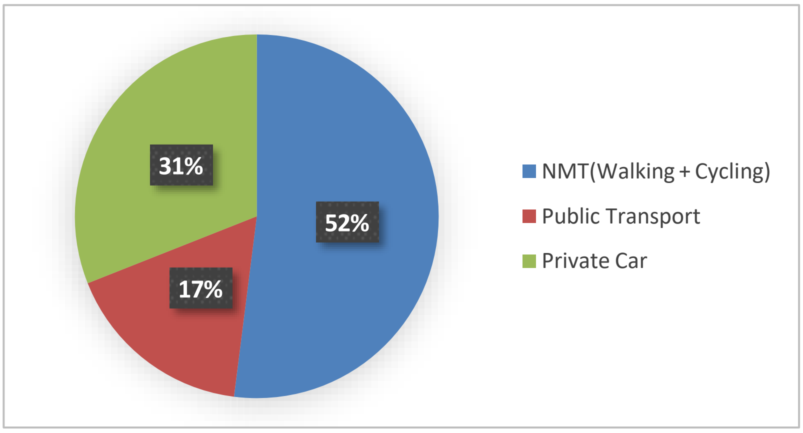
Figure 5: Elevation of the road network of the city

3.1.3. Urban Challenges in the City of Kigali

Rapid urban sprawl and increased motorized transport in Kigali have led to major traffic congestion, adversely affecting public transport (PT). Kigali's PT includes buses, taxis, motorcycles, and bicycles. However, the lack of integration between these modes has resulted in competition rather than complementarity. This has led to complaints about overcrowding during peak hours, long waiting times during off-peak periods, and inadequate services in outlying areas. Consequently, residents in these areas find it difficult to reach their destinations conveniently. To avoid delays, they often resort to more expensive alternatives like motorcycles or taxis, which impose a significant financial burden.

According to ITDP (2021) and TUMI (2023), 52% of Kigali's residents use non-motorized modes (predominantly walking, followed by a minor share of cycling), 17% use public transport (buses), and 31% use personal vehicles (including cars, motos, and taxi services). This growing reliance on motorized transport exacerbates current issues and, if left unaddressed, might lead to even greater traffic congestion and environmental challenges in the future.

The pie chart below depicts the distribution of trips made under different transport modes in Kigali.



Graph 8: Modal share in Kigali

The 2019 Kigali Traffic Report projects an increase in car usage and traffic growth, with the mode split for cars expected to rise from 32% in 2017 to 52% by 2050. Without the implementation of BRT, the car mode share could surge to 60%, translating to an annual growth rate of 1.5% over 30 years, and a traffic increase rate of 2.20% annually until 2050. To address these issues, Nkurunziza et al.(2021) concur that promoting public and non-motorized transport could help alleviate congestion and reduce environmental pollution.

3.1.4. PT and TOD in the Context of Kigali

Kigali's efforts to enhance public transport (PT) are crucial for improving accessibility and livability. The Rwandan government has launched strategic plans and policies, including the Public Transport Policy and Strategy for Rwanda, to improve PT services across the country. This policy aims to make PT more accessible, reliable, and user-friendly, supporting Rwanda's social and economic growth. Additionally, the policy addresses issues stemming from rapid population growth and increased private car use by focusing on a city-wide bus network designed to enhance efficiency and financial sustainability.

Kigali's 2013 Transportation Master Plan aims to enhance PT by expanding road networks, proposing a BRT system, and improving existing bus services and traffic management. The plan envisions transforming Kigali into a transit-oriented city with a sustainable transport network, targeting a 70:30 public-to-private transport use ratio and an average commute time of 60 minutes or less. It highlights collaboration with various stakeholders, using GIS data for traffic modelling and planning, and plans to adapt to changing needs every five years (Kigali Transport Master Plan, 2013).

3.2. Data Collection

3.2.1. Fieldwork and Primary data collection

Fieldwork was conducted between January and February 2024 to gather primary and secondary data. Gratitude is owed to Dr. Alphonse Nkurunziza, a University of Twente(UT) alumnus and senior lecturer at the University of Rwanda, for extending an invitation that allowed me to participate in a workshop organized by the Urban Lab. The Urban Lab is a collaboration between the Centre for Affordable Housing Finance in Africa and the University of Rwanda, commissioned by GIZ on behalf of the German Federal Ministry for Economic Cooperation and Development. This initial engagement proved invaluable in establishing connections with key informants relevant to this study.

Following Kumar's (1989) suggestion of involving 15-30 Key Informants for Key Informant Interviews (KIIs), this study conducted in-depth structured KIIs with 22 participants. Participants included researchers from the University of Rwanda, College of Science and Technology (UR-CST), urban planners from the City of Kigali (CoK), transport planners from the Rwanda Transport and Development Agency (RTDA), policymakers from the Ministry of Infrastructure (MININFRA), Rwanda Housing Authority(RHA) and the National Land Authority (NLA), along with representatives from two Non-Governmental Organizations (NGOs): The World Bank and TRANSITEC. The distribution of participants involved in the KII is provided in Table 3.

Participants Type	Number Interviewed
Researchers	4
Urban Planners	7
Transport Planners	4
Policymakers	5
NGO Staffs	2
Total	22

Table 3: Breakdown of study participants

3.2.1.1. Stakeholder Analysis and Inclusion in primary data collection

Participants were selected using purposive and quota non-probability sampling. This sampling strategy was chosen based on the recommendation by Renjith et al. (2021) to ensure the relevance and richness of the information from the KIIs. Although there is acknowledged importance of including citizens in TOD planning, they were excluded from this study due to the technical depth of the interviews and language barriers. Instead, insights were gleaned from professionals who work closely with citizens.

To ensure a comprehensive understanding of TOD in Kigali, the KIs were selected based on some reasons:

- Researchers from the University of Rwanda, College of Science and Technology (UR-CST), School of Architecture and Built Environment (SABE)

The School of Architecture and Built Environment (SABE) at UR-CST plays a crucial role in the nation's development by promoting advanced skills and research. SABE provides rigorous academic and technical skills to students in architecture and urban planning. Researchers from SABE are actively involved in advising the city and government on urban planning activities. They were therefore involved in this study due to their expertise from both theoretical and practical standpoints.

- Urban Planners from the City of Kigali

Urban planners provide practical knowledge of the city's planning initiatives, challenges, and strategies. They were involved in this study since their insights are essential for understanding the current and future landscape of the city's urban development. Their on-the-ground experience ensures that TOD strategies align with local urban planning efforts, enhancing the relevance and applicability of the research.

- Transport Planners from the Rwanda Transport and Development Agency (RTDA)

RTDA is responsible for planning and implementing transport infrastructure projects across Rwanda. They were involved in this study to gather their insights on both TOD and public transport from a practical perspective.

- Policymakers from the Ministry of Infrastructure (MININFRA)

The Ministry of Infrastructure (MININFRA) oversees infrastructure development in Rwanda, including transport, energy, and housing. Policymakers were included in this study due to their diverse perspectives on the regulatory and policy frameworks that influence TOD and PT. Their insights would help align the study's recommendations with national policies and strategic goals.

- KIs from the Rwanda Housing Authority (RHA) and the National Land Authority (NLA)

The Rwanda Housing Authority (RHA) is responsible for housing development and management, while the National Land Authority (NLA) manages land use and administration. Since TOD is a multidimensional concept integrating land use and transport planning, inputs from KIs from these institutions are sought to better understand the city's master plan and housing policies. This includes insights on land use regulations, housing policies, and their impact on PT and TOD.

- NGO Staff from Non-Governmental Organizations (NGOs)

The World Bank

The World Bank has been involved in financing urban planning projects in Rwanda, including the Rwanda Urban Development Project (RUDP) and the Mpazi Informal settlement upgrading project. The former project aims to improve access to basic services, enhance resilience, and strengthen integrated urban planning and management in Kigali and six secondary cities. The latter aims to upgrade 137 hectares in the Nyarugenge district by improving access roads, sidewalks, street lighting, and public facilities (CoK, 2023). This study involved one staff from this NGO who has local knowledge of the urban planning activities in the city.

TRANSITEC

TRANSITEC specializes in urban mobility issues and has experience working in various cities, including those in the Global South. This study involves one staff member from TRANSITEC who has local knowledge of urban planning activities in Kigali.

The objective of the Key Informant Interview (KII)(attached in appendix) was twofold: to gather insights into stakeholders' perspectives on Potential TOD Index indicators and the proposed TOD Planning Support Tool. For the Potential TOD Index indicators, participants were asked to rank the indicators based on their perceived importance(based on the current state) in realizing TOD. In this evaluation, stakeholders assigned a score from 1 to 10 to each criterion and indicator. This rating scale was used where 1 denoted the least important and 10, being the most critical criterion or indicator. A 10-point scale was preferred due to its granularity, simplicity, and easy interpretation, facilitating comparisons and analysis. Additionally, the KIIs were asked about how these indicators are measured in the local context and which indicators they deemed essential in the contextualization of TOD.

For the PSS, the KIs were asked about the effectiveness of the existing PSS and the potential improvements in the proposed PSS prototype.

Interviews were primarily conducted in professional settings to facilitate open and candid discussions. As per ethical research standards, each key informant was given a consent form (attached in the appendix) to ensure they were fully informed about the study's purpose, confidentiality measures, and voluntary participation.

3.2.1.2. Secondary data collection

The primary sources of data for this study, both spatial and non-spatial, were the City of Kigali (CoK) and OpenStreetMap (OSM). Population data was obtained from Kontur, part of the Humanitarian Data Exchange (HDx), a provider of geospatial data and real-time risk management solutions. This dataset, available at the country level, included population density information in hexagons at a 400-meter resolution. Land use data was provided at the city level with three attributes differing in the level of detail. Building footprint data was obtained from Open Data Source in QGIS, initially available at the national level and subsequently clipped to the boundary of the city of Kigali.

The OSM road network dataset was more comprehensive and relevant to the study than the road network dataset provided by the City of Kigali. Both datasets were compared with ground truth data to determine the most suitable one for the analysis. Ultimately, the data from OSM was selected for its richness in information. The bus stop dataset included details on bus stop names and conditions (whether covered or with a base), comprising a total of 372 bus stops. The bus route data contained attributes such as route number, number of passengers, route name, number of buses operating, route length, and status (operational, abandoned, or never started).

Given that some of these datasets were in different coordinate reference systems (CRS) and scales, adjustments were made to align them to the city scale. This was achieved using either a simple overlay technique in ArcGIS or georeferencing to ensure consistency and accuracy in further analysis.

Secondary data collected are shown in the table below. Detailed information for the collected data is documented in the Appendix.

Data sets	Format	Data Sources
Population Data	Shapefile	Humanitarian Data Exchange
Bus Stops	Geodatabase	City of Kigali
Bus Routes	Geodatabase	City of Kigali
Land Use	Geodatabase	City of Kigali
Road Network	Shapefile	OSM (Open Street Map)
Building Footprint	Shapefile	Open Data from QGIS Software
City Boundary	Shapefile	Open Data from QGIS Software
City Administrative Units	Shapefile	City of Kigali

Table 4: Data collected and their sources

3.3. Data analysis

3.3.1. Primary data analysis

Primary data was analyzed using transcription and thematic/Content analysis. First, the recorded interviews were transcribed to identify common and diverging themes/patterns across different KIIs' perspectives. Further, descriptive statistics were adopted to enrich the KII results. This approach allowed for the identification of the frequency and distribution of KIs' responses during the KIIs.

Primarily, data analysis involved plotting the responses obtained from the stakeholders. The following methods were used to analyze the KIs' perspectives qualitatively and quantitatively:

- **KII Questions 1 and 2**: The weighting of TOD criteria and indicators was analyzed by plotting the weights assigned by each stakeholder during the interviews.

- **KII Question 3**: Responses were categorized into four groups based on participants' familiarity and certainty with the TOD criteria and indicators' measurement:

- "Same": Participants identified the indicators as matching those used in Kigali.
- "Not Sure": Participants were uncertain about how the measurements are made.
- "Not Sure, But…": Participants, despite their uncertainty, suggested additional relevant indicators.
- "Same, But…": Participants acknowledged their familiarity with the indicators but highlighted discrepancies between "planning in documents" and "actual implementation".

- **KII Question 4**: The frequency of each indicator mentioned by key informants was counted.

- **KII Question 5**: The PSS mentioned by each stakeholder was recorded, and the responses were categorized to identify the frequency and types of Planning Support System (PSS) used by different stakeholder groups.

- **KII Questions 7 and 10**: The effectiveness of existing PSS and the potential usefulness of the proposed PSS were rated using a 5-point Likert scale (1 = Not Effective/Useful at All, 5 = Extremely Effective/Useful). This scale was chosen for its simplicity, sensitivity, ease of statistical analysis, and widespread use in research.

- **KII Question 9**: Participants' statements on the proposed PSS were categorized, and the frequency of these statements was visualized.

- **KII Question 11:** Participants' suggestions for improvements in the proposed PSS were categorized, and the frequency of these suggestions was visualized.

- **KII Question 12:** Participants' suggestions for data collection frequencies were categorized and visualized.

- **Other KII Questions:** The identification of common and diverging patterns among participants' responses was conducted for the remaining questions.

Raw data collected during the KIIs can be provided upon request.

3.3.2. Secondary data analysis

3.3.2.1. Identifying Potential TOD Index Indicators

To compute the Potential TOD Index, specific criteria and indicators are evaluated, as outlined in studies by Renne and Wells (2005), Evans and Pratt (2007), and Shastry et al. (2011). This study uses various Potential TOD Index criteria and indicators derived from Singh (2015) based on the following rules:

Rule 1: Density is crucial for fostering TOD.
Rule 2: Diversity contributes to a vibrant environment around a node.
Rule 3: Design promotes walkability and cyclability.
Rule 4: Economic Development correlates with increased TOD.

Following these rules, the following criteria and respective indicators were selected. The list of the selected indicators is shown in table 5 below:

Criteria	Indicators	Adopted/Not adopted
Density	Population density (number of persons/km²)	✓
	Residential density (number of residential buildings/km²)	✓
	Employment density (number of employees/km²)	✓
	Commercial density (number of commercial enterprises/km²)	✓
Diversity	Land use diversity (measured using Entropy Index)	✓
Design	Mixedness of residential land use with other land uses	✓
	Intersection density (number of intersections/km²)	✓
	Total length of road fit for walking and cycling (m or km)	✓
Economic Development	Density of business establishments (Thousands of Euros last year)	✓
	Tax earnings of municipalities	X
	Employment levels	X

Table 5: The indicators selected for measuring the Potential TOD Index

The choice of these indicators accounted for the data availability. In this regard, data for employment levels and tax earnings for the municipality was not available. Thus, these indicators had to be dropped from the analysis.

3.3.2.2. Calculating Potential TOD Index Indicators

Calthorpe (1993) and The City of Calgary (2004) define an actual TOD area as one within a walkable distance of approximately 500m to 800m from a transit node. However, for the Potential TOD Index, there is no predefined boundary or recommended area size. Following the first sub-question of this study (see Table 1), the Potential TOD Index was measured across the entire city. To achieve this, tessellations of space, including grid configurations of 100x100, 200x200, 300x300, and 500x500 meters, were generated using a tessellation approach (Mitchell, 2009). Among all these grid cells, a 300x300-meter cell size was selected as the spatial unit of analysis. This cell size is preferred based on previous studies, such as those by Singh et al. (2014) and Singh (2015). They have utilized this cell size with promising results due to its good computational performance and accuracy.

After overlaying a 300x300-meter grid cell with the 730 km² area of Kigali City, 8459 grid cells were generated. Further, the indicators for the Potential TOD Index were computed for each grid cell within the city.

a. Population, commercial, employment and business densities

The population density data was derived using the apportionment method to disaggregate existing population data from the Humanitarian Data Exchange (HDx). Initially, the population data was available at a coarser resolution. To achieve a more detailed analysis, the data was disaggregated into smaller grid cells of 300 meters by 300 meters using the apportionment method in ArcGIS. This process involved distributing the population counts from larger areas into smaller hexagons. The final step involved calculating the population counts within each grid cell, resulting in a detailed map of population density that provided a granular view of population distribution in the area.

To compute the densities of commercial, business, and employment activities, land use and building footprint data were utilized. The process involved the intersection of respective land use categories (commercial, business, and employment) with the building footprint data to identify buildings associated with these land uses. Next, centroids were generated for the resulting building footprints and the centroids were then counted within each 300x300 meter grid cell using the 'Count Points in Polygon' tool. Finally, the density for each grid cell was calculated as the number of points (representing buildings) per grid cell.
It is important to highlight that for 'Commercial density', buildings for service and retail were used, while buildings for offices, industries and consulting firms were used for 'Business Density'. For 'Employment density', all non-residential land uses were used in the analysis.

b. Land Use Diversity

Land use diversity was assessed using the entropy index. This method is widely utilized to measure diversity levels. It has been adopted in the study by Singh (2015) and Ritsema van Eck and Koomen, 2008) in the Dutch spatial planning context. The index quantifies diversity based on the proportion of different land use types within a defined area. In this study, the formula for computing the entropy index is represented as follows:

$$LU_d(i) = \frac{-\sum_i Q_{lu_i} \times \ln(Q_{lu_i})}{\ln(n)}$$

$$Q_{lu_i} = \frac{S_{lu_i}}{S_i}$$

Where:

- i = area of analysis
- lui represents the land use class (1, 2, ..., n) within the analysis area i.
- Q_{lui} denotes a specific land use share within the analysis area i.
- S_{lui} signifies the area covered by the specific land use within the analysis area i.
- S_i represents the total area of the analysis area i.

In principle, areas with higher entropy index have high land use diversity and high potential for TOD. The land use categories employed in this analysis included residential, industrial, commercial, office complexes, health, educational, sports, and 'others'.

c. Mixedness of residential land uses with other land uses

This indicator evaluates the level of walkability and cyclability in the area. It differs from land use diversity in that it measures the degree of mixedness between residential land uses and other land uses. The concept has been proposed by Jacobs(1961), Zhang and Guindon(2006) and Bach et al.(2006) and was later applied in TOD-related studies such as that of Singh et al.(2014) and Singh(2015). The proposers of this index position that a good mix of residential land uses with other land uses encourages pedestrian and cycling activity for non-work-related trips. The formula that was used to calculate this index in this study is represented as follows:

$$Mixedness\ \ index\ \ (\boldsymbol{MI}) = \frac{\sum_{\bigcap_i} \boldsymbol{Sc}}{\sum_{\bigcap_i} (\boldsymbol{Sc} + \boldsymbol{Sr})}$$

Where:

- i = area of analysis
- M_I represents the mixedness index for the area of analysis i.
- S_c denotes the sum of the total area under non-residential urban land uses within area i.
- S_r signifies the sum of the total area under residential land use within area i

In principle, the value of MI can range from 0 to 1 with 0.5 indicating the equal mix between residential land uses and other land uses in the area.

d. Total length of road fit for walking and cycling

This indicator measures the length of roads in metres that pedestrians and cyclists can access within each TOD area. Adhering to a similar study by Singh(2015) and Schlossberg et al. (2003), the indicator was computed by first excluding roads with speeds greater than 30 km/h, as these are generally not safe for non-motorized transport modes such as walking and cycling. The remaining roads, which were deemed fit for walking and cycling, were then analyzed. The total length of these roads within each grid cell was computed. The density of walkable and cyclable roads was then calculated as the total length of these roads within each grid cell.

e. Intersection density

The road intersections facilitate walking and cycling thereby reducing travel distances along routes(Singh, 2015; Ewing & Cervero, 2010). The first step to derive this indicator involved calculating the road intersections using the road network data in ArcGIS. The density was then obtained by counting the number of road intersections within each grid cell using the 'Count in Polygons' tool.

3.3.3. Spatial Multicriteria Analysis(SMCA)

To derive the Potential TOD Index, Spatial Multicriteria Analysis (SMCA) was applied to the previously computed indicators. At this point, SMCA allowed the aggregation of spatial indicators and involved the processes of standardizing and weighing these indicators.

3.3.3.1. Standardization of Potential TOD Index Criteria and Indicators

Standardization is a method used to ensure that indicators with different units are easily compared and combined. The Min-Max method was employed to achieve this in ArcGIS, where the maximum values of all indicators were set to 1 and all other values were scaled proportionately to fall between 0 and 1. However, there was another standardization required for this step. In ArcGIS, indicators directly related to the TOD index were standardized using the 'benefit' method with the logic that higher values of these indicators increase the index. For instance, the mixed-ness index value is beneficial to the TOD index until it reaches a threshold of 0.5, which represents an optimal balance between residential and other land uses. Beyond this value of 0.5, the mixedness index is treated as a 'cost,' since it impacts the TOD index. For this reason, a combination of standardization methods(benefit and cost) was only applied to the Mixedness Index indicator.

3.3.3.2. Weighing of Potential TOD Index Criteria and Indicators

As previously shown in Table ***5***, the potential TOD Index adopted in this study consists of four criteria, each with its measurable indicators. The weight of each indicator reflects its importance to its respective criterion, and the weight of each criterion indicates its importance in realizing TOD. The most common method for weighing indicators is ranking, which can be done by one or more groups of stakeholders.

As recently mentioned, various stakeholders, including researchers, urban planners, transport planners, policymakers, and NGO staff in Kigali City, participated in key informant interviews. During these interactions, they assigned scores to the indicators and criteria based on their perceived importance in achieving TOD in Kigali. Questions 1 and 2 from the questionnaire (attached in Appendix) were specifically used for this weighing evaluation.

Building on the final results of their ranking in Table 6, this study benefited from similar works by Reilly (2002), Singh et al. (2014), and Singh (2015) to aggregate the ranks using the Borda Count method and the Rank Sum method to convert these ranks to weights (ITC, 2007), according to the following formula:

$$\mathrm{Sc} = \sum_{1}^{n=10} (Kn_i * n)$$

Where:

- Kni is the number of stakeholders who assigned an n^{th} rank to the criterion number i

$$W(k) = \frac{n+1-k}{\sum_{i=1}^{n}(n+1-i)}$$

Where:

- W(k) is the normalized weight for the criterion with rank k,
- n is the total number of criteria/indicators, and
- i is the index, indicating the summation that takes the value from 1 to n.

Criterion	Indicator	Rank Order	Normalised Weight	Indicator % Contribution to Criterion	Standardisation methods
Density		**2**	**0.3**		Minimum-Maximum
	Population density	1	0.5	50 %	
	Commercial density	2	0.33	33 %	
	Employment density	3	0.17	17 %	

Diversity	Land use diversity	**1** 1	**0.4** 1.00	100 %	Minimum-Maximum
Design	Mixedness of residential land use with other land uses	**4** 3	**0.1** 0.17	17 %	Minimum-Maximum
	Intersection density	1	0.5	50 %	
	Total length of road fit for walking and cycling	2	0.33	33 %	
Economic development	Business density	**3** 1	**0.2** 1.0	100 %	Minimum-Maximum

Table 6: Weights assigned to Potential TOD Criteria and Indicators by the participants

Note: Values in bold are the normalized weights and the rank order for the Potential TOD Criteria, while the non-bold values are for the Potential TOD Indicators.

3.4. Computing Composite Potential TOD Index

The Composite TOD Index was calculated by summing the products of the standardized values of various indicators and their corresponding normalized weights. The formula adopted is shown as follows:

$$Si = \sum_{i=1}^{n} (\mathrm{W}i * \mathrm{R}i)$$

Where:

- Si is the composite TOD index for each pixel i,
- Wi is the normalized weight of all indicators,
- Ri is the standardized value of each pixel on the map of the indicator and
- n is the total number of the indicators.

The potential TOD Index was then visualized in the ArcGIS environment. Recognizing the impact of different classification methods on visualization outcomes, various methods were evaluated to determine the most accurate representation of the TOD Index in the city. The natural breaks classification scheme was selected for the city region level map as it best reflected the actual computed index, providing a balanced view compared to other methods. Other classification schemes, such as quantile and equal interval methods, were also tested but were found difficult to interpret. These methods tended to exaggerate higher TOD Index values across the city region, which did not align with on-ground realities.

Despite the overall suitability of the natural breaks classification scheme at the city level, it did not effectively depict the spatial variation of the index within the city centre. To address this, the city centre boundary was overlaid with the city-wide TOD Index results, and manual classification was applied to achieve a clearer interpretation and understanding of the spatial variations.

3.5. PSS Development

3.5.1. Methodology Overview

The approach for developing the PSS prototype involved analyzing four BRT corridors within an ArcGIS environment to compute the TOD Index for each corridor. A 500m buffer around each corridor was created, aligning with the Kigali Master Plan 2050, which envisions TOD enabled by BRT to ensure residents can access key services within this walkable distance.

The initial data table containing variables for computing the TOD Index was imported into the CommunityViz environment. Variables included population for population density, number of commercial units for commercial density, number of jobs for employment density, and number of business establishments for business density indicators. These variables were used to compute the TOD Index based on the previously discussed methodology.

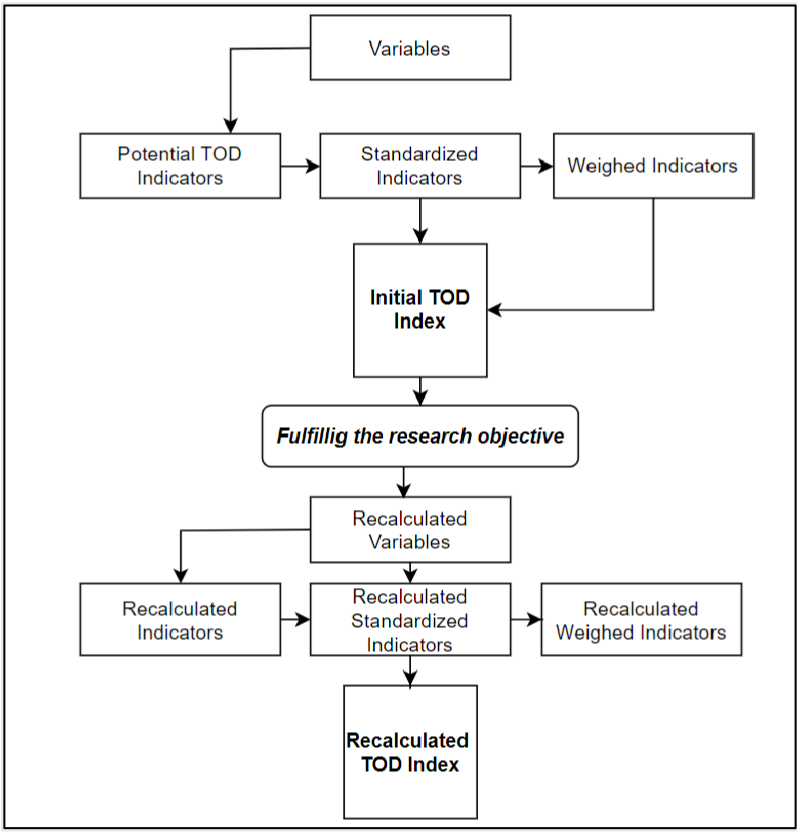


Figure 6: Methodology overview of the functionality of the PSS Prototype

Other variables related to the built environment, such as the total length of walkable paths or the number of road intersections, were excluded from this analysis. Despite their importance in realizing TOD, they were excluded for several reasons. Design indicators like the mixedness index, the total length of walkable paths, or the number of road intersections were dropped because they don't have as strong an impact on TOD as density does. Additionally, they are not considered good indicators for TOD in the local context according to the Key Informants (KIs). Other relevant indicators were excluded due to computational performance issues and the constrained research timeframe.

3.5.2. Process for Building the PSS Prototype and Implementing Scenarios Using CommunityViz

This process outlines the steps followed to build a PSS prototype and implement two distinct scenarios in CommunityViz: the Base or Business as Usual (BAU) scenario and the Increased Density Scenario.

Step 1: Setting Up the Base Scenario

The BAU scenario uses the initial values of commercial units (CU_{init}, i), jobs (J_{init}, i), population (Pop_{in}it, i), and business establishments (BusEstinit, i) for each grid cell of 300m x 300m. These values reflect the current state without any modifications. The values for the base scenario were calculated proportionally to the total number of such variables in the city. This means the value resulting from the area ratio of the BRT Corridor buffer to the total area of the city was multiplied by the total number of each variable value.

BRT Corridor Buffer	Area of the BRT Corridor Buffer (sqm)	Area of the City (sqm)	Area Ratio
BRT Corridor Buffer 1	37,996,500	730,000,000	0.05205
BRT Corridor Buffer 2	21,608,000	730,000,000	0.0296
BRT Corridor Buffer 3	34,018,000	730,000,000	0.0466
BRT Corridor Buffer 4	26,207,000	730,000,000	0.0359

Table 7: Areas and Ratios of BRT Corridor Buffers Relative to the Total City Area

For simplicity, let's take two variables as examples. The values for commercial units (CUinit, i) are used to compute commercial density (CDinit, i) and employment density (EDinit, i) for each grid cell using the formulas below:

$$CD_{\text{init},i} = \frac{CU_{\text{init},i}}{A_i}$$

, where $CD_{init,\ i}$ is the initial commercial density for cell $_i$, $CU_{init,\ i}$ is the initial commercial unit for cell i, and A_i is the area of cell i.

$$ED_{\text{init},i} = \frac{J_{\text{init},i}}{A_i}$$

where $ED_{init,\ i}$ is the initial employment density for cell i, $J_{init,\ i}$ is the initial jobs for cell i, and A_i is the area of cell i.

The next step is to standardize the indicators as done previously using the minimum and maximum method. The standardization is done as follows:

$$CD_{\text{init, std},i} = \frac{CD_{\text{init},i} - CD_{\text{init, min}}}{CD_{\text{init, max}} - CD_{\text{init, min}}}$$

$$ED_{\text{init, std},i} = \frac{ED_{\text{init},i} - ED_{\text{init, min}}}{ED_{\text{init, max}} - ED_{\text{init, min}}}$$

, where CD_{init}, std, $_i$ is the standardized initial commercial density for cell i, CD_{init}, min is the minimum initial commercial density and $CD_{init,\ max}$ is the maximum initial commercial density.

, where ED_{init}, std, i is the standardized initial employment density for cell i, EDinit, min is the minimum initial employment density and ED_{init}, max is the maximum initial employment density.

Weights are then applied to the standardized densities in the following way:

$$WCD_{\text{init},i} = CD_{\text{init, std},i} \times W_{CD}$$

, where $WCD_{init,\ i}$ is the weighted initial commercial density for cell i, and W_{CD} is the weight for commercial density.

$$WED_{\text{init},i} = ED_{\text{init, std},i} \times W_{ED}$$

, where $WED_{ini}t,\ _{i}$ is the weighted initial employment density for cell iii, and W_{ED} is the weight for employment density.

The TOD Index for each grid cell in the base scenario is finally calculated by summing the weighted densities:

$$TOD_{\text{init},i} = WCD_{\text{init},i} + WED_{\text{init},i}$$

, where $TOD_{init,\ i}$ is the initial TOD Index for cell i.

