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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Evaluating Functional Hierarchy of the Road Network Based on Trip Performance

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The Thesis Submitted to the School of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Master of Science Degree in Civil Engineering, Specializing Road and Transport Engineering.

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UNDERTAKING

I affirm that the research work titled **Evaluating Functional Hierarchy of the Road Network Based on Trip Performance** is my original work conducted under the supervision of my advisor, **Yonas Minalu (PhD).** This work has not been submitted to any other institution for evaluation or the conferral of any certificates, diplomas, or degrees, aside from the assessment at **Addis Ababa Institute of Technology.** All pages are formatted in the accepted font and margin alignment, and proper acknowledgment has been given to all utilized information and materials.

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ABSTRACT

The quality and performance of road networks are significantly influenced by the functional hierarchy of roadways in metropolitan area. The functional hierarchy of roads affects the design and operation of road networks, as well as the trip performance. The primary objective of this study was to assess the functional hierarchy of various road network patterns to understand their influence on trip performance.

The scope of study includes evaluating the functional hierarchy of road networks and their impact on trip performance within a urban area of a chosen cites on up to 6 kilometers within a four-square-kilometer section of the city. It has a significant contribution to forecast future trip performance and support proactive planning. Additionally, it provides practical recommendations to guide urban planning agencies in optimizing road network hierarchy, ultimately benefiting urban residents and commuters globally.

Cities with higher junction densities, longer trip lengths, and a higher proportion of residential roads tend to experience longer travel durations within the network. This relationship modeled using a power function with logarism transformation which effectively captures the hierarchical structure of urban road networks. Interestingly, travel duration is significantly negatively affected by the presence of primary and secondary roads. Primary and secondary roads both show negative coefficients, indicating that higher proportions of these roads correlate with slightly reduced travel durations, likely due to their design for efficient travel. While the effect of primary roads is small but significant at p value of 0.00, secondary roads have a more substantial impact, emphasizing their importance in reducing travel time within the network. On the other hand, tertiary roads have a negligible and statistically insignificant effect on travel duration, suggesting that changes in their proportion do not distinctly influence travel time. However, residential roads demonstrate a significant positive relationship with travel duration with p value of 0.00, reflecting the duration of the trip has to be increased due to lower speed limit and existence of frequent stops typical in residential areas. Additionally, junction density showed a significant positive relationship with trip duration, with a p-value of 0.00. This indicates that as junction densities increase within the network, the trip duration also increases. The likely reason for this is that higher junction density implies more road connections from different directions.

Key words: Accessibility, Functional classification, Road hierarchy, Road network, OD Matrix, Mobility. SUMO.

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Acronyms

AIS - Automatic Identification System

AON - All-or-nothing

ANOVA - Analysis of Variance

FEMA - Federal Emergency Management Agency

FSM - Four-Step Model

GIS - Geographic Information System

IGNRN - Integrated Graph of Natural Road Network

MFD - Macroscopic Fundamental Diagram

OSM - OpenStreetMap

OD - Origin-Destination

SO - System Optimal

SUMO - Simulation of Urban Mobility

TAZ - Traffic Analysis Zone

UE - User Equilibrium

USA - United States of America

VBA - Visual Basic for Applications

CHAPTER 1 INTRODUCTION

1.1 Background of the study

The significance of urban roadway networks lies in their potential to influence economic development by reflecting the condition of urban growth, facilitating the movement of individuals, goods, and data, and impacting the productivity and efficiency of cities. The structure and density of road networks are closely related to economic factors such as gross domestic product (GDP) and population growth (Jiawei Xue, 2021). Research demonstrates that the structural configuration of urban streets, delineated by metrics like betweenness and closeness centrality, can serve as an indicator of the economic development level in cities (Bo Liu, 2020). However, urban road networks also face many challenges such as traffic congestion, pollution, accidents, and inefficiency, which affect the quality of life and sustainability of urban areas.

The performance of the road network can also be impacted by how complicated and unpredictable road problems are in urban regions as opposed to rural ones. Considering many elements like vehicle distribution, realignments, traffic delays, and geographical data analysis, allows decision-makers to enhance the management and optimization of road networks' performance. Many factors might impact a road network's performance. The aspect ratio of urban street networks is one factor influencing the performance of road networks (Chao-Yun, 2021), the number of realignments made while a vehicle is moving, traffic jams, delays in traffic, and the state of cars and road surfaces (Peng Wu, 2022).

The quality and performance of road networks are significantly influenced by the functional hierarchy of roadways in metropolitan area. Highways are categorized according to their primary purposes, such as granting access to adjacent land uses, gathering, and allocating traffic inside cities, or creating connections between various urban centers, under a concept of functional hierarchy. Research has indicated that the configuration of road networks affects how mixed functions aggregate in cities, with higher degrees of network structure inviting the aggregation of more functions. For urban development and traffic management, streets and roads must be categorized according to their functional roles. This classification helps with road network optimization and adjustment, which improves efficiency (Deng, 2023).

The functional hierarchy of roads affects the design and operation of road networks, as well as the trip performance(Wu et al., 2021).

Different road types have different characteristics, such as speed, capacity, spacing, and intersection types, that influence the efficiency of traffic movement. Because different types of roads attract different levels of traffic demand and serve distinct objectives, road hierarchy can have a considerable impact on the performance of trip within a network (Gunarathna et al., 2023).

1.2 Statement of the problem

The functional classification of roads within urban networks plays a crucial role in facilitating the efficient movement of vehicles. This classification is organized into a hierarchical structure based on the services provided by the roads, primarily focusing on access and mobility functions. Despite the clear distinction between these functions, the effective proportion and density of road types necessary to optimize these functions is a subject of debate. This research analyzed different hierarchical road network patterns to understand the factors that influence the performance of road network.

1.3 Research question

1. How does the functional hierarchy of road networks impact trip performance?
2. How can a predictive model be developed to forecast trip performance based on identified factors influencing functionally hierarchical road network?
3. What recommendations and suggestions could be provided for road network hierarchy into future urban development planning concepts?

1.4 Objective of the study

The main goal of this study was to evaluate the functional hierarchy of different road network patterns with the aim of determining their impact on trip performance.

1.4.1 Specific objectives

- ✓ Evaluate the impact of different road network patterns on trip performance by assessing their functional hierarchy.
- ✓ Develop a predictive model that utilizes identified factors influencing road trip performance within various hierarchical road network patterns.

- ✓ Provide recommendations and suggestions for urban planning agencies to incorporate the findings into their future urban development planning efforts.

1.5 Scope of the study

The scope of the study incorporates the evaluation of functionally hierarchical road network trip performance within a selected city of defined urban area. Ranging trip length up to 6 kilometers within a four-square-kilometer section of the city. Focused on performance of trips in terms of travel time that could provide valuable understanding for the optimization of the urban transportation planning and improve the overall trip experience of travers in the urban area.

1.6 Significance of the study

The significance of the study is potential to inform urban planning by providing insights into how road network hierarchy impacts trip performance, allowing urban planners to optimize transportation infrastructure and improve city mobility. Additionally, the study offers valuable policy implications by suggesting strategies to alleviate traffic congestion, reduce travel times, and enhance overall transportation efficiency. By examining cities globally, it contributes to the international discourse on urban transportation planning. The development of predictive models can forecast future trip performance and support proactive planning, while practical recommendations can guide urban planning agencies in implementing measures to optimize road network hierarchy, ultimately benefiting urban residents and commuters worldwide.

1.7 Limitation of the study

The kilometer and it's important to note that findings might differ for distances beyond this range. While the outcomes are representative for smaller urban areas and could potentially be applied to larger metropolises, the assumption of uniform origin-destination distribution is a simplification that may not reflect the complex settlement patterns and varying urban layouts found in actual cities. Therefore, while the study provides valuable understandings, its applicability to real-world scenarios should be considered with these limitations in mind

1.8 Structure of the work

The format of thesis is structured based on the type of research being done, the typical thesis structure of this study is as follow.

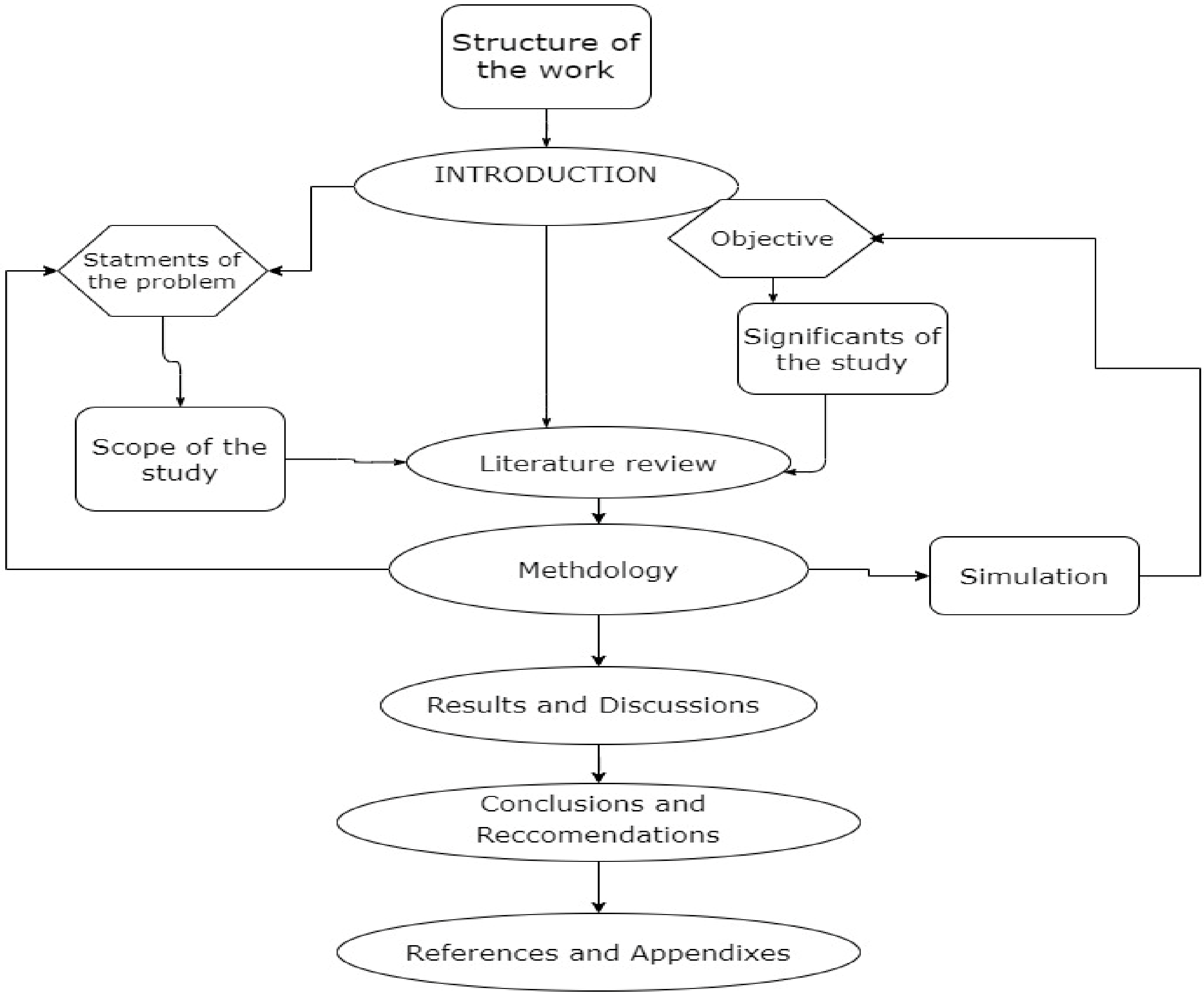


Figure 1: Structure of the work

1.9 Organization of the thesis

Chapter 2 offers a detailed examination of key areas. It begins by explaining the structure of the road network and concept of functional hierarchy in the context of this study. Next, it explores methods for assessing road network performance and efficiency. Finally, the chapter provides a thorough overview of the methodologies used to assign trips. Chapter 3 clearly defines the variables that will be examined to achieve the research objective. It describes the selection of the study area within the metropolitan region, characterized by a varied road network. The chapter also provides a thorough explanation of the methods used to analyze traffic patterns and determine travel routes within the chosen area. Chapter 4 presents an inclusive analysis of road network hierarchy and its impact on trip duration. By examining various road hierarchies and their associated variables, such as junction density and road type proportions, the study reveals a clear correlation between road network characteristics and travel time. Statistical analyses, including correlation analysis and regression modeling, were conducted to quantify these relationships. Chapter 5 presents a summary of the study's key findings and identifies areas for future research. It discusses the limitations of the current study and offers recommendations for further exploration of the topic.

CHAPTER 2 LITERATURE REVIEW

2.1 The concept of literature survey

The aim of this literature review is to provide a comprehensive summary of studies relevant to the proposed research title. This review will cover multiple aspects related to road networks, including an examination of methodologies used in previous studies, identification of factors influencing network hierarchy, exploration of various modelling techniques, and analysis of insights from case studies. Additionally, the review will highlight gaps or areas needing further research, thereby establishing a solid foundation for the proposed study and clarifying its contribution to the existing body of knowledge.

2.2 Road networks

Road networks, when represented as a networked system of edges and nodes, have attracted a lot of attention in the network literature and have been the focus of several studies over the years. The road segments that connect the nodes in these networks constitute the edges, while the intersections of the roadways are represented as nodes. A road network is the essential infrastructure for passenger and freight transport, guaranteeing the effective flow of people and products. It is made up of interconnected roadways that are represented by nodes and edges. A network is the set of paths that make up a system of points, or nodes, in the system. Any single connection between two nodes that is a component of a wider network is referred to as a route. This can include less visible routes like air and sea corridors as well as more tangible ones like roads and railroads (Rodrigue, 2024). The network's structure and design have a crucial role in influencing urban dynamics, going beyond simple connectivity. They affect land-use patterns, retail activity, and the flow of cars and pedestrians (GHALMANE , 2023). Within the network, several kinds of roadways serve different kinds of vehicles; some, such local streets, arterials, and highways, are designated for specific uses. Every one of them fulfils a distinct role in meeting urban functions and transportation needs.

2.2.1 How road network evolves

Road networks are dynamic systems that change over time because of both intentional design and natural growth. The term natural growth processes describe the random and unplanned road construction that frequently takes place in response to an immediate community's demand.

This can involve the natural formation of new roads and pathways as people and cars move between locations in search of the quickest or most convenient routes. When these pathways are utilized more regularly, they may eventually develop into more well-known roadways(Yang et al., 2022). On the other hand, interventions such as urban planning entail a more methodical approach to the construction of transport networks. Road networks are carefully designed by urban planners and engineers to maximize traffic flow, enhance safety, and facilitate the expansion of cities and towns. Road placement strategy, future growth trends, and the integration of many forms of transportation are all part of this process. The objective of urban planning is to provide a coherent system that minimizes negative effects on the environment, promotes population growth, and promotes economic development (Burghardt, 2021).

Research shows that road networks exhibit structural differences both within and between urban regions over time, with a tendency to become less grid-like (Gi Ung Jang, 2020). The evolution of road networks is influenced by factors such as self-organization, urban growth, and resilience (Wang, 2019). Examining how road networks have changed over time in places like Changchun, China, reveals how these changes are correlated with patterns of urban development and population increase (Barthelemy, 2015). Road network evolution may now be tracked effectively with algorithms that depend on graph-theoretic features for comparison (Goodrich, 2016). These results underline how essential it is for sustainable urban development to understand and manage the dynamic nature of road networks.

2.2.2 Topology of the road network

Like many other networks, transport networks are typically represented as a collection of locations and a set of links that indicate relationships between those locations. The topology of a road network refers to the arrangement of its elements, such as intersections, road segments, and key points, and the relationships between them.(Sreelekha et al., 2020). A network's topology refers to how it is connected and arranged; every transport network has a unique topology. The network geometry and connectivity level are the most basic components of such a structure. Transport networks are categorized based on the topological characteristics that characterize them. As a result, a fundamental typology of transport networks that considers their modal and structural properties along with their geographic location may be established (Rodrigue, 2024).

Urban road transport networks play a crucial role in regional development and serve as a significant force in shaping the spatial structure of cities. A well-developed and efficient transport network in urban areas functions much like blood flowing through veins in the human body, ensuring the continuous and dynamic movement essential for the vitality and growth of the city(Foltête et al., 2013; Tsiotas & Polyzos, 2017).

2.2.3 Efficiency of the road network

A road network's efficiency can be defined as its capacity to deliver timely and smooth transport services while reducing delays and optimizing the use of available resources. Network efficiency is influenced by several variables, including as management techniques, infrastructure quality, and traffic patterns. A network's efficiency is determined by how well it can handle flows under operational conditions that satisfy performance standards like speed, capacity, and safety. Network analysis and graph theory can be used to quantify it. These techniques are based on the idea that a network's topology or the arrangement of its nodes and links affects how efficient it is in certain situations. Research highlights the need of incorporating actual data and measuring inefficiencies to enhance planning and operations (Hamm, 2022). To increase efficiency, network performance must be analysed, routes must be optimized, and efficient traffic control strategies must be put in place (Bellocchi, 2016). The overall performance of road networks can be enhanced by planners by assessing variables such as excess delays, average link speeds, and best routing algorithms. This results in better traffic flow, less congestion, and more efficient use of transportation resources.

2.3 Road Network Structures Performance

According to (YunWu, 2020) , the performance measures like traffic flow dynamics, congestion levels, and overall system efficiency are greatly impacted by road network structure. Research has demonstrated that the aspect ratio of urban networks affects the dynamics of the traffic system; square networks, in comparison to rectangular networks, display higher arrival rates but lower congestion densities. In urban networks, the aspect ratio describes how the blocks are shaped within the network, usually by comparing their length and width. According to studies, these blocks' shapes can have a big impact on traffic dynamics. In square networks, where the length and width of blocks are roughly equal, the traffic system tends to have higher arrival rates. This means that vehicles can enter the network at a faster rate because there are more entry points that are evenly distributed. However, square networks also tend to have lower congestion densities. This is because the traffic can disperse more evenly across the network, with multiple alternative routes reducing the likelihood of any single road becoming overly congested. However, the dynamics of rectangular networks, which have longer blocked in a single direction, may be different. Because traffic is channelled through fewer streets and there are fewer access locations along the longer edges of the blocks, these networks may have lower arrival rates. As a result, these networks may experience higher concentrations of congestion since traffic is more likely to be concentrated on specific routes.