Step 2: Setting Up the Increased Density Scenario

To facilitate a comprehensive analysis, an Increased Density Scenario was created to reflect changes in densities. This scenario accounted for planning interventions such as increasing population, commercial, employment, and business densities in alignment with the city's dynamics. Since TOD positively correlates with density indicators, these planning interventions aimed to understand their impact on transit ridership and illustrate the probable prioritization of TOD at specific BRT corridors.

For the Increased Density Scenario, the recalculated TOD Index is determined similarly to the Initial TOD Index but incorporates user inputs through interactive sliders. With these sliders, users can adjust the initial values of commercial units and jobs, resulting in recalculating commercial and employment densities, standardized densities, and weighted densities. The recalculated densities are then summed up to produce the New TOD Index for each grid cell.

4. PSS Development and Implementation

4.1. Planning Support Systems (PSS) in Rwanda

Rwanda's rapid development has increased the need for advanced planning systems. The widespread access to ArcGIS software supports the adoption of digital planning tools, making GIS-based decision support systems essential for planning activities as recognized in Rwanda's National Land Use and Development Master Plan. Collaborations with institutions like the National Institute of Statistics Rwanda (NISR) and ESRI bolster this initiative (Rwanda National Resource Authority, 2010; ESRI, 2011).

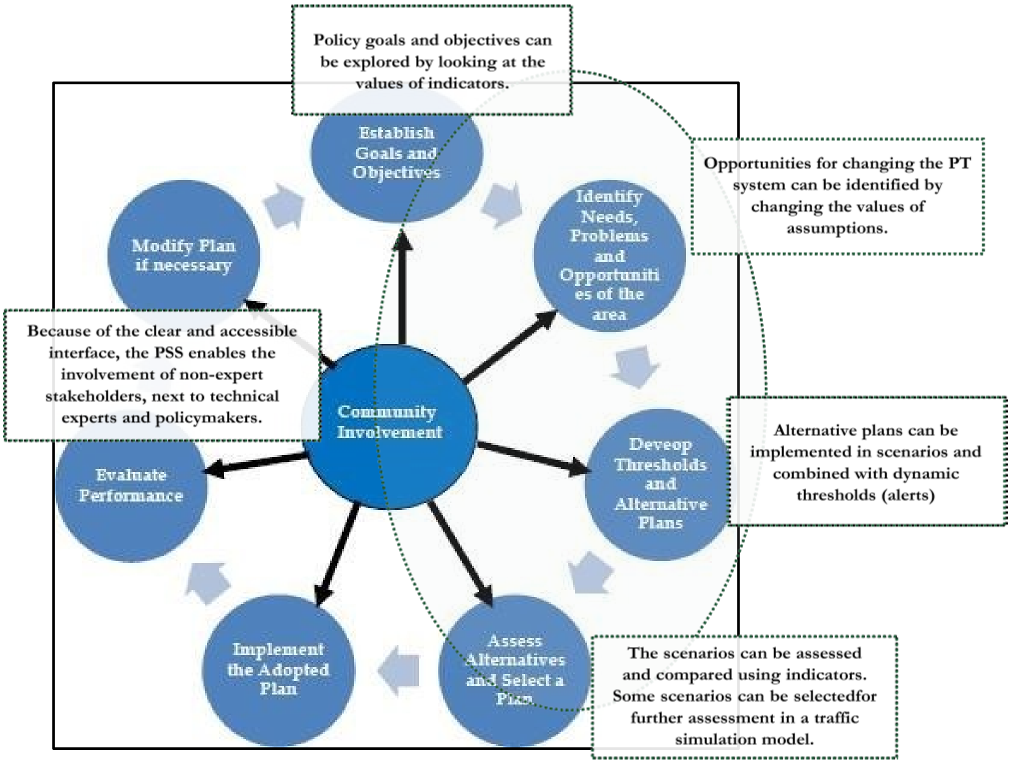


Figure 7: Significance of PSS in bottom-up public transport planning decision-making processes

Note: Derived from Rwanda Ministry of Infrastructure (2012) and Barmentlo (2012)

The Rwandan government favours inclusive public transport planning involving multiple stakeholders through a bottom-up approach. As shown in Figure **7**, Planning Support Systems (PSS) can enhance community participation in planning, ensuring rational, transparent decision-making and effectively engaging diverse stakeholders (Rwanda Ministry of Infrastructure, 2012).

4.2. The need for PSS

Kigali aims to integrate Transit-Oriented Development (TOD) enabled by Bus Rapid Transit (BRT) into its Master Plan 2050. The Transport Master Plan highlights the need for innovative solutions to enhance public transportation planning and implementation. While the current situation has been evaluated via the TOD Index, which highlights areas with potential for TOD, further analysis is required to understand the impact of different planning interventions, such as changes in population density, commercial density, employment density, and business density on the Potential TOD index.

This makes the PSS a crucial tool for dealing with this planning endeavour. Insights from Key Informant Interviews (KIIs) emphasized the need for such a tool that can translate theoretical concepts into actionable urban development strategies. Furthermore, Barmentlo (2012) advocates for a tool that can deliver transparent planning outcomes. Using CommunityViz, the PSS prototype is designed to meet these needs by allowing users to interact with the tool, understand the link between variables and the TOD Index, and explore various scenarios to make well-informed decisions.

4.3. Main Decision Problem

The primary decision problem addressed by this PSS is the prioritization of BRT corridors under different conditions, such as current and increased population, commercial, business and employment densities. This is critical for allocating limited financial resources effectively and achieving the city's planning objectives. For example, the city might aim to build an inclusive BRT targeting the urban poor in informal settlements or maximize profitability by focusing on high-density, economically vibrant areas. An inclusive BRT would prioritize accessibility and affordability for low-income residents, ensuring equitable transport options. In this case, maximizing profitability would involve focusing on areas with higher economic activities and population densities to ensure a quick return on investment. The PSS allows for such flexible decision-making, enabling users to explore different scenarios and make informed choices.

4.4. Intended Users of the PSS

The potential users of this PSS are diverse, encompassing policymakers, urban and transport planners, consultants, NGOs, community representatives, and researchers.

Policymakers, including officials from the Ministry of Infrastructure (MININFRA), Rwanda Utilities Regulatory Authority (RURA), and the City of Kigali (CoK), are responsible for urban planning and transport policy. This tool may provide them with data-driven insights to make informed policy decisions, helping them prioritize investments and interventions in BRT corridors based on objective criteria, and ensuring efficient allocation of public resources.

Urban and transport planners from CoK and the Rwanda Transport Development Agency (RTDA) require detailed analysis and visualization capabilities to support their planning and implementation processes. This tool may help assess various scenarios and their impacts on TOD success. For instance, using socioeconomic data, the tool can help prioritize BRT corridors that maximize profitability or provide alternative transport modes in areas with low affordability.

Consultants, including private sector consultants, transport experts, and professionals from the Rwanda National Resources Authority (RNRA), often provide technical expertise and innovative solutions to urban planning projects. This PSS allows them to conduct detailed feasibility studies and impact assessments of the BRT corridors, providing informed recommendations to their clients.

Non-Governmental Organizations (NGOs) and community representatives play a crucial role in ensuring that the planning process is inclusive and addresses the needs of all community members. The tool's interactive and user-friendly interface allows NGOs and community representatives to engage actively in the planning process, understanding the implications of different planning scenarios, and fostering informed community participation and support.

Researchers involved in the planning process of the city can benefit from this tool by bringing their existing expertise in urban and transport planning. By using this PSS, they can provide insights into how the TOD indicators can be improved to achieve a higher TOD Index.

4.5. Conceptual Framework of the PSS Prototype

The PSS is composed of various components, including inputs, processing, analysis, and outputs. The PSS offers several key functionalities that enhance its utility for users. With its dynamic analysis capability, the PSS built in this study allows users to alter input variables and observe real-time changes in TOD Index scores, facilitating scenario testing and sensitivity analysis. Besides TOD Index assessment along the BRT Corridors, it helps users visualize the variables and indicators via maps and charts and obtain reports. Users can also compare scenarios to identify the most favourable conditions for TOD along the corridors.

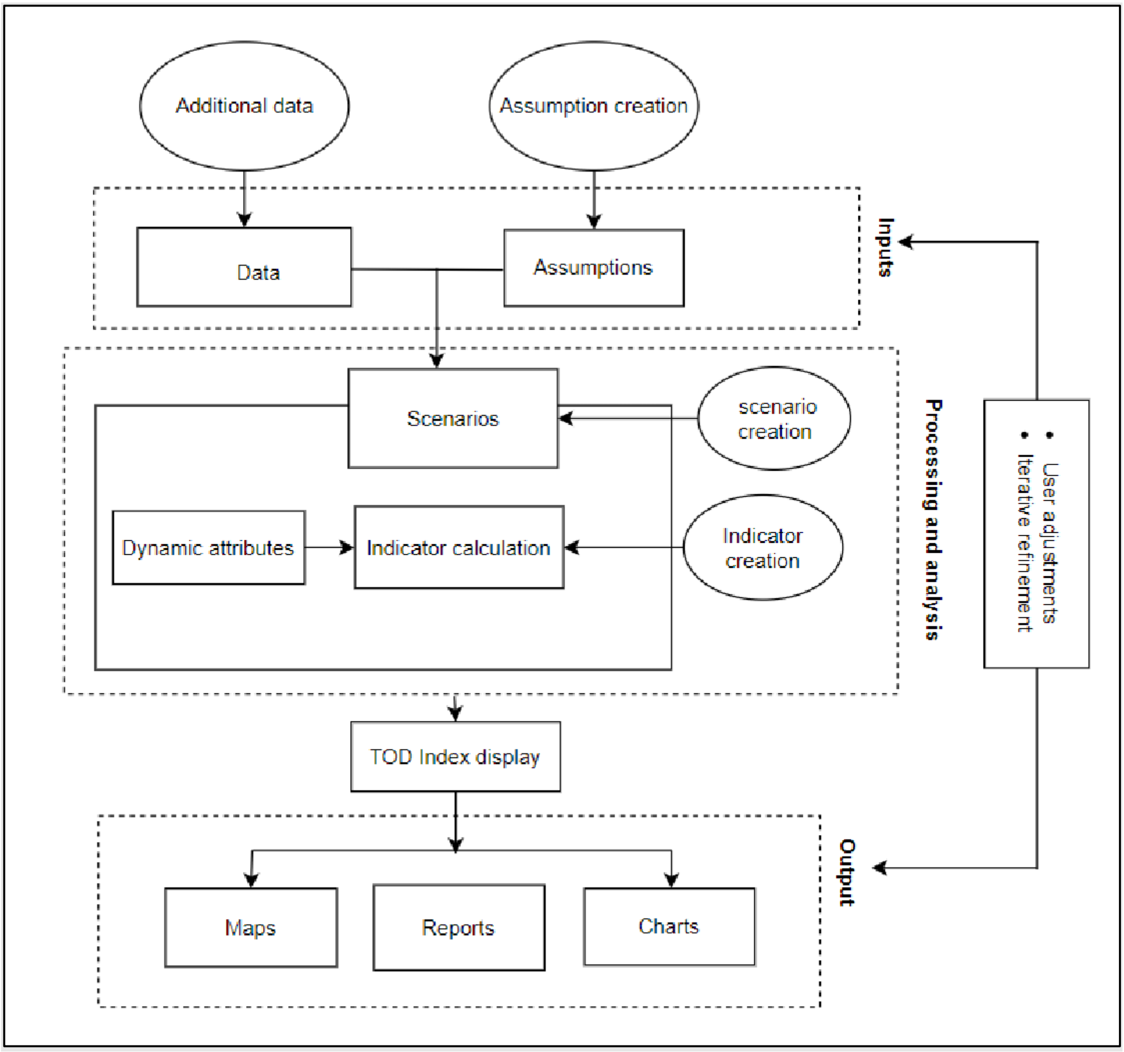


Figure 8: Conceptual Framework of the PSS Prototype

The data inputs for this PSS are the indicator variables mentioned previously. They are again used to calculate the indicators in CommunityViz. Assumptions are set to facilitate the interactive analysis. The tool could leverage other data, including specific data identified by key informants as crucial to localizing TOD. However, this data was not part of the current analysis due to availability issues.

The second part of the PSS prototype is the processing and analysis. CommunityViz relies on calculations and formulas to function properly. Formulas are used to link variables to their indicators and indicators to the TOD Index. Base and alternative scenarios are also established to facilitate the analysis. CommunityViz can also provide reports of all analysis steps carried out and their respective formulas. The final output is the mean TOD Index Score at each BRT Corridor. The initial and new TOD Index Scores are charted in the PSS Interface to show the difference in their values as variables are adjusted by users. This helps users understand the impact level of each variable on TOD and identify the most effective planning strategies.

4.6. Implementation and Scenario Values

To provide a more reasonable estimate for the increased density scenario, a planning horizon that aligns with Kigali's urban development plans is considered. Typically, urban planning scenarios are projected over a medium-term horizon of 10 to 20 years. However, for this analysis, a one-year planning horizon is used for monitoring purposes. This allows for tracking progress annually and adjusting based on year-on-year performance.

Given the Kigali City Master Plan 2050's projection of the population increasing from 1.3 million in 2018 to 3.8 million by 2050 (Kigali City Master Plan 2050), an average annual growth rate of approximately 4.5% for the city's population is estimated. This translates to annual growth in population, commercial units, jobs, and business establishments.

Variables	BRT Corridor	Area of the BRT Corridor Buffer (sqm)	Area of the City (sqm)	Area Ratio	Base Scenario	Increased Density Scenario	Annual Growth Rate
Population	Corridor 1	37,996,500	730,000,000	0.05205	26,044	27,214	4.5%
	Corridor 2	21,608,000	730,000,000	0.0296	4,637	4,846	4.5%
	Corridor 3	34,018,000	730,000,000	0.0466	21,913	22,896	4.5%
	Corridor 4	26,207,000	730,000,000	0.0359	11,901	12,436	4.5%
Commercial Units	Corridor 1	37,996,500	730,000,000	0.05205	1,583	1,594	0.7%
	Corridor 2	21,608,000	730,000,000	0.0296	505	509	0.7%
	Corridor 3	34,018,000	730,000,000	0.0466	579	583	0.7%
	Corridor 4	26,207,000	730,000,000	0.0359	517	521	0.7%
Number of Jobs	Corridor 1	37,996,500	730,000,000	0.05205	1,607	1,652	2.9%
	Corridor 2	21,608,000	730,000,000	0.0296	1,582	1,626	2.9%
	Corridor 3	34,018,000	730,000,000	0.0466	4,452	4,576	2.9%
	Corridor 4	26,207,000	730,000,000	0.0359	1,643	1,689	2.9%
Business Establishments	Corridor 1	37,996,500	730,000,000	0.05205	593	597	0.7%
	Corridor 2	21,608,000	730,000,000	0.0296	353	355	0.7%

	Corridor 3	34,018,000	730,000,000	0.0466	299	301	0.7%
	Corridor 4	26,207,000	730,000,000	0.0359	282	284	0.7%

Table 8: Variables used in the scenarios

The impact of infrastructure projects like the Mpazi informal settlement upgrading and the Urban Fabric Initiative (UFI) is expected to result in steady growth in commercial units and business establishments. The Mpazi project, launched in February 2023 by the City of Kigali in partnership with the Ministry of Infrastructure and supported by the World Bank, aims to upgrade 137 hectares in the Nyarugenge district by improving access roads, sidewalks, street lighting, and public facilities (CoK, 2023). Similarly, the UFI focuses on enhancing public spaces and community infrastructure, promoting economic activities.

With Kigali's economic diversification and investment in the services and industrial sectors, a steady annual growth rate of 2.8% in job opportunities is reasonable over a 20-year horizon. This aligns with the World Bank report of 2023 on the same status of the city’s economic development. This means that the number of jobs in Corridor 1 is expected to increase significantly.

Formula Adopted:
The annual growth rate is applied using the formula:
Future Value=Current Value×(1+Annual Growth Rate)
Where:
Future Value is the projected value after one year.
The current Value is the base scenario value.
Annual Growth Rate is the growth rate per year (e.g., 4.5% for population).

5. Results

5.1. Primary Data Analysis Results

The results for the KIIs are explained below. For their visual representation, See Graph 8-30 in the Appendix. For the sake of clarity, the interview results are split into two parts (TOD and PSS). This part describes the results for TOD; the interview results for the PSS will be covered later in the chapter dedicated to PSS.

5.1.1. Weighing and Measuring Potential TOD Criteria/ Indicators

In assessing the criteria and indicators for Potential TOD, stakeholders across various sectors—including researchers, urban planners, transport planners, and policymakers—recognized density as a crucial factor. They emphasized the importance of population, employment, and commercial densities in enhancing public transport efficiency. However, several challenges hinder high-density development and access to public transport, including uneven density distribution, informal settlements, and Kigali's topography. Urban planners noted that cultural preferences for single-family homes also pose a barrier to increasing urban density. Despite these challenges, stakeholders acknowledged governmental efforts to increase densities through master plans and national land use policies.

Diversity was identified as another critical criterion by stakeholders. They recognized its potential to reduce travel demand and promote economic opportunities through mixed-use development. However, stakeholders pointed out that Kigali lacks sufficient land-use diversity, with most commercial activities concentrated in a single Central Business District (CBD). This concentration leads to increased travel and congestion. While some stakeholders were optimistic about the master plan's potential to enhance diversity, others criticized the uneven spatial distribution of land use. They emphasized the need for more evenly distributed mixed-use areas to alleviate congestion and support sustainable urban development.

Economic development was commonly seen as crucial for TOD's success. Stakeholders highlighted Kigali's economic growth, noting the increasing number of jobs in the city. However, concerns were raised about the prevalence of informal jobs. Additionally, the uneven spatial distribution of economic opportunities, predominantly centred in CBDs, was identified as a hindrance to accessibility and economic vibrancy across different areas of the city.

Criteria	Rank Order	Indicator	Rank Order
Density	2	Population density	1
		Commercial density	2
		Employment density	3
Diversity	1	Land Use Diversity	1
Design	4	Mixedness of residential land use with other land uses	3
		Intersection density	1
		Total length of road fit for walking and cycling	2
Economic Development	3	Business density	1

Table 9: Ranking results for the Potential TOD Index criteria and indicators

Due to the low rating of the design criterion, stakeholders stressed the need for efforts to enhance street connectivity and promote non-motorized transport (NMT). However, stakeholders identified Kigali's topography as a significant challenge, limiting the development of a walkable and bikeable environment. They advocated for a more robust urban design framework to support compact development and better street connectivity, particularly in peripheral areas.

Lastly, common concerns about public transport efficiency and affordability were expressed by stakeholders. They noted that the public transport system struggles to meet growing demand, leading to increased reliance on private cars, especially during peak hours. This situation poses challenges for low-income residents who find it difficult to afford regular public transport services. Stakeholders emphasized the need for government subsidies to enhance public transport accessibility.

With how the potential TOD criterion/indicators are measured, the KII revealed mixed perspectives and uncertainty among participants. For this question, some identified consistency with existing measurements, while others expressed uncertainty or suggested additional indicators that they deemed to be used in measuring TOD(See Graph 21 in the appendix). For instance, service diversity, social mix, resilience to natural hazards, public transport level of ridership, accessibility to public transport, and connectivity with neighbouring cities were highlighted. Additionally, several other indicators including industrial areas, the income of neighbourhood dwellers, social equity, culture, topography, accessibility to informal modes of transport, inclusivity, school location, participatory planning, density and intensity of urban development, job accessibility, social/affordable housing, and mode share were also mentioned. These insights emphasize the importance of a holistic approach to TOD planning which accounts for local nuances and challenges

5.2. Secondary Data Analysis Results

5.2.1. Potential TOD Index Indicators

a. Density Indicators

The analysis of density indicators revealed a clear concentration of activities in the city centre(See Figure 10-13). Population density is highest in the central areas and gradually decreases toward the outskirts, where peripheral regions are less populated. This pattern extends to commercial density, with the vibrant urban core with commercial activities while peripheral areas have fewer such zones. Employment density also follows this trend, with more job opportunities centrally located. Business density is similarly concentrated in the Central Business District (CBD), indicating that major business activities are centralized, leaving the outskirts with minimal business presence. This spatial distribution highlights a clear gradient from the centre to the periphery, where central areas act as the main hub for commercial, employment, and business activities, while peripheral regions remain less developed and less densely populated. Stakeholders noted that this major concentration of densities in the city centre significantly impacts the spatial distribution of commercial, business, and employment activities. They concurred that the existence of a single major CBD where almost all activities take place leads to increased travel to the city centre. This centralization results in higher ownership of private cars, which in turn causes increased traffic congestion and poor public transport performance.

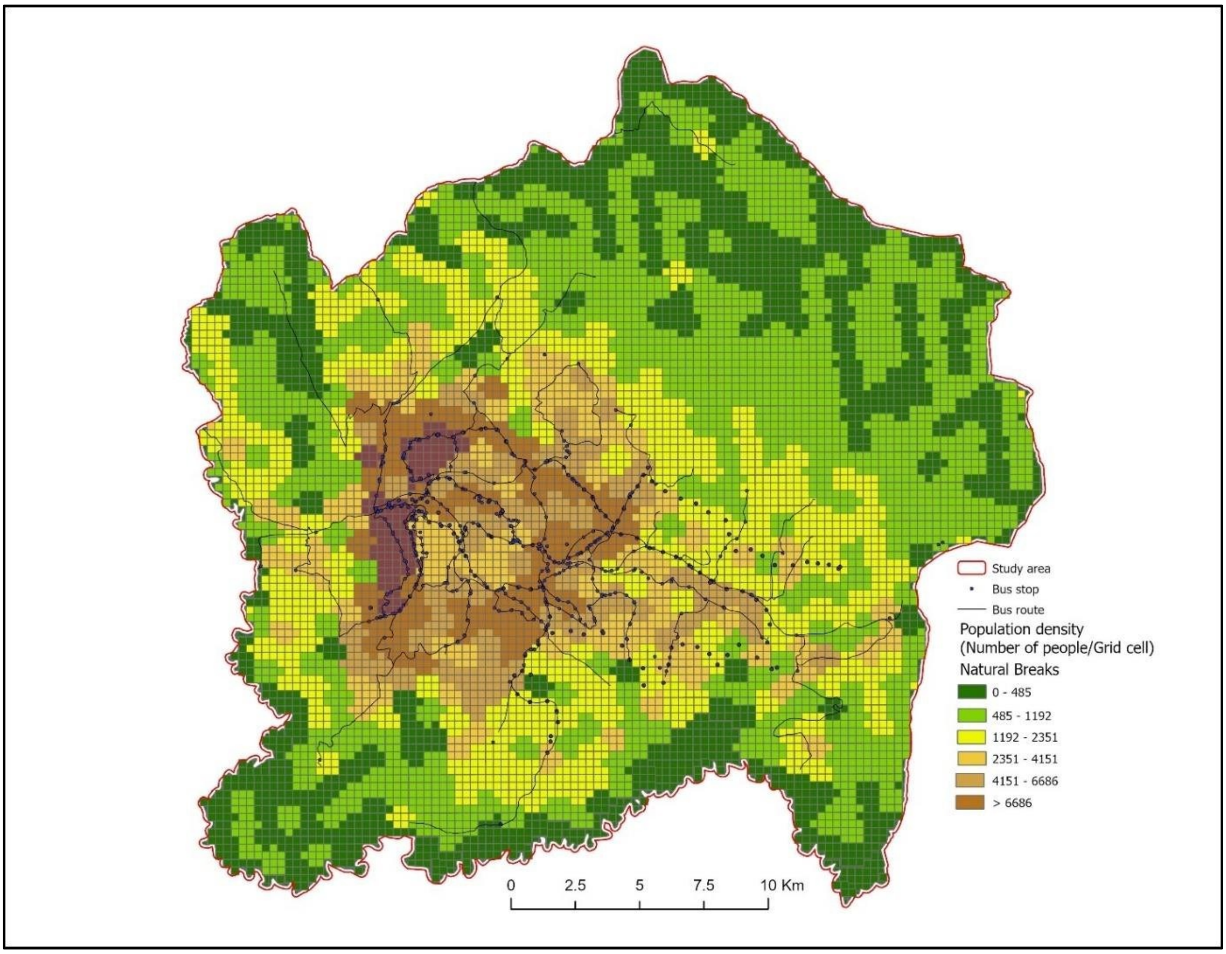


Figure 9: Population Density (Number of people per grid cell).

Note: The highest value: is 20158, Lowest value: is 0. High values indicate densely populated areas, while low values indicate sparsely populated regions.

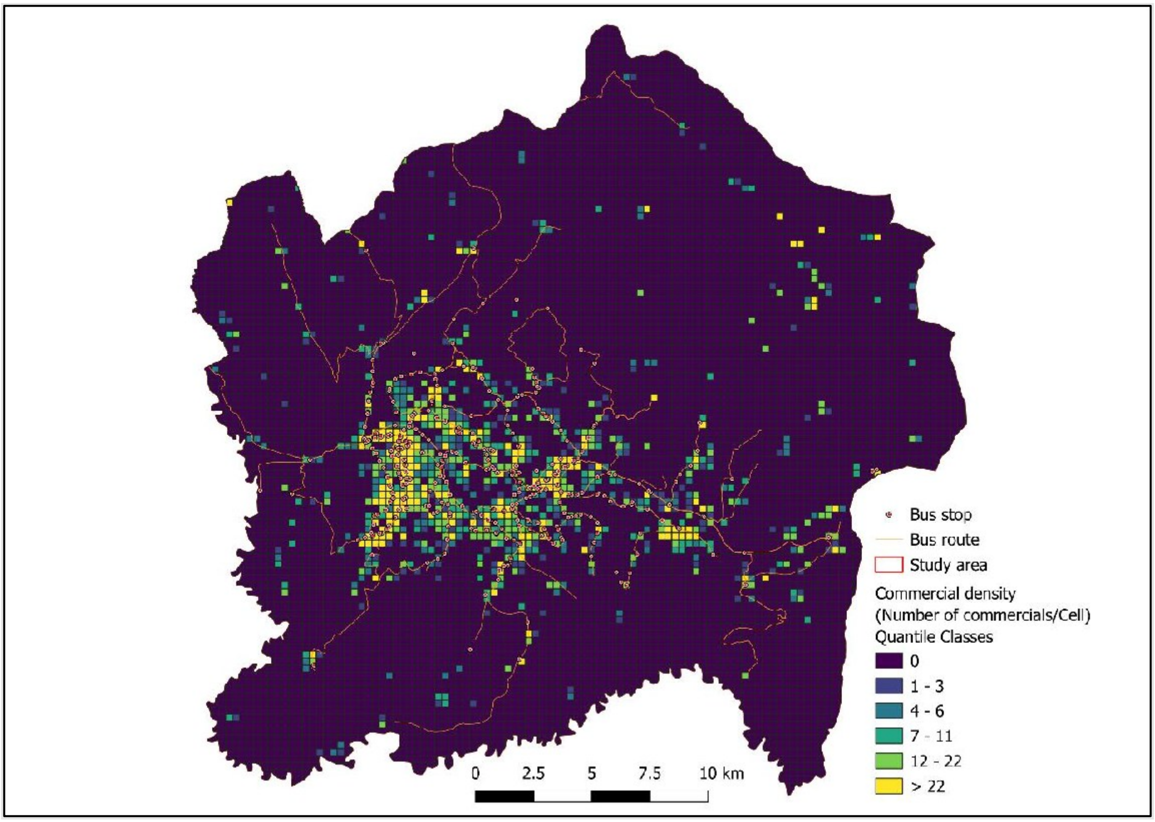


Figure 10: Commercial density (Number of commercial units per cell)

Note: The highest value: is 400 Lowest value is 0. High values indicate areas with many commercial units, suggesting strong economic activity, while low values indicate areas with few or no commercial units.

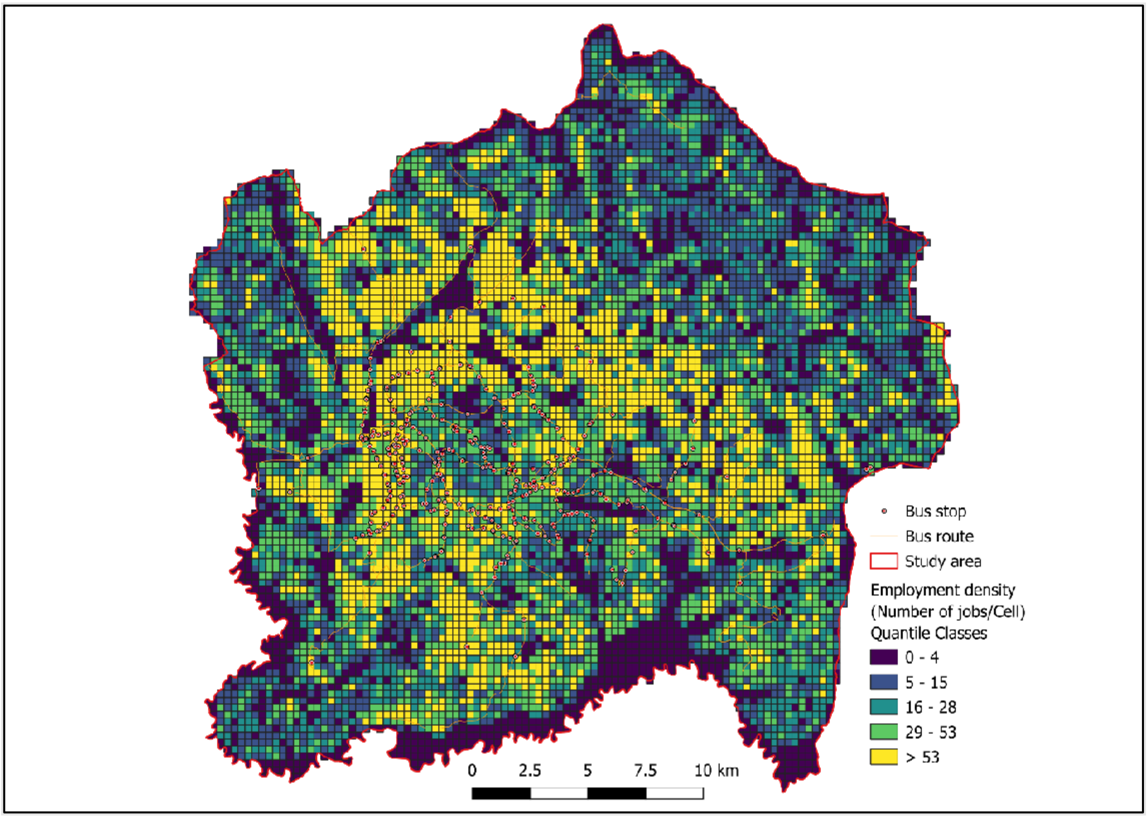


Figure 11: Employment density (Number of jobs per cell).

Note: The highest value = 615 jobs, Lowest value= 0 job. High values indicate areas with many jobs, reflecting employment hubs, while low values indicate areas with few or no jobs.

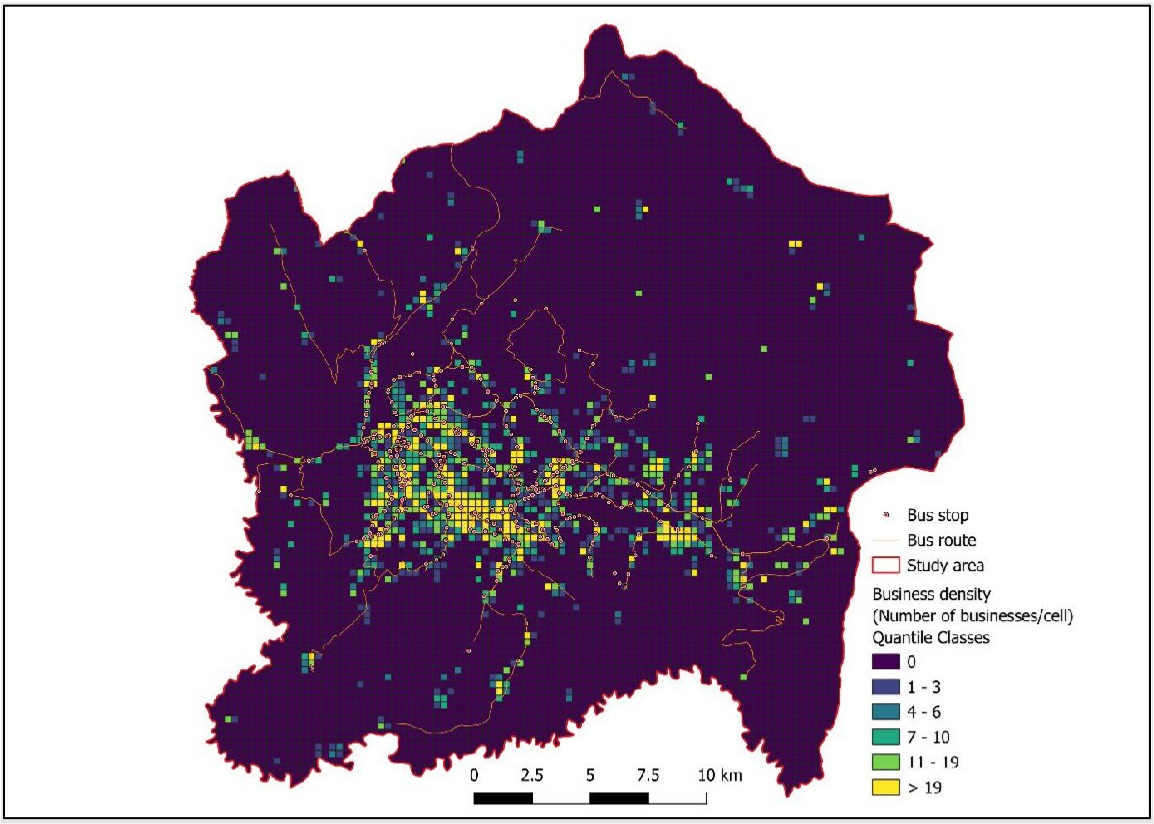


Figure 12: Business density (Number of businesses per cell)

Note: The highest value= 97 business units, the lowest value=0 business unit. High values indicate areas with many businesses, while low values indicate areas with few or no businesses

b. Land use diversity

The analysis of land use diversity showed a fairly balanced distribution of various land uses throughout the city(See Figure 14). However, clusters of diverse land use are scattered, leaving some areas with poor diversity in between.

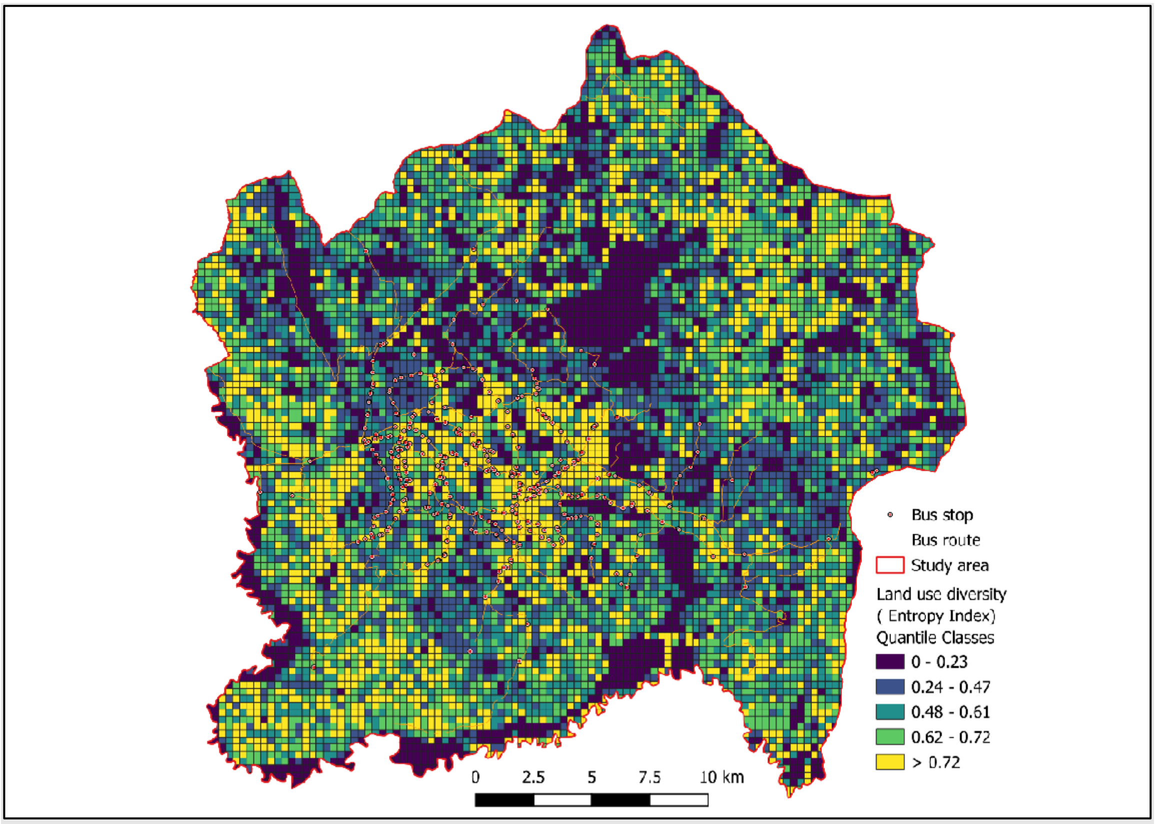


Figure 13: Land Use Diversity (Entropy Index).

Note: The highest value = 1, the lowest value = 0. High values indicate diverse land use, suggesting a balanced mix of different land uses, while low values indicate homogeneous land use, such as predominantly residential or industrial areas.

The low-diversity areas are primarily occupied by agriculture, open space, and nature areas. This pattern indicates that while some parts of the city exhibit a rich mix of land uses, promoting vibrancy in the area, other parts remain dominated by single land use types.

c. Mixedness of residential land uses with other land uses

There is significant variation in the mix between residential and other land uses across the city (See Figure 15). Inner-city areas have a high mix of residential land uses with other land uses, while peripheral areas have low mixedness index values. The low Mixedness Index in the outskirts is due to the absence of residential areas, which are instead dominated by agriculture, nature areas, and open space. Unfortunately, some areas with a high mixedness index do not have good coverage of public transport.

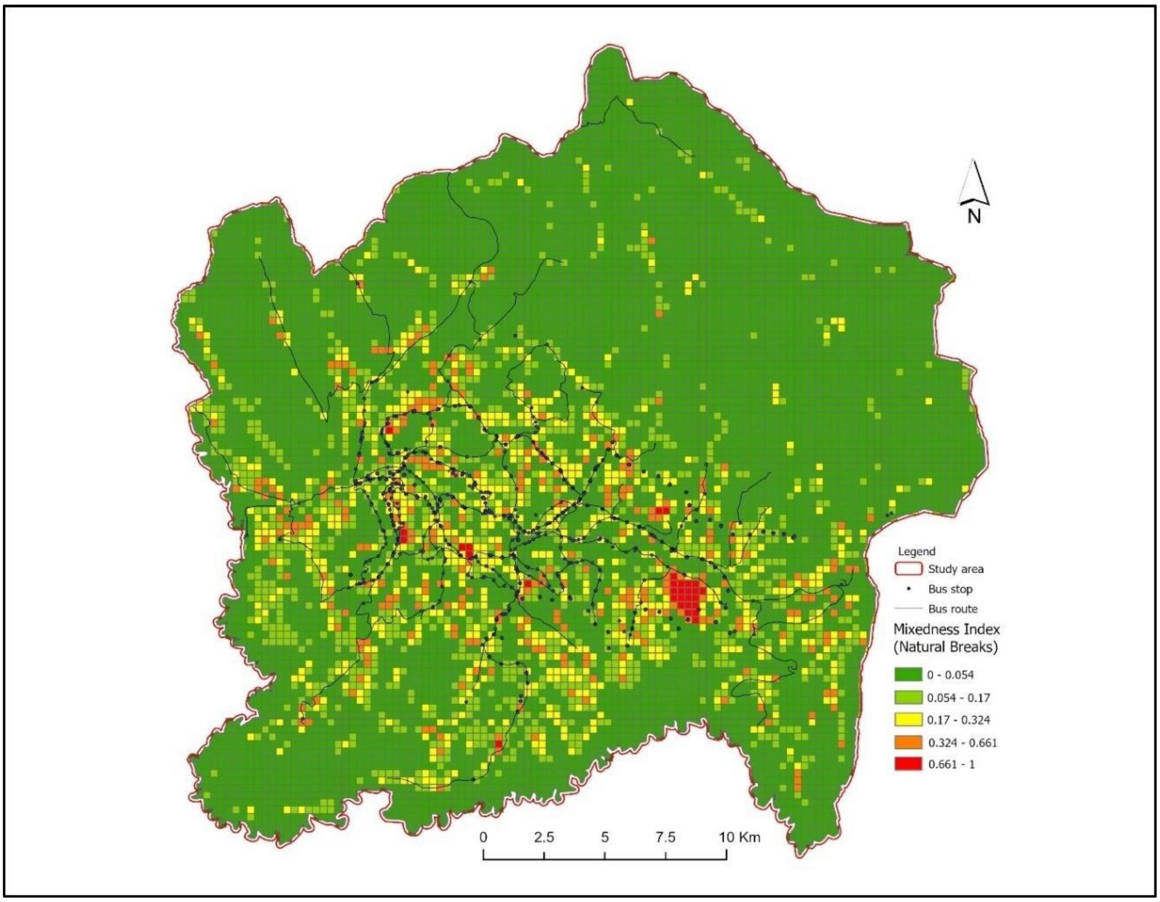


Figure 14: Mixedness of Residential Land Use with other land uses

Note: The highest value =1, the lowest value = 0. High values indicate areas with a high degree of land use mixing, promoting a vibrant urban environment, while low values indicate areas with limited land use diversity.

d. Total length of road fit for walking and cycling

The analysis revealed a disparity in pedestrian and cycling infrastructure between the city centre and outlying areas (See Figure 16). The most walkable streets are located in the inner-city parts and their surrounding areas, while the urban periphery exhibits poor walkability

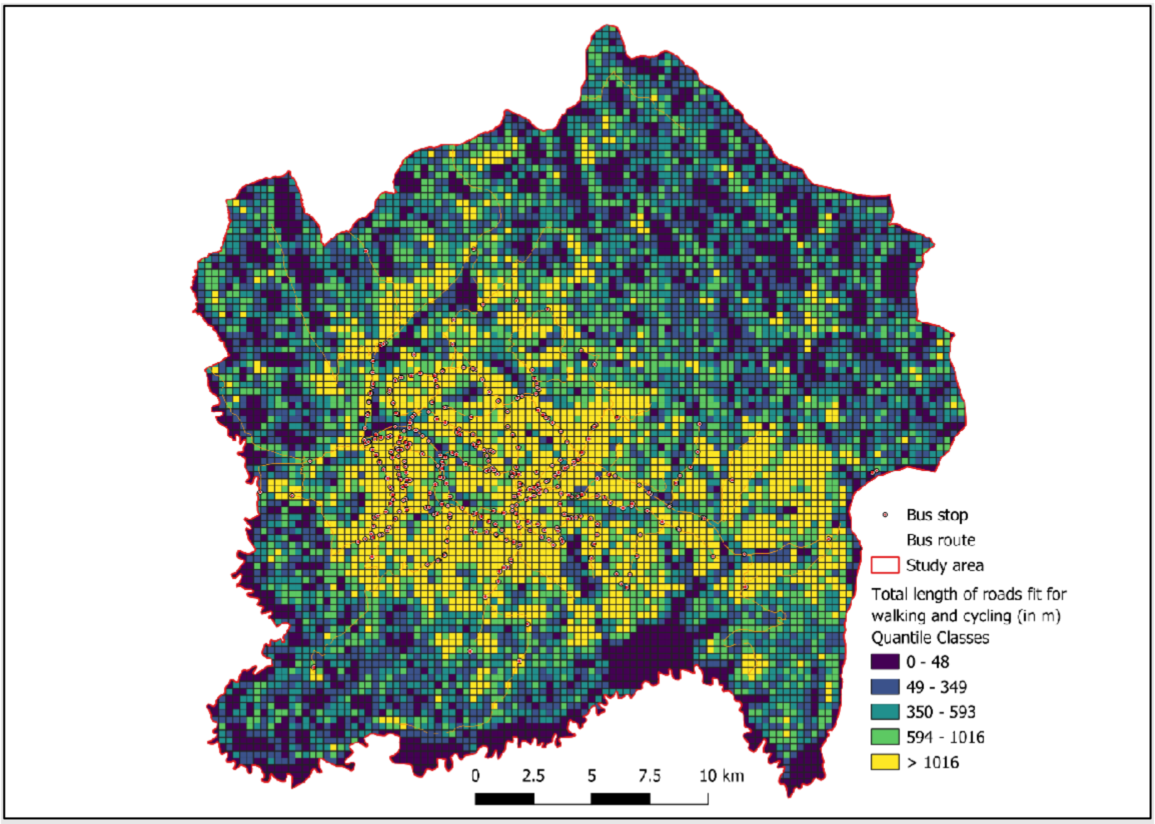


Figure 15: Total length of roads fit for walking and cycling (meters per cell).

Note: The highest value = 3,253.346 metres, and the Lowest value = 0 metres. High values indicate areas with a good infrastructure supporting non-motorized transport, while low values indicate areas with limited or unsuitable roads for walking and cycling.

e. Intersection density

The analysis showed that roads most suitable for walking and cycling are mainly found in inner-city areas and nearby neighbourhoods (See Figure 15). This pattern aligns with the previous indicator, due to the high intersection density and good street connectivity in the Central Business District (CBD) and its surrounding areas. In contrast, the outer areas of the city suffer from poor walkability, indicating a lack of infrastructure for pedestrians and cyclists. However, it is noteworthy that as the city expands eastward, new developments are aligned with better pedestrian infrastructure, which promises to improve walkability and connectivity in these growing regions.

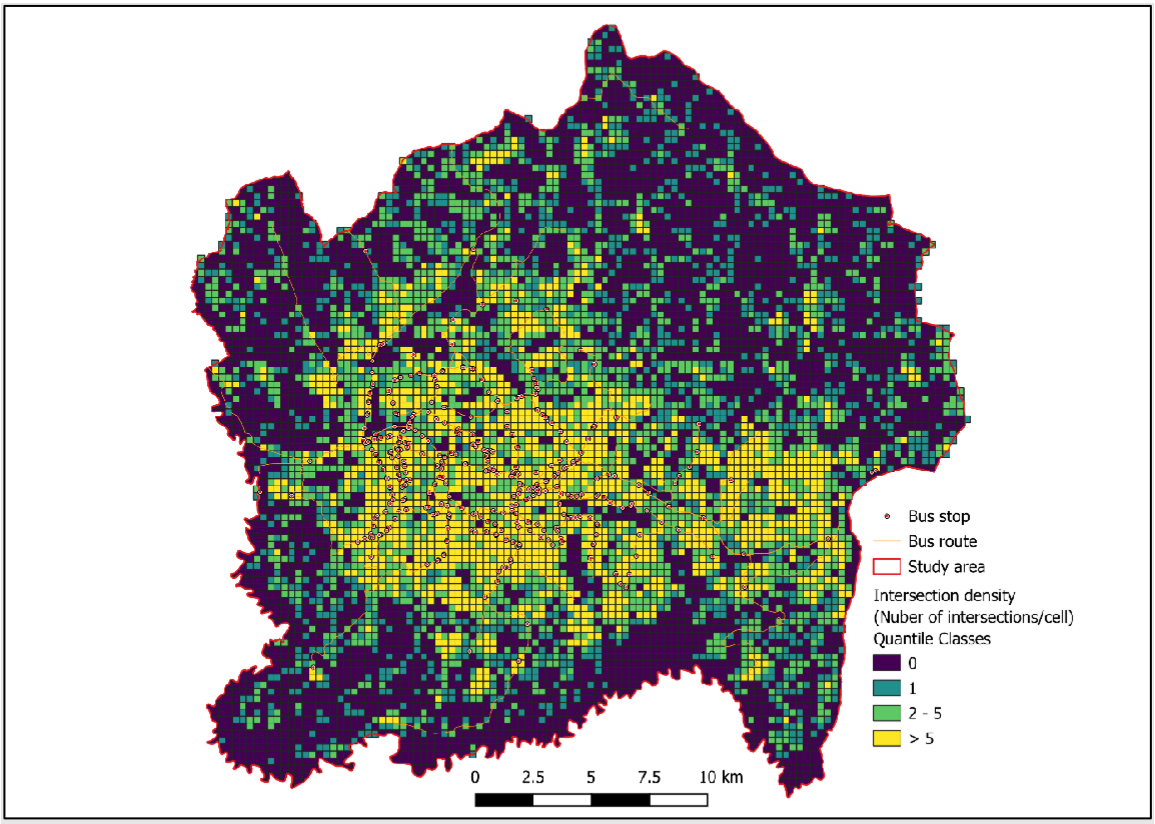


Figure 16: Intersection Density (Number of intersections per grid cell).

Note: The highest value = 52 intersections, the Lowest value = 0 intersection. High values indicate well-connected areas with many intersections, while low values indicate poorly connected regions with few intersections.

5.2.2. Composite Potential TOD Index

The results of the Potential TOD Index revealed distinct spatial variations in TOD potential across different areas of the city(See Figure 18). High TOD index values(greater than 0.5) in the city centre are prominently displayed in red. This indicates that the core urban areas possess the most favourable conditions for TOD, likely due to their higher density, better transit connectivity, and a greater mix of land uses.

Moving outward from the city centre to the peri-urban and peripheral areas, the TOD index values moderate, as shown in yellow patches on the map. These areas have TOD index values ranging from 0.2 to 0.5, signifying moderate potential for transit-oriented development. The relatively lower but still substantial TOD potential in these zones could be attributed to a mix of growing transit networks and emerging urban development that have not yet reached the levels of the central city.

In the outermost peri-urban and peripheral areas, the TOD index values are low, marked in green patches. These regions exhibit the least potential for TOD, possibly due to lower population densities, limited public transportation options, and less diverse land use patterns. Enhancing TOD potential in these areas would likely require targeted interventions, such as improving transit accessibility and encouraging mixed-use developments, to better integrate them into the broader urban fabric.

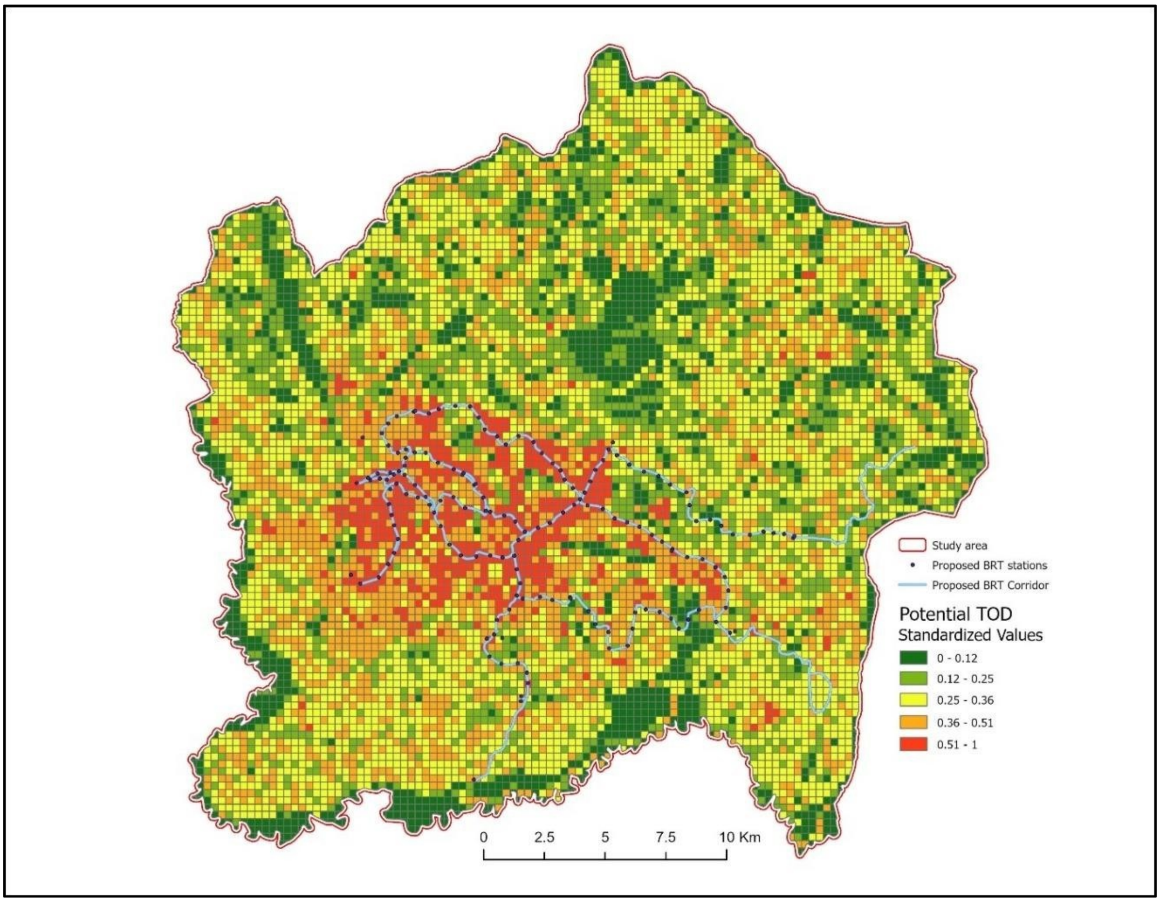
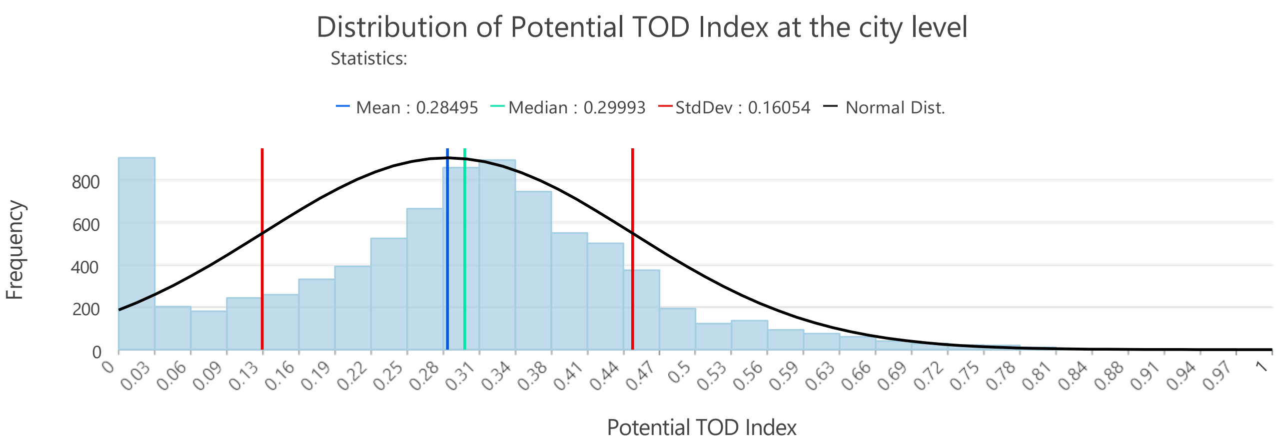


Figure 17: Potential TOD Index for the city of Kigali (Standardized Values).

Note: The highest value = 1, the lowest value = 0. High values indicate areas optimal for TOD, with good access to transit, high population and employment density, and diverse land uses, while low values indicate areas less suitable for TOD.

The histogram below illustrates the distribution of the Potential TOD Index across approximately 8,459 grid cells. The mean Potential TOD Index is 0.28495, and the median is 0.29993, indicating a slightly right-skewed distribution of TOD potential across the 8,459 grid cells analyzed. The low average value of the index can be explained by the highest portion of the city's area predominantly occupied by agriculture.



Graph 9: Potential TOD Index distribution at the City level

The mean Potential TOD Index is 0.28495, and the median is 0.29993, indicating a slightly right-skewed distribution of TOD potential across the 8,459 grid cells analysed. The low average value of the index can be explained by the highest portion of the city's area predominantly occupied by agriculture.

The histogram shows that many grid cells have lower TOD Index values, with a sharp decline in frequency as the index value increases. Specifically, the 25th percentile (first quartile) is around 0.16, with 1,942 grid cells (23%) below this value. The 50th percentile (median) is approximately 0.30, consisting of 3,852 grid cells (45.5%). The 75th percentile is around 0.37, covering 6,354 grid cells (75.1%). The peak frequency occurs at the lowest index range (0.03), with 905 grid cells (10.7%), indicating a concentration of low TOD potential areas. The distribution of the Potential TOD Index indicates that most grid cells have low to moderate TOD potential, with fewer cells achieving higher index values. This suggests a need for targeted interventions to enhance TOD potential in lower-scoring areas.

Looking at the city centre, the TOD index values reveal significant spatial variations in TOD potential. The city centre, displayed in red on the map, shows the highest TOD index values (greater than 0.6) concentrated in the central urban areas, marked in orange and red. These high-value areas, totalling 246 grid cells (8.7% of the city centre), benefit from dense urban fabric, superior transit connectivity, and diverse land uses, making them highly suitable for TOD. Moderate TOD index values (0.4 to 0.6), shown in yellow, indicate areas with improving TOD potential. There are 978 grid cells (34.6%) in this category. Lower TOD index values (0 to 0.4), marked in green and light yellow, are found in the outer sections of the city centre. These lower-value areas, totalling 1,602 grid cells (56.7%), exhibit limited TOD potential due to lower density, transit accessibility, and mixed-use development.

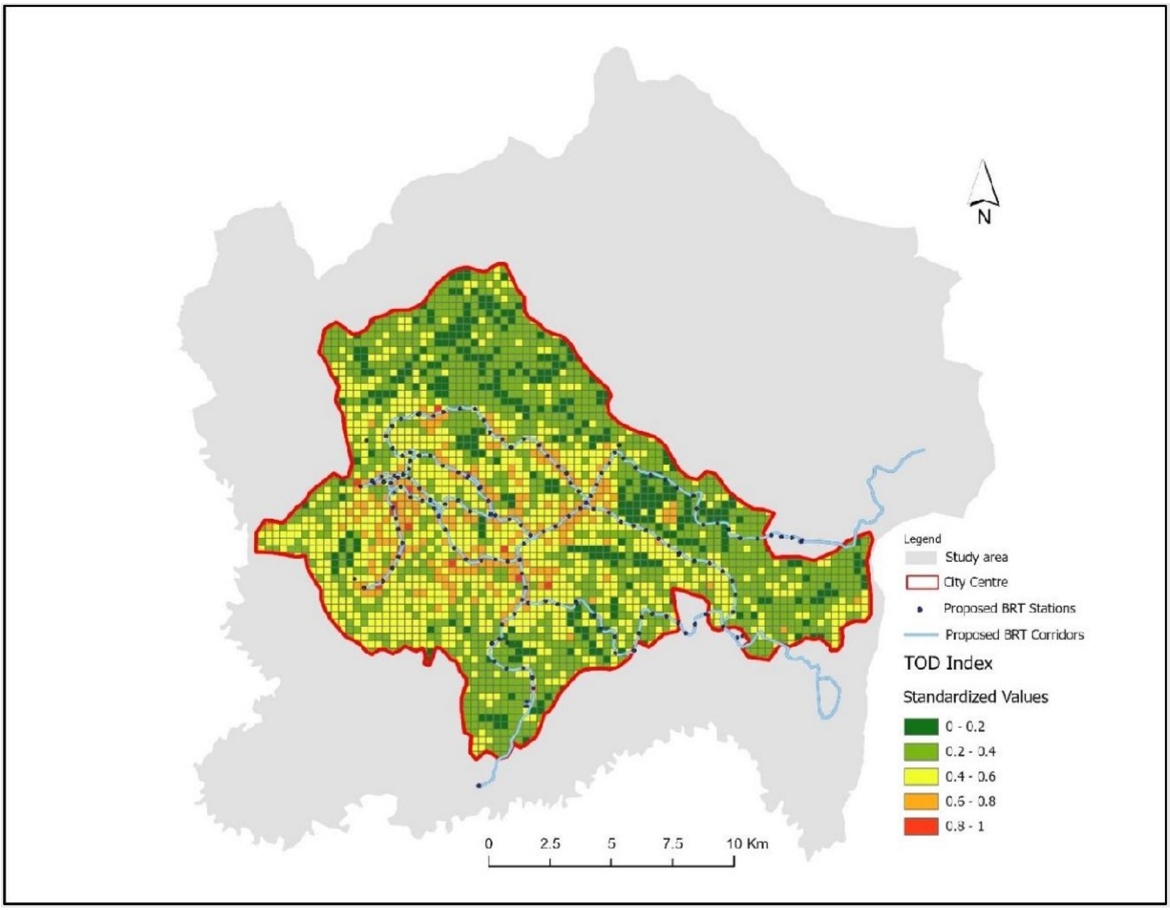
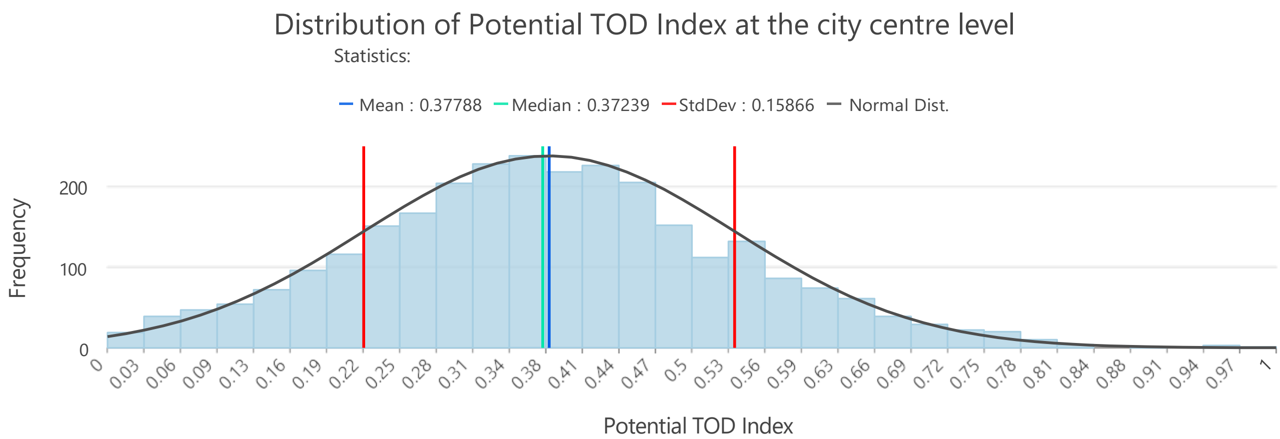


Figure 18: Potential TOD Index Map at the city centre level

Note: The highest value= 1, the lowest value= 0. High values indicate areas optimal for TOD, with good access to transit, high population and employment density, and diverse land uses, while low values indicate areas less suitable for TOD.