This (YunWu, 2020) , paper explores the relationship between the structure of urban road networks and traffic performance. It employs cellular automata models to simulate traffic and uses the Macroscopic Fundamental Diagram (MFD) to assess traffic flow efficiency. The study reveals that square-shaped road networks can handle high traffic arrival rates but are disposed to quicker congestion. In contrast, elongated networks, with a higher aspect ratio, experience lower arrival rates but can sustain more cars before congestion sets in. This is explained by the distribution of vehicles, the demands for turning movements, and the average distance traveled within these networks. Essentially, the paper provides insights into how different road network designs can influence urban traffic dynamics, which is crucial for urban planning and management. Usually, a road network structure's performance is assessed using a few important criteria like efficiency, resilience, accessibility robustness and safety.

2.3.1 **Accessibility**

The ease and effectiveness with which people and products can use the road infrastructure to go to different locations within a specific area is referred to as the road network's accessibility. Road network accessibility metrics are essential for assessing transport systems. Innovative methods to measuring accessibility based on network topology, connectivity, and physical distances have been presented in several research. To quantify node accessibility across various geographic scales, the research article (Divya Kwatra, 2023) presents three unique accessibility metrics based on the k-core decomposition of transport networks. Using network topology and the application of edge weights such as travel cost, duration, distance, and service frequency, the suggested core-based metrics can fully capture the network hierarchy and evaluate accessibility. The study shows how responsive these metrics are to topology changes in the transport network by using them to assess the accessibility of places connected by air transport services in India. Variations in accessibility were found by comparing the domestic air services network's pre- and post-COVID periods. This research demonstrated how well the metrics captured network changes and their effects on accessibility levels.

(Kumar, 2023) uses graph theory and GIS technologies to analyse the accessibility of the road network in Bhojpur district, Bihar. The study assesses the accessibility and connectivity of the road network using graph theory, and the buffering approach helps to comprehend the physical accessibility of the area. A thorough evaluation of the network accessibility magnitude is made possible by the application of the Shimbel Index and the Shortest Path Matrix. Furthermore, the effectiveness of the road network accessibility is demonstrated using the GIS tool Inverse Distance Weighted (IDW), which indicates increased accessibility in the study area, especially in the vicinity of the main Centre (district headquarters). By using these approaches, the study illuminates the spatial connections between different places and hubs in the Bhojpur district, highlighting the importance of accessibility analysis in the field.

The study examines how access variety is distributed spatially on urban road networks, highlighting the importance of accessibility in assessing how well urban road systems support social and commercial activity. Conventional metrics in urban science emphasize user-based accessibility, but they frequently overlook the ways in which road network topology and structure affect accessibility levels. To close this gap, the paper presents an improved random-walk-based accessibility technique that incorporates geometric distance data to improve accessibility analysis in road networks. The research illustrates how spatial accessibility can capture differences in topological and spatial patterns, highlighting spatially accessible regions and clarifying the relationship between road structures and accessibility distributions in urban environments. This is achieved by applying this modified method to empirical road networks in three global metropolitan cities with diverse structures (Kim, 2021).

Adjustments to current accessibility measure that consider variables such as journey time, distance, and network structure have been proposed to improve the precision of vulnerability evaluations in road networks. and, to assess road accessibility after hazardous events, a probabilistic framework has been presented forth. This underscores how crucial it is to comprehend how hazards affect road networks to plan for efficient disaster response and recovery. The evaluation of road accessibility in the context of cascading risks emphasizes the vital role that road networks play in enabling emergency response operations. Recognizing the inherent uncertainty in hazard events and the response of road network components, it calls for a comprehensive approach to modelling hazards and their influence on road accessibility. A probabilistic framework that methodically considers damage to various network elements and many risks is suggested as a solution to this problem. The approach creates many road damage scenarios to compute accessibility probability by connecting uncertainty in hazard modelling to road asset fragility using a Monte Carlo simulation. The study showcases the application of this framework in Napier City, New Zealand, specifically for a Mw8.4 earthquake, resulting in the creation of accessibility probability maps crucial for post-event response planning. These maps serve as valuable resources for local authorities in enhancing resilience planning and offer insights into resilience intervention strategies to ameliorate accessibility in affected suburbs (Moratalla, 2023) .Together, these many methods advance our overall knowledge of accessibility in road networks.

2.3.2 Robustness

(Fang, 2023) defined, road network's robustness is determined by how well it can operate in a variety of scenarios, such as normal traffic, heavy traffic, accidents, and natural disasters. Road networks must be robust to function well in a variety of conditions. Research has examined various facets of the resilience of the road network. Studies conducted in China contrasted the robustness of province-level highway networks, highlighting variations in performance. The study compares the robustness of the highway networks in five important Chinese provinces and cities: Chongqing, Hunan, Shandong, Shaanxi, and Sichuan. Through the application of complex network theory, the research examines the highway networks' topology structure and computes key characteristics such as average degree, degree distribution, clustering coefficient, path length, and network width to enable a thorough comparison. Numerous factors are measured while evaluating the robustness of a highway network, including turn rate, robustness r, network efficiency, and connection. The findings suggest that Chongqing and Shaanxi are quite resilient, whereas Hunan is less effective. The study proposes an approach to improve route options for drivers by placing route planning directions strategically in locations where drivers have few options. This would strengthen network resilience. In the end, the study emphasises how important these conclusions are for guiding the future construction of China's roadway systems.

(Immers, 2004) provides a thorough analysis of road network topologies, highlighting the vital role that these structures play in preserving resilience and robustness. Finding a network structure that is both effective in normal traffic situations and has the extra capacity needed to handle crises is the major goal. The authors assess different network structures using simulation approaches, and they recommend a hierarchical structure with interconnected subsystems in the end. This method performs better in terms of resilience, displaying a smooth breakdown in the event of disturbances. The results indicate that building dedicated emergency lanes is more expensive than using minor routes as emergency bypasses. The computation of the ideal spare capacity for network links as the discussion's end shows the value of robust systems and efficient event management techniques in urban planning.

(Fengjie Xie, 2023) studied the robustness analysis and optimization of the double-layer freight relationship network within the framework of "The Silk Road Economic Belt.This initiative aims to strengthen trade connectivity among countries and regions across the Eurasian continent by establishing cross-border freight infrastructure. The study constructs a double-layer freight relationship network, examining the geospatial characteristics of the region and the speed differentials between railway and air transportation. By systematically attacking varying proportions of railway and airlines based on transportation distance weights, the paper evaluates the network's robustness using transportation efficiency and cost as pivotal metrics. Also, a multi-objective model is formulated to enhance the network's resilience, offering valuable understanding for the strategic planning of cross-border transportation within the Silk Road Economic Belt. In essence, this research contributes significantly to advancing the understanding and optimization of freight networks, thereby fostering more efficient and reliable trade connections along the Silk Road Economic Belt.

The (Joubert, 2016) investigates the vulnerability of the global container shipping network to targeted link disruption. The objective is to evaluate how the network responds to disruption strategies based on link betweenness and link salience. Using AIS data from 5,069 container vessels in 2012, a directed, weighted network of ports was constructed to simulate disruptions. The study iteratively applied disruption strategies and evaluated the network's robustness and flexibility. Results indicated that the network remained largely robust to the strategies, with the weakly connected component staying intact even after a significant number of links were removed. The study sheds light on the network's resilience to large-scale service reconfigurations, emphasizing its ability to adapt and maintain functionality despite targeted disruptions.

(Amirhassan Kermanshah, 2017) explore the robustness of road networks in urban areas such as New York City and Chicago when faced with extreme flooding events. By adopting a deterministic approach and utilizing FEMA (Federal Emergency Management Agency) floodplains data, the study simulates these events by removing sections of road systems to analyse the impact on travel demand, GIS properties, and network topological indicators. Using GIS technology, the research evaluates the effects of extreme events on road transportation systems, focusing on measuring their robustness using various metrics. The results indicate a significant redistribution of betweenness centrality in the road networks post-flooding, particularly affecting critical road segments like major bridges and highways. This redistribution highlights the vulnerability and adaptability of road systems to extreme flooding, emphasizing the importance of understanding and enhancing the resilience of urban infrastructure in the face of natural disasters.

2.4 Review of performance measurement

Researchers worked on the how the structure of the road network measured in a different way as network performance measures. (Levinson, 2006) in their research quantitatively measure the structure of road networks by proposing three supplemental measures: entropy, connection patterns, and continuity. By evaluating 16 test networks derived from idealized base networks and applying measures like ringness, webness, beltness, circuitness, and treeness, the study effectively identifies and quantifies predefined connection patterns of arterial roads. The entropy measure is utilized to assess the heterogeneity of road networks, departing from traditional power-law distribution approaches. The findings demonstrate the efficiency of the proposed measures in evaluating network structures, identifying connection patterns, and assessing network quality from travellers' perspectives. Additionally, the paper discusses the distinction between scale-free and random networks, using examples like the U.S. highway system and the U.S. airline system to illustrate network characteristics. Overall, the research provides valuable insights into the application of these measures in urban planning and transportation practice, highlighting their significance in describing and comparing network structures. And (Selim Reza, 2022) focuses on analysing the structure of road networks, specifically the Porto Road network, using a network science perspective. The study employed Python NetworkX package for analysis and conducted comparative studies on various network properties such as degree distributions, clustering coefficients, centrality measures, connected components, k-nearest neighbours, and shortest paths between different regions of Porto. Additionally, the research explored community structures, page rank, and small-world analysis of the road network. Findings revealed that while most nodes in the network have a small degree, a few exhibit a large degree, and the network does not entirely follow a power-law distribution. The analysis highlighted the high reachability and dense connectivity of road networks, showcasing small-world properties with an average shortest path length. Moreover, the study identified key nodes based on centrality measures, providing valuable insights into the efficiency and characteristics of the Porto Road network.

In (Farhad Ahmadzai, 2018) author focuses on the evaluating and modelling of urban road networks using the Integrated Graph of Natural Road Network (IGNRN) method, which evaluates the importance of nodes and road segments simultaneously. It emphasizes the crucial role of road networks as indicators for measuring the sustainability of urban extension in both existing and proposed urban areas, necessitating in-depth studies by transportation engineers and urban planners. Through a GIS-based approach involving data preparation, IGNRN modelling/generation, and measuring centrality classes like closeness, betweenness, and straightness, the methodology is validated using a case study of the Kandahar City Road network, showcasing the accuracy and utility of the IGNRN method in deriving valuable insights. Additionally, the paper explores the application of graph theory in spatial road network representation, highlighting the significance of nodes, edges, connectivity, shortest paths, and network topologies. Furthermore, the paper provides equations for calculating centrality measures such as closeness centrality, incorporating factors like Euclidean distance and node weights.

(NCHRP, 2000) structured inventory of performance measurements in a wide-ranging framework that incorporates various aspects of transportation system performance.

1. **Accessibility**: measures how easily people can reach their destinations. It includes metrics like average travel time by mode, trip length, and mode split, which help in understanding the efficiency of different transportation facilities and routes. It also considers the impact of physical barriers such as low clearances and weight limits on bridges.
2. **Mobility**: metrics focus on the movement of people and goods across the network. They include origin-destination travel times, total travel time, and vehicle miles travelled (VMT) under different congestion levels. These measurements ease in assessing the fluidity of traffic and identifying bottlenecks.
3. **Economic Development**: evaluates the economic impact of the transportation system. It looks at the number of jobs supported or created, both directly and indirectly, and the economic costs associated with accidents and time lost due to inefficiencies.
4. **Quality of Life** reflects the transportation system's effects on individuals' daily lives. It includes the time lost to congestion, safety perceptions, accident rates, and environmental impacts like vehicle emissions.

5. **Environmental and Resource Conservation**: its focus is on the sustainability of the transportation system. Metrics such as mode split, pollution levels, fuel usage, and accidents involving hazardous waste provide insights into the environmental footprint of transportation.
6. **Safety**: Safety metrics are crucial for evaluating the risk associated with transportation. They include the frequency of accidents, response times to incidents, and public perception of safety. This category also looks at the condition of infrastructure, such as pavement and bridges, and their safety ratings.
7. **Operational Efficiency**: assesses how well the transportation system operates. It includes measurements like travel times, volume-to-capacity ratios, cost per ton-mile, and average vehicle occupancy, which help in determining the efficiency of the system.
8. **System Condition and Performance**: this looks at the overall health of the transportation infrastructure. It considers the percentage of the system below standard conditions and the age distribution of assets to gauge the need for preservation and maintenance.

2.5 Functional Hierarchy in the road network

(ICSM, 2006) defined `functional, administrative, and structural types of road hierarchy that differ according to their intended purpose. The most popular version, known as a functional hierarchy, arranges roadways in order of anticipated functionality with respect to local through-traffic. It acknowledges the roads' role in an interconnected network and tackles the conflicting road uses of mobility and access in doing so, both land access and traffic mobility are essentially the two functions that streets and highways carry out. In the hierarchy, each route will be ranked according to the percentage of service it provides.

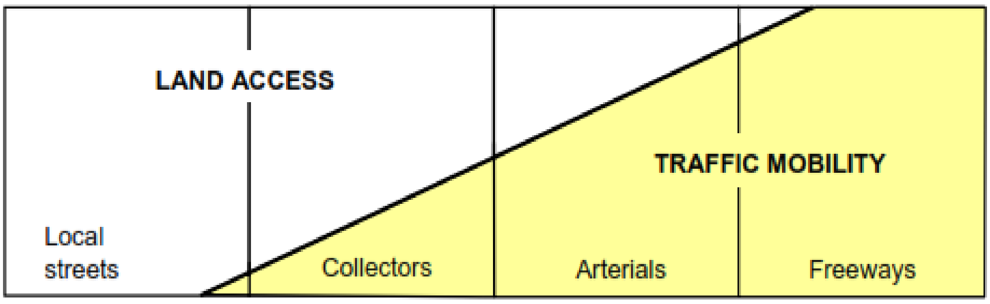


Figure 2. 1 Land Access Versus Traffic Mobility

And roads are arranged in an administrative hierarchy according to the federal, state, or local governments in charge of overseeing a specific road segment. A different, less popular approach of classifying roads in a road hierarchy is to order them based on the structural guidelines that are used for a particular road segment. Depending on the goal of the classification, several structural determinants, or geometric designs, either alone or in combination, may be used to categorise a given route. Road width, surface type, gradient, rainy weather conditions, load bearing, and height restriction are examples of variables that are frequently measured.

The concept of functional hierarchy within road networks plays a crucial role in determining the efficiency of transportation systems. Classifying roads into different categories based on their intended function, capacity, and level of service is referred to as the functional hierarchy of the road. there are two essential needs which must be met in the function viewpoint. This are the traffic movement, or mobility, function that is providing how people and goods can move from one place to another. This have low travel friction from vehicle access because it Provides few opportunities for entry and exit; and the access function that is providing access to properties and land uses adjacent to the road, for it Provides many opportunities for entry and exit, it will create potentially higher friction from vehicle access (Administration, 2013).

To manage traffic efficiently by segregating through traffic from accessing, parking and nonmotorized traffics road network functional hierarchy classifies individual roads into several levels (Nakamura, 2016). For effective transportation planning, infrastructure design, and policymaking, understanding functional hierarchy of road networks is essential. Because it provides awareness's into the spatial distribution of different road types and their roles within the network. Employing various methodologies, models, and analytical techniques to assess its dynamics and implications, researchers and experts have dedicated to evaluating and analyse the functional hierarchy of road networks.

The research paper (Nakamura, 2016) aims to develop a functionally hierarchical road classification system for Japan by considering the distribution of region/district centers and the impact of terrain. The study seeks to determine the required hierarchical levels, set target travel speeds, and road spacing to enhance network performance efficiently. Drawing inspiration from the German guideline RIN, the objective is to address the absence of consideration for regional variations in road classification. The methodology involves defining region/district centres, creating alternative road classification scenarios, mathematically formulating travel time in a grid road network, and evaluating scenarios based on average trip lengths, system cost differences due to terrain, and variations in travel demand. Findings include the consideration of two target travel speeds, 30km/h and 50km/h, evaluation of scenarios based on the percentage of connected center pairs within target travel times, simplified travel time calculations using Euclidean distance, and the potential need for center reallocation like Community Centers (CMCs) for improved network access.

(Miyagawa, 2009) develops an analytical model to determine the hierarchical system of road networks, focusing on a grid road network in Tokyo. By classifying roads based on widths and travel speeds, the study aims to optimize road areas to minimize average and maximum travel times. Through closed-form expressions, the paper identifies optimal ratios of road areas, highlighting the need for more major arterial roads with higher travel speeds to minimize maximum travel time efficiently. The findings provide valuable understandings for transportation planners, emphasizing the significance of an optimal hierarchical system and the impact of travel speeds on road requirements. The study concludes by suggesting future research directions to refine the model and explore alternative network structures beyond the grid system.