Graph 10: Potential TOD Index values distribution at the city centre level

The distribution of the Potential TOD Index across the city centre is illustrated in Graph 8. The mean Potential TOD Index is 0.37788, and the median is 0.37239, indicating a slightly right-skewed distribution of TOD potential across the grid cells analyzed. The standard deviation is 0.15866, suggesting moderate variability in TOD potential values. Comparing this to the regional level TOD Index statistics (Graph 7), it becomes obvious that the city centre has a higher average TOD potential and slightly lower variability compared to the broader region. The distribution at the regional level is also slightly right-skewed but shows a higher concentration of lower TOD index values most probably due to the predominance of agricultural and less urbanized areas.

5.3. Spatial Statistical and Cluster Analysis Results

5.3.1. Global Local Moran I

To analyze the clustering of the potential TOD index, spatial statistical methods were employed. While a closer look at Figure 18 reveals some level of clustering. However, this is not always the case as the symbology applied in the classification process may give a bad perception of the state. This makes Spatial statistical analysis a necessary step to have a big picture in the clustering patterns of the data being analyzed.

The spatial autocorrelation in the potential TOD index data was assessed using the Global Moran's I statistic, which tests the null hypothesis of complete spatial randomness. The analysis used a distance band of 500 meters. This method considers cells within this distance as neighbours and compares them against the average scores of the entire region. The Moran's I analysis applied to the potential TOD index scores resulted in significant findings.

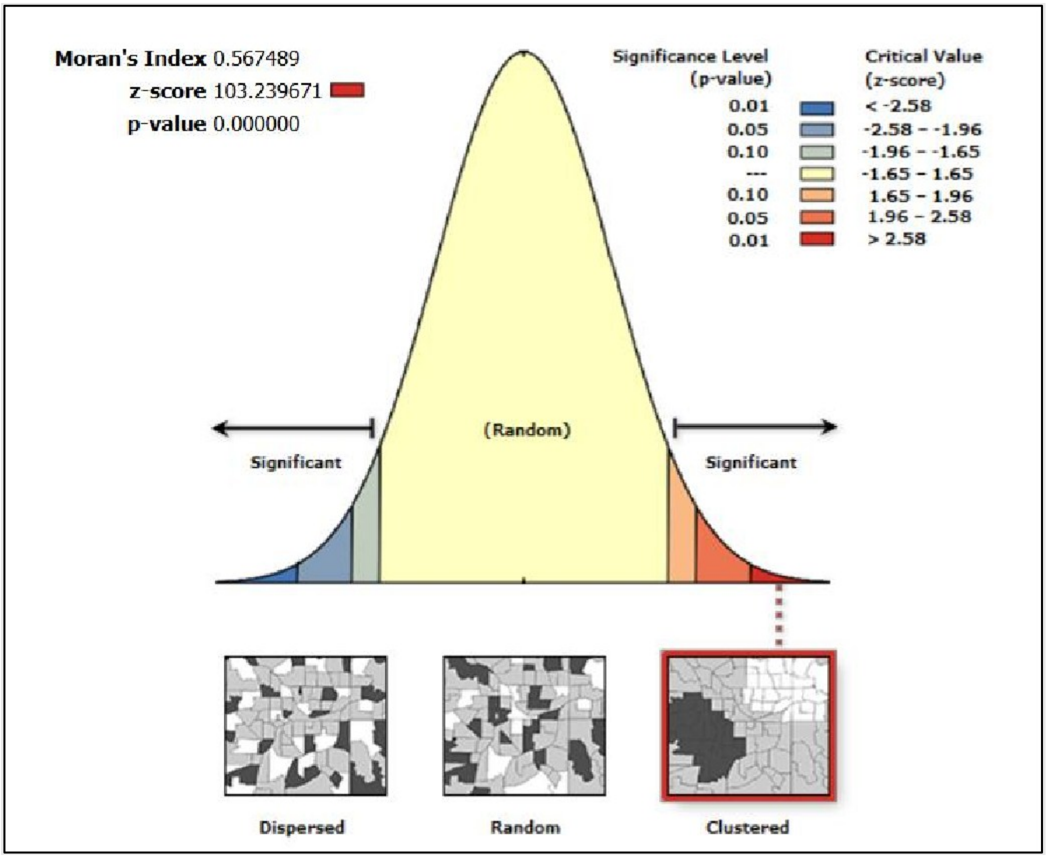


Figure 19: Results of spatial autocorrelation (Global Local Moran I)

Note:

The results revealed a Moran's I value of 0.567489, indicating a positive spatial autocorrelation, meaning that similar values are more clustered together than would be expected under a random distribution. This result is further supported by a high z-score of 103.239671 and a p-value of 0.000000, confirming the statistical significance of the clustering pattern. The z-score indicates that there is less than a 1% likelihood that this clustered pattern is due to random chance, reinforcing the presence of significant spatial clustering of high TOD index values.

5.3.2. Anselin Local Moran I

Spatial patterns were further analyzed to identify the locations of clusters. In this step, cluster mapping methods were employed with three local statistical techniques to identify areas with high or low-value concentrations, commonly referred to as 'hot' and 'cold' spots. This approach builds on methodologies highlighted by Páez and Scott (2005) and Singh(2015). The methods used were Anselin Local Moran I and the Getis-Ord Gi* statistic (Getis and Ord, 1992).

Anselin Local Moran I is used to detect clusters of high or low values. On the other hand, the Getis-Ord Gi* statistic technique helps to pinpoint hot spots with high values that are also surrounded by other high values. It is done by comparing the sum of these values to the overall sum across the study area, identifying statistically significant differences.

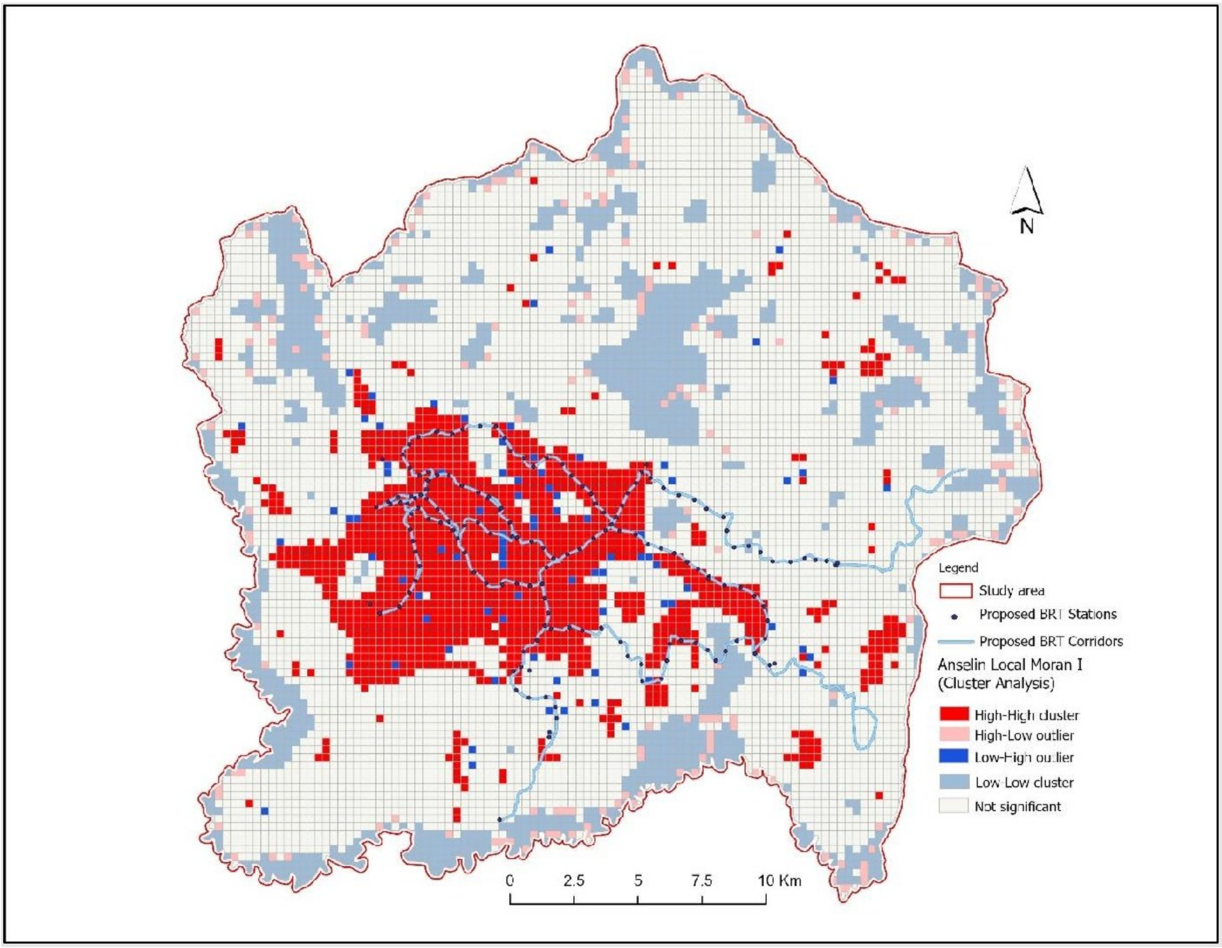


Figure 20: Results of Anselin Local Moran I

5.3.3. Hotspot Analysis

Using the Getis-Ord Gi*/Hot Spot Analysis, the location and intensity of clusters for every grid cell across the city were mapped. This method identified statistically significant hot spots at a 99% confidence level.

The many light yellowish areas likely indicate either dispersed, randomly distributed Potential TOD Index values or homogeneous, non-urbanized regions with low variation in TOD values. In this city, the latter seems more probable, meaning these areas have low TOD levels and are not of interest. The red areas represent hot spots identified by both statistics, with clusters of grid cells having significantly higher average index values and these are recommended for transit connectivity. With Anselin Local Moran's I, more hotspots were identified because it emphasizes similarity over value magnitude and offers a better representation of clusters. Consequently, its results were used for further analysis. The final hot spots are shown in Figure 22.

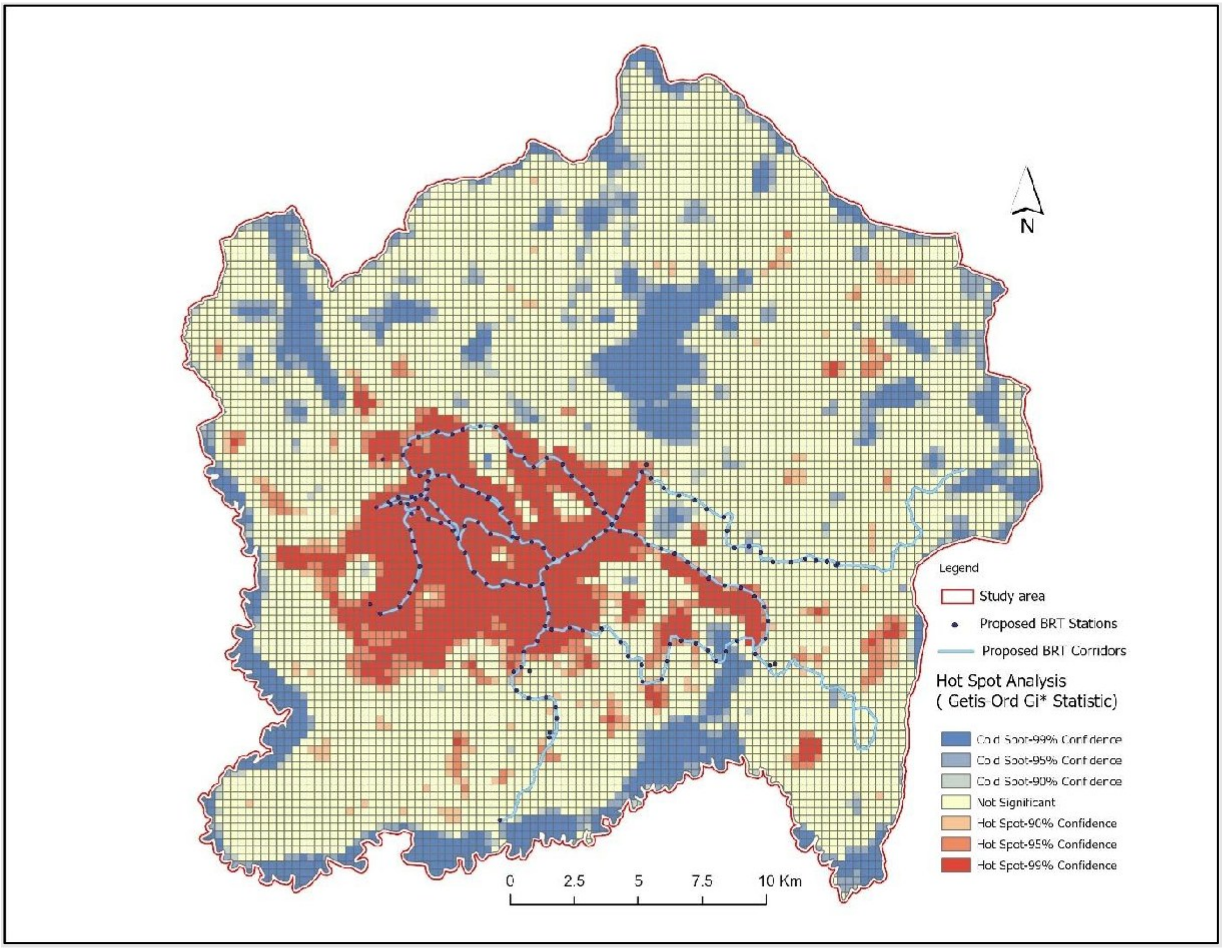


Figure 21: Results of Getis Ord Gi* (Hotspot analysis)

5.4. PSS Results

5.4.1. Base scenario results

The base scenario results, generated using CommunityViz, employed weights derived from Key Informant Interviews (KII). The TOD Index values for each BRT corridor were calculated through Spatial Multi-

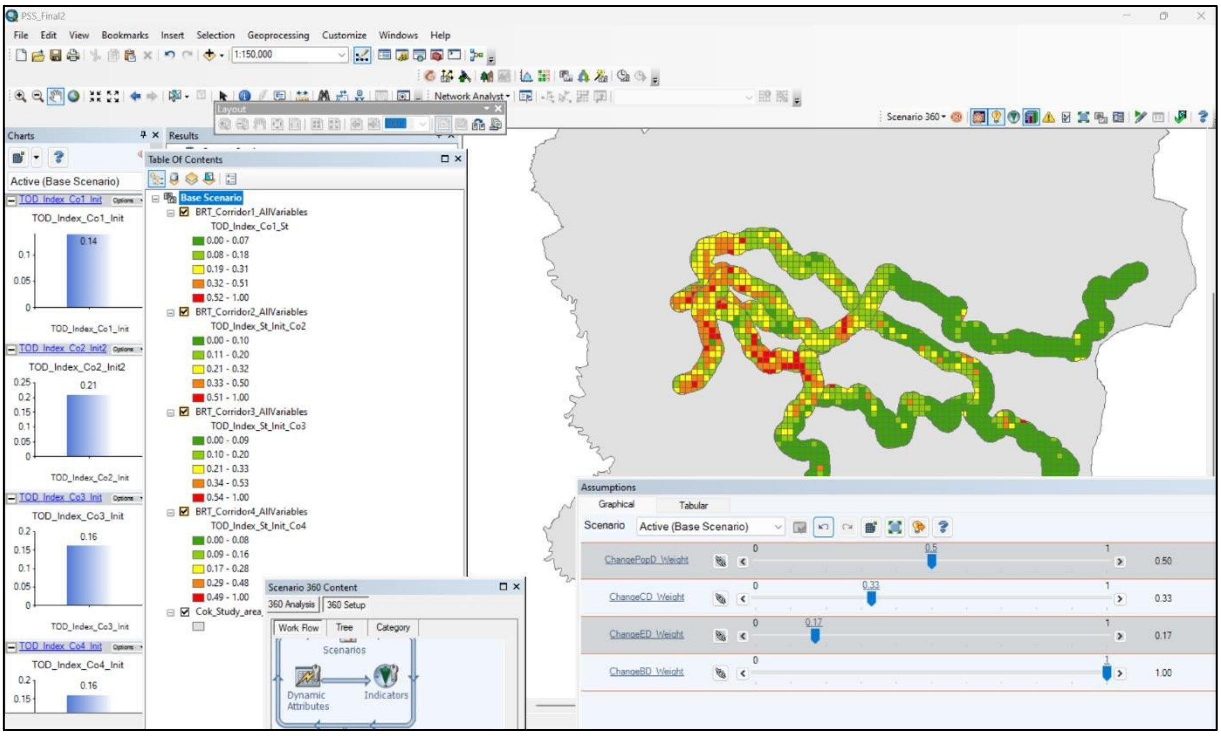


Figure 22: TOD Index results for all the BRT Corridors under the Base Scenario

Criteria Analysis (SMCA), which involves standardising and weighing various indicators. The indicators evaluated under this scenario were population density, commercial density, employment density, and business density. The values are categorised using the Natural Breaks classification scheme to illustrate the distribution of TOD potential across the four BRT corridors. The TOD Index results for all 4 corridors are displayed in the Figure below.

BRT Corridor 2 scored the highest mean TOD Index value of 0.21. This high index for this corridor is likely due to its higher population and employment densities, coupled with substantial commercial activity, making it a prime candidate for transit connectivity enhancements. BRT Corridors 3 and 4 each displayed a mean TOD Index value of 0.16. These corridors show substantial potential for TOD but not as high as Corridor 2. The moderate TOD Index values suggest significant commercial and residential development, making these corridors suitable for subsequent phases of TOD implementation. However, they may not provide as immediate returns as Corridor 2.

BRT Corridor 1, with the lowest mean TOD Index value of 0.14, might offer the least potential for BRT development. This corridor may require incremental improvements to gradually enhance its TOD potential. The lower index value suggests initial investments might not yield as significant returns as those in the other corridors.

5.4.2. Increased Density Results

The increased density scenario utilized annual growth rates of 4.5% for population, 0.7% for commercial and business development, and 2.8% for jobs. This scenario aimed to reflect potential changes in densities

FFigure 23: Figure 24: TOD Index results for all the BRT Corridors under the Increased Base Scenario due to planning interventions and to understand their impact on transit ridership and TOD potential. The results of this scenario were generated using CommunityViz and involved recalculating the TOD Index values for each BRT corridor using Spatial Multi-Criteria Analysis (SMCA).

In this scenario, the TOD Index values for each BRT corridor were recalculated, considering the increased densities. The values were categorised using the Natural Breaks classification scheme to highlight the changes in TOD potential across the corridors. The recalculated TOD Index results for all four corridors under the increased density scenario are displayed in the figure below.

The results indicate changes in TOD potential with increased densities. BRT Corridor 2 still scored the highest mean TOD Index value of 0.21, reaffirming its suitability for TOD interventions. This consistency suggests that even with increased densities, Corridor 2 remains the most favourable for transit connectivity enhancements.

BRT Corridors 3 and 4, which previously had moderate TOD Index values, saw an improvement in their scores under the increased density scenario. The recalculated TOD Index values for these corridors suggest enhanced TOD potential, making them more viable for subsequent phases of TOD implementation. This indicates that strategic density increases can significantly improve the TOD potential of these corridors.

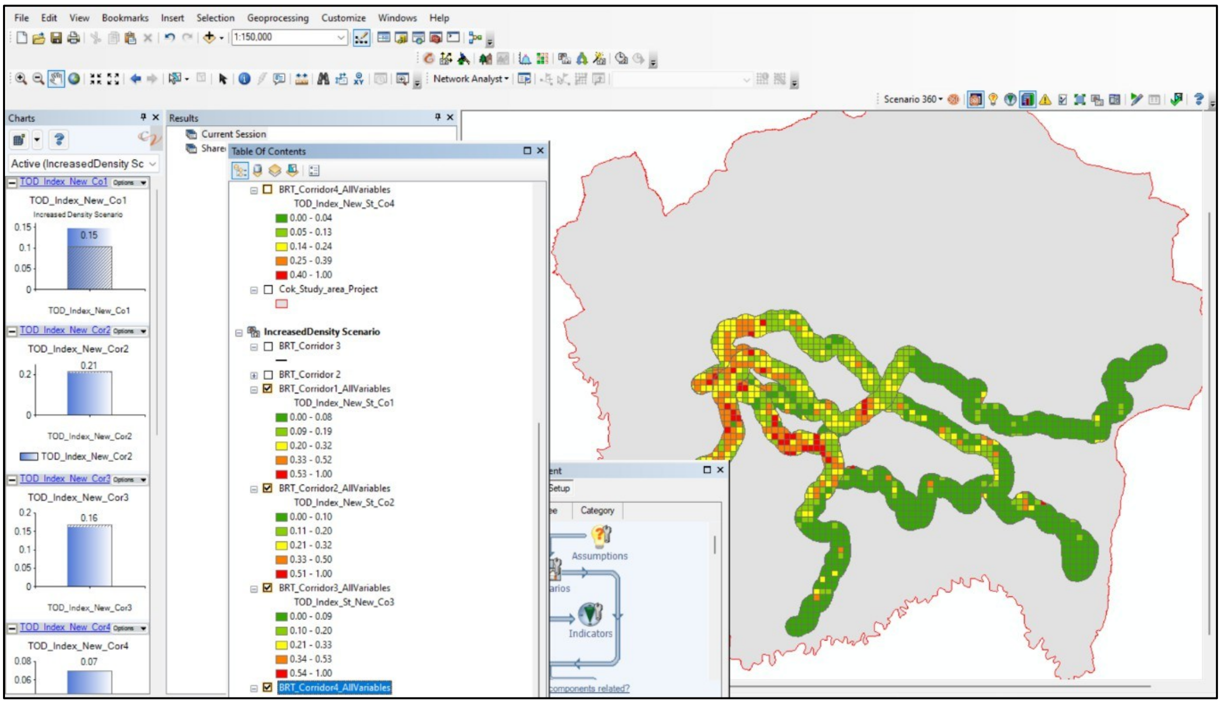


Figure 25: TOD Index results for all the BRT Corridors under the Increased Density Scenario

BRT Corridor 1, despite showing some improvement, still has the lowest TOD Index value among the four corridors. This indicates that while increasing densities may enhance its TOD potential, it may still require additional focused interventions to become a prime candidate for BRT development. The incremental improvements suggested by the increased density scenario reflect a gradual enhancement approach for Corridor 1 to achieve better TOD outcomes. For Details about scenarios and the process involved in the analysis in CommunityViz, see the analysis report in the appendix.

6. Discussion

6.1. Interpretation of the KII Results

The Key Informant Interviews (KIIs) highlight the need to contextualize TOD for Kigali, emphasizing density, diversity, and economic development as critical elements. Despite Kigali's ambitious urban planning initiatives, challenges such as topographical constraints, cultural preferences for single-family dwellings, and the prevalence of informal settlements persist. These challenges reveal a significant gap between planning aspirations and practical implementation. According to the fieldwork results, density and land-use diversity are crucial for enhancing public transit efficiency and reducing dependency on private vehicles.

This emphasis on density and land-use diversity aligns with sustainable urban development principles noted by Cervero (2006). However, Kigali's uneven distribution of economic activities and the dominance of informal jobs mirror challenges seen in other African cities, where integrating formal and informal sectors into spatial planning is difficult (Bickford & Behrens, 2015).

These results underscore the need for context-sensitive TOD strategies that consider local socio-economic and geographical realities. This approach ensures that TOD plans are not only ambitious but also feasible, promoting long-term urban resilience and growth (Suzuki et al., 2013). Moreover, Kigali's hilly terrain complicates the development of dense, mixed-use neighbourhoods, further emphasizing the need for innovative urban design solutions to integrate non-motorized transport (NMT) into the city's transportation network (Mbereyaho et al., 2018).

The findings from the KIIs support the theory that TOD must be adapted to local contexts to be effective. The integration of economic policies with spatial planning to facilitate diverse job opportunities and support sustainable business development adds to the body of knowledge on inclusive urban development. The need for enhanced participatory planning processes, engaging a broader spectrum of stakeholders, including local communities, is crucial to ensuring that TOD plans are pragmatic and reflective of the city's diverse needs.

Practically, these results suggest that Kigali must enhance its participatory planning processes to engage a broader spectrum of stakeholders, ensuring TOD plans reflect the city's diverse needs. This approach has proven successful in other cities like Curitiba, Brazil, where inclusive planning has led to sustainable urban outcomes (Rabinovitch & Leitman, 1996). Additionally, increasing affordable housing is critical to accommodate low-income households, ensuring they benefit from improved urban infrastructure without facing displacement pressures (International Growth Centre, 2023; Uwayezu & de Vries, 2020).

A strength of this analysis is its use of KIIs to gather in-depth insights from a range of stakeholders, providing a comprehensive understanding of local challenges and opportunities for TOD. The diverse perspectives collected through interviews offer a nuanced view of the practical issues affecting TOD implementation in Kigali. However, the KIIs are limited by the potential biases inherent in qualitative interviews and the subjective nature of the participants' perspectives. These limitations might affect the generalizability of the findings to other contexts.

6.2. Interpretation of Potential TOD Index Results

The analysis of density indicators reveals the centralization of population, commercial, employment, and business activities in Kigali's city centre, impacting overall mobility and transport dynamics. This unequal distribution leads to increased travel demand to the city centre, higher private car ownership, traffic congestion, and poor public transport performance(Nkurunziza, Tafahomi, & Faraja, 2021). The stakeholder insights align with these findings, emphasizing the need for targeted TOD interventions to address these issues.

These findings are consistent with studies of Johannesburg, where historical spatial patterns have led to reliance on private cars among wealthier residents and public transport dependence among poorer communities (Bickford & Behrens, 2015). This comparison highlights the need for tailored TOD approaches that consider diverse stakeholder needs and integrate affordable housing options within TOD precincts.

The results emphasize the necessity for targeted interventions to promote mixed-use developments and enhance transit connectivity, particularly in lower-scoring areas. This approach aligns with international examples where targeted investments in transit infrastructure have significantly improved TOD outcomes (ITDP, 2023). Furthermore, the analysis of land use diversity and the mix of residential land uses with other uses in Kigali suggests potential for targeted interventions to promote mixed-use developments, particularly in peripheral areas.

The findings contribute to theories on sustainable urban development by highlighting the importance of equitable infrastructure development. They suggest that improving land use diversity and transit connectivity can create vibrant, accessible neighbourhoods, supporting broader urban resilience. Additionally, the disparity in pedestrian and cycling infrastructure between the city centre and outlying areas indicates a need for improvement, aligning with findings from other African cities (Bickford & Behrens, 2015).

Practically, Kigali should focus on enhancing pedestrian and cycling infrastructure and promoting mixed-use developments in peripheral areas. Leveraging strong governance and sustainability initiatives can drive successful TOD implementation, transforming the city's socio-spatial patterns and reducing car dependency. Addressing infrastructure disparities, especially in pedestrian and cycling facilities, is critical to achieving a balanced and sustainable urban development (Nkurunziza et al., 2021).

This analysis' methodological rigour in using spatial multi-criteria analysis (SMCA) to develop the Potential TOD Index is a key strength. This approach provides a robust quantitative assessment of areas with high TOD potential, offering a clear basis for prioritizing interventions.

The analysis is limited by the availability and quality of data. Future research should incorporate more comprehensive datasets, including real-time data sources, to enhance the accuracy and relevance of the findings. Additionally, the high cost of infrastructure development and limited funding present challenges that need strategic solutions.

6.3. Interpretation of Spatial and Cluster Analysis Results

Spatial statistical and cluster analysis reveals that high TOD index values are clustered rather than randomly distributed. Specific hot spots with high TOD potential were identified, which are prime candidates for targeted TOD initiatives. These findings align with the city's strategic objectives to enhance public transport and promote mixed-use developments.

The findings are consistent with international examples, such as studies in South African cities, demonstrating the efficacy of using spatial statistical methods to guide TOD planning and implementation (Bickford & Behrens, 2015). This comparison underscores the validity of the methods used and the relevance of the findings to broader urban planning contexts.

These results highlight the importance of optimizing resource allocation and policy implementation in areas with the highest TOD potential. This strategic approach is crucial given Kigali's topographical challenges and limited infrastructure development funding (Nkurunziza et al., 2021). Furthermore, focusing on identified hot spots for TOD can drive significant improvements in urban mobility and connectivity.
The findings support theories advocating for the use of spatial statistical methods in urban planning. They suggest that identifying and focusing on TOD hot spots can enhance the effectiveness of urban development strategies, ensuring that resources are directed towards areas with the highest potential for impact.

Practically, Kigali should prioritize Bus Rapid Transit (BRT) systems in identified hot spots. BRT is generally less expensive and quicker to implement compared to metro systems, making it a feasible option for improving overall urban mobility. By focusing on these areas, the city can achieve substantial improvements in public transport efficiency and urban connectivity.

A strength of this analysis is the detailed spatial statistical methods used, providing a clear identification of areas with the highest TOD potential. This methodological rigour enhances the reliability of the findings and their applicability to policy decisions.

6.4. Interpretation of PSS results

The base scenario results indicate that BRT Corridor 2 should be prioritized for TOD implementation due to its higher mean TOD Index value of 0.21. This suggests optimal conditions for transit connectivity and economic development, aligning with national land use policy and master plan initiatives. The city's and country's initiatives to increase densities align with this recommendation, indicating a strategic approach to enhancing TOD potential.

Similarly, the increased density scenario reinforces the prioritization of BRT Corridor 2, which retains its top TOD Index value. This consistency across both scenarios highlights the corridor's robust potential for TOD, making it a prime candidate for immediate investment. The recalculated TOD Index values under the increased density scenario further illustrate that strategic density increases can significantly enhance TOD potential, particularly in already high-potential areas.