2.6 Trip Assignment

(Qisheng Pan, 2021)After categorizing trip counts by mode of transportation we evaluate the routes that commuters particularly those using private cars take from their starting point to their destination. This step known as trip assignment is the most complex part of the FSM model. Initially, the shortest path is used to assign trips for each origin-destination pair, based on either travel costs or time. (David Levinson, 2009)The process of choosing routes (also known as alternative paths) between points of origin and destination in transportation networks is known as route assignment, route choice, or traffic assignment. After trip generation, destination choice, and mode choice, it is the fourth stage in the traditional transportation forecasting model. numerous valuable results can be produced from the last step model of the FSM and by analysing the results, the planner can gain understanding into the strengths and weaknesses of different transportation plans. This result could be the pattern of vehicular traffic and the flow in the system, costs of travel between trip origins and destinations, aggregated network metrics such as total vehicle flow, vehicle miles travelled (VMT), and vehicle travel time (VTT), modelled link flows highlighting congested corridors, turning movements analysis for future intersection design, determination of OD using link, simulation individual assignment for each pair of the origin destination and many more. Using different types of paths choice algorism the private car traffic assignment models done reasonably, this methods include all-or-nothing**,** user equilibrium, system optimum assignment**,** incremental, capacity-restrained**,** iterative feedback loop, Stochastic user equilibrium assignment, Dynamic traffic assignment

All-or-nothing

(Hui, 2014) All-or-nothing assignment, also known as the 0-1 assignment method, is a technique used in the non-balance assignment model, characterized by the following aspects:

- It disregards the impact of congestion on travel time, assuming a constant travel time for all paths regardless of traffic flow volume.
- All drivers sharing the same origin-destination (OD) pair option for the same route.

Hence, the primary computational step involves utilizing various algorithms to identify the shortest path and assigning all traffic flows from all OD pairs to this path accordingly. Commonly employed algorithms in the all-or-nothing assignment method include Dijkstra, Ford, and Moore algorithms.

User Equilibrium

(Qisheng Pan, 2021) User Equilibrium (UE) method in traffic assignment is based on Wardrop equilibrium conditions, where travellers choose the shortest path and equilibrium is reached when no traveller can reduce travel impedance by changing paths. UE principle states that travel time on all used paths for an origin-destination pair is equal and less than or equal to travel time on any unused path. The UE model assumes equal travel times on all paths, users have complete knowledge of path costs, and travel time increases with network loading. The UE assignment is an optimization problem formulated with equations, including variables like equilibrium flow, travel time, flow on paths, trip rates, and constraint functions.

System optimal

(Qisheng Pan, 2021) the System Optimum (SO) traffic assignment model, guided by the Wardrop principle, prioritizes minimizing total system costs to decrease total system travel time. It is versatile in solving problems such as optimizing departure time for a single commuting route, minimizing total travel time from multiple origins to one destination, and reducing travel time in stochastic time-dependent OD flows.

Incremental Increase model

(Qisheng Pan, 2021)incremental Increase model is based on the AON model and involves assigning fractions of total traffic volume in each step to calculate travel time for each route. Travel time is updated in each step based on the allocated traffic volume until all trips are assigned. The steps for the incremental increase traffic assignment model include finding shortest paths between O-D pairs, assigning portions of trips to these paths, updating travel time after each iteration, and continuing until all trips are assigned, with results being summed up in the end.

Capacity Restraint Assignment

(Qisheng Pan, 2021) based on the idea of transportation network optimization, the term "link capacity" refers to the maximum amount of flow (e.g., vehicles) that the route or segment of the network can accommodate without causing congestion or delays. When discussing algorithms or rules for assigning flow in transportation the networks it is critical to consider the capacity constraints of the links. In the Traditional approach flow assignment is typically based only on travel time where the goal is to minimize the overall travel time for all trips in the network. This means that the flow is directed towards routes with lower travel times without considering the capacity limitations of the links. In this model with capacity restraint assignment after each iteration of assigning flow the total number of trips on a link is compared with the link's capacity. This comparison helps in understanding how much the travel time increases when the assigned volume approaches or exceeds the link's capacity. The iteration process in this model stops when the added volume of flow in the current step (n) does not result in a change in the travel time that was updated in the previous step (n-1). This stopping criterion ensures that the algorithm does not continue assigning flow in a way that would exceed the capacity constraints and lead to inefficiencies or congestion. By incorporating the constraint of link capacity into the flow assignment process, the cost or performance function of the optimization model is changed. This means that the objectives and outcomes of the algorithm will differ from those of previous algorithms that did not consider capacity constraints. The visualization in Figure 13.6 helps in understanding how flow and travel time are interrelated when capacity constraints are considered

Stochastic User Equilibrium Traffic Assignment

(Qisheng Pan, 2021) Stochastic user equilibrium traffic assignment model introduces uncertainty in link choice based on utility functions allowing for different perceptions of costs among drivers. It uses a logistic model for discrete choice analysis contrary to the traditional Wardrop principle where all drivers perceive costs identically. In this model flow is assigned to all links from the start reflecting real-world scenarios better. The probability of using each path is calculated using a logit formula considering the utility function for each path.

Dynamic Traffic Assignment

(Qisheng Pan, 2021) dynamic traffic assignment is based on the Wardrop principle where travellers choose routes with minimum cost, but congestion causes delays. Equilibrium under these conditions is not theoretically proven. Various algorithms are developed for traffic assignment problems, but real-world networks with thousands of nodes require more sensitivity to dynamic changes. Travel demand models may not accurately reflect travellers' limited knowledge and rational decision-making. Urban transportation systems have dynamic feedback loops between travellers' route choices and links' level of service. Real-world scenarios with complex networks require more sophisticated models to account for dynamic changes and travellers' limited knowledge.

2.7 Gaps in literature review

The exploration of road network hierarchies in different global cities reveals a significant gap in trip performance evaluations. Most existing research tends to be region-specific or centered around isolated case studies, limiting the applicability of findings to broader contexts. For example, many studies focus on a single city or country, examining factors such mobility, connectivity, and road classification within that specific locale. While these studies provide valuable insights, they often cannot be generalized to other regions due to variations in urban planning practices, socio-economic conditions, and geographical constraints.

Some studies use quantitative methods such as network analysis, while others rely on qualitative assessments or case studies. This methodological diversity complicates the ability to draw broad conclusions about road network functionality and to identify universal principles applicable across different cities.

In light of these challenges, conducting a study that evaluates trip performance in road networks using traffic simulation could offer a more standardized approach. By setting common variables applicable to all cities, it is possible to mitigate the effects of regional differences. While some variables may have varying degrees of impact, their presence across all regions ensures that the study can produce more generalizable findings. This approach would help to bridge the gap in understanding how road network hierarchies' function in diverse urban contexts and could lead to the identification of universal principles applicable to global cities.

CHAPTER 3 METHODOLOGY

3.1 Introduction

This section of the paper discusses about the methodology employed during the whole research execution by commencing the way how the study area selected, certain criteria used, how the data for this study extracted, sorted, and organized, and finally how the analysis conducted.

3.2 Study Area

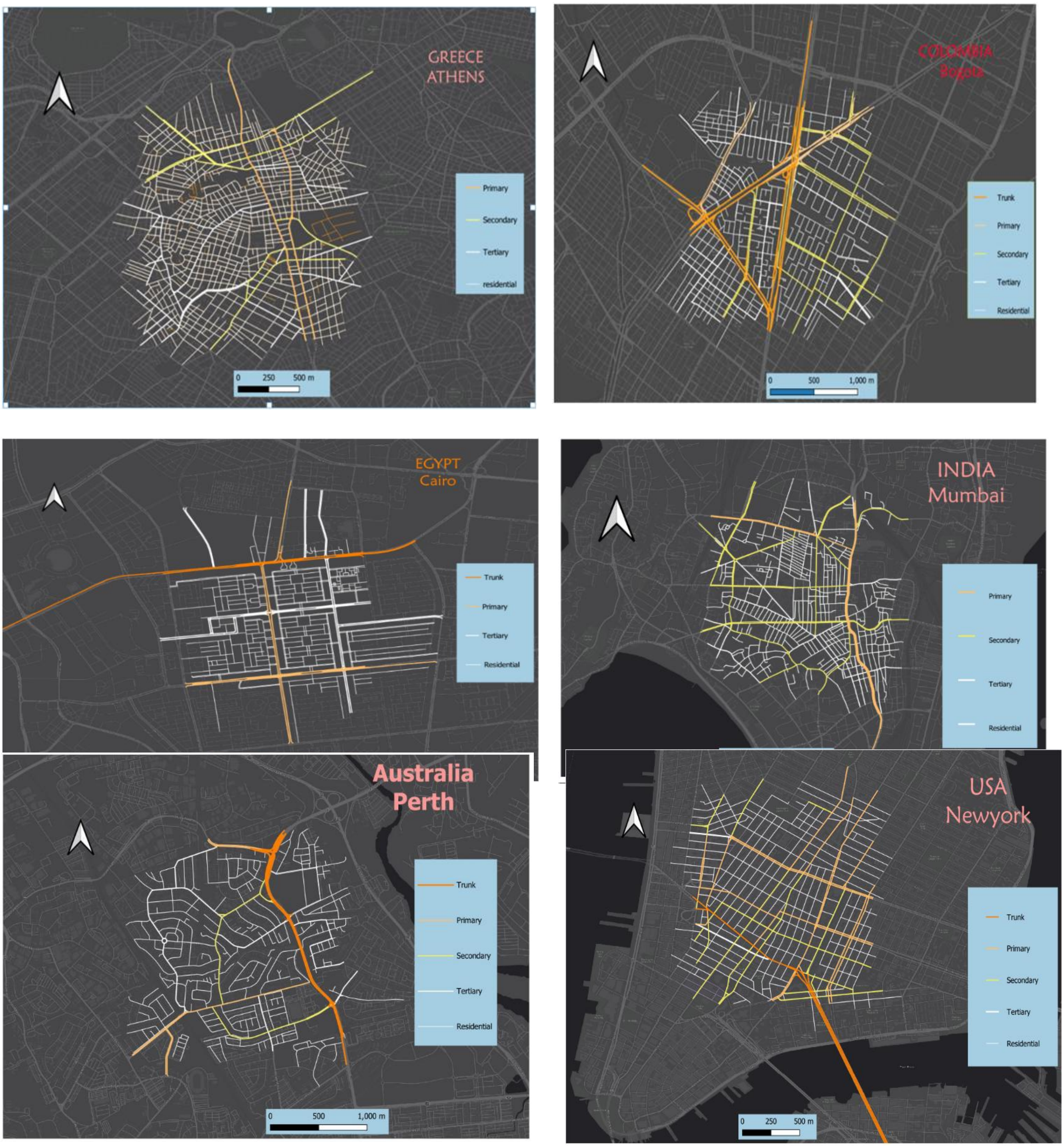
The study area covers different urban road networks from the globe by deliberately picked to get the diverse road structures and the criteria is the road network designs and their impact on traffic flow performance. In a variety of factors, the road networks differ from on city to another by the density and the hierarchical structure of the road network and the proportion of the road. The grid network, in which the streets run at right angle to each other forming a grid pattern and those which are tree networks just like the branches of the tree branching out of the main routes in the hierarchical pattern of the road. For example, cities like Minisk, Istambul, Athens, New York, Tokyo and Sydney had a more grid-like network structure which typically allows for more direct routes and easier navigation but may also lead to more intersections. The rest of the cities are not patterned network in their structure which could result in fewer intersections and potentially smoother traffic flow on main streets but might also lead to longer travel times for local access.

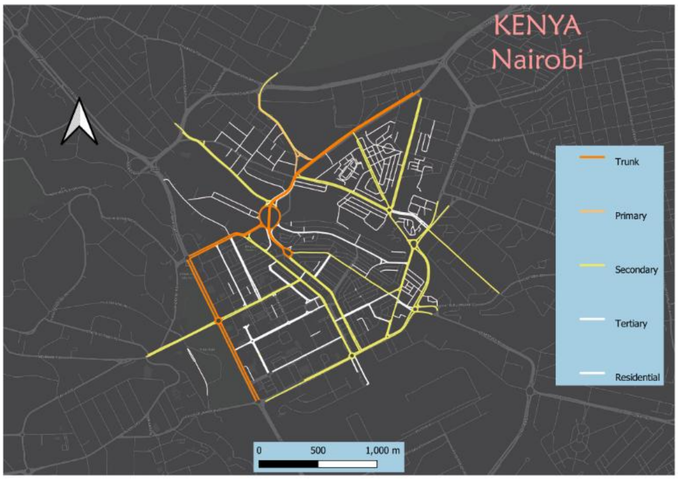
The study examines various urban road networks from around the globe, purposely selected to capture diverse road structures. The focus is on evaluating different road network designs and their impact on traffic flow performance. It compares non-patterned networks, which may result in fewer intersections and smoother traffic flow, with grid networks, where streets form right-angle grids, and tree networks, which branch out from main routes like tree branches.

Table 1: Study area table

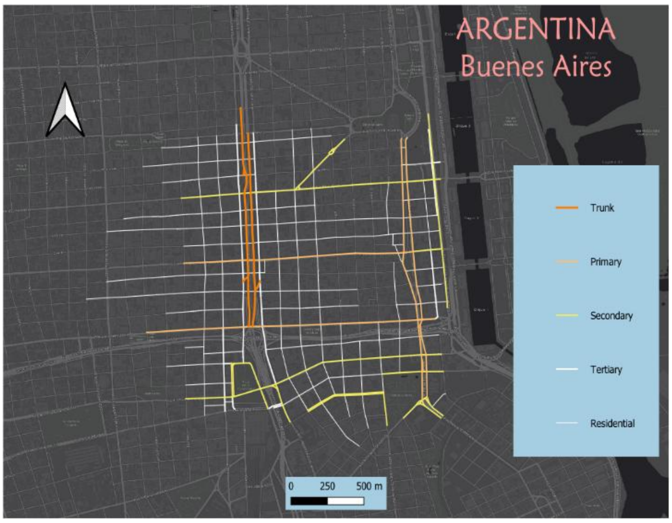
Continent	**Country**	**Cities**
Africa	Ethiopia	Addis Ababa
	Egypt	Cairo
	Kenya	Nairobi
Asia	Turkey	Istanbul
	South Korea	Seoul
	Japan	Tokyo
	India	Mumbai
Europe	Greece	Athens
	Russia	Moscow
North America	Colombia	Bogota
	United States	New York,
South America	Brazil	Brasilia
	Argentina	Buenos Aires
Australia	Fremantle	Perth
	New South Wales	Sydney

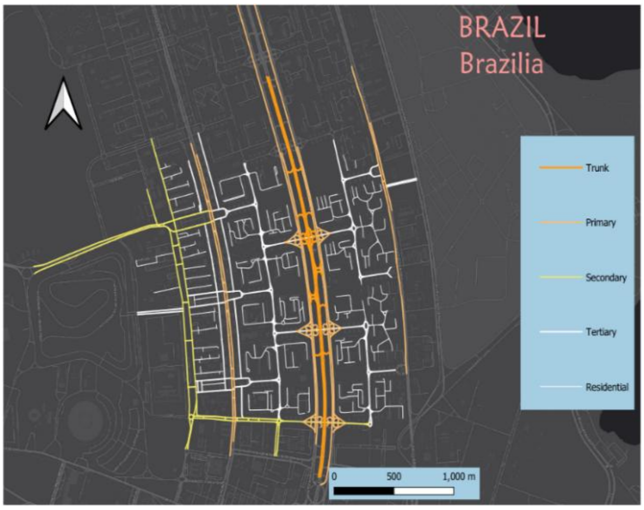
The table 1 above provides a clear representation of the study's countries along with the cities involved.

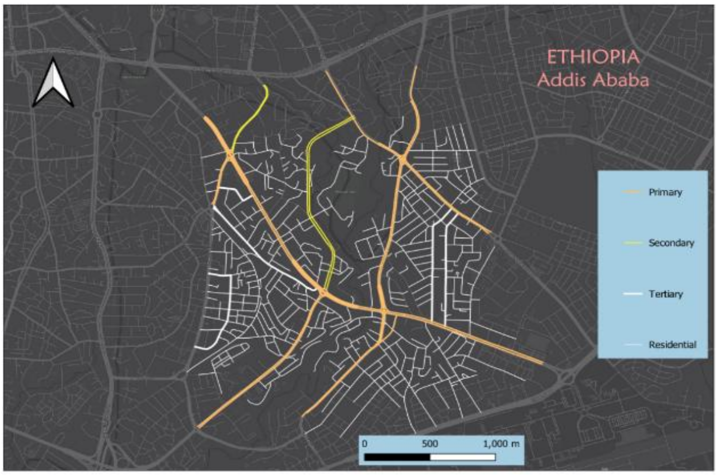

GREECE
ATHENS
Primary
Secondary
Tertiary
residential
0 250 500 m
COLOMBIA
Bogota
Trunk
Primary
Secondary
Tertiary
Residential
0 500 1,000 m
EGYPT
Cairo
Trunk
Primary
Tertiary
Residential
INDIA
Mumbai
Primary
Secondary
Tertiary
Residential
Australia
Perth
Trunk
Primary
Secondary
Tertiary
Residential
0 500 1,000 m
USA
Newyork
Trunk
Primary
Secondary
Tertiary
Residential
0 250 500 m

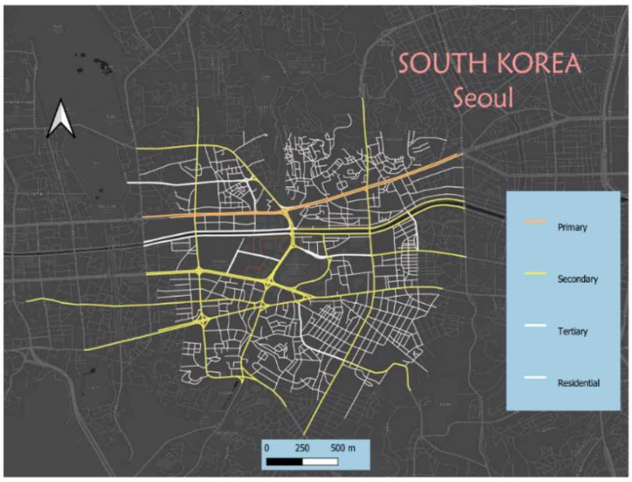

KENYA
Nairobi
Trunk
Primary
Secondary
Tertiary
Residential
0 500 1,000 m


RUSSIA
Moscow
Primary
Secondary
Tertiary
Residential
0 250 500 m


ARGENTINA
Buenes Aires
Trunk
Primary
Secondary
Tertiary
Residential
0 250 500 m


BRAZIL
Brazilia
Trunk
Primary
Secondary
Tertiary
Residential
0 500 1,000 m


ETHIOPIA
Addis Ababa
Primary
Secondary
Tertiary
Residential
0 500 1,000 m


SOUTH KOREA
Seoul
Primary
Secondary
Tertiary
Residential
0 250 500 m

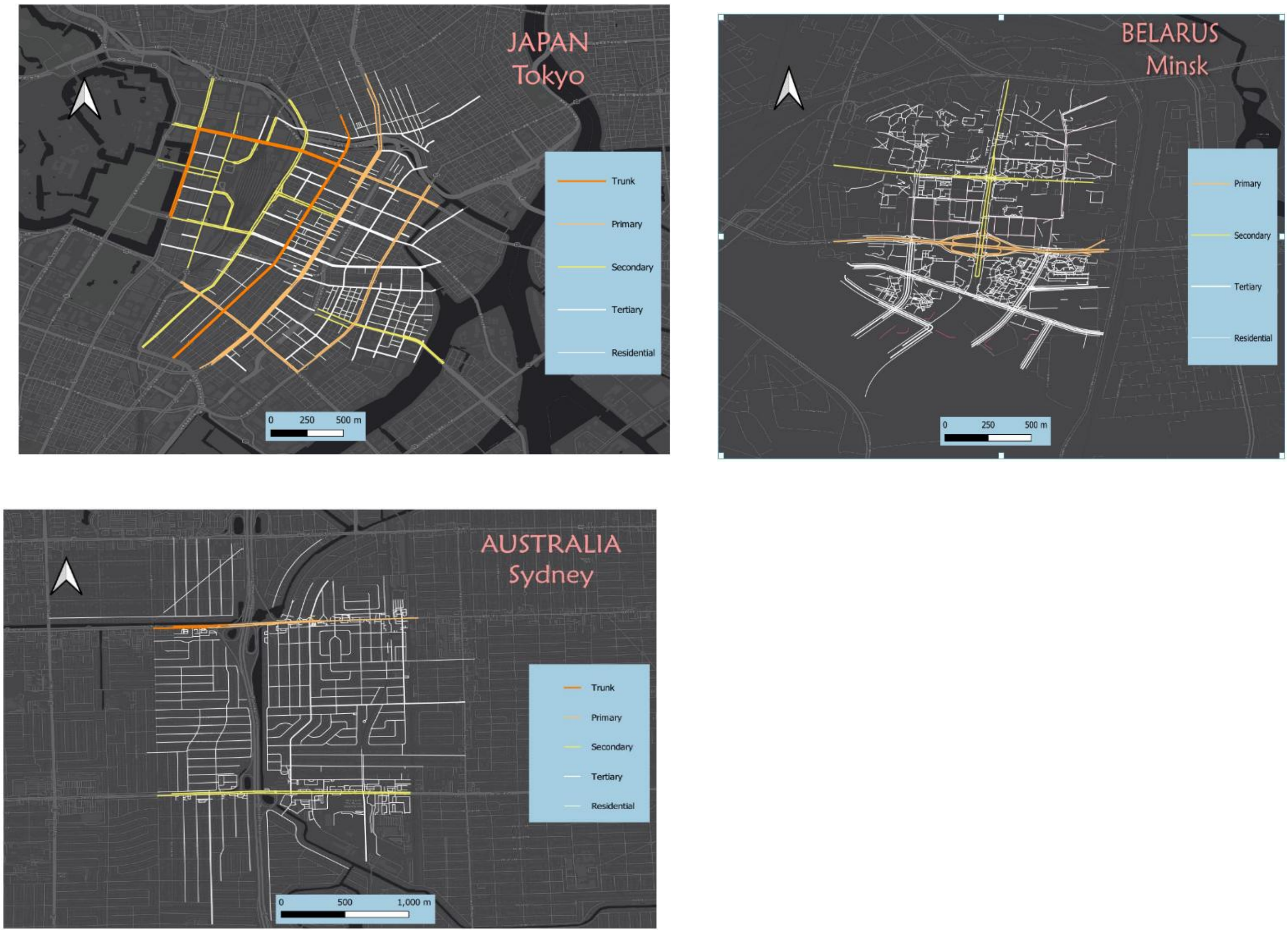


Figure 2: Road network of study city

As it shown in figures 2, the selected city road classification with in the network was shown on the map.

Table 2: Attribute of the cities network data extracted using GIS tool.

City	Road hierarchy	Length (m)	Proportion	Intersection Density/ (km)
Addis Ababa	Primary	167853	0.39	0.58
	Secondary	16226	0.04	0.62
	Tertiary	15235.5	0.04	1.44
	Residential	218298.5	0.51	2.22
Buenos_Aires	Primary	7,504.62	0.13	1.20
	Secondary	9,625.43	0.17	2.49
	Tertiary	5,862.23	0.10	3.24
	Residential	30,484.27	0.54	5.74
Athens	Primary	4,965.00	0.04	1.81
	Secondary	9,128.00	0.08	3.29

	Tertiary	11,778.00	0.10	3.65
	Residential	87,671.00	0.77	11.25
	Primary	2,976.63	0.13	9.41
	Secondary	4,774.49	0.20	6.07
	Tertiary	9,828.26	0.41	2.95
Minsk	Residential	6,200.70	0.26	5.00
	Primary	19,895.22	0.24	6.79
	Secondary	10,560.09	0.13	11.74
	Tertiary	17,171.41	0.21	12.52
Brazilia	Residential	27,283.96	0.33	8.25
	Primary	10,847.00	0.13	3.60
	Secondary	14,704.00	0.00	
	Tertiary	21,846.00	0.19	4.26
Cairo	Residential	69,827.00	0.60	6.92
	Primary	6,092.07	0.06	9.36
	Secondary	15,360.50	0.15	5.34
	Tertiary	12,042.22	0.11	3.24
Bogota	Residential	56,577.28	0.54	7.09
	Primary	2,643.00	0.04	10.22
	Secondary	3,930.00	0.05	3.56
	Tertiary	6,001.00	0.08	6.50
Sydeny	Residential	57,277.00	0.80	3.28
	Primary	4,636.79	0.08	6.69
	Secondary	3,886.71	0.06	7.98
	Tertiary	8,978.31	0.15	9.91
Fremantle	Residential	40,343.96	0.65	4.39
	Primary	4,910.78	0.17	4.07
	Secondary	3,027.63	0.11	9.91
	Tertiary	3,594.02	0.13	9.46
Istambul	Residential	16,752.54	0.59	8.89
	Primary	17,767.00	0.16	0.56
	Secondary	13,851.00	0.13	2.60
	Tertiary	11,634.00	0.11	2.92
Mexico_City	Residential	64,858.00	0.60	6.57
	Primary	15,445.95	0.43	3.50
	Secondary	2,886.17	0.08	6.24
	Tertiary	10,715.67	0.30	3.36
Moscow	Residential	5,250.26	0.15	0.19
	Primary	12,409.00	0.13	0.97
	Secondary	19,127.00	0.21	7.42
	Tertiary	9,800.00	0.11	4.90
Mumbai	Residential	50,800.00	0.55	8.82

Nairobi	Primary	1,127.00	0.01	7.99
	Secondary	24,586.00	0.29	4.80
	Tertiary	11,355.00	0.13	8.54
	Residential	22,011.00	0.26	8.86
Newyork	Primary	16,034.00	0.20	1.43
	Secondary	10,813.00	0.13	3.14
	Tertiary	1,095.00	0.01	8.22
	Residential	44,194.00	0.54	7.76
Ottawa	Primary	4,170.71	0.16	1.44
	Secondary	5,193.85	0.20	3.27
	Tertiary	295.66	0.01	3.38
	Residential	10,980.78	0.43	3.64
Perth	Primary	4,754.78	0.07	3.15
	Secondary	3,505.80	0.05	2.00
	Tertiary	6,363.56	0.09	1.26
	Residential	46,375.71	0.64	6.73
Seoul	Primary	4,708.00	0.05	4.67
	Secondary	22,656.00	0.22	6.14
	Tertiary	5,715.00	0.06	9.97
	Residential	67,017.00	0.66	10.18
Tokyo	Primary	17,077.00	0.15	8.49
	Secondary	14,929.00	0.13	7.77
	Tertiary	18,038.00	0.15	1.39
	Residential	17,840.00	0.15	7.06
Washington DC	Primary	2,055.24	0.03	1.95
	Secondary	1,605.27	0.02	3.74
	Tertiary	19,481.97	0.30	2.87
	Residential	39,321.08	0.60	5.87

The author determined the trip length for each level of road within the network and computed their respective percentage contributions, which were then used to derive proportions for assessment. The attribute of the 16 cities network-related data obtained for this study were shown in table 2 above, revealing variations in proportion of functional hierarchy per trip length and junction density of each road hierarchy across cities.

3.3 Research approach

For evaluating hierarchical road networks, simulation-based traffic analysis involving the evaluation of the road network performance using travel time would be employed. In which could center on key metrics such as travel time, trip distance, and junction density, offering insights into network performance and hierarchy. Additionally, techniques such as correlation analysis and statistical modelling would help uncover relationships and patterns within the data, enhancing understanding.

3.4 Sample size and sampling technique

The population for the study would encompass capital cities of the content. The sample was established using stratified sampling, with continents serving as strata (Iliyasu & Etikan, 2021; Semiz, 2016). Cities were then selected from OpenStreetMap (OSM) across various global regions, employing a purposive sampling technique. This approach ensured a diverse representation of traffic patterns. Emphasizing pattern diversity, cities were chosen to capture a wide range of urban road network hierarchies.

3.5 Study Variables

In this research, both dependent and independent variables were utilized for the analysis of the performance of the road network.

3.5.1 Dependent Variable

The dependent variable for the study was duration from origin to destination in second.

3.5.2 Independent Variables

In this research the independent variable could be as follows.

- **The trip length**: which is the distance that the vehicle travels from the origin traffic analysis zone to another destination traffic analysis zone within the network.
- **The Junction Density**: in this research the junction density is the number of the intersections or nodes per unit length of the trip from the origin TAZ to the destination TAZ.
- **Primary road proportion**: these are major roads designed for large volumes of traffic and usually have higher speed limits, potentially reducing travel time and often connecting significant urban center’s or serving as main arteries within cities.

- **Secondary road proportion:** this road has moderate traffic and speed limits that serves as the feeder for the primary road impacting the travel time variably.
- **Tertiary road proportion**: connects the local areas with the lower speed limits and potentially higher travel time as it compared to the primary and secondary road.
- **Residential Road proportion**: a road that provides direct access to the property or intended for local traffic typically have the lowest speed limits and the highest frequency of stops leading to longer travel times for through traffic.

3.6 Data type

In the conducted study, the OpenStreetMap (OSM) dataset served as a fundamental source of information, providing details on the road network. This dataset involves various categories of roads such as primary, secondary, tertiary, and residential, along with critical data points like intersections and the lengths of trips.

3.7 Data collection procedures

The data collection procedure begins by extracting detailed road network data from OpenStreetMap (OSM) of four-square-kilometers (4 km^2) area of deliberately selected capital cities of various countries. Relevant OSM data, including road classifications (primary, secondary, tertiary, residential), intersections were downloaded. This road network was then converted into a format compatible with the Simulation of Urban Mobility (SUMO) software using the "netconvert" tool. The converted data was imported into SUMO, Traffic Assignment Zones (TAZs) were defined using SUMO's grid tool to specify departure and arrival areas, ensuring consistency across networks. Trips were generated from the OD matrix using the command and routes were created using the shortest path method with duarouter. Finally, the duration data of each trip with in the network were generated from the simulation and exported to excel for analyses.

3.8 Data Analysis

To ensure consistency and control for external variables in the analysis of road networks, the researcher standardized the area for all selected urban regions by defining a fixed size. Specifically, a uniform boundary of four-square kilometers (4 km^2) was used for each urban area under study. This standardization was crucial for controlling the variable of area size, allowing for a more accurate and reliable comparison of road network structures across different urban settings. By maintaining a consistent area size, the author was able to minimize the impact of external factors and ensure that variations in road network structures were not influenced by differences in the size of the areas being analyzed.

OpenStreetMap (OSM) uses degrees for specifying boundary areas, so the four-kilometer square was converted into degree units. This conversion ensured that the area was exactly defined on the map. Then the size of the area calculated inserted into the input box provided by open street map and using the panning tool in the boundary created we move and fine tune the accurate position to incorporate the desired urban road network.

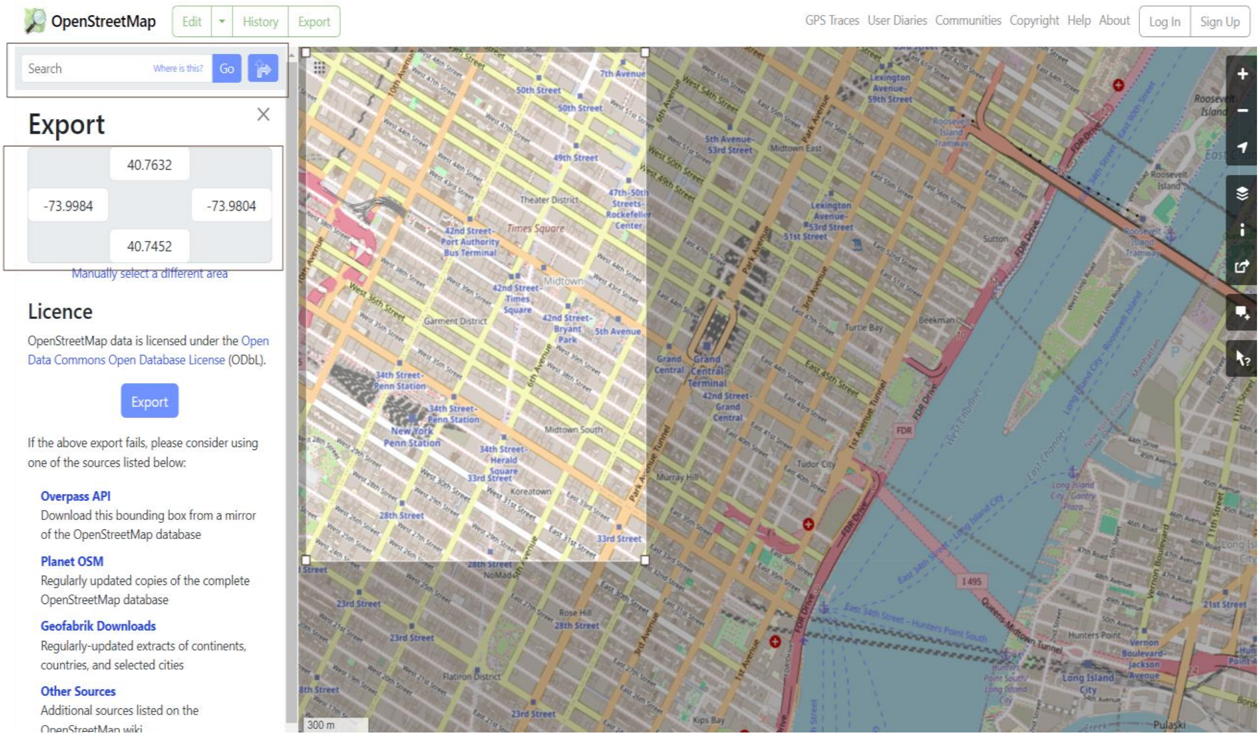


Figure 3: Select study area road network and download from the OSM

As it shown in figure 3, the study employed the Overpass API, JOSM, and OSM API to retrieve the necessary road network data from OpenStreetMap for analysis purposes. These tools facilitate the extraction of highly detailed and tailored data pertaining to the designated study area.

3.8.1 Data conversion to SUMO format

The study employed the "net convert" command in the Windows command line (CMD) to convert OSM data into a SUMO network format within the working directory. This process ensured that each road type in OSM was accurately translated into the corresponding SUMO road type.

By using the command [net convert –osm-files map.osm -o NEW_FILE_NAME.net.xml], the input file map.osm, containing road network data from OpenStreetMap, was converted into the SUMO network format, with the output saved as NEW_FILE_NAME.net.xml

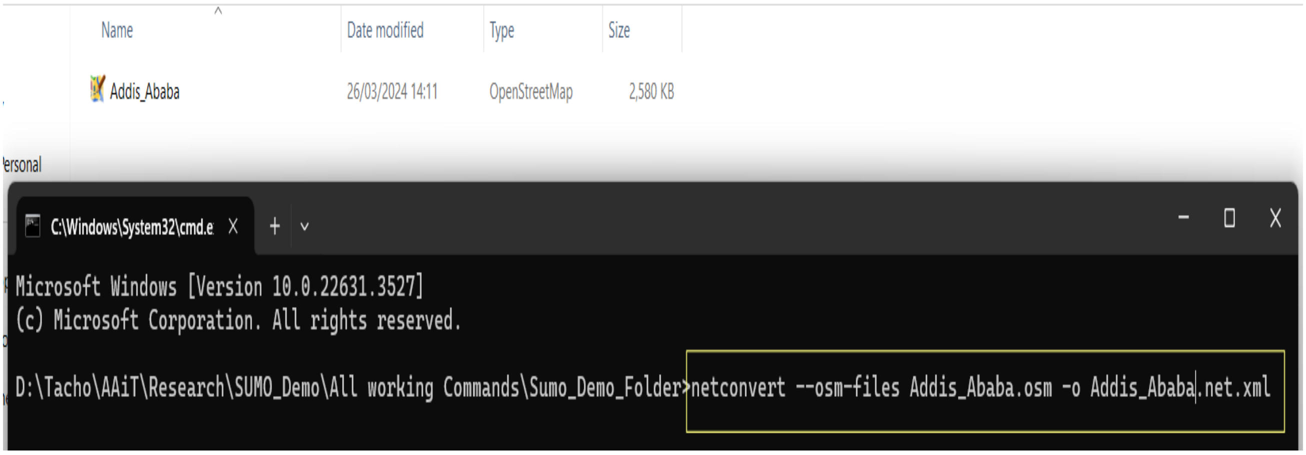


Figure 4: Example of Convert the OSM file to .Net.xml (for Addis Ababa)

As shown above figure 4, confirms the conversion process from an OSM file to Net.xml. This visual representation explains the steps involved in transforming the raw OSM data into the structured Net.xml format.