BRT Corridors 3 and 4, with mean TOD Index values of 0.16 under the base scenario, also present significant potential for TOD. These corridors saw improvements in their TOD Index values under the increased density scenario, indicating that targeted density increases can make these corridors more viable for TOD implementation. This finding suggests that while these corridors may not provide as immediate returns as Corridor 2, they hold substantial promise for future TOD phases.

BRT Corridor 1, with the lowest mean TOD Index value of 0.14 under the base scenario, showed some improvement under the increased density scenario but remains the lowest among the corridors. This indicates that while density increases can enhance its TOD potential, additional focused interventions are required to transform it into a prime candidate for BRT development.

The findings align with strategies seen in other cities where high-potential areas are prioritized for TOD to maximize immediate benefits. However, they also suggest the need to balance this with fostering TOD in lower-scoring areas to promote broader urban development. This dual approach can ensure both immediate improvements and long-term growth. Such a strategy is crucial in avoiding the pitfall of only improving already well-developed areas while neglecting regions with lower initial potential.

These results emphasize the mutual influence between urban development and transport development. While focusing on high-potential areas can yield immediate benefits, fostering TOD in lower-scoring areas can create new opportunities and support balanced urban growth. This approach is supported by international examples where TOD has driven development in underdeveloped regions (Cervero & Sullivan, 2011).

The findings contribute to the understanding of TOD implementation by highlighting the strategic choice between concentrating efforts in high-potential areas and driving development in lower-scoring regions. This supports the theory that TOD can be a tool for both enhancing existing urban areas and stimulating development in underdeveloped regions, promoting overall urban resilience.

Practically, Kigali should adopt a balanced approach, using TOD to drive development in underdeveloped areas while maximizing benefits in high-potential regions. This strategy can ensure sustainable and inclusive urban growth, promoting vibrancy and reducing traffic congestion. For example, the improved TOD Index values in Corridors 3 and 4 under the increased density scenario demonstrate how targeted interventions can elevate the potential of these areas, thereby fostering more equitable urban development.

The development of the PSS tool using CommunityViz is a significant strength, providing a practical and user-friendly solution for urban planners and policymakers. The tool's interactive scenario analysis capability allows stakeholders to explore various planning scenarios, making informed decisions. The ability to visualize and simulate different density scenarios offers clear insights into how various interventions can impact TOD potential.

This analysis in CommunityViz was constrained by the unavailability of socioeconomic data and timeframe, which affected the in-depth exploration of the PSS tool's assessment. Future research should integrate more comprehensive datasets, including those suggested by the KIs(See Graph 23-24 in the appendix), to enhance the tool's accuracy and relevance. This integration will provide a more dynamic and accurate representation of urban conditions, enabling more precise planning and policy decisions.

7. Policy Recommendations

Based on the study findings and insights from the KIs and Kigali Transportation Master Plan, the following policy recommendations are provided to enhance TOD effectiveness and improve public transportation in Kigali:

- Expanding the PT Network

The public transport (PT) network should be expanded to link the city centre with peripheral areas. This expansion aims to reduce traffic congestion and travel times, making public transportation a more attractive option compared to private vehicles. Enhanced connectivity can better integrate suburban regions into the broader urban fabric, supporting economic and social development across all parts of Kigali.

- Encouraging Mixed-Use Development

To create vibrant, walkable neighbourhoods, mixed-use development should be encouraged and enforced through the master plan. Integrating residential, commercial, and recreational spaces can reduce the need for long commutes and promote local economic activity. Placing essential services and amenities within proximity enhances residents' quality of life and fosters a sense of community. This approach may stimulate local economies, create job opportunities, and contribute to a more sustainable urban environment.

- Redistributing and Diversifying Services

To support mixed-use developments, redistributing and diversifying services across the city is crucial. Strategic planning should ensure that healthcare, education, retail, and recreational facilities are evenly distributed and easily reachable by public transport. A balanced service distribution reduces pressure on central areas and promotes equitable development, improving access to essential services in all parts of the city.

- Providing Economic Incentives

To attract investment in Kigali’s peripheral areas, economic incentives for businesses and developers should be provided. These incentives, such as tax breaks, subsidies, and development incentives, can stimulate economic growth in underdeveloped regions. By making these areas more attractive for investment, job opportunities and essential services can be established, leading to more balanced urban development, and reducing disparities between different parts of the city.

- Prioritizing Affordable Housing

To prevent displacement and ensure equitable access to new amenities and services, policies supporting the development of affordable housing units are crucial. Subsidies, inclusionary zoning, and partnerships with private developers can help maintain the social mix and prevent gentrification. Ensuring affordable housing allows all residents to benefit from improved urban infrastructure without facing displacement pressures, supporting the social equity goals of TOD.

- Strengthening Capacity-Building Initiatives

To effectively execute these plans, capacity-building initiatives and training for policymakers and planners are essential. The study revealed a lack of understanding of TOD concepts among stakeholders. Continuous training and professional development opportunities can enhance their understanding of TOD and best practices, ensuring planners are well-prepared to develop and implement effective and sustainable urban planning strategies.

- Enhance Participatory Planning

Engaging residents, particularly low-income groups, through workshops, surveys, and public meetings ensures that development projects reflect their needs and priorities. This inclusive approach builds trust and fosters community support, making urban development strategies more equitable and responsive. A participatory planning process leads to urban policies better aligned with community needs, enhancing their effectiveness and acceptance.

- Maintain Master Plan Integrity and Flexibility
It is crucial to recognize that master plans often have long time horizons that can be misaligned with the shorter-term priorities of practical developments, leading to a tension between long-term goals and immediate needs. To address this, master plans must be flexible and adaptable to evolving conditions while maintaining a clear vision for long-term growth. Establishing clear governance structures, accountability mechanisms, and legal frameworks will help uphold the integrity of the master plan. Consistent enforcement, combined with the ability to adapt to changing circumstances, ensures that Kigali can navigate the dynamic landscape of urban planning and achieve sustainable and inclusive urban growth.

- Consider Local Conditions
TOD strategies in Kigali should critically consider local conditions such as topography, culture, social mix, affordable housing, income levels, and connectivity with neighbouring cities. This contextualized approach ensures that TOD initiatives are tailored to the city's unique characteristics, promoting functional, culturally sensitive, and socially sustainable urban development.

- Additionally, it is essential to recognize the challenges associated with master plan implementation. Master plans often have long time horizons that can be misaligned with the shorter-term priorities of practical developments. This tension can lead to changes in priorities over time. Addressing this, Kigali's urban development strategies must be flexible and adaptable to evolving conditions while maintaining a clear vision for long-term growth. This balance will help navigate the dynamic landscape of urban planning, ensuring that both immediate needs and future goals are met effectively.

8. Summary Of Findings, Limitations And Future Research

This study aimed to improve public transport (PT) in developing cities by creating a Transit-Oriented Development (TOD) Index and PSS Prototype specifically for Kigali City, Rwanda. The literature review and case studies highlighted TOD's potential benefits, such as reducing traffic congestion, promoting sustainable transportation, and enhancing urban livability. However, they also underscored issues prevalent in developing countries, including inadequate infrastructure, financial constraints, and governance challenges. These insights stress the importance of tailored strategies that consider local contexts and actively involve stakeholders.

Objective 1: Investigate and compute indicators for the Potential TOD Index. Research

Question: What indicators are used for the Potential TOD Index calculation?
Indicators such as population density, commercial density, employment density, business density, land use diversity, mixedness of residential land use with other land uses, intersection density, and the total length of roads suitable for walking and cycling were used. The data analysis revealed that the highest population densities were concentrated in the central urban areas of Kigali, particularly in the city centre and surrounding neighbourhoods, such as Nyarugenge and Kiyovu. Commercial density followed a similar pattern, with the highest values found in the CBD and nearby commercial hubs like Nyabugogo. Employment and business densities were also highest in these central areas, reflecting the concentration of

jobs and business establishments. Land use diversity was more evenly distributed, though still higher in the city centre, indicating a mix of residential, commercial, and institutional land uses. However, the mix of residential land uses with other land uses showed gaps in the peripheral areas, where single-use zoning predominated. Intersection density and the length of roads suitable for walking and cycling were highest in the central areas, enhancing walkability and accessibility. In contrast, peripheral areas lacked adequate pedestrian and cycling infrastructure.

Objective 2: Use spatial analytical methods (GIS and SMCA) to derive a Potential TOD Index from specified indicators.

Research Question: How is the Potential TOD Index calculated?

The Potential TOD Index was calculated using spatial multi-criteria analysis (SMCA), which involved standardizing and weighting the selected indicators. The results indicated that central urban areas have the most favourable conditions for TOD due to higher densities and better transit connectivity. However, disparities in potential TOD were identified across Kigali, necessitating targeted interventions to enhance transit connectivity and promote mixed-use developments in lower-scoring areas.

Objective 3: Apply spatial statistical methods to analyze TOD index values.

Research Question: What areas have significantly high and low TOD index values?

Spatial statistical methods, including Global Moran's I and Local Moran's I, were employed to analyze the TOD index values. The analysis confirmed the clustering of high TOD index values, identifying specific hotspots for TOD implementation. The results showed that certain areas, especially in the city centre, have higher TOD Index values, while peri-urban and peripheral areas have lower values. These findings emphasize the need for strategic planning to address these disparities and promote balanced urban development.

Objective 4: Develop a TOD Planning Support Tool using Potential TOD Index values to prioritize PT along the main BRT Corridors.

Research Question: How can the TOD Planning Support Tool leverage the Potential TOD Index to prioritize BRT development along the proposed BRT Corridors?

The TOD Planning Support Tool, built in CommunityViz, leveraged the Potential TOD Index to identify and prioritize BRT corridors with the highest potential TOD Index. The tool's interactive scenario analysis capability allows the users to explore the planning scenarios, helping them make informed decisions. The results demonstrated that the tool could support the prioritization of investments and interventions, ensuring efficient allocation of resources to the most favourable areas for TOD.

Despite achieving this study’s objectives, some limitations were encountered, particularly due to the unavailability of socioeconomic data and data suggested by the KIs and a constrained research timeframe. These limitations affected the depth of the PSS tool's assessment. In this regard, future research should focus on integrating more datasets to enhance the tool's functionality and relevance. This integration may provide a better understanding of urban conditions, enabling more informed planning and policy decisions.

Understanding the cultural context of Kigali is crucial for the successful implementation of TOD. Local customs, values, and social behaviours significantly influence how residents interact with public transportation and urban spaces. For instance, the lack of willingness to adopt mixed-use development and live in apartments is s still a thing of culture in the country as evidenced by the majority living in individual buildings. In this regard, future research should delve into these cultural aspects to ensure that TOD strategies are culturally sensitive and tailored to the unique needs of Kigali's residents. Engaging with community leaders and conducting ethnographic studies can provide deeper insights into the local culture and its impact on TOD planning.

Kigali's hilly terrain presents unique challenges for urban planning and public transportation. Therefore, it is essential to investigate strategies for effectively implementing TOD in such topographically challenging environments. This could involve exploring innovative engineering solutions, such as the use of funiculars or inclined elevators, to improve accessibility. Additionally, urban design should focus on creating pedestrian-friendly pathways that can navigate the terrain effectively. Case studies from other cities with similar topographical challenges could provide valuable lessons and best practices.

The success of TOD initiatives depends on the buy-in and active participation of the local community. Therefore, it is vital to incorporate the perspectives of residents in future research. Engaging the community through public consultations, surveys, and participatory planning workshops can help understand their needs, preferences, and concerns. By prioritizing areas for TOD based on resident feedback, planners can ensure that developments align with the community's aspirations and address their most pressing issues. This participatory approach not only fosters a sense of ownership among residents but also enhances the likelihood of successful implementation and long-term sustainability.

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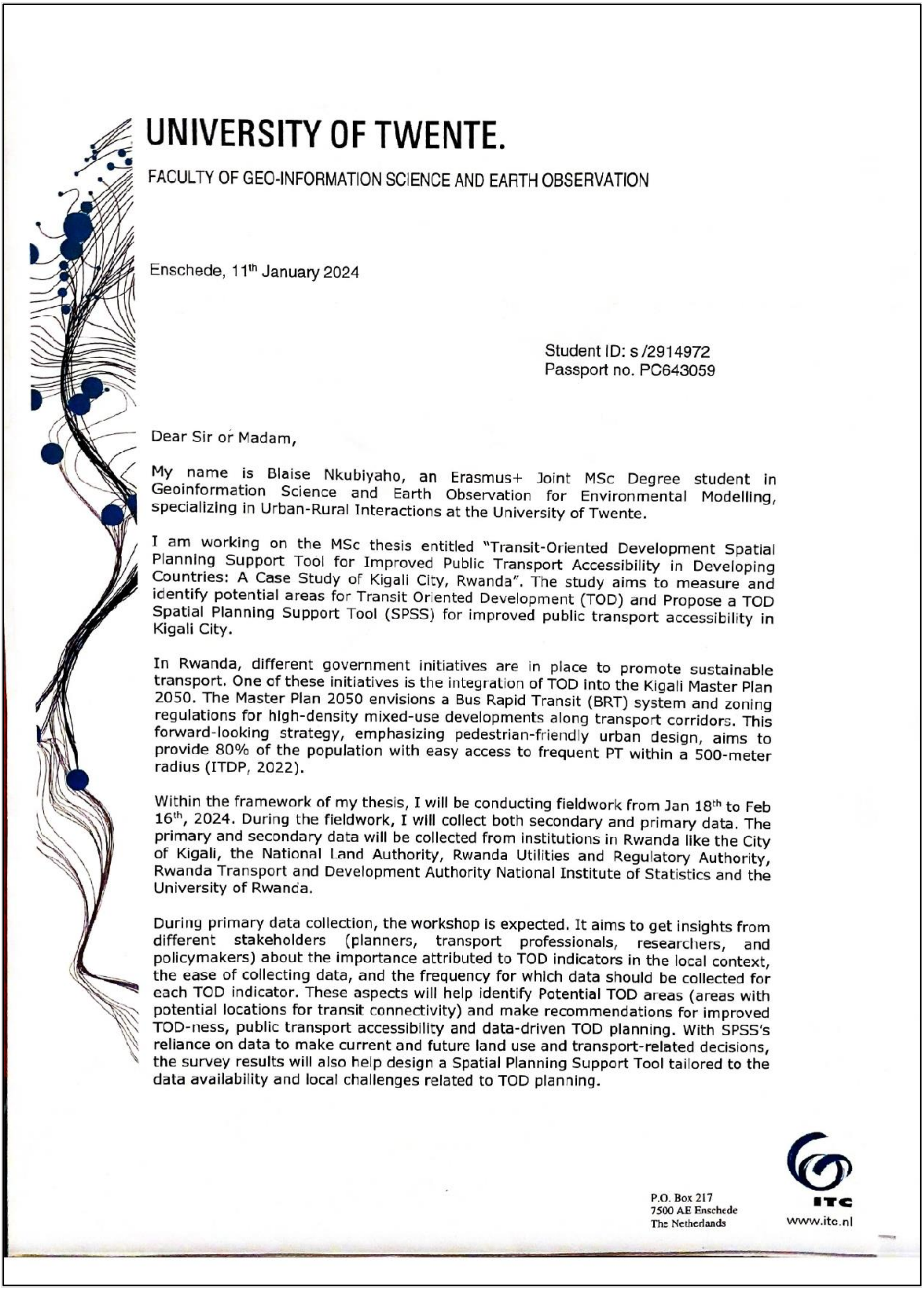
Appendix

Table 10: Data documentation

Data Sets	Format	Data Sources	Data Owner	Restrictions and License	Data Form	Data Format	Contains Personal Data (Yes/No)
Population Data	Shapefile	Humanitarian Data Exchange (HDx)	Kontur	No restriction	Geospatial	Hexagons at 400m resolution	No
Bus Stops	Geodatabase	City of Kigali	City of Kigali	No restriction	Geospatial	Geodatabase	No
Bus Routes	Geodatabase	City of Kigali	City of Kigali	No restriction	Geospatial	Geodatabase	No
Land Use	Geodatabase	City of Kigali	City of Kigali	No restriction	Geospatial	Geodatabase	No
Road Network	Shapefile	Open Street Map (OSM)	OSM	No restriction	Geospatial	Shapefile	No
Building Footprint	Shapefile	Open Data from QGIS Software	QGIS Software	No restriction	Geospatial	Shapefile	No
City Boundary	Shapefile	Open Data from QGIS Software	QGIS Software	No restriction	Geospatial	Shapefile	No
City Administrative Units	Shapefile	City of Kigali	City of Kigali	No restriction	Geospatial	Shapefile	No

Figure 26: Official letter for fieldwork from the University of Twente



UNIVERSITY OF TWENTE.

FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

Enschede, 11th January 2024

Student ID: s /2914972
Passport no. PC643059

Dear Sir or Madam,

My name is Blaise Nkubiyaho, an Erasmus+ Joint MSc Degree student in Geoinformation Science and Earth Observation for Environmental Modelling, specializing in Urban-Rural Interactions at the University of Twente.

I am working on the MSc thesis entitled "Transit-Oriented Development Spatial Planning Support Tool for Improved Public Transport Accessibility in Developing Countries: A Case Study of Kigali City, Rwanda". The study aims to measure and identify potential areas for Transit Oriented Development (TOD) and Propose a TOD Spatial Planning Support Tool (SPSS) for improved public transport accessibility in Kigali City.

In Rwanda, different government initiatives are in place to promote sustainable transport. One of these initiatives is the integration of TOD into the Kigali Master Plan 2050. The Master Plan 2050 envisions a Bus Rapid Transit (BRT) system and zoning regulations for high-density mixed-use developments along transport corridors. This forward-looking strategy, emphasizing pedestrian-friendly urban design, aims to provide 80% of the population with easy access to frequent PT within a 500-meter radius (ITDP, 2022).

Within the framework of my thesis, I will be conducting fieldwork from Jan 18th to Feb 16th, 2024. During the fieldwork, I will collect both secondary and primary data. The primary and secondary data will be collected from institutions in Rwanda like the City of Kigali, the National Land Authority, Rwanda Utilities and Regulatory Authority, Rwanda Transport and Development Authority National Institute of Statistics and the University of Rwanda.

During primary data collection, the workshop is expected. It aims to get insights from different stakeholders (planners, transport professionals, researchers, and policymakers) about the importance attributed to TOD indicators in the local context, the ease of collecting data, and the frequency for which data should be collected for each TOD indicator. These aspects will help identify Potential TOD areas (areas with potential locations for transit connectivity) and make recommendations for improved TOD-ness, public transport accessibility and data-driven TOD planning. With SPSS's reliance on data to make current and future land use and transport-related decisions, the survey results will also help design a Spatial Planning Support Tool tailored to the data availability and local challenges related to TOD planning.

P.O. Box 217
7500 AE Enschede
The Netherlands

ITC
www.itc.nl

Figure 27: Official letter for fieldwork from the University of Twente

UNIVERSITY OF TWENTE.

DATE

PAGE
2 of 2

Thank you for contributing your insights. Your input will guide the prioritisation of TOD indicators for the urban development in Kigali.

Yours sincerely,

Blaise Nkubiyaho

MSc Student, Faculty ITC
University of Twente

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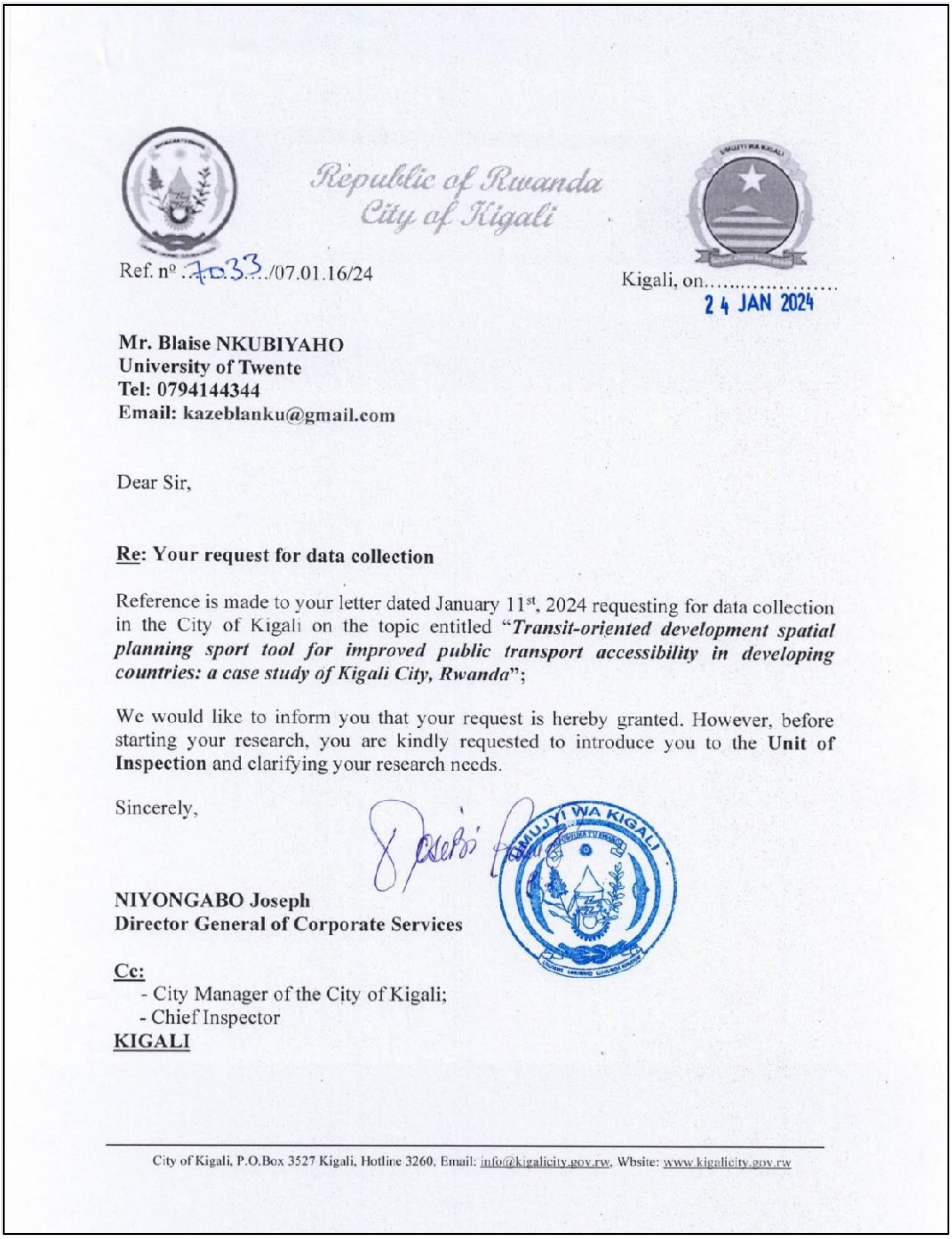
Figure 28: Authorization for collecting data from the City of Kigali



Republic of Rwanda
City of Kigali

Ref. nº ..7033../07.01.16/24

Kigali, on..........24 JAN 2024

Mr. Blaise NKUBIYAHO
University of Twente
Tel: 0794144344
Email: kazeblanku@gmail.com

Dear Sir,

Re: Your request for data collection

Reference is made to your letter dated January 11st, 2024 requesting for data collection in the City of Kigali on the topic entitled "***Transit-oriented development spatial planning sport tool for improved public transport accessibility in developing countries: a case study of Kigali City, Rwanda***";

We would like to inform you that your request is hereby granted. However, before starting your research, you are kindly requested to introduce you to the **Unit of Inspection** and clarifying your research needs.

Sincerely,

NIYONGABO Joseph
Director General of Corporate Services

Cc:
- City Manager of the City of Kigali;
- Chief Inspector

KIGALI

City of Kigali, P.O.Box 3527 Kigali, Hotline 3260, Email: info@kigalicity.gov.rw, Wbsite: www.kigalicity.gov.rw

Figure 29: Consent Form

Key Informant Interview

Consent Form

Title of the Study: Transit Oriented Development (TOD) Spatial Planning Support Tool for Improved Public Transport in Developing Countries: A Case Study of Kigali City, Rwanda.

Researcher's Name: Blaise Nkubiyaho

Affiliation: University of Twente

Dear Participant,

I am inviting you to participate in a research study titled "Transit Oriented Development (TOD) Spatial Planning Support Tool for Improved Public Transport in Developing Countries: A Case Study of Kigali City, Rwanda." The purpose of this study is to develop a TOD Spatial Planning Support Tool for Kigali. The tool utilises TOD criteria and indicator data to generate a TOD Index, facilitating targeted recommendations for improved accessibility.

Procedure, confidentiality, and risks/benefits

Participation in this study is entirely voluntary, and you have the right to refuse or withdraw at any time without consequences. As part of the research, conversations will be recorded for analysis and may be included in the findings, ensuring strict confidentiality with personal identifiers removed. The data will be securely stored and accessible only to the research team. There are no anticipated risks associated with participating in this study. Benefits include contributing valuable information to Transit-Oriented Development and Spatial Decision-making in developing countries, particularly Kigali.

Consent

I have read and understood the information provided above. I have had the opportunity to ask questions, and any concerns I had have been addressed to my satisfaction. By providing my consent, I agree to participate in the study and allow the recording of conversations.

Participant's Name: ________________________ Date: _______________

Participant's Signature: _______________________

Researcher's Statement

I have explained the nature, purpose, and potential risks and benefits of the study to the participants. I have answered their questions to the best of my ability. I confirm that the participant has voluntarily agreed to participate.

Researcher's Name: Blaise Nkubiyaho________________________ Date: _______________

Researcher's Signature: _______________________

Contact Information

Blaise Nkubiyaho

Email: b.nkubiyaho@student.utwente.nl

Tel:+31687822633

7511 AE, Enschede,

The Netherlands.

Figure 30: Key informant Interview Questions

KEY INFORMANT INTERVIEW: Transit-Oriented Development Planning in Kigali

Dear Participant,

My name is Blaise Nkubiyaho from Rwanda, researching a Transit-Oriented Development (TOD) Spatial Planning Tool for improved public transport in Developing Countries: A Case Study of Kigali City, Rwanda".

Aligned with Kigali's Master Plan 2050, aiming for sustainable transport through TOD enabled by the Bus Rapid Transit (BRT) system, my study focuses on developing a TOD Spatial Planning Support Tool for Kigali. The tool utilizes TOD criteria and indicator data to generate a TOD Index, facilitating targeted recommendations for improved accessibility.

This interview seeks perspectives on two key aspects: (1) the significance of TOD indicators in the planning process and (2) the proposed TOD Spatial Planning Support Tool.

SECTION 1: POTENTIAL TOD INDEX CRITERIA AND INDICATORS ASSESSMENT

Potential TOD Index is measured based on the following criteria and indicators (See the table below):

Before ranking criteria and indicators, let's have a look at their link with TOD:

Density: High urban densities are vital for efficient TOD. They ensure optimal use of transit systems, making public transportation both viable and effective.

Diversity: Diverse land uses around transit nodes create a vibrant environment, enhancing the area's appeal and functionality for a dynamic community.

Design: Walkable and bike-friendly urban design is essential for TOD's success. It promotes sustainable transportation by encouraging short trips on foot or by bike.

Economic Development: High economic development supports TOD by driving increased ridership, revenues, and optimal utilization of transit capacity in the surrounding area.

Question 1: Please, assign a weight to each criterion and indicator on a scale from 1 to 10 based on their relevance in Kigali, where:

- 1 indicates the least important,
- 10 indicates the most important.

a) Weighing of Potential TOD criteria

Criteria	Weight	Why?
Density		
Diversity		

Figure 31: Key informant Interview Questions

Design		
Economic development		

b) Weighing of indicators that measure Potential TOD Criteria.

Criteria	Indicator and measurement	Weight	Why?
Density	Population density (number of persons /km2)		
	Employment density (number of employees/km2)		
	Commercial density (number of commercial enterprises/ km2)		
Diversity	Land use diversity		
Design	Mixed-ness of residential land use with other Land uses		
	Intersection density (number of intersections/km2)		
	Total length of road fit for walking and cycling (meters or km)		
Economic development	The density of business establishments (number of business establishments/ km2)		
	Tax earnings of municipalities (thousand Rwfs in last year)		
	Employment levels		

Question 3: How are the criteria and indicators for the Potential TOD Index measured in the planning process in the context of Kigali?

Question 4: Are there any other indicators that you believe should be considered for inclusion in the measurement of the Potential TOD Index?

Figure 32: Key Informant Interview Questions

SECTION 2: SPATIAL PLANNING SUPPORT TOOL

Question 5: Which planning support tool/s do you use in the planning process?

Question 6: How do these tools work?

Question 7: On a scale from 1 to 5, where 1 is 'Not Effective at All' and 5 is 'Extremely Effective,' please rate the effectiveness of the planning support tool/s you use in the planning process.

Not Effective at All	Slightly Effective	Moderately Effective	Very Effective	Extremely Effective

Question 8: What types of training and capacity-building initiatives are provided to planners in the context of planning?

Question 9: What aspects of the proposed tool do you find interesting?

Question 10: On a scale from 1 to 5, where 1 is 'Not Useful at All' and 5 is 'Extremely Useful,' how would you rate the potential usefulness of the tool presented to you in the context of Kigali?

Not Useful at All	Slightly Useful	Moderately Useful	Very Useful	Extremely Useful

Question 10: What could be improved in the proposed tool?

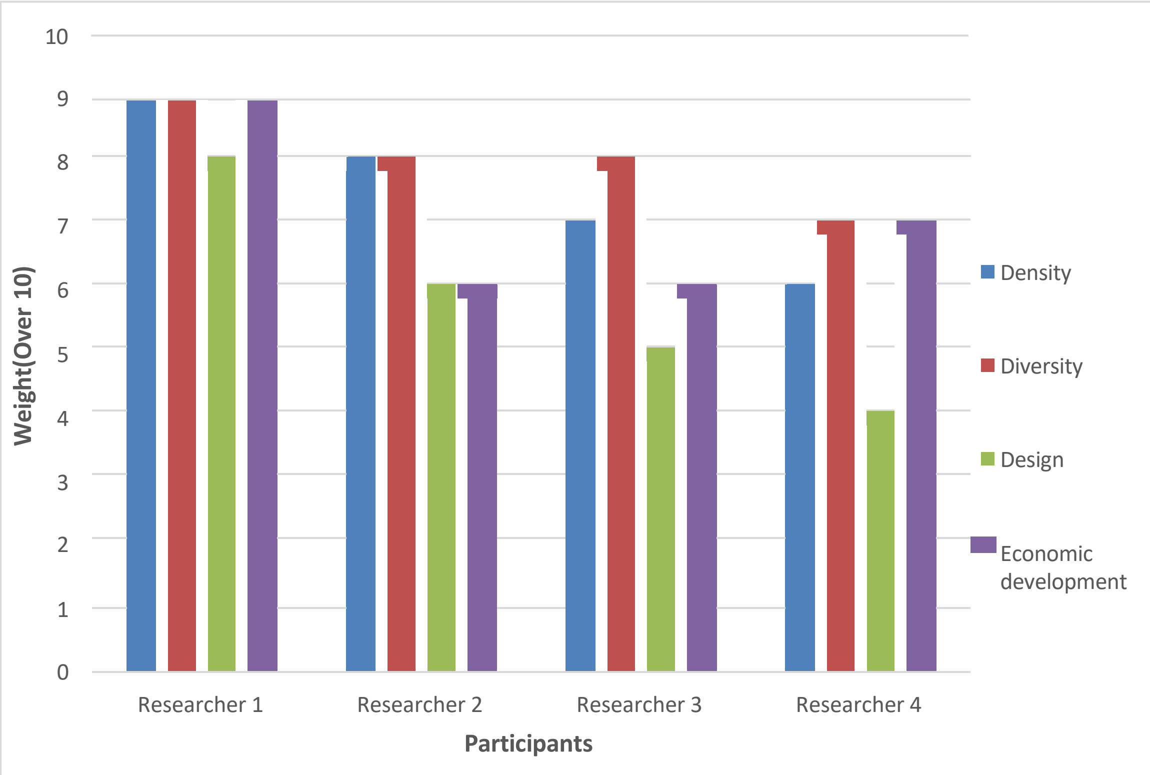
Question 11: If the proposed tool is in place, how frequently do you currently collect data for these indicators to address different planning interventions? Choose from the options and say why this frequency is chosen.