3.9 Traffic Assignment Zone (TAZ)

Traffic Analysis Zone (TAZ) delineates the area where individuals either commence their journey (origin zone) or conclude their travels (destination zone) within the road network. Comprising numerous interconnected routes, this TAZ facilitates comprehensive network coverage. In this study, twenty-six TAZs were uniformly distributed across all networks to ensure consistency, with identical TAZ locations adopted for all networks to mitigate potential biases stemming from coordinate system disparities. To synchronize with other road networks, the TAZ grid tool within the SUMO software was employed for assignment purposes. The general structure of TAZ is displayed below figure 5.

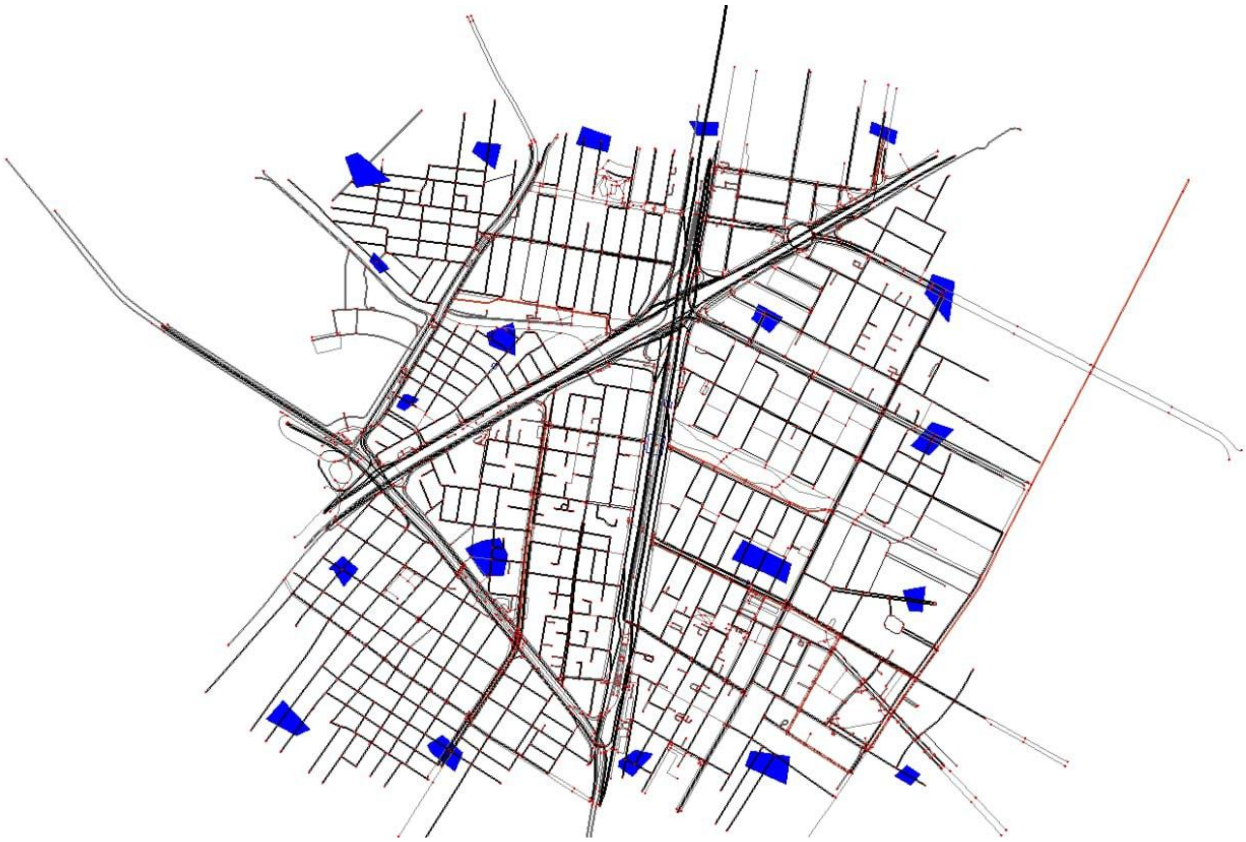


Figure 5: Example of Traffic Assignment Zone of the Bogota

3.9.1 Trip generation from the OD matrix.

To generate trips, the study utilized the following command in the working directory to generate trips: [od2trips -c PATH.od2trips.config.xml -o PATH.odtrips.xml]. This command merges the OD matrix file and the TAZ file specified in the configuration file to produce trips. The -c flag denotes the configuration file containing essential parameters for trip generation, while the -o flag specifies the output file for storing the generated trips. Through this command execution, the study effectively generates trips, adhering to the specified origin-destination relationships and TAZ definitions outlined in the configuration file.

```
$O;D2
* From-Time To-Time
0.00 1.00
* Factor
1.00
*
* some
* additional
* comments
        1       2       3
        1       3       3
        1       4       3
        1       5       3
        1       6       3
        1       7       3
        1       8       3
        1       9       3
        1       10      3
        1       11      3
```

Figure 6: Sample OD metrics file saved as.od.xml.

Figure 6 displays a sample OD metrics file saved as.od.xml. This file likely contains essential information regarding origin-destination (OD) metrics, providing insights into travel patterns. Analyzing this file could reveal details about the distribution of trips between different origins and destinations within the study area. The rest of data were placed in appendix of the study.

```
<configuration>
<input>
<taz-files value="Addis_Ababa.add.xml"/>
<od-matrix-files value="Addis_Ababa.od.xml"/>
</input>
</configuration>
```

Figure 7: The TAZ and OD matrix in the config.xml file

As shown in figure 7, the generated trips linking to each Traffic Analysis Zone (TAZ) were crafted utilizing the provided OD matrix and TAZ files. Throughout the trip assignment process, demand conditions were disregarded, and each trip was independently allocated, assuming free-flow travel behavior. This methodology guarantees that each trip's assignment remains unaffected by the presence of other travelers, facilitating an isolated assessment of the road network structure's impact on travel patterns.

```xml
<?xml version="1.0" encoding="UTF-8"?>

<!-- generated on 2024-02-27 16:40:34 by Eclipse SUMO od2trips Version 1.19.0
<configuration xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://sumo.dlr.de/xsd/od2tripsConfiguration.xsd">

    <input>
        <taz-files value="Brazilia.add.xml"/>
        <od-matrix-files value="Brazilia.od.xml"/>
    </input>

    <output>
        <output-file value="Brazilia.odtrips.xml"/>
    </output>

</configuration>
-->

<routes xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://sumo.dlr.de/xsd/routes_file.xsd">
    <trip id="297" depart="8.55" from="41659371#0" to="782117647" fromTaz="14" toTaz="13" departLane="free" departSpeed="max"/>
    <trip id="221" depart="11.12" from="916375245#0" to="971627507#1" fromTaz="12" toTaz="7" departLane="free" departSpeed="max"/>
    <trip id="640" depart="12.32" from="41573807#0" to="261281081#2" fromTaz="4" toTaz="11" departLane="free" departSpeed="max"/>
    <trip id="151" depart="13.05" from="261281081#2" to="916409826#0" fromTaz="11" toTaz="3" departLane="free" departSpeed="max"/>
    <trip id="860" depart="19.77" from="286120605" to="261322958#1" fromTaz="7" toTaz="9" departLane="free" departSpeed="max"/>
```

Figure 8: Trip Generated from OD matrix and TAZ

The figure 8 shown above displaying trips generated from the Origin-Destination (OD) matrix and Traffic Analysis Zones (TAZ) offers valuable insights into travel patterns within the study area. By merging the OD matrix, which outlines trip flows between origins and destinations, with TAZ data representing geographic zones, this visualization provides a comprehensive overview of travel behavior. It highlights the movement of individuals or vehicles between TAZs, revealing connectivity and interdependencies within the transportation network. Analyzing these trips helps identify key travel corridors, and areas of high demand.

3.10 Route Assignment

The shortest path algorithm concept in road network analysis was used in this work to determine the most efficient route from origin to destination within a network. This has meaningful applications in simulations for example Dijkstra's algorithm is a popular method for finding the shortest paths between nodes in a graph which represents a network. It works by systematically selecting the nearest node not yet processed until it covers all nodes. In the context of traffic simulations tools like duarouter are part of the SUMO (Simulation of Urban Mobility) suite it computes vehicle routes based on shortest path calculations and can perform dynamic user assignment (DUA). This research implemented this algorism to analyze the network.


```xml
<?xml version="1.0" encoding="UTF-8"?>

<!-- generated on 2024-02-27 16:41:01 by Eclipse SUMO duarouter Version 1.19.0
<configuration xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://sumo.dlr.de/xsd/
duarouterConfiguration.xsd">

    <input>
        <net-file value="Brazilia.net.xml"/>
        <route-files value="Brazilia.odtrips.xml"/>
    </input>

    <output>
        <output-file value="Brazilia.odtrips.rou.xml"/>
    </output>

    <report>
        <xml-validation value="never"/>
        <ignore-errors value="true"/>
        <no-step-log value="true"/>
    </report>

</configuration>
-->

<routes xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://sumo.dlr.de/xsd/routes_file.xsd">
    <vehicle id="297" depart="8.55" departLane="free" departSpeed="max" fromTaz="14" toTaz="13">
        <route edges="41659371#0 41659371#1 918402200 41573087#1 41573087#2 41573087#3 918347190 41659368#0 41659368#1 41659368#2
        41659368#3 41659368#4 41659368#5 508259280 41659362#0 782117647"/>
    </vehicle>
    <vehicle id="640" depart="12.32" departLane="free" departSpeed="max" fromTaz="4" toTaz="11">
        <route edges="41573807#0 41573807#1 41573807#2 917502513 41573091#1 917502516 -917884013 -917884012#1 -917884012#0 -41573806
        917884010 918373725 41573081#5 917884008 -261266081#3 -261266081#2 -261266081#1 -261266081#0 -262445152 -781029065 -916428807
        -262445151 -781029067 -781029066 -262445153 -781029069 -781029068 -262445150 -261266079 -124494181#2 -124494181#1 -124494181#0
        302982308 41573078#2 917484698 917484697 102288557 -102288541 41659200#0 41659200#1 292931161#1 292931161#2 292931161#3 302982307
        -41659199 780974303 41574497#2 41574497#3 41574497#4 330543924#0 330543924#1 -41659198 559788286 918315143 115434317#3 115434317#4
        115434317#5 559788287 -41659197 559788285#0 559788285#1 918316561 295039987#0 295039987#1 41659049#0 41659049#1 918317577
        918319779 41574500#0 41574500#1 776422142#0 776422142#1 41659050#0 41659050#1 776422140 918335790 918335791 918335788 776422144
        41659051#0 41659051#1 918335786 261322867#3 261322867#4 261322867#5 776422136#0 776422136#1 776422136#2 261281082#0 261281082#1
        261281082#2 261281081#0 261281081#1 261281081#2"/>
```


Figure 9: Route Generated from the Trip Assigned

Figure 9 presents the routes generated from the assigned trips, alongside a sample of the SUMO network. This serves as a sample process representing the process applied to all route assignments within the city.

3.11 Setting up the SUMO configuration and running the Simulation

```
<configuration>
<input>
<net-file value="A.net.xml"/>
<route-files value="A.odtrips.rou.xml"/>
</input>
<time>
<begin value="0"/>
<end value="5000"/>
</time>
</configuration>
```

Figure 10: SUMO configuration file

Figure 11: Simulation structure of SUMO

Figure 10 displays the SUMO configuration file, while figure 11 illustrates the setup process and execution of the simulation within the SUMO framework.

```
Sub find()
For i = 1 To 2108
    Worksheets("sheet1").Range("a1:bv699").Select
    Selection.Replace What:=Cells(i, 74).Value, Replacement:=Cells(i, 75).Value, LookAt:=xlPart, SearchOrder:=xlByRows, MatchCase:=False
     Worksheets("sheet1").Cells(1, 1).Select
     Next
     End Sub
    Sub find2()
For i = 1 To 2108
    Worksheets("sheet2").Range("a1:bv699").Select
    Selection.Replace What:=Cells(i, 74).Value, Replacement:=Cells(i, 76).Value, LookAt:=xlPart, SearchOrder:=xlByRows, MatchCase:=False
     Worksheets("sheet2").Cells(1, 1).Select
     Next
     End Sub
Sub Macro3fillbekka()


    Dim i As Integer, j As Integer
    Dim sheet1 As Worksheet, Sheet2 As Worksheet, Sheet3 As Worksheet
    Dim lastRow1 As Integer, lastRow2 As Integer

    Set sheet1 = ThisWorkbook.Sheets("Sheet1")
    Set Sheet2 = ThisWorkbook.Sheets("Sheet2")
    Set Sheet3 = ThisWorkbook.Sheets("Sheet3")

    lastRow1 = sheet1.Cells(sheet1.Rows.Count, "A").End(xlUp).Row
    lastRow2 = Sheet2.Cells(Sheet2.Rows.Count, "A").End(xlUp).Row

    j = 1
    For i = 1 To WorksheetFunction.Max(lastRow1, lastRow2)
        If i <= lastRow1 Then
            sheet1.Range("A" & i & ":BV" & i).Copy Sheet3.Range("A" & j)
            j = j + 1
        End If
        If i <= lastRow2 Then
            Sheet2.Range("A" & i & ":BV" & i).Copy Sheet3.Range("A" & j)
            j = j + 1
        End If
    Next i
End Sub
```

Figure 12: Code used to extract the data on visual basics

As it shown in figure 12 demonstrates the VBA code's functionality in passing through the XML structure. It locates each edge ID referenced in the vehicle routes and matches them with corresponding edge details in the .net.xml file. Subsequently, it extracts essential attributes such as road hierarchical and their length from these matched edges.

CHAPTER 4 RESULTS AND DISCUSSIONS

The evaluation of the road network hierarchy is the key for understanding the efficiency and effectiveness of transportation infrastructure. By analyzing various road hierarchies within the network and their impact on trip duration the author tried to identify variables that were extracted from the network such as the proportion of primary, secondary, tertiary, and residential roads, as well as junction density. Table 3 presents the sample simulation outputs for Bogota city, detailing the duration required for a vehicle to navigate the given trip length in (TAZ) Traffic Analysis Zone and the variables generated from the network.

Table 3: Final output for durations and junction density, Hierarchical roads

Duration (s)	Length(m)	Junction density/ trip length in (m)	Primary proportion	Secondary proportion	Tertiary proportion	Residential proportion
144	1322.22	0.040084101	0.264449184	0.101806053	0.274334075	0.359410688
135	1233.5	0.041345764	0.283469801	0.109128496	0.222140251	0.385261451
167	1318.56	0.044745783	0.129671763	0.332097136	0.045762043	0.492469057
153	1075.89	0.036249059	0.236808596	0.186710537	0.322783928	0.253696939
272	1946.36	0.045726382	0.087846031	0.42068271	0.063986107	0.427485152
268	1892.24	0.046505729	0.090358517	0.432714666	0.065816176	0.411110641
197	1754.05	0.041047861	0.199344374	0.076742396	0.277683076	0.446230153
233	1685.77	0.039744449	0.155418592	0.257727923	0.073877219	0.512976266
231	1699.93	0.041766426	0.205690823	0.079185614	0.286523563	0.428600001
273	2389.28	0.045201902	0.071561307	0.183272785	0.417573495	0.327592413
128	1620.78	0.016041659	0.214606547	0.588235294	0.08373129	0.113426869
135	1772.5	0.015232722	0.196236953	0.537884344	0.076564175	0.189314528
137	2764.04	0.018089463	0.202149752	0.165337694	0.491526895	0.140985659
143	2583.3	0.018967987	0.216293113	0.176905508	0.45595169	0.150849688
148	2583.3	0.018967987	0.216293113	0.176905508	0.45595169	0.150849688
199	1343.81	0.015627209	0.256628541	0.383067547	0.134498181	0.225805731
197	1372.83	0.015296869	0.251203718	0.374969953	0.263310097	0.110516233
111	2636.5	0.017068083	0.211928693	0.342378153	0.18288261	0.262810544
133	2420.32	0.018592583	0.230857903	0.408917003	0.199217459	0.161007635
127	2333.29	0.018857493	0.239468733	0.386870042	0.206648123	0.167013102
173	2274.15	0.020227338	0.138218675	0.493305191	0.222786536	0.145689598
180	2172.99	0.020708793	0.14465322	0.516270208	0.233157999	0.105918573
199	2172.99	0.020708793	0.14465322	0.516270208	0.233157999	0.105918573
97	849.23	0.032971044	0.242242973	0.466846437	0.007336057	0.283574532
102	874.77	0.033151571	0.235170388	0.453216274	0.007121872	0.304491466
101	856.68	0.03501891	0.391441378	0.304932997	0.057209226	0.246416398
92	1079.69	0.030564329	0.273430336	0.549139105	0.000185238	0.17724532
127	1054.15	0.030356211	0.280055021	0.562443675	0.000189726	0.157311578

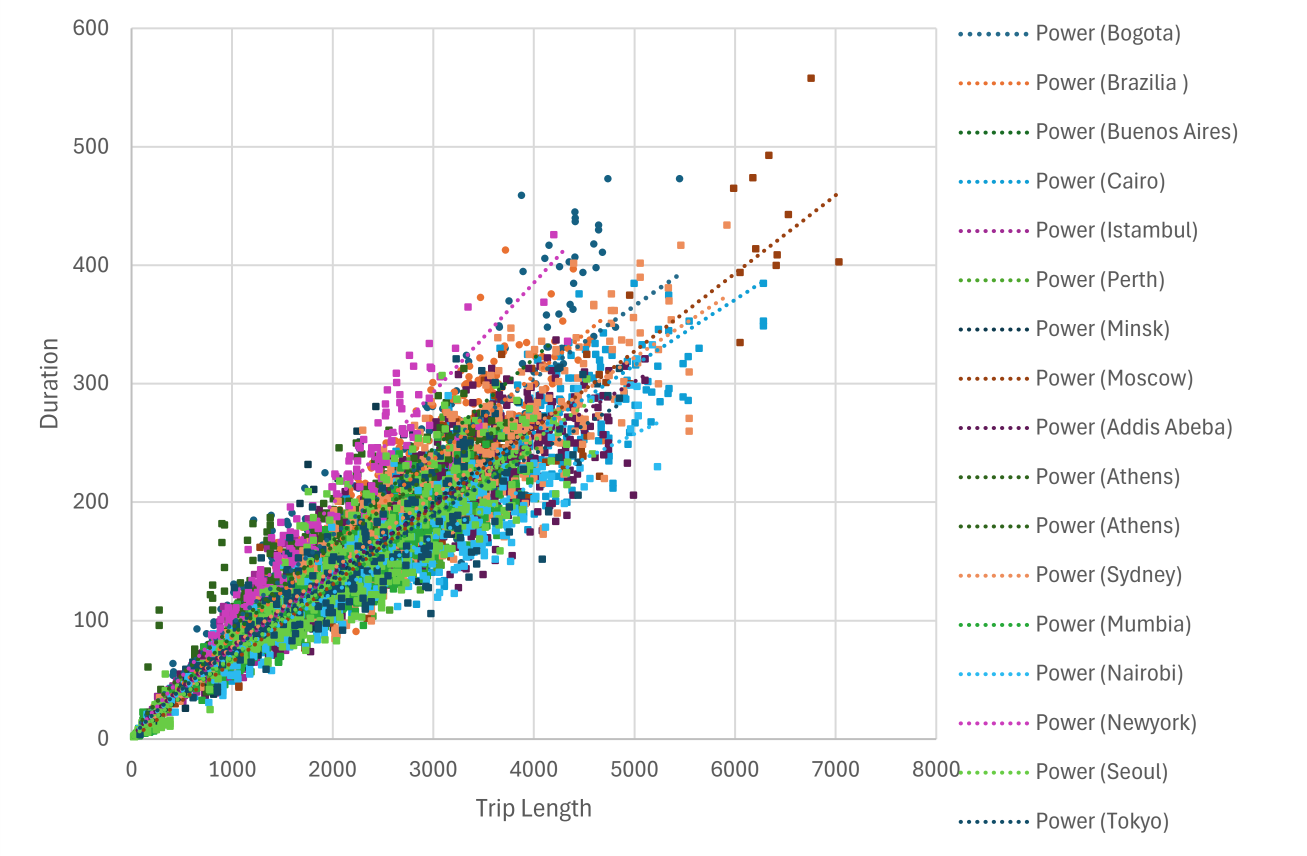


Figure 13: Scatter plot of Duration Vs trip length

The scatter plot shown in the results section, as shown in figure 13, confirms a clear relationship between trip length and duration. As expected, the duration of a vehicle's trip is significantly influenced by the distance covered. This trend indicates that longer trips generally require more time, confirming a positive correlation between these two variables. Additionally, the results also show differences in trip durations across various countries, even for similar trip lengths. For instance, as the trip length increases from 0 to 100 meters, the duration also changes from 0 to 100 seconds, with almost all of the cities showing similar durations at the beginning. However, as the trip length increases further, the duration differences become more distinct. At a trip length of 3000 meters, the duration varies from 145 to 298 seconds, and at 4000 meters, the duration varies from 200 to 459 seconds. This variation suggests that factors such as characteristics of road network among cites including junction density, road hierarchy such as (primary, secondary, tertiary, and residential), differ from country to country, affecting the overall duration of trips. Therefore, there will be a need for a common model to better understand and predict trip durations across different cities and countries.

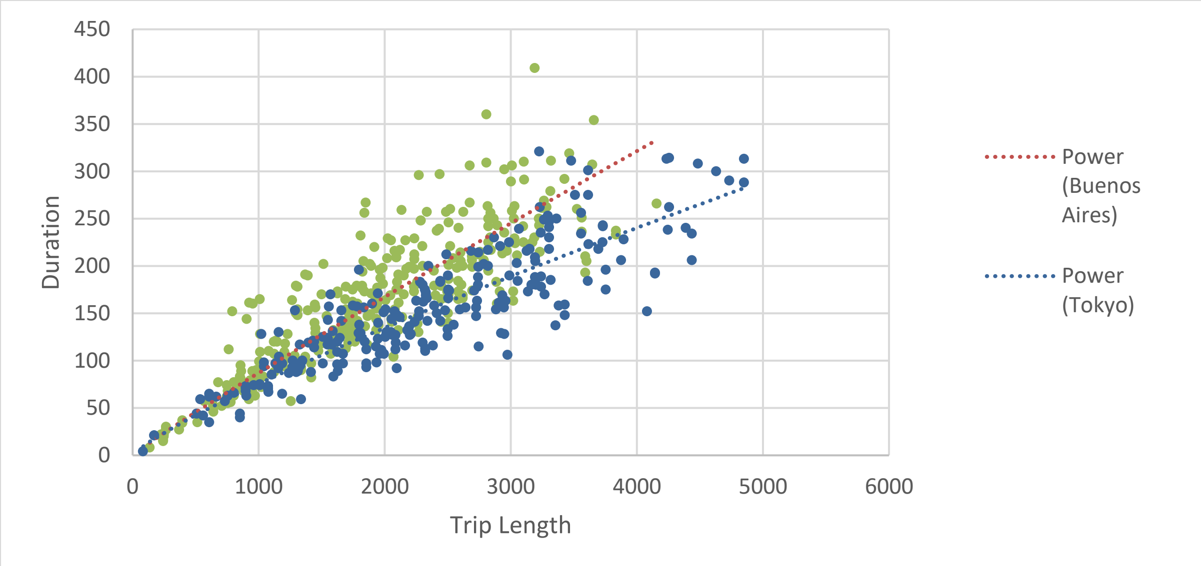


Figure 14:Duration Vs Trip length for Tokyo and Buenos Aires

As mentioned above, the scatter plot at figure 14 indicates that at a length of 1000 meters, the duration is approximately 100 seconds for the two cities. When the length reaches 2000 meters, the duration is 151 seconds for Tokyo and 181 seconds for Buenos Aires. Additionally, at a length of 3000 meters, the duration is 173 seconds for Tokyo and 258 seconds for Buenos Aires. This variation suggests that factors such as the characteristics of the road network, including junction density and road hierarchy (primary, secondary, tertiary, and residential roads), differ from city to city. These differences impact the overall duration of trips.

4.1 Modeling functional hierarchy of the road network using trip performance

When conducting statistical analyses, one often assumes that the data follow a normal distribution, this assumption of data normality underlies many statistical methods, particularly parametric tests, and its validity could significantly influence the results and conclusions. Several methods can be used to assess whether data follow a normal distribution. Descriptive statistics, such as skewness and kurtosis, provide insights into the shape and symmetry of the data distribution; ideally, for a normal distribution, both skewness and kurtosis should be close to zero.

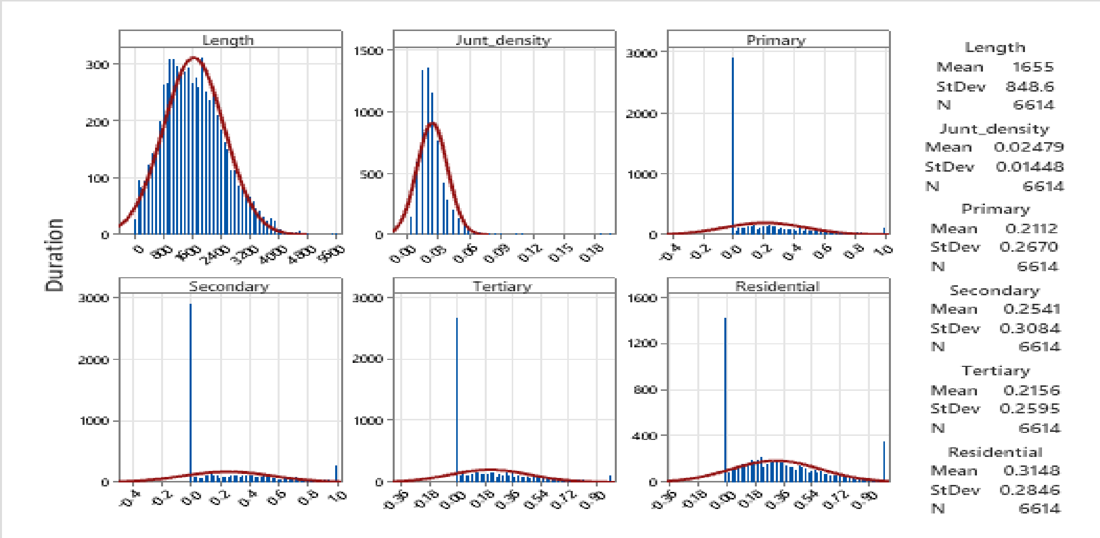


Figure 15: Normality test of the data using scatter plot

Figure 15 above shows the histogram outputs of the data, confirming a deviation from the assumption of normality, particularly showcasing right-skewed data. This deviation challenges the assumption typically required for many statistical analyses. In cases like this, where the data distribution does not align with a normal distribution, alternative approaches were necessary to ensure the validity of statistical inferences. This might involve employing non-parametric tests or applying data transformations to normalize the distribution, thereby mitigating the impact of skewness on subsequent analyses. By acknowledging and addressing these deviations from normality, researchers can ensure the robustness and accuracy of their findings.

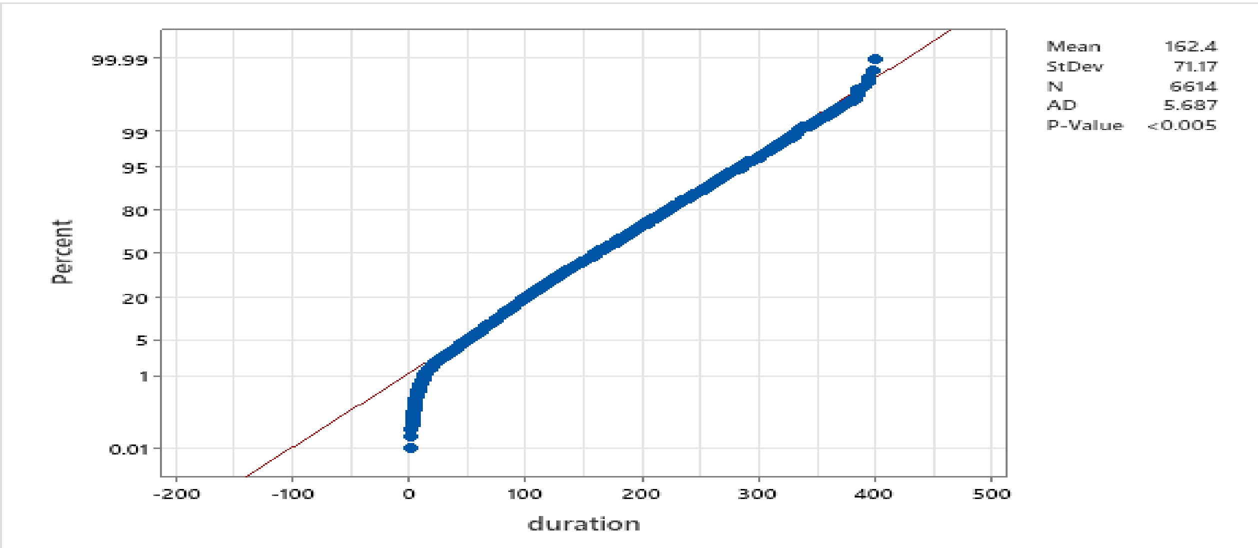


Figure 16: Anderson Darling value tastes of normality

Additionally, statistical tests which is the Anderson-Darling was shown p-value was less than 0.005 (chosen significance level, 0.05), it suggests strong evidence against the null hypothesis of normality which means the data were significantly different from a normal distribution.

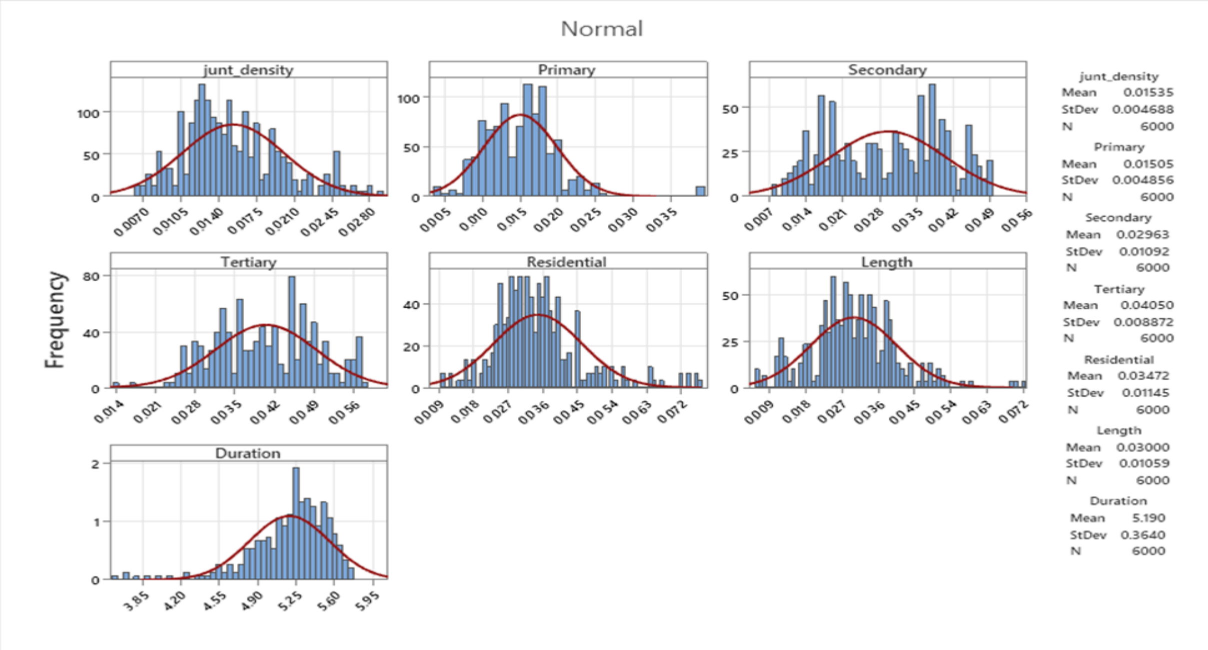


Figure 17: The Normality Test of transformed data.

As it is shown in Figure 17 above the transformed data fitted a normal distribution.

Table 4:Correlation coefficient of variables

	Duration	*Length*	*Junt_density*	*Primary*	*Secondary*	*Tertiary*	*Residential*
Duration	1						
Length	0.73292	1					
Junt_density	0.034428	-0.26866	1				
Primary	0.073456	0.18021	0.040927	1			
Secondary	-0.08251	-0.02819	0.062793	-0.37024	1		
Tertiary	0.101356	0.059098	0.060767	-0.25674	-0.34636	1	
Residential	-0.07857	-0.20538	-0.15083	-0.3081	-0.41251	-0.28548	1

The correlation result, as shown in table 4 above, is less than 0.71, indicating that there is not a multicollinearity problem. However, it is important to note that high correlation between predictors in a regression model can lead to multicollinearity issues. When predictors are highly correlated, they have a linear relationship where one predictor can be linearly predicted from the others with a substantial degree of accuracy. This high collinearity can lead to large variances for the regression coefficients, making them unstable and difficult to interpret. Consequently, the standard errors of the coefficients increase, leading to less reliable statistical tests.

4.2 Model summary

In this study, a log transformation was applied as an approach to address the right-skewed nature of the data distribution. A log transformation involves taking the natural logarithm (ln) or logarithm base 10 (log10) of each data point. The formulas are x=ln(x) for the natural logarithm.

$$\ln y = \ln \beta 0 + \beta 1 \cdot \ln(x1) + \beta 2 \cdot \ln(x2) + \cdots + \beta n \cdot \ln(xn)$$

- $\ln(y)$ represents the natural logarithm of the dependent variable which is duration of time.
- $\ln(x1)$,$\ln(x2)$,…,$\ln(xn)$ were the natural logarithm transformations of the independent variables.
- $\beta 0$,1,$\beta 2$,…,βn are the coefficients of the model.

Table 5: Model summary

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.794562295
R Square	0.631329241
Adjusted R Square	0.630994441
Standard Error	0.36547531
Observations	6614

The multiple correlation coefficient (R) indicates the strength and direction of the linear relationship between the independent variable(s) and the dependent variable after log transformation. In this case, R=0.79 suggesting a moderately strong positive linear relationship.

R Square: R squared represents the proportion of the variance in the dependent variable that is explained by the independent variables in the model. In this case, R squared is 0.63, suggesting that approximately 63% of the variability in the dependent variable is accounted for by the independent variables in the model.

Adjusted R Square: Adjusted R squared is a modified version of R squared that adjusts for the number of predictors in the model. It penalizes the addition of unnecessary predictors and generally provides a more accurate estimate of the model's explanatory power, particularly in cases of multiple regression. In this case, the adjusted R squared is also 0.63, indicating that the model's explanatory power remains consistent after considering the number of predictors.

Standard Error: This represents the standard deviation of the residuals, or the differences between the observed values of the dependent variable and the values predicted by the regression model. A lower standard error indicates that the model's predictions are closer to the observed values. In this case, the standard error is 0.37.

Observations: This indicates the number of data points used in the regression analysis. In this case, there are 6614 observations. Overall, the summary output suggests that the regression model has a good fit to the data, as indicated by the high multiple R and R squared values. However, further analysis, such as examining the significance of individual predictors were.