4 times per year	3 times per year	2 times per year	Once a year	Less than a year

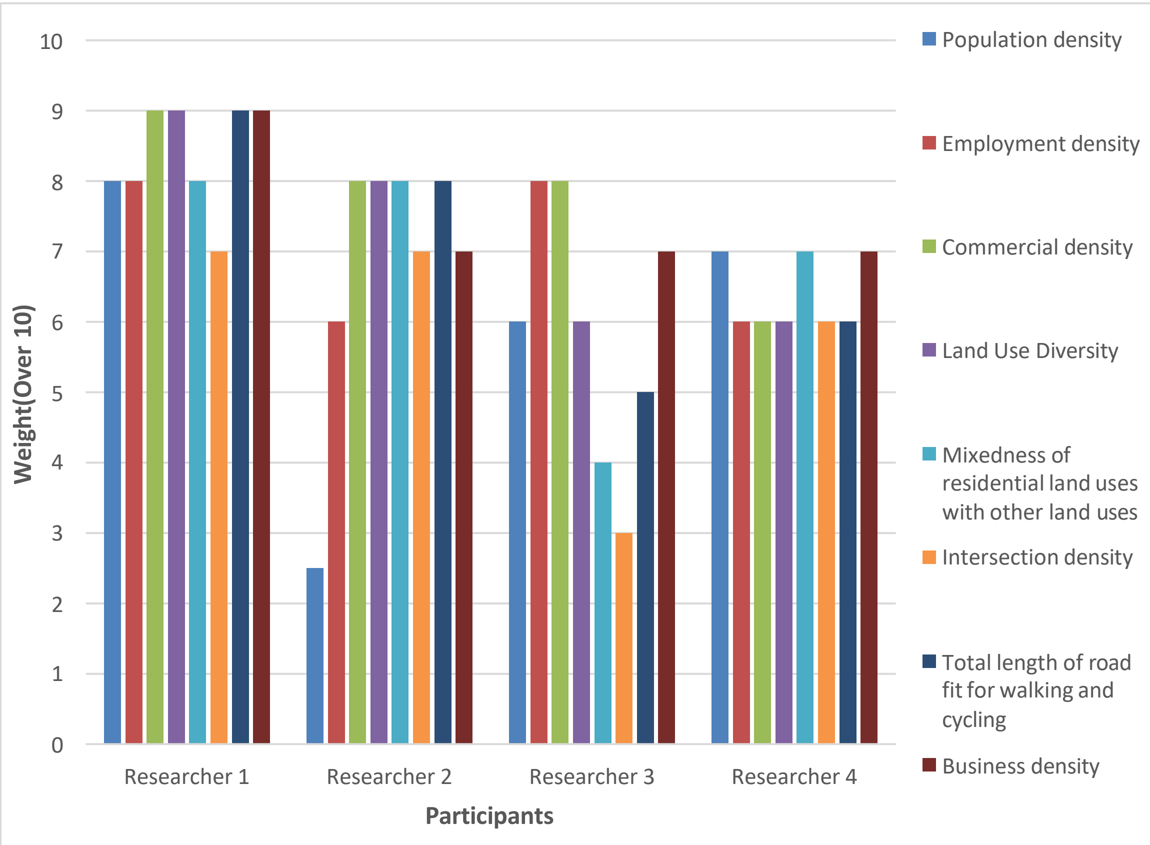
Question 12: Are there any additional comments you would like to provide regarding the TOD planning process, support tools, or any other related aspects?

Thank you for contributing your insights. Your input will contribute to advancing the understanding of the TOD concept in the context of Kigali.

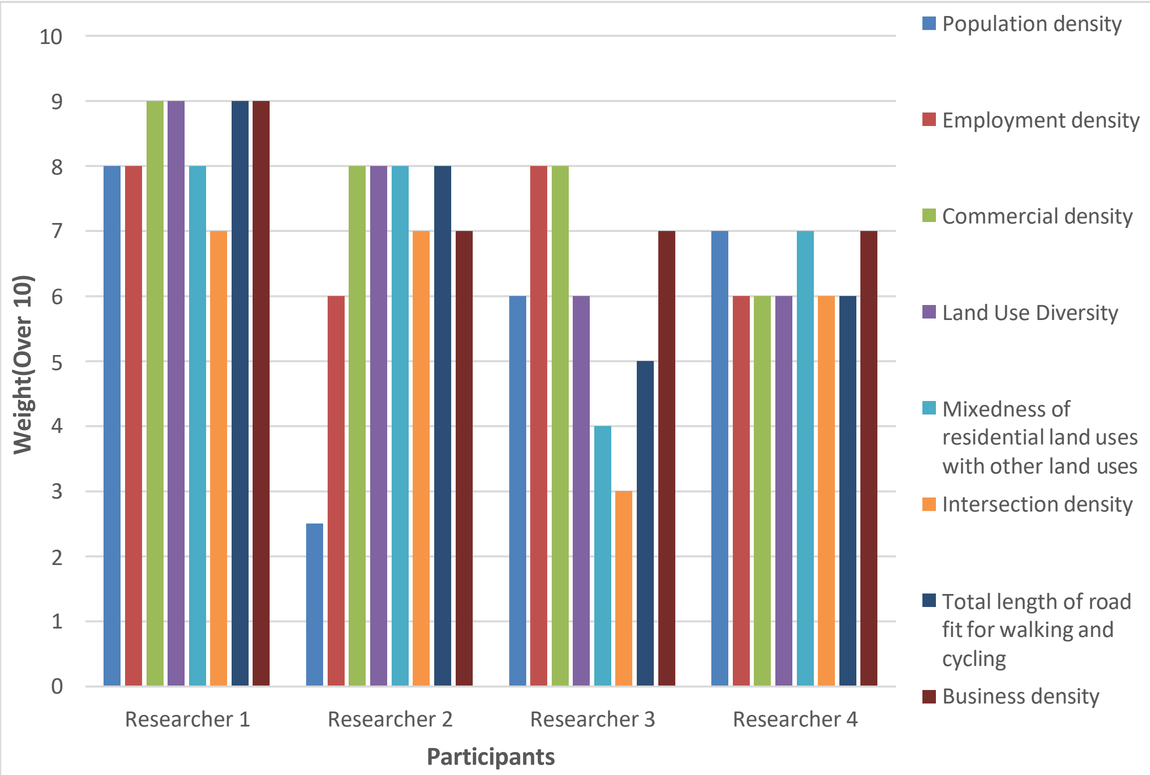
Interview Analysis Results



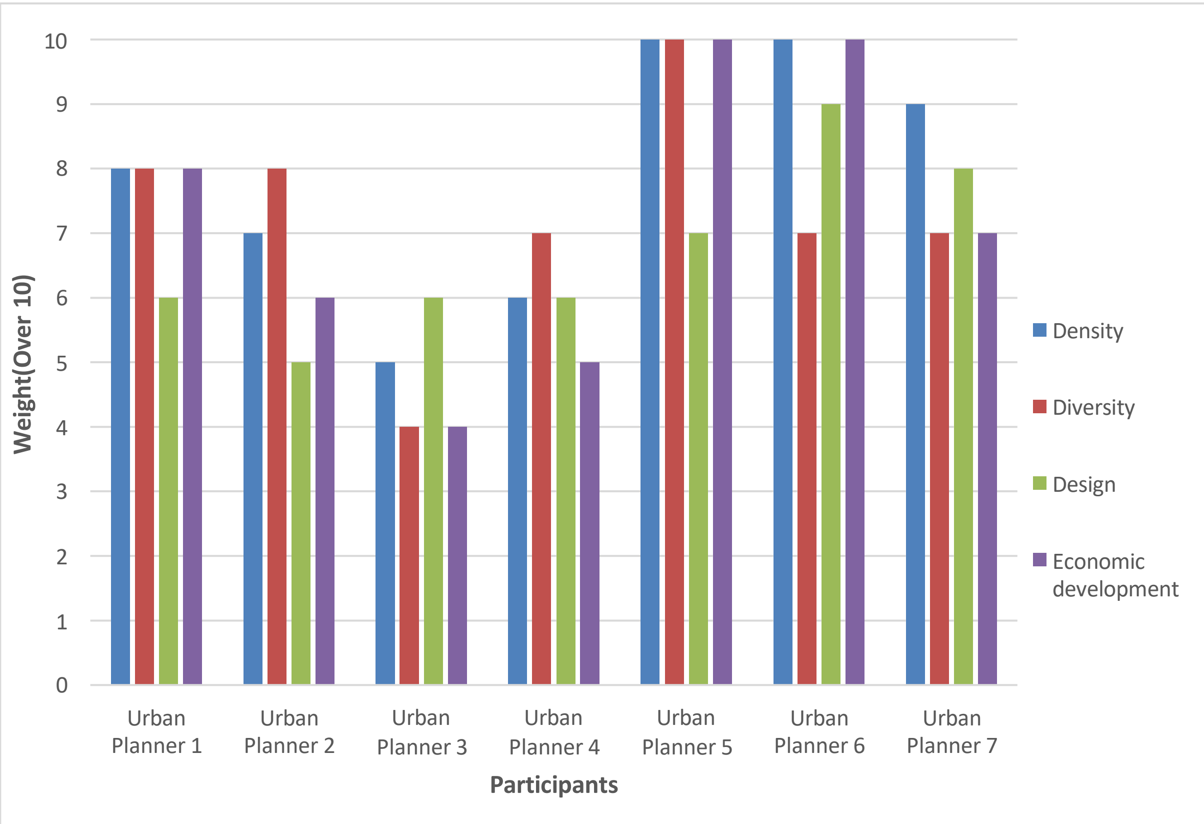
Graph 11: Weighing of Potential TOD Index criteria by researchers



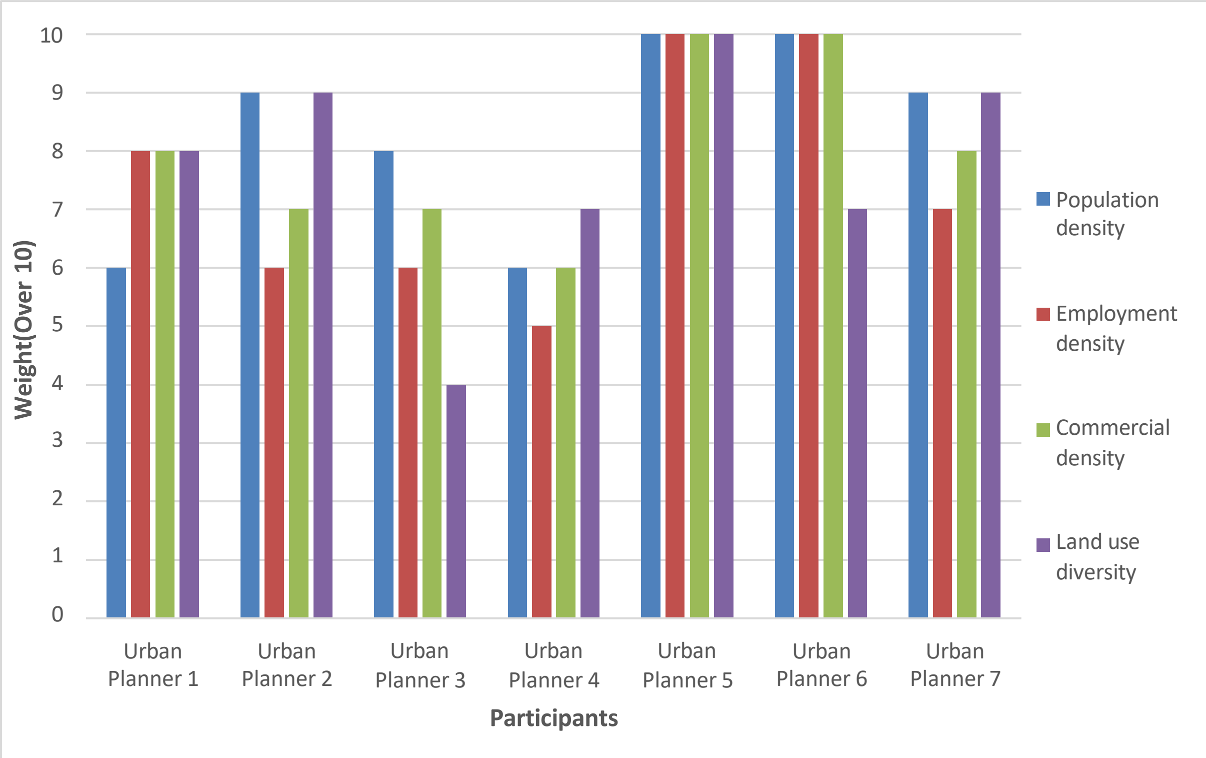
Graph 12: Weighing of Potential TOD Index indicators by researchers



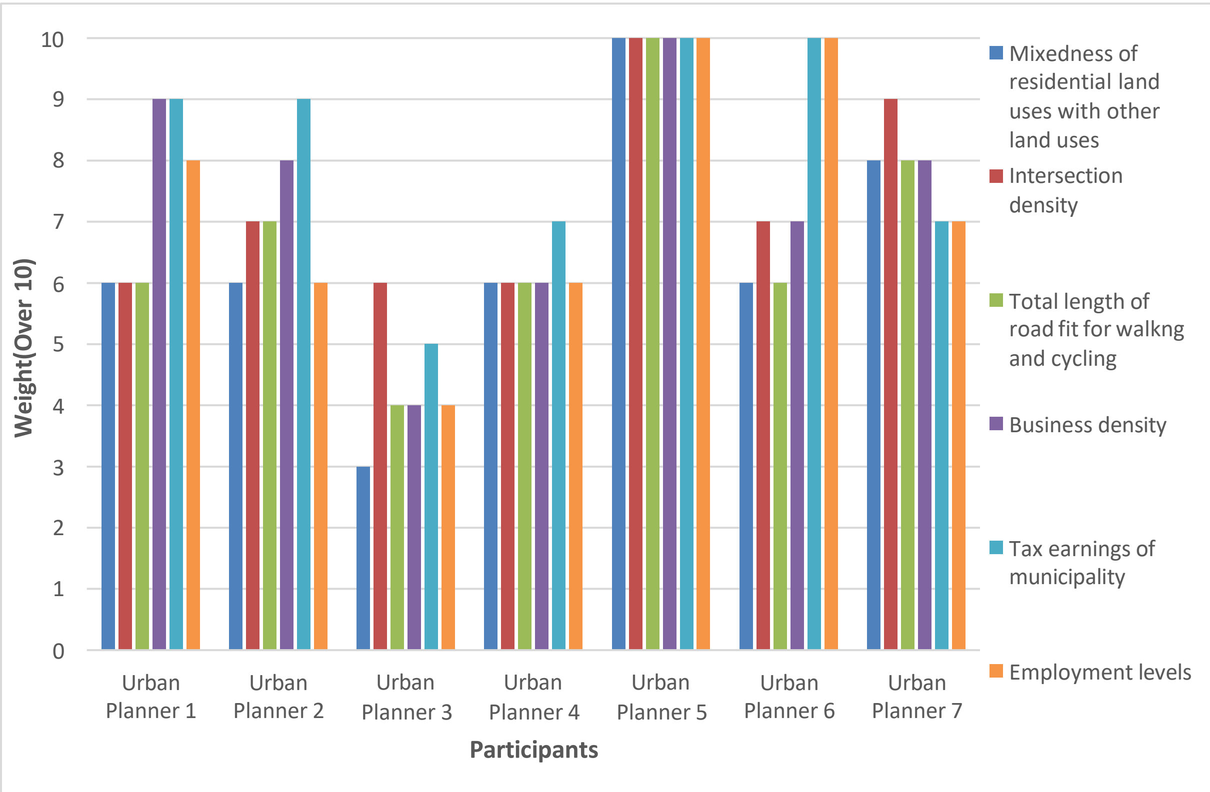
Graph 13: Weighing of Potential TOD Index indicators by researchers



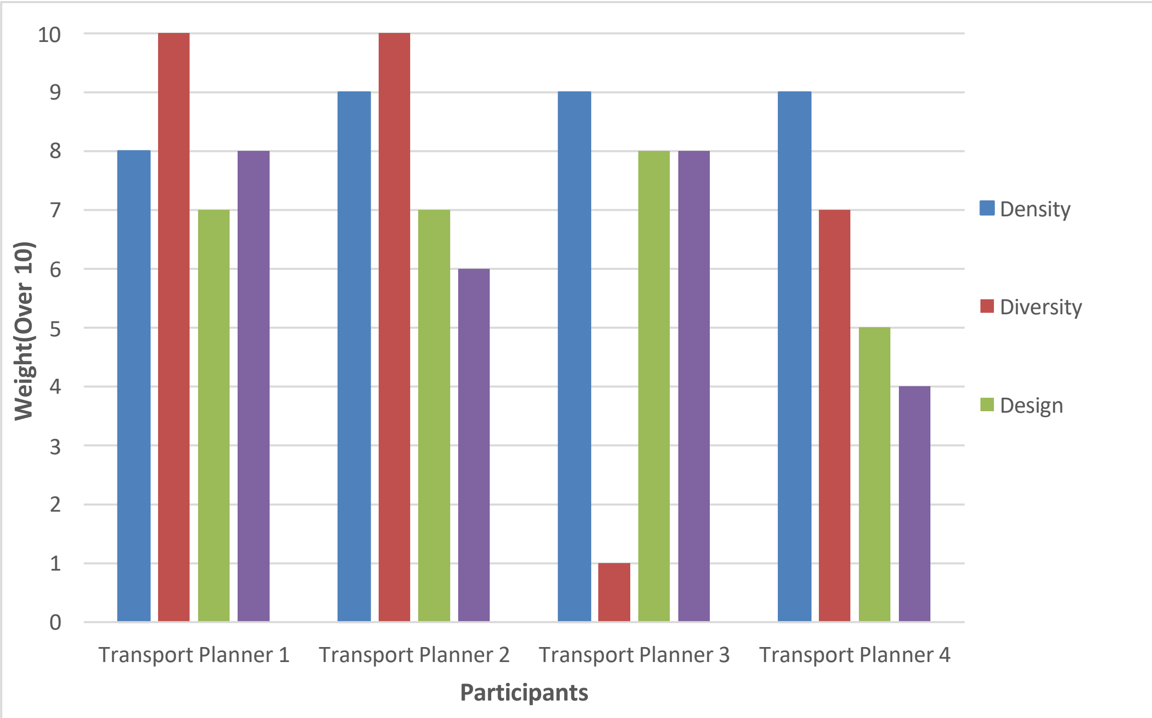
Graph 14: Weighing of Potential TOD Index criteria by urban planners



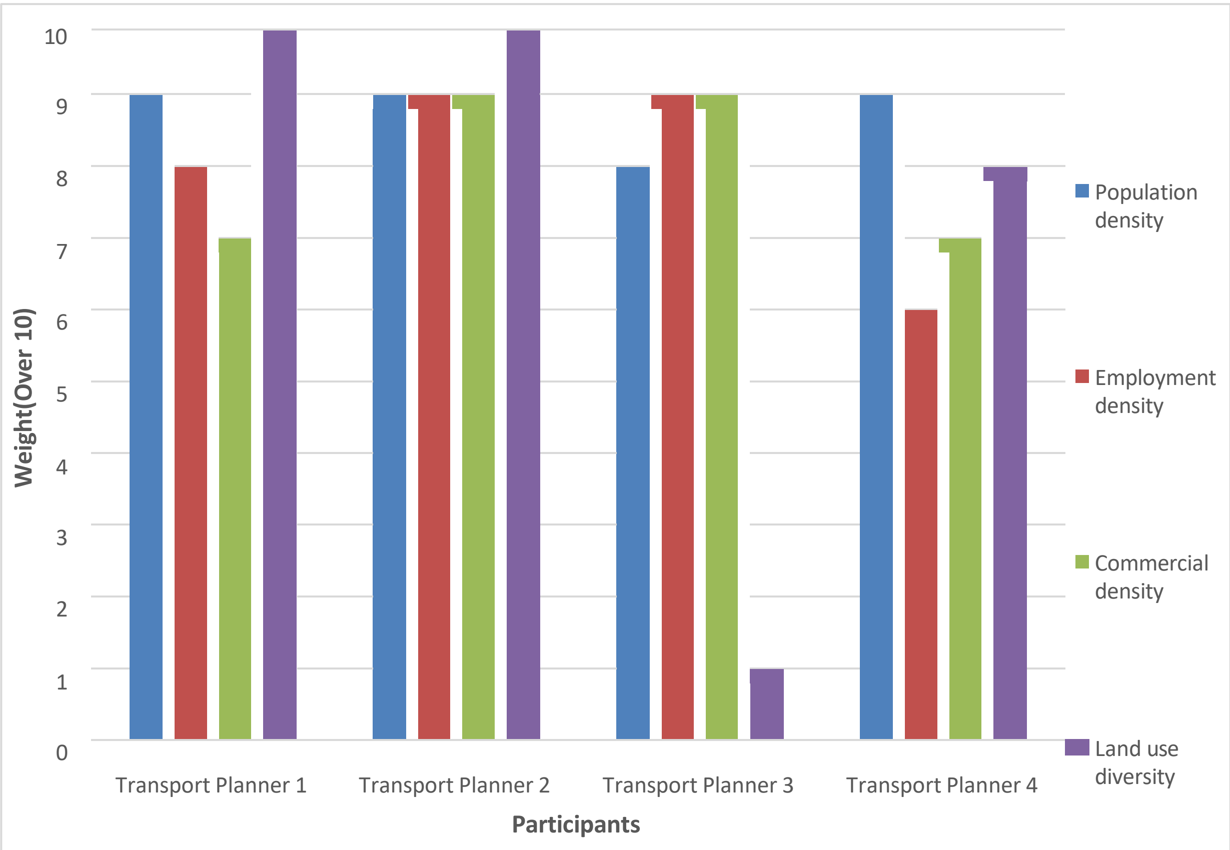
Graph 15: Weighing of Potential TOD Index criteria by urban planners



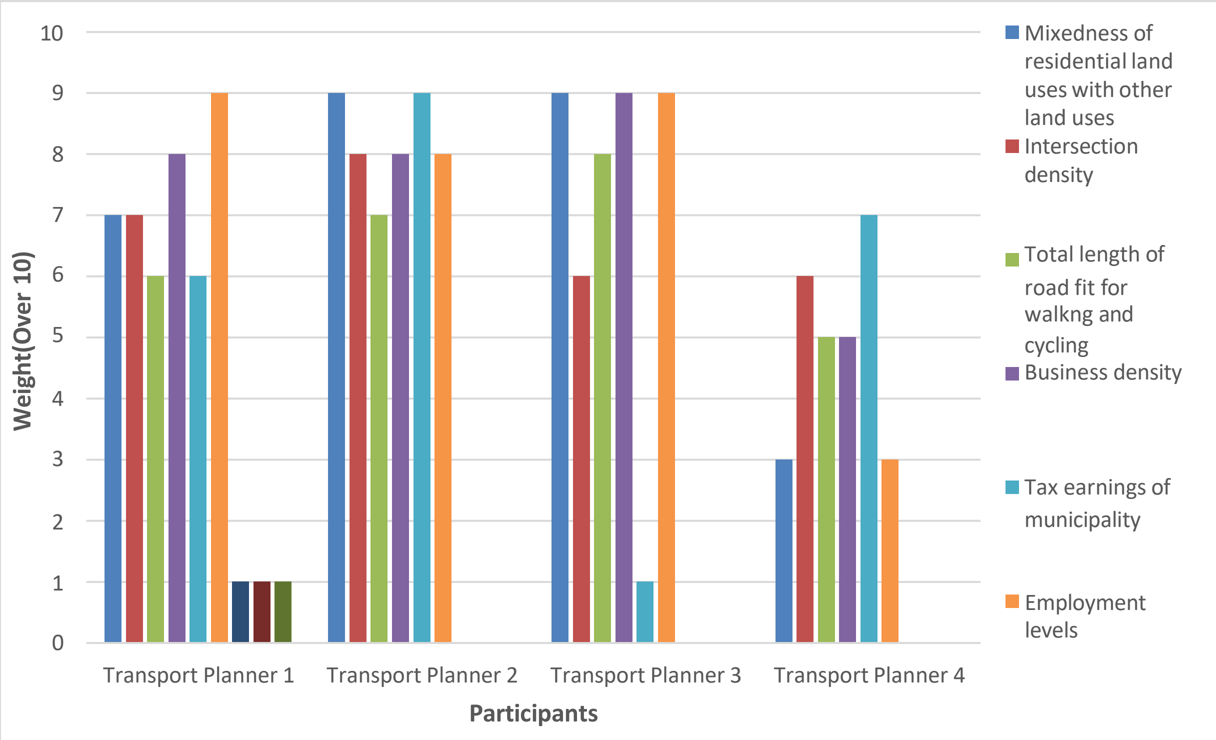
Graph 16: Weighing of Potential TOD Index Indicators by urban planners



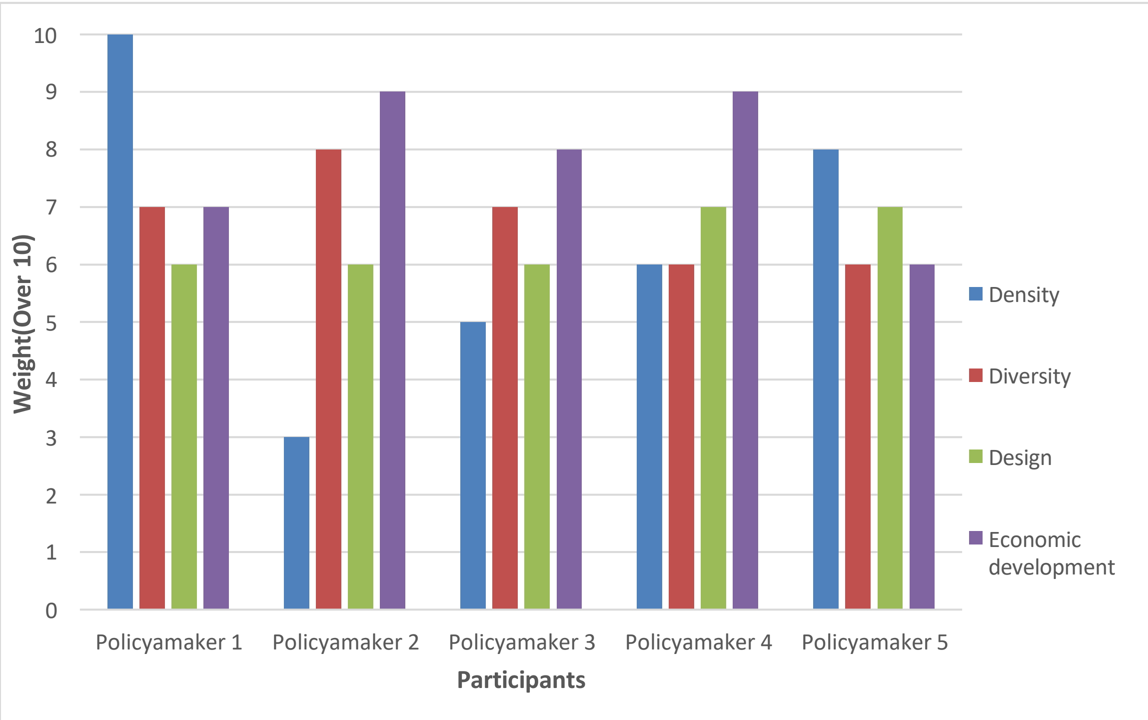
Graph 17: Weighing of Potential TOD Index Criteria by Transport Planners



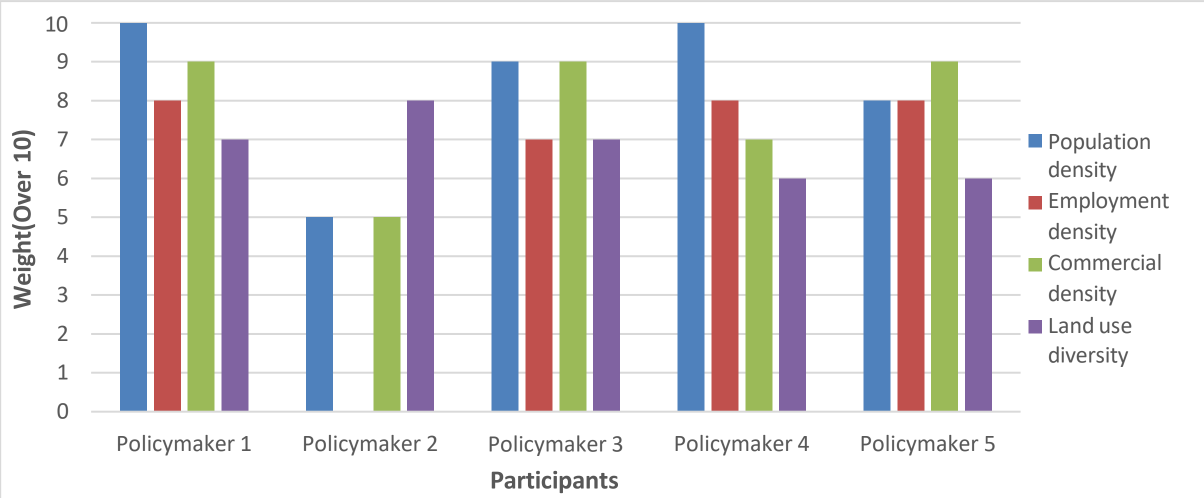
Graph 18: Weighing of Potential TOD Index indicators by transport planners