Table 6: Model significant level

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	1511.254	251.8757	1885.69	0
Residual	6607	882.5115	0.133572		
Total	6613	2393.766			

The ANOVA table 5 above summarizes the analysis of variance for the logarithmically transformed regression model. The regression component, with 6 degrees of freedom, explains a substantial portion of the total variability in the dependent variable, as indicated by the high sum of squares (SS) of 1511.25. The mean square (MS) value of 251.87 suggests that each degree of freedom in the regression model explains a significant amount of variance in the dependent variable. The F-statistic of 1885.68 is highly significant ($p < 0.05$), indicating that the regression model is a good fit for the data. The low MS value of 0.13 for the residuals suggests that the variance unexplained by the regression model is relatively small. Therefore, ANOVA results demonstrate that the logarithmically transformed regression model significantly explains the variability in the dependent variable, providing valuable insights into the relationship between the independent and dependent variables.

Table 7: Model variables coefficient

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.27140648	0.058179	21.85351	2.8E-102	1.157357622	1.385455338
length	0.675190914	0.00723	93.38664	0	0.661017663	0.689364165
Junction	0.322051054	0.009669	33.30816	5.2E-225	0.303097017	0.341005092
Primary	-0.001306678	0.000517	-2.52975	0.011437	-0.002319232	-0.00029412
Secondary	-0.004705237	0.000521	-9.03897	2.04E-19	-0.005725684	-0.00368479
Tertiary	0.000485376	0.000511	0.949742	0.342278	-0.000516468	0.001487219
Residential	0.003099726	0.00058	5.347196	9.23E-08	0.001963342	0.004236109

$$D = 1.27 + \text{Length}^{0.675} + \text{junction}^{0.322} + \text{Primary}^{-0.001} + \text{Secondary}^{-0.005} + \text{Residential}^{0.003}$$

where D= *Duration in seconds*

This equation represents the logarithmic relationship between the dependent variable (Duration in second) and the independent variables (length, junction, primary, secondary, tertiary and residential residential) with the respective coefficients. Each coefficient represents the effect of the corresponding independent variable on the dependent variable after log transformation.

Intercept (1.271): The intercept represents the estimated value of duration when all independent variables are zero. it indicates the expected value of the duration in second when the lengths of trips, densities of junctions, and proportions of different road types are all zero. The intercept is statistically significant with a very low p-value 0.00.

Length (0.675): For each unit increase in the natural logarithm of the trip length, the natural logarithm of the duration in seconds is expected to increase by approximately 0.675 units, holding all other predictors constant. This suggests that longer trips are associated with longer durations, with a statistically significant relationship ($p < 0.05$).

Junction (0.322): Similarly, for each unit increase in the natural logarithm of junction density, the natural logarithm of the duration in seconds is expected to increase by approximately 0.322 units, holding all other predictors constant. This indicates that areas with higher junction densities tend to have longer durations, with a highly statistically significant relationship ($p < 0.05$).

Primary (-0.001): The coefficient for the proportion of primary roads suggests that, for each unit increase in the natural logarithm of the proportion of primary roads, the natural logarithm of the duration in seconds is expected to decrease by approximately 0.001 units, holding all other predictors constant. This effect is small and statistically significant ($p < 0.05$).

Secondary (-0.0047): Similarly, for each unit increase in the natural logarithm of the proportion of secondary roads, the natural logarithm of the duration in seconds is expected to decrease by approximately 0.0047 units, holding all other predictors constant. This effect is larger than that of primary roads and highly statistically significant ($p < 0.05$).

Tertiary (0.0005**)**: The coefficient for the proportion of tertiary roads suggests that there is no significant effect on the natural logarithm of the duration in seconds for changes in the proportion of tertiary roads. This coefficient is close to zero and not statistically significant ($p > 0.05$).The coefficient for the proportion of tertiary roads suggests that, for each unit increase in the natural logarithm of the proportion of tertiary roads, the natural logarithm of the duration in seconds is expected to increase by approximately 0.0005 units, holding all other predictors constant. This effect is statistically significant ($p < 0.05$).

Residential (0.003): For each unit increase in the natural logarithm of the proportion of residential roads, the natural logarithm of the duration in seconds is expected to increase by approximately 0.003 units, holding all other predictors constant. This effect is statistically significant ($p < 0.05$), indicating that areas with higher proportions of residential roads tend to have longer durations.

To illustrate how a developed model can predict a dependent variable the hypothetical data could be used. To test the predictive model using hypothetical data by assuming different levels of junction density and trip lengths and analyze their impact on travel duration. Let's start by assuming three different scenarios for trip lengths: 1000 meters, 2000 meters, and 4000 meters, proportion, 10%,20%,70& the junction density of the 3,5, and 7 can be used.

$$D = 1.27(\text{Length}^{0.675} + \text{junction}^{0.322} + \text{Primary}^{-0.001} + \text{Secondary}^{-0.005} + \text{Residential}^{0.003}).$$

At length =1000m the sample calculation for duration would be $D = 1.27 * 1000^{0.675} + 3^{0.322} + 0.1^{-0.001} + 0.2^{-0.005} + 0.7^{0.003}$)= 140.1512second.

when length= 2000m at a junction density 3, the duration would be D= $1.27 * 2000^{0.675} + 5^{0.322} + 0.1^{-0.001}$+$0.2^{-0.005}$+$0.7^{0.003}$)= 220.408 seconds. And the rest of combination will shown below8.

Table 8: Hypothetical model test

Length(m)	Junction Density (Per km)	Primary Proportion	Secondary Proportion	Residential Proportion	Predicted Duration Using the Model
1000	3	0.2	0.3	0.5	140.1512035
1000	5	0.2	0.3	0.5	140.4746277
1000	10	0.2	0.3	0.5	141.0078647
2000	3	0.2	0.3	0.5	220.4085175
2000	5	0.2	0.3	0.5	220.7319416
2000	10	0.2	0.3	0.5	221.2651786
3000	3	0.2	0.3	0.5	288.0232985
3000	5	0.2	0.3	0.5	288.3467226
3000	10	0.2	0.3	0.5	288.8799596
4000	3	0.2	0.3	0.5	348.5470859
4000	5	0.2	0.3	0.5	348.87051
4000	10	0.2	0.3	0.5	349.4037471

As it shown above table8, the hierarchical structuring of road networks within urban area significantly influences travel time and efficiency. Primary and secondary roads, which form the upper tiers of the hierarchy, are designed for mobility and typically facilitate faster travel times due to their direct routes and limited access points. Conversely, roads that provide property access, often lower in the hierarchy, tend to increase travel time within the network due to more frequent intersections and potential congestion. A well-planned hierarchy, with clear distinctions between road types and their intended use, could optimize travel times. However, higher connectivity and junction density, while beneficial for access, can lead to increased travel times as they introduce more points of potential conflict and delay. Therefore, the balance between road hierarchy and connectivity is crucial for efficient urban mobility and requires careful planning and management. This study is supported by the research conducted in Germany (Friedricha, 2017), Transport network planning is a critical process in urban and regional planning that shapes the structure and function of transport networks. This process involves determining not just the physical form of the network but also the roles and characteristics of its various elements. One fundamental concept in road network planning is the functional classification of roads, which involves categorizing roads based on their intended use and function within the overall network.

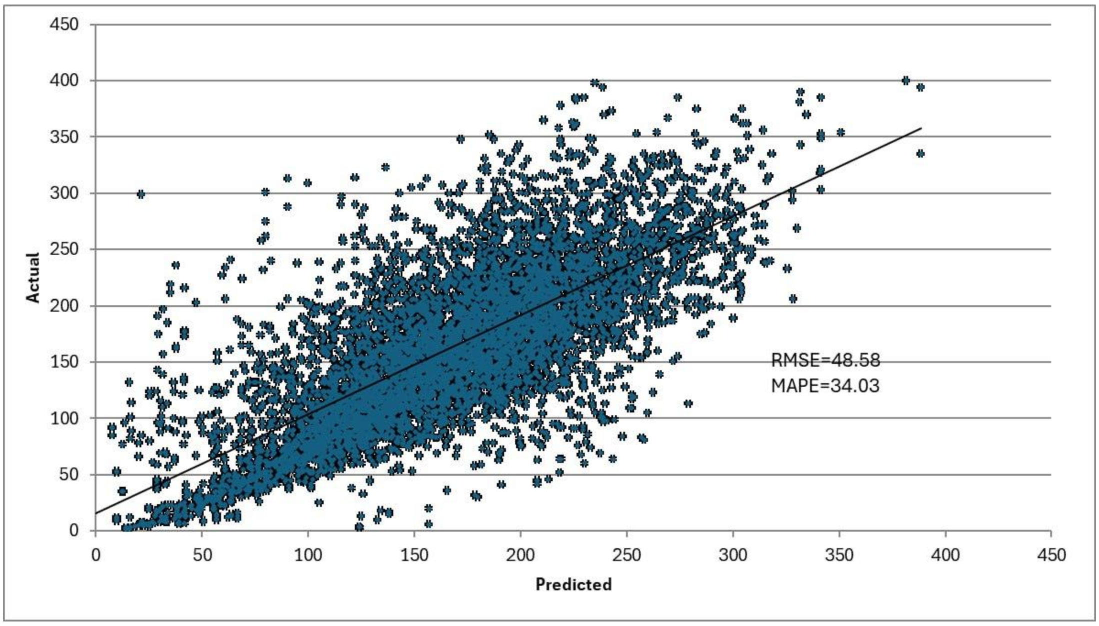


Figure 18: Predicted Vs Actual

Figure 18 scatter plot provides a visual representation of the model's predictive performance, revealing that while its predictions generally align closely with actual values, there's noticeable variability, especially evident at higher values. This dispersion suggests the presence of prediction errors, highlighting areas where the model's accuracy may be less reliable. When considering the RMSE value of 48.58 units, it becomes apparent that while the average prediction error is moderate, it's crucial to contextualize this within the range of actual values and the acceptable level of error for the specific application. Meanwhile, the MAPE value of 34.03% signifies a substantial average prediction error relative to the actual values.

CHAPTER 5 CONCLUSIONS AND RECCOMONDATIONS

5.1 Conclusions

- ✓ The hierarchical organization of roads in urban areas significantly impacts trip performance and overall urban development. Cities with higher junction densities, longer trip lengths, and a greater proportion of residential roads tend to experience longer travel durations within their road networks.
- ✓ Primary and secondary roads had significant role in reducing travel time due to their efficient design.
- ✓ Tertiary roads have minimal impact on travel duration, while residential roads contribute to longer trips because of lower speed limits and frequent stops typical in residential areas.
- ✓ Additionally, higher junction density correlates with increased trip duration, likely because of the greater number of road connections from different directions.

5.2 Recommendations

- ✓ For future studies, it is recommended to incorporate an analysis of road design and capacity, considering factors such as the number of lanes, road width, speed limits, and infrastructure like bridges and tunnels, as these significantly impact a road's hierarchical status. Additionally, evaluating traffic control measures, including traffic signals, stop signs, and roundabouts, and considering the effects of congestion. Combining these elements will help understand their impact on trip performance and the overall road hierarchy.
- ✓ Finally, implementing this study will enable urban planners and transportation authorities to make informed decisions, improve traffic management strategies, and enhance the overall efficiency of transportation systems. This approach not only supports better infrastructure planning but also contributes to reduced travel times and lower congestion levels.

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CHAPTER 7 APPINDEXS

7.1 Cites output for durations and junction density, Hierarchical roads

Cities	Duration(s)	Length(m)	Junt_density	Primary	Secondary	Tertiary	Residential
	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
Athens	5	63.67	0.031412	1E-09	0.000000001	1	1E-09
	23	124.81	0.032049	1E-09	0.000000001	1E-09	1
	133	433.14	0.050792	0.634414	0.000000001	0.136399	0.229187
	41	533.12	0.028136	1E-09	0.000000001	1	1E-09
	71	635.84	0.0173	1E-09	0.000000001	1E-09	1
	76	735.81	0.032617	0.696715	0.000000001	0.000272	0.303013
	109	838.15	0.054883	0.7059	0.000000001	0.070489	0.223612
	96	968.05	0.036155	0.832457	0.000000001	1E-09	0.167543
	139	1068.94	0.039291	0.0148	0.000000001	0.134208	0.850993
	148	1144.96	0.031442	0.088807	0.211064142	0.40632	0.293809
	171	1243.27	0.040217	0.111633	0.000000001	0.241629	0.646738
	196	1338.11	0.035871	0.420048	0.357384669	1E-09	0.222568
	189	1431.19	0.03843	0.077921	0.436671581	1E-09	0.485407
	176	1520.26	0.044729	1E-09	0.710549511	1E-09	0.28945
	192	1625.29	0.047376	0.295603	0.186600545	0.113844	0.403953
	194	1729.35	0.028334	1E-09	0.000000001	0.523081	0.476919
	212	1832.99	0.040371	0.622207	0.000000001	0.00731	0.370482
	335	1936.54	0.041311	0.781135	0.103731397	1E-09	0.115133
	233	2029.6	0.043851	0.53007	0.307922743	0.026168	0.13584
	249	2127.2	0.033377	0.255082	0.217736931	0.24293	0.284252
	286	2232.9	0.050159	0.50167	0.135823369	0.362506	1E-09
	286	2332.16	0.040735	0.232664	0.153544354	0.395003	0.218789
	332	2448.26	0.037578	0.221631	0.14626306	0.244578	0.387528
	257	2557.54	0.048093	0.187852	0.362942515	0.341406	0.107799

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
Addis Ababa	40	624.37	0.017618	1	0.000000001	1E-09	1E-09
	174	1829.57	0.012571	0.465055	0.000000001	0.168865	0.366081
	198	2533.82	0.009472	0.42625	0.000000001	1E-09	0.55515
	250	3951.81	0.009616	0.670796	0.000000001	1E-09	0.329204
	269	4419.31	0.007015	0.722773	0.000000001	1E-09	0.277227
	171	2638.56	0.008717	0.516092	0.000000001	1E-09	0.483908
	210	2332.7	0.012432	0.146881	0.000000001	0.022901	0.830218
	303	4645.68	0.008825	0.496511	0.000000001	1E-09	0.263718
	115	1735.75	0.008642	0.436762	0.000000001	1E-09	0.536085
	203	3232.34	0.011137	0.784228	0.000000001	1E-09	0.215772
	185	2232.5	0.019261	0.44727	0.000000001	0.023928	0.528802
	81	1328.11	0.014306	0.565887	0.000000001	0.23239	0.201723
	49	535.84	0.016796	1E-09	0.000000001	1E-09	1
	103	1120.54	0.024096	1E-09	0.000000001	0.43878	0.56122
	130	1423.98	0.025281	0.631736	0.000000001	0.037515	0.330749
	45	407.03	0.019655	1E-09	0.000000001	1E-09	1
	123	1016.3	0.022631	0.195976	0.000000001	0.090013	0.647063
	204	3324.79	0.011429	0.79485	0.000000001	1E-09	0.20515
	253	3134.03	0.019464	0.65076	0.000000001	0.105114	0.244127
	184	3629.67	0.014602	0.914516	0.000000001	1E-09	0.085484
	196	2733.26	0.016464	0.836924	0.000000001	1E-09	0.145833
	5	51.52	0.03882	1E-09	0.000000001	1E-09	1
	98	1224.27	0.022054	0.543303	0.000000001	0.107558	0.349139
	26	232.73	0.01289	1E-09	0.000000001	0.524857	0.475143
	254	3421.69	0.012275	0.34122	0.397096172	1E-09	0.166912
	293	3530.75	0.010196	0.138667	0.384830418	1E-09	0.292892
	131	2032.41	0.009349	0.641416	0.000000001	1E-09	0.325239
	68	913.41	0.016422	0.660853	0.000000001	1E-09	0.286892
	33	353.22	0.008493	1E-09	0.000000001	1E-09	0.595323
	11	121.24	0.016496	1E-09	0.000000001	1E-09	1
	218	2836.95	0.017272	0.571924	0.000000001	0.168671	0.259405
	74	1630.67	0.008585	1	0.000000001	1E-09	1E-09
	154	3036.3	0.008892	0.877548	0.000000001	1E-09	0.122452
	103	1525.45	0.013766	0.76072	0.000000001	1E-09	0.175489
	272	4070.62	0.0113	0.780316	0.000000001	1E-09	0.219684
	183	1932.01	0.01501	0.185775	0.000000001	0.226671	0.587554
	230	2936.44	0.016346	0.410473	0.388068546	1E-09	0.20139
	251	2432.07	0.023026	0.413841	0.000000001	0.294482	0.291677
	264	3829.74	0.017234	0.322547	0.402361518	0.10642	0.168672
	71	722.88	0.023517	1E-09	0.000000001	0.38164	0.61836
	86	823.3	0.021863	1E-09	0.000000001	0.33509	0.66491
	192	2126.61	0.016928	0.209916	0.000000001	0.101321	0.358458
	280	3728.12	0.016362	0.149491	0.41332897	0.087039	0.350142
	233	4330.57	0.012469	0.585417	0.355828448	1E-09	0.058754
	240	4170.74	0.011509	0.445302	0.369464412	1E-09	0.185233

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
	91	128.1	0.070258	1	0.000000001	1E-09	1E-09