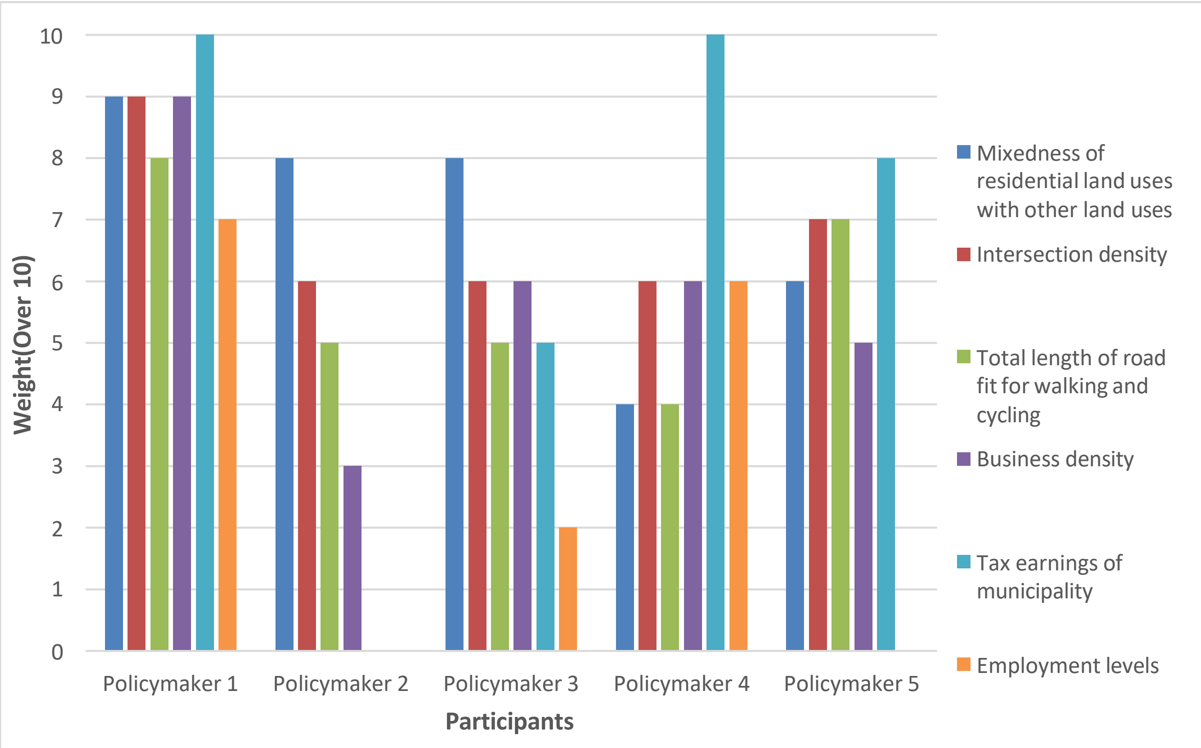
Graph 19: Weighing of Potential TOD Index indicators by transport planners



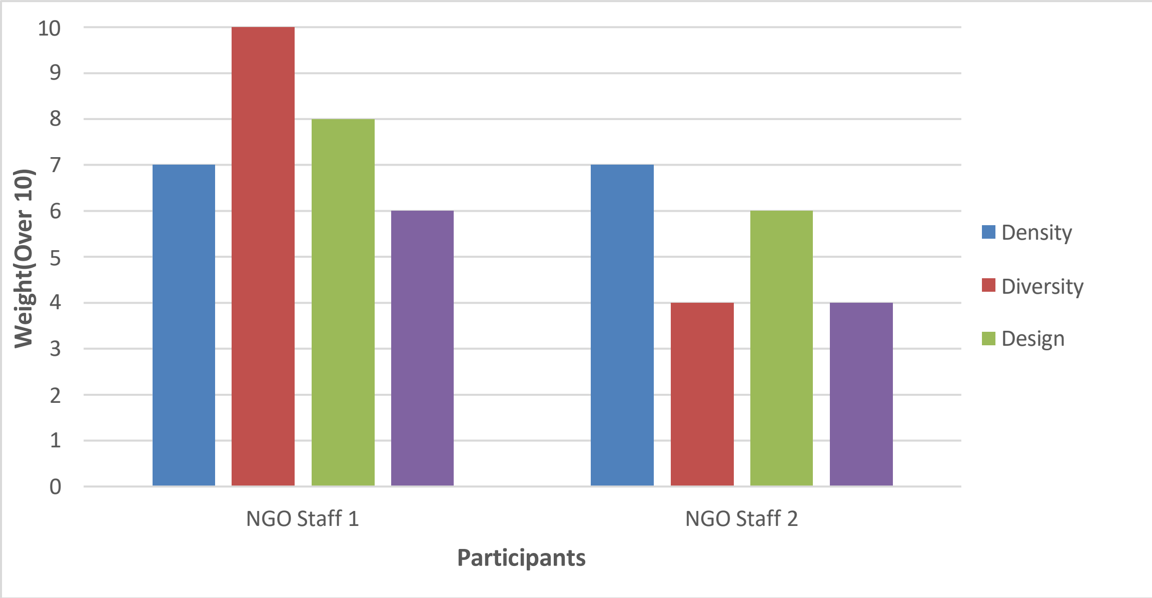
Graph 20: Weighing of Potential TOD Index criteria by policymakers



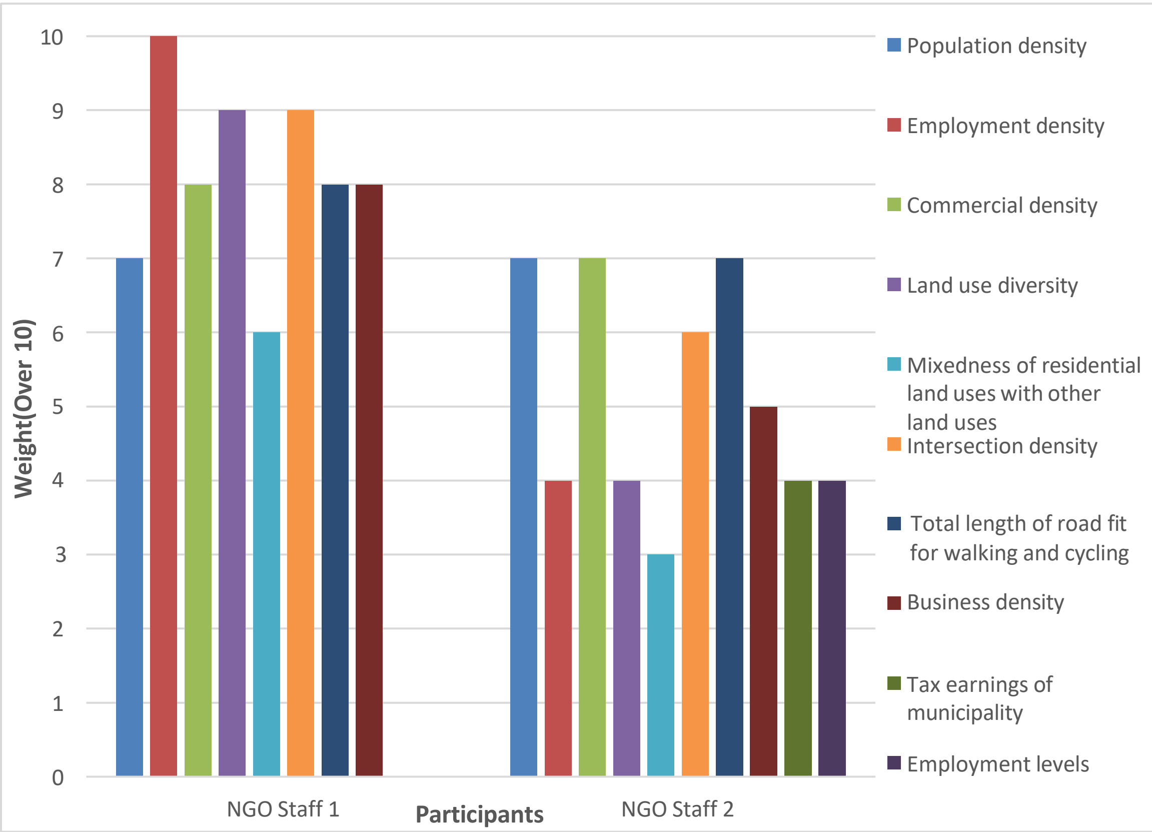
Graph 21: Weighing of Potential TOD Index indicators by policymakers



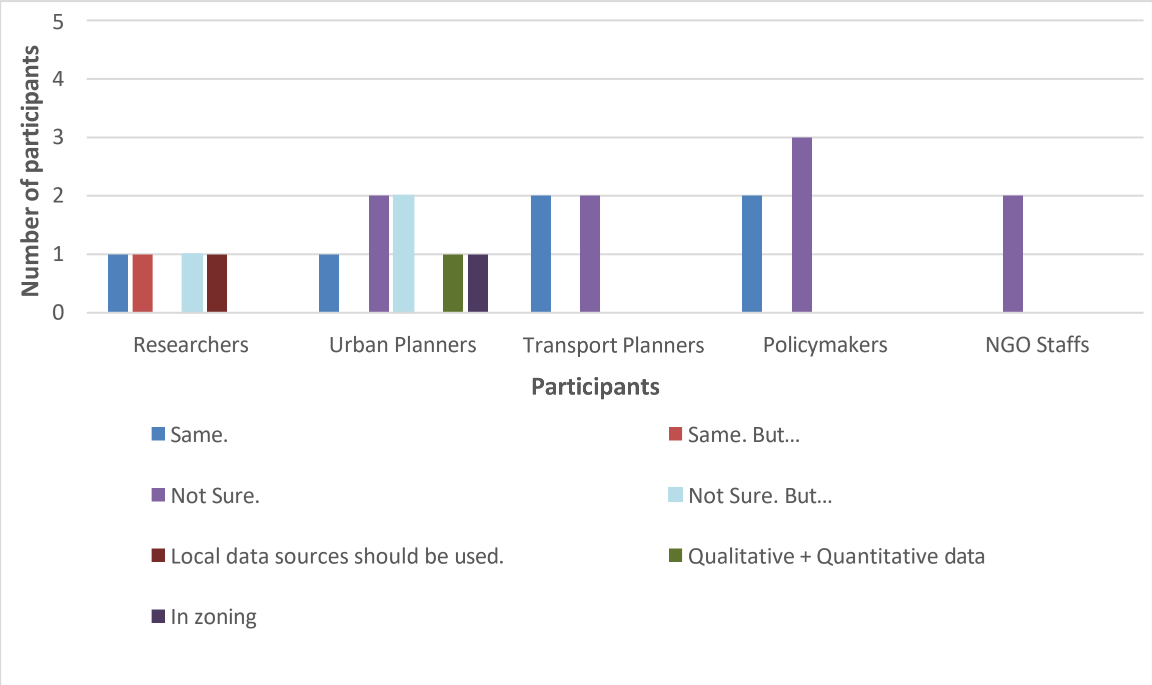
Graph 22: Weighing of Potential TOD Index indicators by policymakers



Graph **17:** Weighing of Potential TOD Index indicators by NGO Staffs

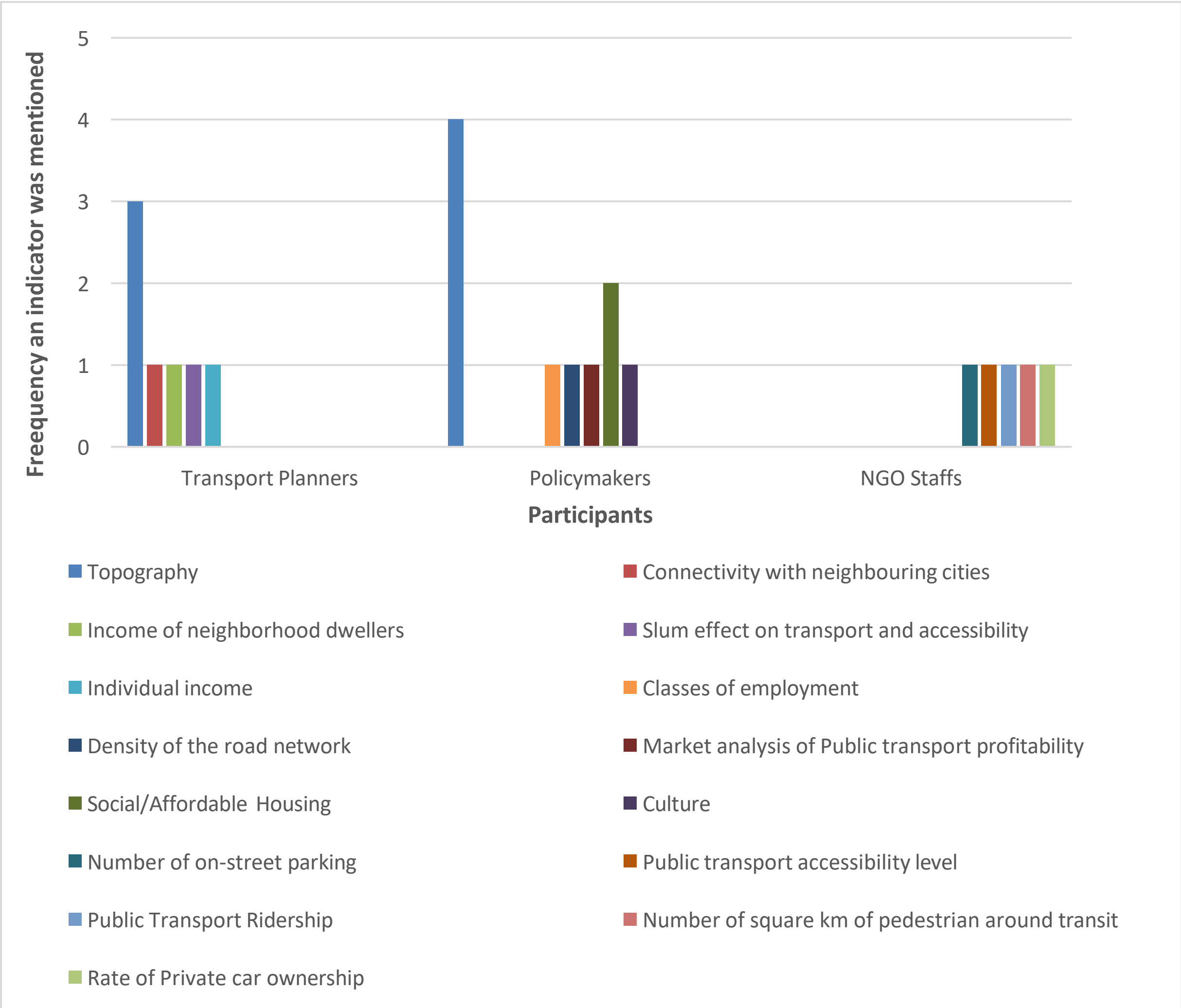


Graph 23: Weighing of Potential TOD Index indictors by NGO staff

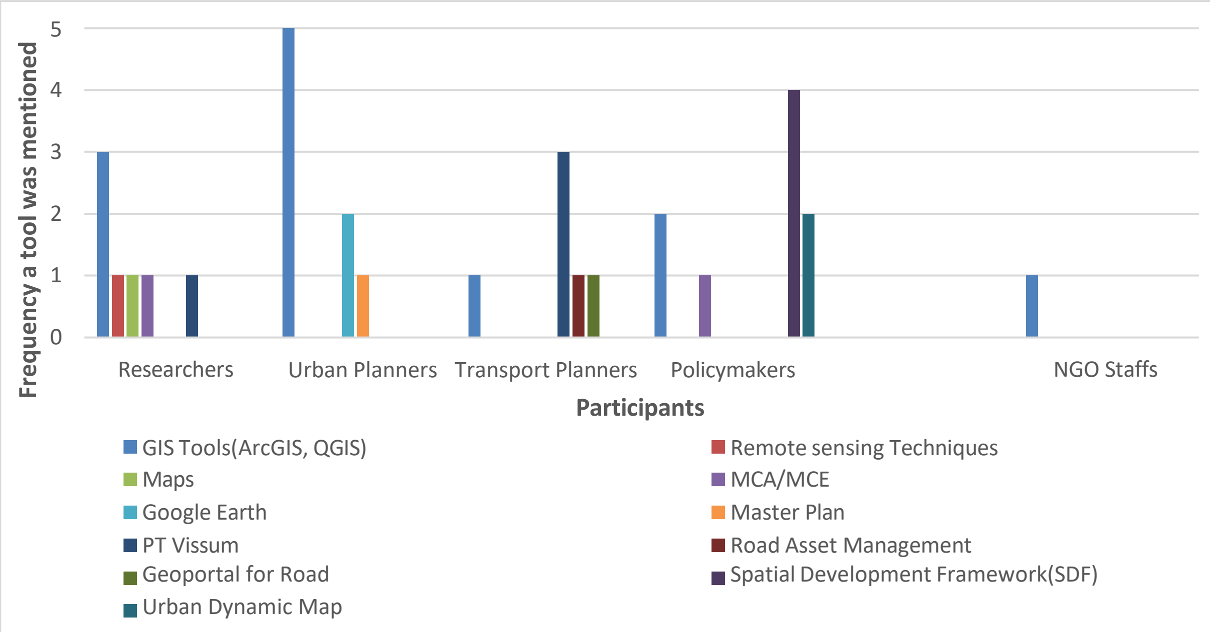


Graph 24: Participants' perspectives on the measurement of Potential TOD indicators in the CoK

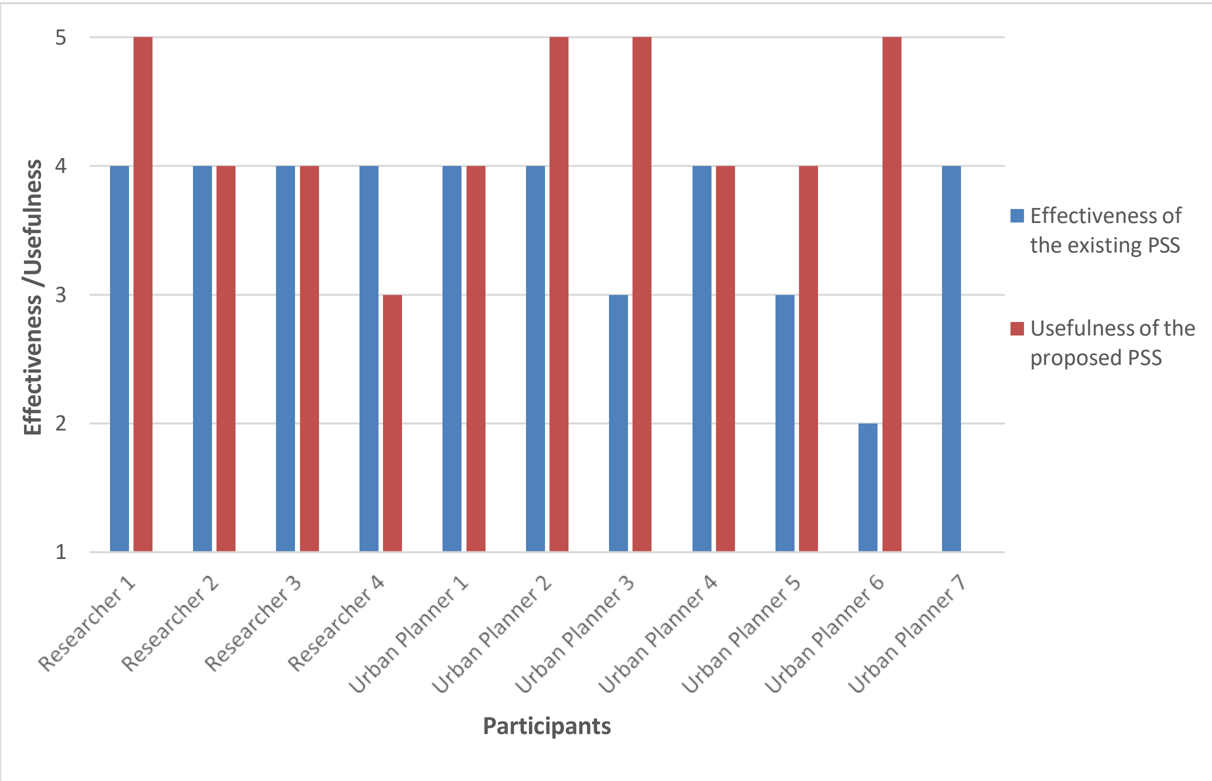
Graph 25: Potential TOD Indicators recommended by the participants



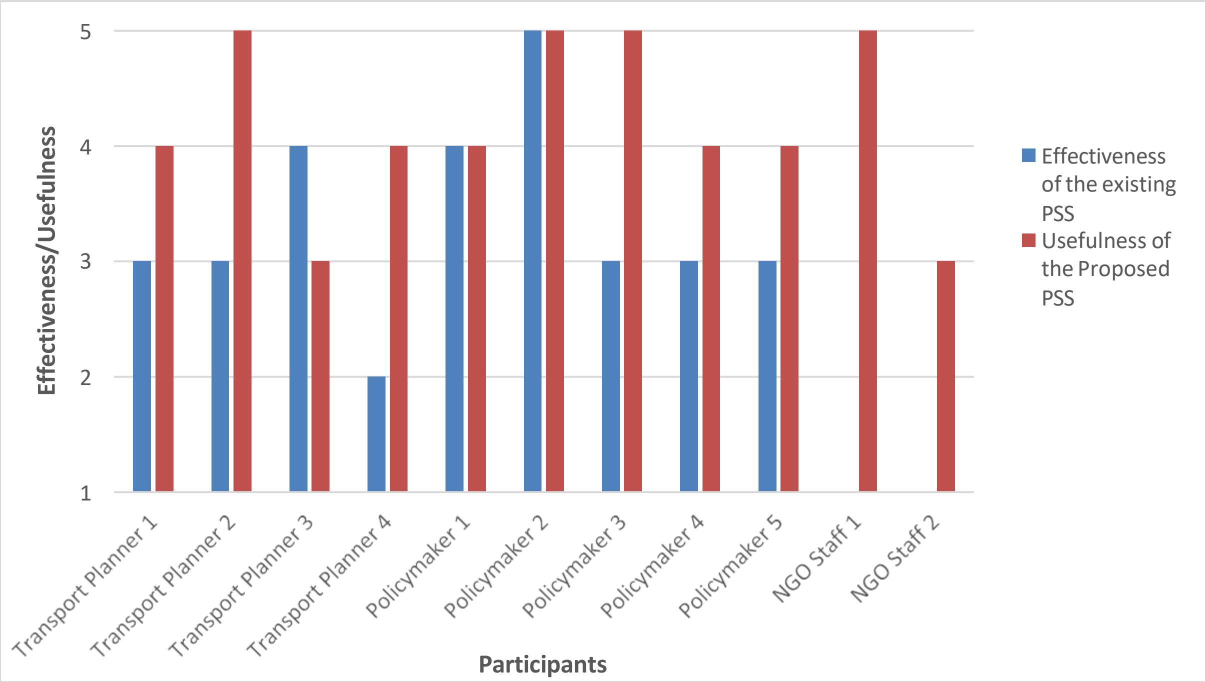
Graph 26: Potential TOD Indicators recommended by the participants



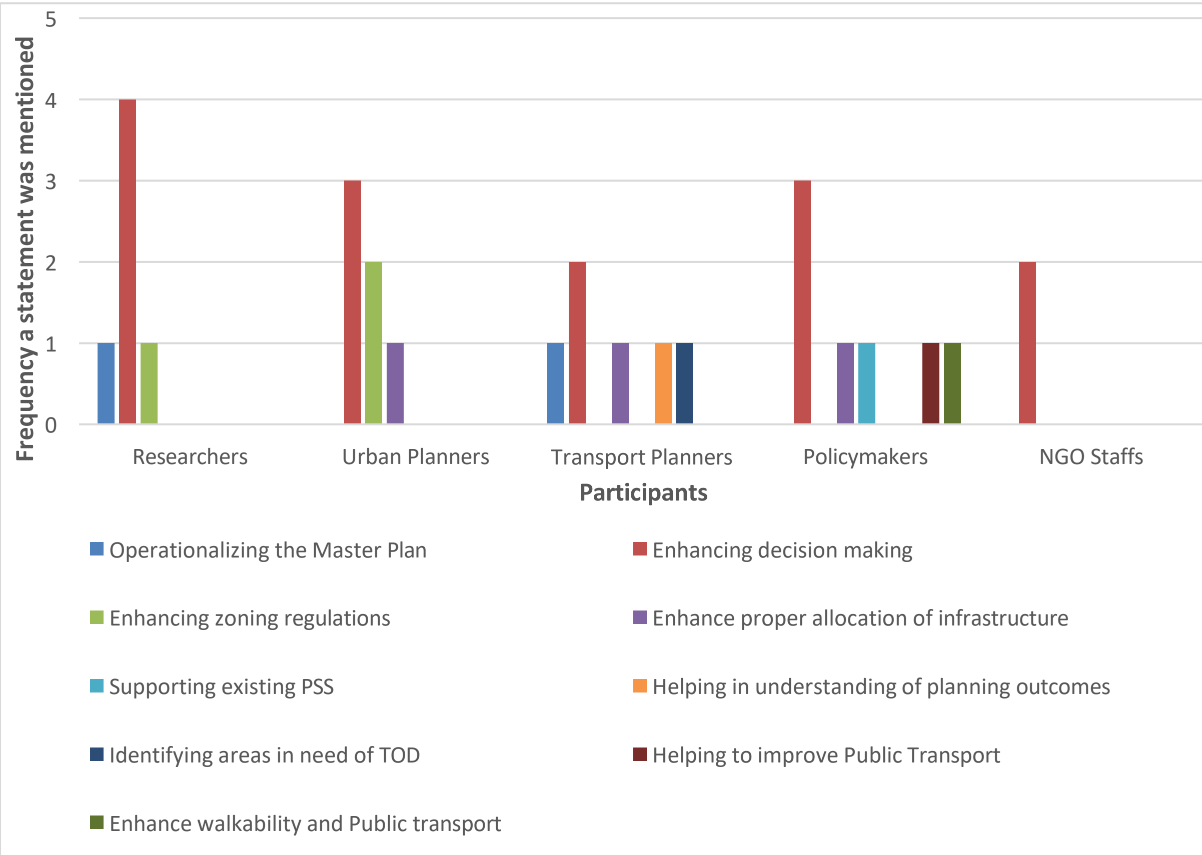
Graph 27: Existing PSS used by the participants



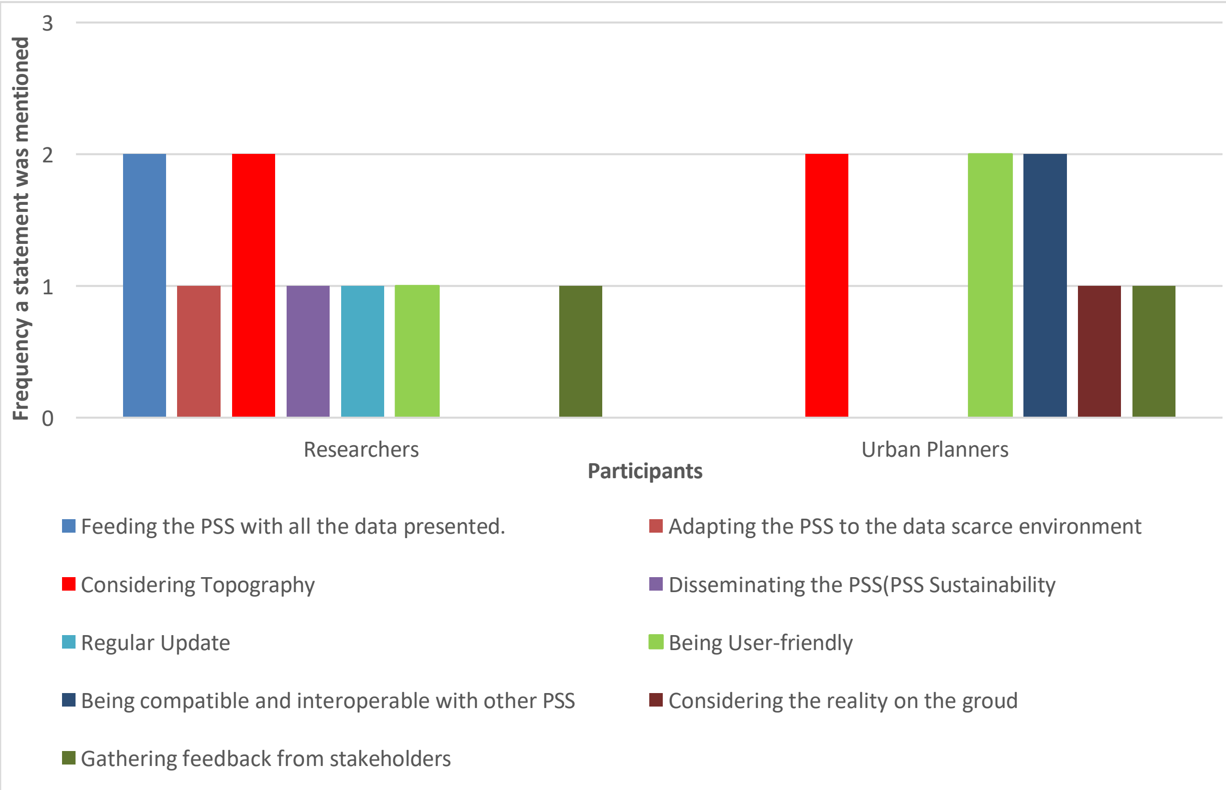
Graph 28: Rating of the effectiveness of the existing PSS and potential usefulness of the proposed PSS



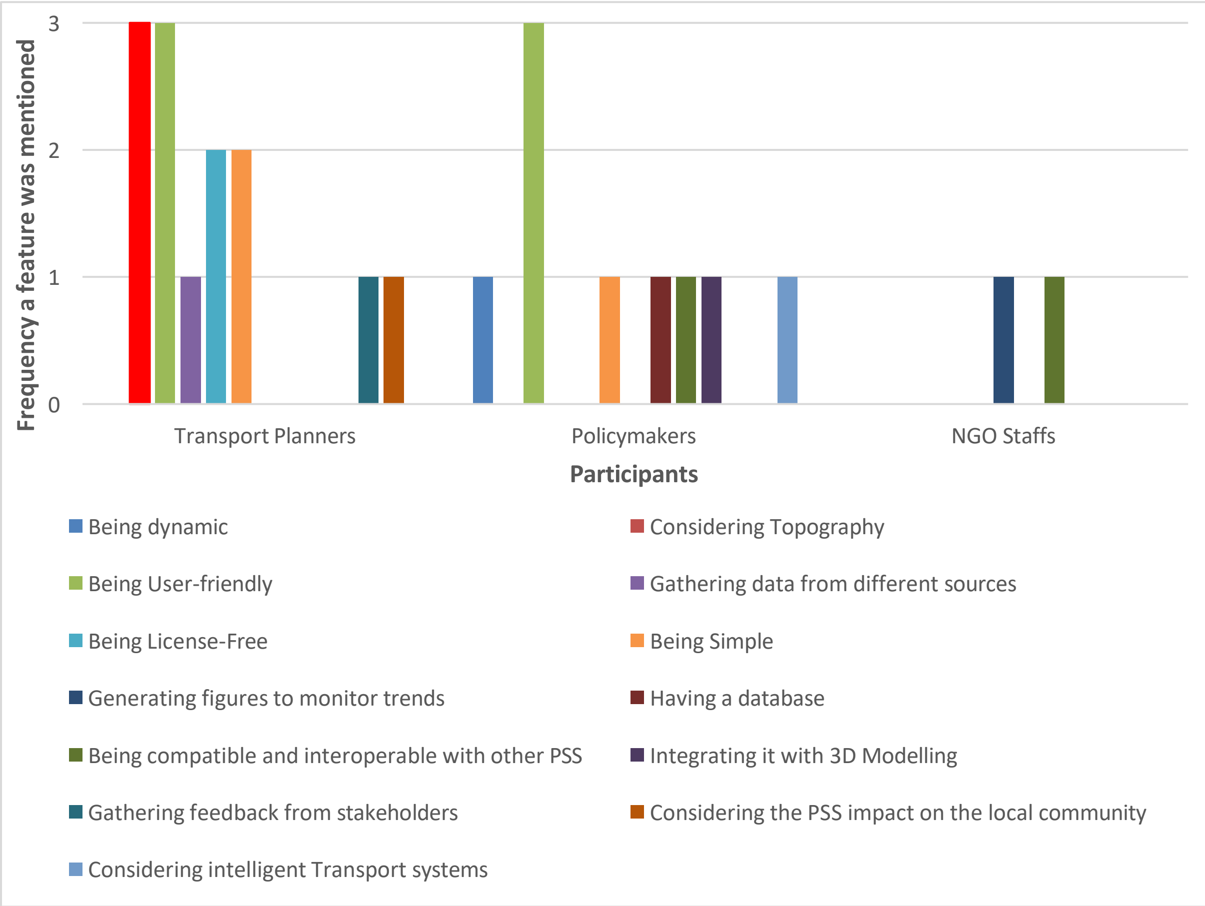
Graph 29: Rating of the effectiveness of the existing PSS and potential usefulness of the proposed PSS



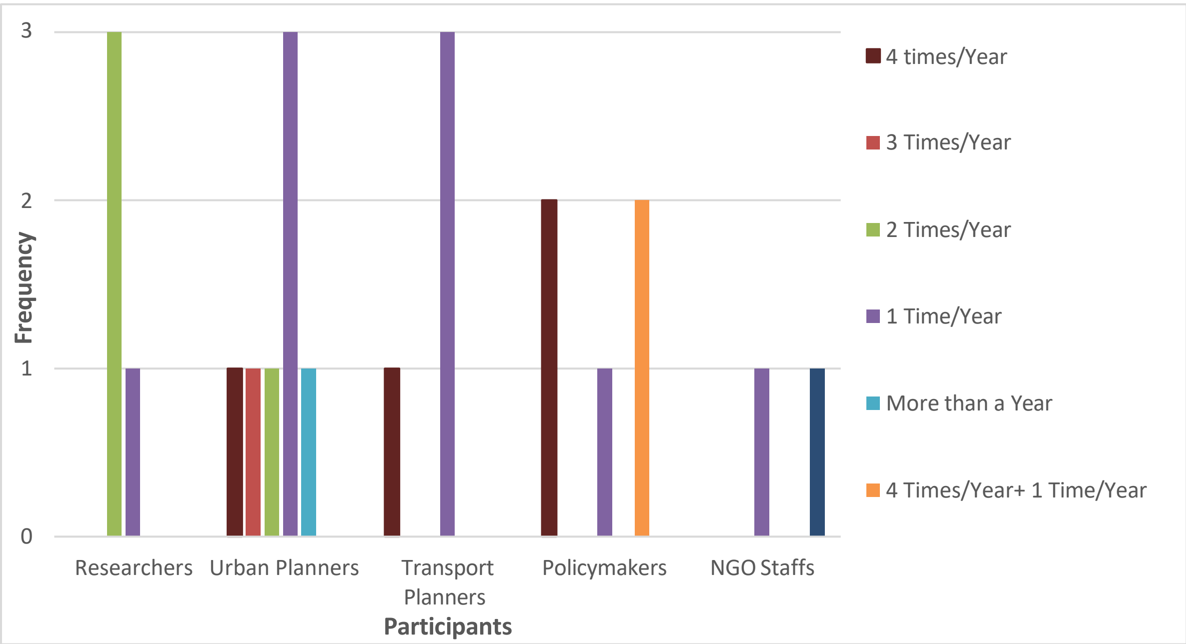
Graph 30: Participants' sentiments on the proposed PSS



Graph 31: Features of the proposed PSS recommended by the researchers and urban planners



Graph 32: Features of the proposed PSS recommended by the transport planners, policymakers and NGO Staff



Graph 33: Participants' perspectives on the data collection frequency required to feed the proposed PSS

PSS Report

printer-friendly

PSS_Final2 Summary

Report Contents

Expand All Scroll to End Collapse All

Analysis Description

analysis description displays here

Scenarios in this Analysis

What is a scenario?

Base Scenario

This is the scenario under the existing situation of all the TOD Index indicators previously used in the analysis.

IncreasedDensity Scenario

This is the scenario that considers the increase in population, commercial, employment and business density.

Report Summary

Report Date/Time: Tuesday, July 9, 2024 6:55 AM

Assumptions

What is an assumption?

Assumptions

Assumption	Default	Base Scenario	IncreasedDensity Scenario	Base Scenario	IncreasedDensity Scenario	Units
ChangeBD_Weight	1	1	1	1	1	
ChangeCD_Weight	0.33	0.58	0.33	0.58	0.33	
ChangeED_Weight	0.17	0.37	0.17	0.37	0.17	
ChangePopD_Weight	0.5	0.77	0.5	0.77	0.5	

Assumption Info

Assumption	Details
General	
ChangeBD_Weight	Type: Number Range: 0 - 1 Default: 1 Units:
ChangeCD_Weight	Type: Number Range: 0 - 1 Default: 0.33 Units:

ChangeED_Weight	Type: Number Range: 0 - 1 Default: 0.17 Units:
ChangePopD_Weight	Type: Number Range: 0 - 1 Default: 0.5 Units:

Assumption Descriptions

Assumption	Description
ChangeBD_Weight	This is the assumption used for changing the weight assigned to business density indicator under the base scenario.
ChangeCD_Weight	This is the assumption used for changing the weight assigned to commercial density indicator under the base scenario.
ChangeED_Weight	This is the assumption used for changing the weight assigned to employment density indicator under the base scenario.
ChangePopD_Weight	This is the assumption used for changing the weight assigned to population density indicator under the base scenario.

Indicators

What is an indicator?

Indicators

Indicator	Base Scenario	IncreasedDensity Scenario	Base Scenario	IncreasedDensity Scenario	Units
TOD_Index_New_Co1	0.17	0.15	0.17	0.15	
TOD_Index_New_Cor2	0.24	0.21	0.24	0.21	
TOD_Index_New_Cor3	0.19	0.16	0.19	0.16	
TOD_Index_New_Cor4	0.07	0.07	0.07	0.07	

Indicator Info

Indicator	Details
General	
TOD_Index_New_Co1	Units: Formula: Mean ([Attribute:BRT_Corridor1_AllVariables:TOD_Index_New_St_Co1])
TOD_Index_New_Cor2	Units: Formula: Mean ([Attribute:BRT_Corridor2_AllVariables:TOD_Index_New_St_Co2])
TOD_Index_New_Cor3	Units: Formula: Mean ([Attribute:BRT_Corridor3_AllVariables:TOD_Index_St_New_Co3])
TOD_Index_New_Cor4	Units: Formula: Mean ([Attribute:BRT_Corridor4_AllVariables:TOD_Index_New_St_Co4])

Indicator Descriptions

Indicator	Description
TOD_Index_New_Co1	This is the averaged TOD index for the BRT Corridor 1 under the increased density scenario.
TOD_Index_New_Cor2	This is the averaged TOD Index at the BRT Corridor 2 under the increased density scenario.
TOD_Index_New_Cor3	This is the averaged TOD Index at the BRT Corridor 3 under the increased density scenario.
TOD_Index_New_Cor4	This is the averaged TOD Index at the BRT Corridor 4 under the increased density scenario.

Dynamic Attributes

What is a dynamic attribute?

Attribute Info

Attribute	Details
BRT_Corridor1_AllVariables	
BD_St_Co1_Init	Type: Double Formula: ([Attribute:BusEst] - Min ([Attribute:BRT_Corridor1_AllVariables:BusEst])) / (Max ([Attribute:BRT_Corridor1_AllVariables:BusEst]) - Min ([Attribute:BRT_Corridor1_AllVariables:BusEst]))
BD_St_New_Co1	Type: Double Formula: ([Attribute:BusEst_New_Co1] - Min ([Attribute:BRT_Corridor1_AllVariables:BusEst_New_Co1])) / (Max ([Attribute:BRT_Corridor1_AllVariables:BusEst_New_Co1]) - Min ([Attribute:BRT_Corridor1_AllVariables:BusEst_New_Co1]))
BD_Weighed_Co1_Init	Type: Double Formula: [Attribute:BD_St_Co1_Init] * [Assumption:ChangeBD_Weight]
BD_Weighed_New_Co1	Type: Double Formula: [Attribute:BD_St_New_Co1] * [Assumption:ChangeBD_Weight]
BusEst_New_Co1	Type: Double Formula: [Attribute:BusEst] + ([Attribute:BusEst] * 0.7) / 100
ComD_St_Co1_Init	Type: Double Formula: ([Attribute:ComUnits] - Min ([Attribute:BRT_Corridor1_AllVariables:ComUnits])) / (Max ([Attribute:BRT_Corridor1_AllVariables:ComUnits]) - Min ([Attribute:BRT_Corridor1_AllVariables:ComUnits]))
ComD_St_New_Co1	Type: Double Formula: ([Attribute:ComUnits_New_Co1] - Min ([Attribute:BRT_Corridor1_AllVariables:ComUnits_New_Co1])) / (Max ([Attribute:BRT_Corridor1_AllVariables:ComUnits_New_Co1]) - Min ([Attribute:BRT_Corridor1_AllVariables:ComUnits_New_Co1]))
COmD_Weighed_Co1_Init	Type: Double Formula: [Attribute:ComD_St_Co1_Init] * [Assumption:ChangeCD_Weight]

ComD_Weighed_New_Co1	Type: Double Formula: [Attribute:ComD_St_New_Co1] * [Assumption:ChangeCD_Weight]
ComUnits_New_Co1	Type: Double Formula: [Attribute:ComUnits] + ([Attribute:ComUnits] * 0.7) / 100
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ED_Weighed_New_Co1	Type: Double Formula: [Attribute:ED_St_New_Co1] * [Assumption:ChangeED_Weight]
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PopNew_Co1	Type: Double Formula: [Attribute:Pop] + ([Attribute:Pop] * 2.8) / 100
TOD_Index_Co1_Init	Type: Double Formula: Sum ([Attribute:PopD_Weighed_Co1_Init], [Attribute:BD_Weighed_Co1_Init], [Attribute:COmD_Weighed_Co1_Init])
TOD_Index_Co1_St	Type: Double Formula: ([Attribute:TOD_Index_Co1_Init] - Min ([Attribute:BRT_Corridor1_AllVariables:TOD_Index_Co1_Init])) / (Max ([

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PopD_Weighed_New_Co2	Type: Double Formula: [Attribute:PopD_St_New_Co2] * [Assumption:ChangePopD_Weight]
TOD_Index_Init_Co2	Type: Double Formula: Sum ([Attribute:BD_Weighed], [Attribute:CD_Weighed], [Attribute:ED_Weighed_Init_Co2], [Attribute:PopD_Weigh_Co2_Init])
TOD_Index_New_Co2	Type: Double Formula: Sum ([Attribute:BD_Weighed], [Attribute:CD_Weighed], [Attribute:ED_Weighed_Init_Co2], [Attribute:PopD_Weighed_New_Co2])
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BD_St_New_Co3	Type: Double Formula: ([Attribute:BusEst_New_Co3] - Min ([Attribute:BRT_Corridor3_AllVariables:BusEst_New_Co3])) / (Max ([Attribute:BRT_Corridor3_AllVariables:BusEst_New_Co3]) - Min ([Attribute:BRT_Corridor3_AllVariables:BusEst_New_Co3]))
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BD_Weighed_New_Co3	Type: Double Formula: [Attribute:BD_St_New_Co3] * [Assumption:ChangeBD_Weight]
BusEst_New_Co3	Type: Double Formula: [Attribute:BusEst_init_Co3] + ([Attribute:BusEst_init_Co3] * 0.7) / 100
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ED_Weighed_New_Co3	Type: Double Formula: [Attribute:ED_St_New_Co3] * [Assumption:ChangeED_Weight]
Jobs_New_Co3	Type: Double Formula: [Attribute:Jobs_Init_Co3] + ([Attribute:Jobs_Init_Co3] * 2.9) / 100
Pop_New_Co3	Type: Double Formula: [Attribute:Pop_Init_Co3] + ([Attribute:Pop_Init_Co3] * 4.5) / 100
PopD_St_Init_Co3	Type: Double Formula: ([Attribute:Pop_Init_Co3] - Min ([Attribute:BRT_Corridor3_AllVariables:Pop_Init_Co3])) / (Max ([Attribute:BRT_Corridor3_AllVariables:Pop_Init_Co3]) - Min ([Attribute:BRT_Corridor3_AllVariables:Pop_Init_Co3]))
PopD_St_New_Co3	Type: Double Formula: ([Attribute:Pop_New_Co3] - Min ([Attribute:BRT_Corridor3_AllVariables:Pop_New_Co3])) / (Max ([Attribute:BRT_Corridor3_AllVariables:Pop_New_Co3]) - Min ([Attribute:BRT_Corridor3_AllVariables:Pop_New_Co3]))
PopD_Weighed_Init_Co3	Type: Double Formula: [Attribute:PopD_St_Init_Co3] * [Assumption:ChangePopD_Weight]
PopD_Weighed_New_Co3	Type: Double Formula: [Attribute:PopD_St_New_Co3] * [Assumption:ChangePopD_Weight]
TOD_Index_Init_Co3	Type: Double Formula: Sum ([Attribute:BD_Weighed_Init_Co3], [Attribute:CD_Weighed_Init_Co3], [Attribute:ED_Weighed_Init_Co3], [Attribute:PopD_Weighed_Init_Co3])
TOD_Index_New_Co3	Type: Double Formula: Sum ([Attribute:BD_Weighed_New_Co3], [Attribute:CD_Weighed_New_Co3], [Attribute:ED_Weighed_New_Co3], [Attribute:PopD_Weighed_New_Co3])
TOD_Index_St_Init_Co3	Type: Double Formula: ([Attribute:TOD_Index_Init_Co3] - Min ([Attribute:BRT_Corridor3_AllVariables:TOD_Index_Init_Co3])) / (Max ([

	Attribute:BRT_Corridor3_AllVariables:TOD_Index_Init_Co3]) - Min ([Attribute:BRT_Corridor3_AllVariables:TOD_Index_Init_Co3]))
TOD_Index_St_New_Co3	Type: Double Formula: ([Attribute:TOD_Index_New_Co3] - Min ([Attribute:BRT_Corridor3_AllVariables:TOD_Index_New_Co3])) / (Max ([Attribute:BRT_Corridor3_AllVariables:TOD_Index_New_Co3]) - Min ([Attribute:BRT_Corridor3_AllVariables:TOD_Index_New_Co3]))
BRT_Corridor4_AllVariables	
BD_St_Init_Co4	Type: Double Formula: ([Attribute:BusEst_Init_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:BusEst_Init_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:BusEst_Init_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:BusEst_Init_Co4]))
BD_St_New_Co4	Type: Double Formula: ([Attribute:BusEst_New_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:BusEst_New_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:BusEst_New_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:BusEst_New_Co4]))
BD_Weighed_Init_Co4	Type: Double Formula: [Attribute:BD_St_Init_Co4] * [Assumption:ChangeBD_Weight]
BD_Weighed_New_Co4	Type: Double Formula: [Attribute:BusEst_New_Co4] * [Assumption:ChangeBD_Weight]
BusEst_New_Co4	Type: Double Formula: [Attribute:BusEst_Init_Co4] + ([Attribute:BusEst_Init_Co4] * 2.8) / 100
CD_St_Init_Co4	Type: Double Formula: ([Attribute:ComUnits_Init_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:ComUnits_Init_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:ComUnits_Init_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:ComUnits_Init_Co4]))
CD_Weighed_Init_Co4	Type: Double Formula: [Attribute:CD_St_Init_Co4] * [Assumption:ChangeCD_Weight]
ComD_St_New_Co4	Type: Double Formula: ([Attribute:ComUnits_New_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:ComUnits_New_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:ComUnits_New_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:ComUnits_New_Co4]))
ComD_Weighed_New_Co4	Type: Double Formula: [Attribute:ComD_St_New_Co4] * [Assumption:ChangeCD_Weight]
ComUnits_New_Co4	Type: Double Formula: [Attribute:ComUnits_Init_Co4] + ([Attribute:ComUnits_Init_Co4] * 0.7) / 100
ED_St_Init_Co4	Type: Double Formula:

	([Attribute:Jobs_Init_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:Jobs_Init_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:Jobs_Init_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:Jobs_Init_Co4]))
ED_St_New_Co4	Type: Double Formula: ([Attribute:Jobs_New_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:Jobs_New_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:Jobs_New_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:Jobs_New_Co4]))
ED_Weighed_Init_Co4	Type: Double Formula: [Attribute:ED_St_Init_Co4] * [Assumption:ChangeED_Weight]
ED_Weighed_New_Co4	Type: Double Formula: [Attribute:ED_St_New_Co4] * [Assumption:ChangeED_Weight]
Jobs_New_Co4	Type: Double Formula: [Attribute:Jobs_Init_Co4] + ([Attribute:Jobs_Init_Co4] * 2.9) / 100
Pop_New_Co4	Type: Double Formula: [Attribute:Pop_Init_Co4] + ([Attribute:Pop_Init_Co4] * 4.5) / 100
PopD_St_Init_Co4	Type: Double Formula: ([Attribute:Pop_Init_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:Pop_Init_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:Pop_Init_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:Pop_Init_Co4]))
PopD_St_New_Co4	Type: Double Formula: ([Attribute:Pop_New_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:Pop_New_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:Pop_New_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:Pop_New_Co4]))
PopD_Weighed_Init_Co4	Type: Double Formula: [Attribute:PopD_St_Init_Co4] * [Assumption:ChangePopD_Weight]
PopD_Weighed_New_Co4	Type: Double Formula: [Attribute:PopD_St_New_Co4] * [Assumption:ChangePopD_Weight]
TOD_Index_Co4_init_Co4	Type: Double Formula: Sum ([Attribute:BD_Weighed_Init_Co4], [Attribute:CD_Weighed_Init_Co4], [Attribute:ED_Weighed_Init_Co4], [Attribute:PopD_Weighed_Init_Co4])
TOD_Index_New_Co4	Type: Double Formula: Sum ([Attribute:ComD_Weighed_New_Co4], [Attribute:ED_Weighed_New_Co4], [Attribute:PopD_Weighed_New_Co4], [Attribute:BD_Weighed_New_Co4])
TOD_Index_New_St_Co4	Type: Double Formula: ([Attribute:TOD_Index_New_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:TOD_Index_New_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:TOD_Index_New_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:TOD_Index_New_Co4]))

TOD_Index_St_Init_Co4	Type: Double Formula: ([Attribute:TOD_Index_Co4_init_Co4] - Min ([Attribute:BRT_Corridor4_AllVariables:TOD_Index_Co4_init_Co4])) / (Max ([Attribute:BRT_Corridor4_AllVariables:TOD_Index_Co4_init_Co4]) - Min ([Attribute:BRT_Corridor4_AllVariables:TOD_Index_Co4_init_Co4]))

Attribute Descriptions

Attribute	Description
BRT_Corridor1_AllVariables	
BD_St_Co1_Init	This is the standardized business density in BRT Corridor q under base scenario.
BD_St_New_Co1	This is the standardized business density in each grid cell of BRT Corridor 1 under the increased density scenario.
BD_Weighed_Co1_Init	This is the weighed business density in BRT Corridor 1 under base scenario.
BD_Weighed_New_Co1	This is the weighed business density in each grid cell of BRT 1 under the increased density scenario.
BusEst_New_Co1	This is the number of business establishments in each grid cell of BRT Corridor 1 under the increased density scenario.
ComD_St_Co1_Init	This is the standardized commercial density in BRT Corridor 1 under base scenario
ComD_St_New_Co1	This is the standardized commercial density in each grid cell of BRT Corridor 3 under the increased density scenario.
COmD_Weighed_Co1_Init	This is the weighed commercial density in BRT Corridor 1 under base scenario.
ComD_Weighed_New_Co1	This is the weighed commercial density in each grid cell of BRT Corridor 1 under the increased density scenario.
ComUnits_New_Co1	This is the number of commercial units in each grid cell of BRT Corridor 1 under the increased density scenario.
ED_St_Init_Co1	This is the standardized employment density for BRT Corridor in base scenario
ED_St_New_Co1	This is the standardized population density in each grid cell of BRT Corridor 1 under the increased density.
ED_Weighed_Init_Co1	This is the weighed employment in BRT Corridor 1 under the base scenario.
ED_Weighed_New_Co1	This is the weighed employment density in each grid cell for BRT Corridor 1 under the increased density.
Jobs_New_Co1	This is the number of jobs in each grid cell of BT Corridor 1 under the increased density density scenario.
PopD_St_Co1_Init	This is the standardized population density for BRT Corridor 1 under the base scenario.
PopD_St_New_Co1	This is the standardized population density in each grid cell of BRT Corridor 1 under the increased density scenario.
PopD_Weighed_Co1_Init	This is the weighed population density for BRT Corridor 1 under the base scenario.
PopD_Weighed_New_Co1	This is the weighed population density in each grid cell of BRT Corridor 1 under the increased density scenario.
PopNew_Co1	This is the number of people in each grid cell of BRT Corridor 1 under the increased density scenario.
TOD_Index_Co1_Init	This is the TOD index for BRT Corridor 1 under base scenario.

TOD_Index_Co1_St	This is the standardized TOD index for BRT Corridor 1 under base scenario.
TOD_Index_New_Co1	This is the revised TOD Index in each grid cell of BRT Corridor 1 under the increased density scenario.
TOD_Index_New_St_Co1	This the revised standardized TOD index in each grid cell of BRT Corridor 1 under the increased density.
BRT_Corridor2_AllVariables	
BD_St_Init	This is the standardized business density in BRT Corridor 2 under the base scenario.
BD_St_New_Co2	This is the standardized business density in each grid cell of BRT Corridor 2 under the increased density scenario.
BD_Weighed	This is the weighed business density in BRT Corridor 2 under the base scenario.
BD_Weighed_New_Co2	This is the weighed business density in each grid cell of BRT Corridor 2 under the increased density scenario.
BusEst_New_Co2	This is the number of business establishments in each grid cell of BRT Corridor 2 under the increased density scenario.
CD_St_Init	This is the standardized commercial density in each grid cell of BRT Corridor 2 under the base scenario.
CD_Weighed	This is the weighed commercial density in each grid cell of BRT Corridor 2 under the base scenario.
ComD_St_New_Co2	This is the standardized commercial density in each grid cell of BRT Corridor 2 under the increased density scenario.
ComD_Weighed_New_Co2	This is the weighed commercial density in each grid cell of BRT Corridor 2 under the increased density scenario.
ComUnits_New_Co2	This is the number of commercial units in each grid cell of BRT Corridor 2 under the increased density scenario.
ED_St_Init_Co2	This is the standardized employment density in eah grid cell of BRT Corridor 2 under the base scenario.
ED_St_New_Co2	This is the standardized employment density in each grid cell of BRT Corridor 2 under the increased density scenario.
ED_Weighed_Init_Co2	This is the weighed employment density in each grid cell of BRT Corridor 2 under the base scenario.
ED_Weighed_New_Co2	This is the weighed employment density in each grid cell of BRT Corridor 2 under the increased density scenario.
Jobs_New_Co2	This is the number of jobs in each grid cell of BRT Corridor 2 under the increased density scenario.
Pop_New_Co2	This is the number of people in each grid cell of BRT Corridor 2 under the increased density scenario.
PopD_St_In_Co2	This is the standardized population density in each grid cell of BRT Corridor 2 under the base scenario.
PopD_St_New_Co2	This is the standardized population density in each grid cell of BRT Corridor 2 under the increased density scenario.
PopD_Weigh_Co2_Init	This is the weighed population density in each grid cell of BRT Corridor 2 under the base scenario.
PopD_Weighed_New_Co2	This is the weighed population density in each grid cell of BRT Corridor 2 under the increased density scenario.
TOD_Index_Init_Co2	This is the TOD Index for each grid cell in BRT Corridor 2 under the base scenario.
TOD_Index_New_Co2	This is the revised TOD Index in each grid cell of BRT Corridor 2 under the increased density scenario.

TOD_Index_New_St_Co2	This is the standardized TOD Index in each grid cell of BRT Corridor 2 under the increased density scenario.
TOD_Index_St_Init_Co2	This is the standardized TOD Index for each grid cell of BRT Corridor 2 under the base scenario.
BRT_Corridor3_AllVariables	
BD_St_Init_Co3	This is the standardized business density in each grid cell of BRT Corridor 3 under the base scenario.
BD_St_New_Co3	This is the standardized business density in each grid cell of BRT Corridor 3 under the increased density scenario
BD_Weighed_Init_Co3	This is the weighed business density in each grid cell of BRT Corridor 3 under the base scenario.
BD_Weighed_New_Co3	This is the weighed business density in each grid cell of BRT Corridor 3 under the increased density scenario
BusEst_New_Co3	This is the number of business establishments in each grid cell of BRT Corridor 3 under the increased density scenario.
CD_St_Init_Co3	This is the standardized commercial density in each grid cell of BRT Corridor 3 under the base scenario.
CD_St_New_Co3	This is the standardized commercial density in each grid cell of BRT Corridor 3 under the increased density scenario
CD_Weighed_Init_Co3	This is the weighed commercial density in each grid cell of BRT Corridor 3 under the base scenario.
CD_Weighed_New_Co3	This is the weighed commercial density in each grid cell of BRT Corridor 3 under the increased density scenario.
ComUnits_New_Co3	This is the number of commercial units in each grid cell of BRT Corridor 3 under the increased density scenario
ED_St_Init_Co3	This is the weighed employment density in each grid cell of BRT Corridor 3 under the base scenario.
ED_St_New_Co3	This is the standardized employment density in each grid cell of BRT 3 under the increased density scenario
ED_Weighed_Init_Co3	This is the weighed employment density in each grid cell of BRT Corridor 3 under the base scenario.
ED_Weighed_New_Co3	This is the weighed employment density in each grid cellunder the increased density scenario.
Jobs_New_Co3	This is the number of jobs in each grid cell of BRT Corridor 3 under the increased density scenario
Pop_New_Co3	This is the population number in each grid cell of BRT Corridor 3 under the increased density scenario.
PopD_St_Init_Co3	This is the standardized population density in each grid cell of BRT Corridor 3 under the base scenario.
PopD_St_New_Co3	This is the standardized population density in each grid cell of BRT Corridor 3 under the increased density scenario.
PopD_Weighed_Init_Co3	This is the weighed population density in each grid cell of BRT Corridor 3 under base scenario.
PopD_Weighed_New_Co3	This is the weighed population density in each grid cell of BRT Corridor 3 under the increased density scenario.
TOD_Index_Init_Co3	This is the TOD Index in each grid cell of BRT Corridor 3 under base scenario.
TOD_Index_New_Co3	This is the revised TOD Index in each grid cell of BRT Corridor 3 under the increased density scenario.
TOD_Index_St_Init_Co3	This is the standardized TOD Index in each grid cell of BRT Corridor 3 under the base scenario.
TOD_Index_St_New_Co3	This is the standardized TOD Index in each grid cell of BRT Corridor 3 under the increased density scenario.

BRT_Corridor4_AllVariables	
BD_St_Init_Co4	This is the standardized business density in each grid cell of BRT Corridor 4 under the base scenario.
BD_St_New_Co4	This is the standardized business density in each grid cell of BRT Corridor 4 under the increased density scenario.
BD_Weighed_Init_Co4	This is the weighed business density in each grid cell of BRT Corridor 4 under the base scenario.
BD_Weighed_New_Co4	This is the weighed business density in each grid cell of BRT Corridor 4 under the increased density scenario.
BusEst_New_Co4	This is the number of business establishments in each grid cell of BRT Corridor 4 under the increased density scenario.
CD_St_Init_Co4	This is the standardized commercial density in each grid cell of BRT Corridor 4 under base scenario.
CD_Weighed_Init_Co4	This is the weighed commercial density in each grid cell of BRT Corridor 4 under base scenario.
ComD_St_New_Co4	This is the standardized commercial density in each grid cell of BRT Corridor 4 under the increased scenario.
ComD_Weighed_New_Co4	This is the weighed commercial density in each grid cell of BRT Corridor 4 under the increased scenario.
ComUnits_New_Co4	This is the number of commercial units in each grid cell of BRT Corridor 4 under the increased scenario.
ED_St_Init_Co4	This is the standardized employment density in each grid cell of BRT Corridor 4 under the base scenario.
ED_St_New_Co4	This is the standardized employment density in each grid cell of BRT Corridor 4 under the increased density scenario.
ED_Weighed_Init_Co4	This is the weighed employment density in ech grid cell of BRT Corridor 4 under the base scenario.
ED_Weighed_New_Co4	This is the weighed employment density in each grid cell of BRT Corridor 4 under the increased density scenario.
Jobs_New_Co4	This is the number of jobs in each grid cell of BRT Corridor 4 under the increased density scenario
Pop_New_Co4	This is the population number in each grid cell of BRT Corridor 4 under the increased density scenario.
PopD_St_Init_Co4	This is the standardized population density in each grid cell of BRT Corridor 4 under the base scenario
PopD_St_New_Co4	This is the standardized population density in each grid cell of BRT Corridor 4 under the increased density scenario.
PopD_Weighed_Init_Co4	This is the weighed Population density in each grid cell of BRT Corridor 4 under the base scenario
PopD_Weighed_New_Co4	This is the weighed population density in each grid cell of BRT Corridor 4 under the increased density scenario.
TOD_Index_Co4_init_Co4	This is TOD index in each grid cell of BRT Corridor 4 under the base scenario
TOD_Index_New_Co4	This is the revised TOD index in each grid cell of BRT Corridor 4 under the increased density scenario
TOD_Index_New_St_Co4	This is the standardized TOD Index in each grid cell of BRT Corridor under the increased density scenario.
TOD_Index_St_Init_Co4	This is the standardized TOD Index in each grid cell of BRT Corridor 4 under the base scenario.

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