	19	224.92	0.013338	1E-09	0.000000001	1	1E-09
	40	327.64	0.012209	1E-09	0.000000001	1	1E-09
	147	411.93	0.033986	0.917947	0.000000001	0.082053	1E-09
	58	514.94	0.02913	1E-09	0.000000001	1	1E-09
	76	629.37	0.0286	1E-09	0.000000001	1	1E-09
	66	715.69	0.012575	0.289203	0.710796574	1E-09	1E-09
	108	816.98	0.023256	1E-09	0.000000001	1	1E-09
	111	927.29	0.032352	1E-09	0.000000001	0.576465	0.423535
	184	1026.49	0.039942	1E-09	0.000000001	1	1E-09
	122	1127.56	0.031927	0.133705	0.830235198	0.03606	1E-09
	117	1228.91	0.017088	0.403496	0.000000001	0.596504	1E-09
	140	1327.22	0.028631	0.113591	0.886409186	1E-09	1E-09
	141	1432.09	0.020948	0.578176	0.000000001	0.150863	0.270961
	190	1527.53	0.017021	0.85927	0.118472305	0.022258	1E-09
	164	1624.68	0.044932	1E-09	0.152122264	0.626967	0.220911
	250	1722.8	0.033086	0.1763	0.215643139	0.608057	1E-09
	272	1829.97	0.051913	1E-09	0.000000001	1	1E-09
	206	1926.92	0.037884	1E-09	0.000000001	0.843315	0.156685
Brazilia	202	2020.65	0.04355	1E-09	0.318174845	0.504204	0.177621
	218	2130.71	0.032384	1E-09	0.000000001	0.507737	0.492263
	210	2223.63	0.025184	0.583402	0.000000001	0.416598	1E-09
	293	2329.23	0.034775	1E-09	0.126535379	0.873465	1E-09
	216	2425.48	0.021851	0.412974	0.000000001	0.271522	0.315505
	245	2523.51	0.021795	0.437212	0.000000001	0.562788	1E-09
	306	2629.86	0.033462	0.38088	0.000000001	0.506966	0.112154
	322	2727.65	0.032629	0.367225	0.000000001	0.488791	0.143985
	243	2822.67	0.025862	1E-09	0.490981943	0.408539	0.100479
	264	2964.14	0.021929	0.581649	0.193729041	0.128938	0.095684
	229	3025.53	0.010577	0.730612	0.000000001	0.126983	0.142405
	330	3131.71	0.027461	1E-09	0.373054976	0.626945	1E-09
	335	3291.16	0.022181	1E-09	0.421091652	0.578908	1E-09
	300	3370.91	0.022546	0.135047	0.418427072	0.446526	1E-09
	225	3475.15	0.007482	0.853296	0.000000001	0.146704	1E-09
	282	3559.19	0.012643	0.805034	0.000000001	0.112096	0.08287
	333	3673.61	0.026405	0.123919	0.584071254	0.29201	1E-09
	296	3759.4	0.012502	0.762162	0.000000001	0.106126	0.131713
	337	3870.38	0.019895	0.339716	0.603597063	0.056687	1E-09

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
	12	124.3	0.01609	1E-09	0.000000001	1E-09	1
	21	234.55	0.008527	1E-09	0.000000001	1E-09	1
	34	376.85	0.007961	1E-09	0.000000001	1E-09	1
	57	554.979	0.014415	0.291415	0.000000001	1E-09	0.708585
Cairo	54	636.5	0.009427	1E-09	0.000000001	1E-09	1

	86	723.27	0.020739	1E-09	0.000000001	0.377245	0.622755
	49	839.43	0.028591	0.847313	0.000000001	1E-09	0.152687
	94	961.77	0.008318	1E-09	0.000000001	1E-09	1
	116	1034.91	0.011595	1E-09	0.000000001	1E-09	1
	148	1151.56	0.025183	1E-09	0.000000001	0.544053	0.455947
	112	1238.55	0.013726	0.28074	0.000000001	1E-09	0.71926
	132	1335.91	0.023954	1E-09	0.000000001	0.309961	0.690039
	142	1426.806	0.025932	0.252228	0.000000001	1E-09	0.747772
	176	1522.519	0.021018	1E-09	0.000000001	0.607854	0.392146
	231	1611.805	0.017992	0.366397	0.000000001	0.125676	0.507927
	156	1718.347	0.019205	0.435405	0.000000001	1E-09	0.564595
	202	1830.415	0.019121	0.485119	0.000000001	0.110666	0.404214
	168	1923.63	0.013516	0.518343	0.000000001	1E-09	0.481657
	242	2025.01	0.018272	1E-09	0.000000001	0.732609	0.267391
	172	2125.8	0.006115	1E-09	0.000000001	0.426033	0.573967
	227	2222.21	0.018	1E-09	0.000000001	0.515302	0.484698
	198	2313.45	0.012103	1E-09	0.000000001	0.357561	0.642439
	237	2421.846	0.02271	0.2714	0.000000001	0.195004	0.533595
	223	2526.751	0.015831	1E-09	0.000000001	0.627589	0.372411
	147	2631.098	0.013302	0.802763	0.000000001	1E-09	0.197237
	289	2732.221	0.015738	0.381411	0.000000001	0.084459	0.53413
	199	2827.507	0.016976	1E-09	0.000000001	0.720319	0.279681
	249	2924.197	0.018125	1E-09	0.000000001	0.779331	0.220669
	234	3031.23	0.007588	1E-09	0.000000001	0.381706	0.618294
	325	3157.026	0.018372	0.208199	0.000000001	0.254071	0.537729
	285	3236.623	0.021319	1E-09	0.000000001	0.915069	0.080297
	385	3339.221	0.014375	0.049302	0.000000001	0.168512	0.782186
	262	3425.856	0.01693	0.047208	0.000000001	0.665211	0.287581
	343	3518.448	0.01279	0.321852	0.000000001	1E-09	0.678148
	219	3636.053	0.014026	0.850032	0.000000001	1E-09	0.149968
	279	3771.281	0.013788	0.016109	0.000000001	0.420483	0.563408
	330	3878.671	0.015985	1E-09	0.000000001	0.764241	0.231891
	282	3913.668	0.015331	0.638892	0.000000001	0.051758	0.309349
	259	4063.413	0.013782	0.82922	0.000000001	1E-09	0.17078
	349	4646.533	0.018293	0.538124	0.000000001	0.268206	0.193669

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
	12	122.64	0.024462	1E-09	0.605756686	1E-09	0.394243
	31	224.57	0.031171	1E-09	0.33886984	0.446186	0.214944
	36	320.35	0.021851	1E-09	0.000000001	0.536819	0.463181
	32	426.34	0.018764	1E-09	0.772833888	1E-09	0.227166
	48	524.43	0.017161	1E-09	0.000000001	1	1E-09
	61	628.07	0.031844	0.637684	0.000541341	0.095531	0.266244
Istanbul	65	728.36	0.024713	0.634563	0.000466802	1E-09	0.364971

	65	828.99	0.025332	0.353949	0.514590043	1E-09	0.131461
	79	930.22	0.020425	0.528251	0.000000001	0.376029	0.095719
	94	1032.98	0.023234	0.126363	0.081937695	0.7917	1E-09
	96	1133.64	0.022935	0.148874	0.461345754	0.195944	0.193836
	117	1236.93	0.025871	0.105527	0.440704001	0.254663	0.199106
	158	1331.756	0.01652	0.466264	0.380006548	1E-09	0.153729
	148	1429.296	0.026587	0.091325	0.372838097	0.111768	0.424069
	120	1528.76	0.026165	0.497835	0.296115806	0.206049	1E-09
	139	1656.39	0.02596	0.459475	0.273299163	0.096445	0.170781

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
	12	33.34	0.059988	1	0.000000001	1E-09	1E-09
	35	333.5	0.032984	1E-09	0.09964018	1E-09	0.90036
	64	420.345	0.049959	1E-09	0.142216513	1E-09	0.857783
	49	519.32	0.023107	1E-09	0.316510052	1E-09	0.68349
	86	642.33	0.028023	0.10381	0.000000001	1E-09	0.89619
	38	738.28	0.018963	1E-09	0.000000001	1	1E-09
	82	838.08	0.011932	1E-09	0.000000001	1E-09	1
	146	940.65	0.037208	0.283549	0.000000001	0.716451	1E-09
	71	1078.83	0.015758	1E-09	0.000000001	1	1E-09
	91	1143.91	0.020981	1E-09	0.999825161	1E-09	0.000175
	118	1243.31	0.035389	0.040223	0.68233184	1E-09	0.277445
	220	1336.5	0.018706	1E-09	1	1E-09	1E-09
	98	1431.91	0.023745	0.248102	0.751897815	1E-09	1E-09
	131	1526.945	0.028816	0.229046	0.535395839	1E-09	0.235559
	166	1630.655	0.025757	1E-09	0.478102358	1E-09	0.521898
	112	1719.36	0.019193	1E-09	0.760323609	1E-09	0.239676
	118	1837.53	0.019047	0.165804	0.834195904	1E-09	1E-09
	171	1956.51	0.018911	0.181578	0.818421577	1E-09	1E-09
	191	2033.785	0.02606	0.149804	0.652178082	1E-09	0.198017
	176	2134.195	0.027645	0.132631	0.383057781	0.315777	0.168534
	158	2235.14	0.018343	0.136309	0.863690865	1E-09	1E-09
	189	2322.46	0.025404	1E-09	0.24269094	0.565624	0.191685
	235	2469.775	0.025104	0.11461	0.33100991	0.271369	0.283012
	207	2538.36	0.021274	0.108318	0.240009297	0.458907	0.192766
	225	2621.835	0.024029	0.107963	0.311812147	0.25563	0.324595
	219	2770.075	0.030685	1E-09	0.264769004	0.444356	0.290875
	201	2892.38	0.016595	0.076518	0.667433048	0.256049	1E-09
	256	3049.475	0.020659	0.072576	0.434956837	0.213391	0.279076
	213	3128.79	0.019816	0.070737	0.648292151	0.280971	1E-09
	272	3280.855	0.026517	1E-09	0.223548435	0.427785	0.348667
Minisk	247	3414.26	0.020795	0.08053	0.559011323	0.360459	1E-09

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
	8	57.51	0.069553	0.966093	0.000000001	0.033907	1E-09
	77	177.76	0.045005	1	0.000000001	1E-09	1E-09
	102	242.15	0.041297	1	0.000000001	1E-09	1E-09
	30	401.45	0.009964	1E-09	0.93720264	0.062797	1E-09
	55	716.22	0.032113	1E-09	0.000000001	0.793318	0.206682
	98	815.39	0.026981	0.344289	0.655710764	1E-09	1E-09
	114	907.35	0.016532	0.309395	0.690604508	1E-09	1E-09
	162	1007.57	0.03573	1E-09	0.000000001	1	1E-09
	179	1134.49	0.034377	0.269478	0.140045307	0.408518	0.181958
	154	1209.65	0.024801	0.275551	0.000000001	0.724449	1E-09
	91	1305.55	0.006894	1E-09	0.000000001	1	1E-09
	164	1400.34	0.019281	0.327656	0.000000001	0.672344	1E-09
	193	1512.01	0.029762	0.176143	0.192657456	0.412973	0.218226
	228	1622.056	0.032058	0.346295	0.000000001	0.271797	0.381908
	147	1732.04	0.016166	0.179424	0.314623219	0.505953	1E-09
	190	1833.56	0.030542	0.296445	0.070916687	0.632638	1E-09
	243	1947.26	0.019001	0.235629	0.000000001	0.764371	1E-09
	267	2042.476	0.029866	0.092197	0.000000001	0.676884	0.230919
	152	2149.96	0.014884	1E-09	0.000000001	1	1E-09
	158	2241.12	0.008032	1E-09	0.000000001	1	1E-09
	153	2342.68	0.010672	0.06306	0.000000001	0.93694	1E-09
	210	2437.91	0.015177	0.042368	0.000000001	0.817729	0.139903
	325	2548.89	0.031779	0.130716	0.165299405	0.703985	1E-09
	246	2634.1	0.024676	0.206351	0.049364109	0.744285	1E-09
	222	2749.76	0.008001	1	0.000000001	1E-09	1E-09
	223	2889.6	0.012112	0.051125	0.000000001	0.948875	1E-09
	244	2952.47	0.018628	0.1841	0.044041091	0.771859	1E-09
	224	3097.84	0.013235	0.46923	0.000000001	0.53077	1E-09
	280	3165.79	0.020216	0.238133	0.000000001	0.69672	0.065146
	289	3392.93	0.009726	0.059026	0.000000001	0.940974	1E-09
	301	3479.73	0.019254	0.16259	0.037367842	0.800042	1E-09
	204	3557.41	0.008714	0.741812	0.000000001	0.258188	1E-09
	300	3639.496	0.015936	0.106768	0.000000001	0.763641	0.129591
	235	3786.93	0.011619	0.383847	0.000000001	0.616153	1E-09
	256	3826.28	0.010977	0.142057	0.183922766	0.67402	1E-09
	375	3913.42	0.017632	0.138894	0.033226692	0.827879	1E-09
	325	4095.13	0.013675	0.048904	0.000000001	0.951096	1E-09
	239	4116.02	0.00826	0.353157	0.000000001	0.646843	1E-09
	400	5489.78	0.007468	0.056609	0.082513325	0.140244	0.720634
Moscow	335	5637.27	0.007805	0.468122	0.000000001	0.531878	1E-09

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
Nairobi	35	18.98	0.105374	1E-09	0.000000001	1E-09	1
	68	124.76	0.040077	1E-09	1	1E-09	1E-09
	23	319.38	0.031311	1E-09	1	1E-09	1E-09
	63	416.91	0.035979	1E-09	1	1E-09	1E-09
	125	549.48	0.012739	1E-09	0.000000001	1E-09	1
	133	645.01	0.020155	1E-09	0.000000001	0.891475	0.108525
	114	729.59	0.02193	1E-09	0.363903014	0.079565	0.556532
	157	831.41	0.024056	1E-09	0.930419408	0.069581	1E-09
	111	932.361	0.025741	1E-09	0.353264454	0.293095	0.353641
	78	1040.28	0.003845	1E-09	1	1E-09	1E-09
	160	1152.291	0.026035	1E-09	0.285839254	0.237154	0.477007
	93	1249.37	0.028014	1E-09	1	1E-09	1E-09
	145	1344.79	0.025283	1E-09	1	1E-09	1E-09
	223	1451.96	0.019973	1E-09	0.836607069	0.163393	1E-09
	101	1542.71	0.017502	1E-09	1	1E-09	1E-09
	183	1651.76	0.019979	1E-09	0.461592483	0.30907	0.229337
	150	1755.16	0.018802	1E-09	1	1E-09	1E-09
	216	1858	0.017761	1E-09	0.653778256	0.127686	0.218536
	158	1955.64	0.021988	1E-09	1	1E-09	1E-09
	154	2055.72	0.018971	1E-09	0.791406417	0.186178	0.022416
	156	2149.586	0.018608	1E-09	0.580511782	0.380681	0.038807
	191	2256.04	0.014184	1E-09	0.80331909	0.196681	1E-09
	255	2349.67	0.020854	1E-09	0.462460686	0.406112	0.131427
	216	2442.85	0.027427	1E-09	0.795820456	0.111865	0.092314
	163	2561.16	0.019522	1E-09	1	1E-09	1E-09
	186	2628.91	0.022443	1E-09	1	1E-09	1E-09
	199	2729.05	0.016856	1E-09	1	1E-09	1E-09
	188	2839.576	0.014791	1E-09	0.711821061	0.288179	1E-09
	226	2925.04	0.013333	1E-09	0.89496212	0.081107	0.023931
	239	3034.156	0.018786	1E-09	0.730301936	0.269698	1E-09
	229	3242.766	0.019119	1E-09	0.74765185	0.252348	1E-09
	221	3441.78	0.017142	1E-09	1	1E-09	1E-09
	222	3525.2	0.01702	1E-09	0.976336094	1E-09	0.023664
	285	3636.36	0.02035	1E-09	1	1E-09	1E-09

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
New York	13	91.44	0.043745	1	0.000000001	1E-09	1E-09
	82	326.14	0.061323	1E-09	1	1E-09	1E-09
	132	435.905	0.06194	1E-09	0.680113786	1E-09	0.319886
	157	536.33	0.044749	0.06056	0.248839334	1E-09	0.690601
	87	614.657	0.034165	0.097209	0.000000001	1E-09	0.902791
	88	729.797	0.039737	0.156345	0.028364052	1E-09	0.815291

	133	845.65	0.055579	0.502099	0.064624845	1E-09	0.433276
	166	948.7	0.05165	0.147223	0.852482344	1E-09	0.000295
	223	1047.11	0.070671	0.421799	0.105127446	1E-09	0.473074
	196	1148.57	0.04005	0.028279	0.40020199	1E-09	0.571519
	218	1257.18	0.066021	0.226586	0.773254427	1E-09	0.000159
	160	1360.688	0.025722	0.124577	0.081407347	1E-09	0.794016
	159	1459.246	0.049341	0.566217	0.000000001	1E-09	0.433783
	235	1562.44	0.049922	0.020788	0.472498144	1E-09	0.506714
	214	1672.08	0.044256	0.331228	0.220414095	0.10042	0.347938
	181	1748.146	0.041759	0.637904	0.000000001	1E-09	0.362096
	263	1825.55	0.05423	0.433283	0.049979458	1E-09	0.516737
	251	1946.85	0.049824	0.548748	0.22293962	1E-09	0.228312
	262	2058.73	0.049059	0.693612	0.288265095	1E-09	0.018123
	257	2161.69	0.044872	0.089601	0.474512997	1E-09	0.435886
	365	2249.41	0.06046	0.175246	0.655918663	1E-09	0.168835
	314	2335.33	0.049672	0.564331	0.311326451	1E-09	0.124342
	275	2420.686	0.047094	0.460593	0.185823358	1E-09	0.353584
	288	2540.886	0.04526	0.438804	0.224339069	1E-09	0.336857
	306	2813.386	0.035544	0.507055	0.343722831	1E-09	0.149222

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
	7	59.41	0.033664	1E-09	0.000000001	1E-09	1
	18	157.26	0.019077	1E-09	0.000000001	1E-09	1
	9	250.26	0.003996	1E-09	1	1E-09	1E-09
	12	347.23	0.00288	1E-09	1	1E-09	1E-09
	54	451.22	0.044324	0.45592	0.283121316	1E-09	0.260959
	42	566.24	0.028257	1E-09	0.742600311	1E-09	0.2574
	81	656.403	0.041133	1E-09	0.329756263	0.169058	0.501186
	73	753.19	0.031864	1E-09	0.622645017	1E-09	0.377355
	97	849.23	0.032971	0.242243	0.466846437	0.007336	0.283575
	94	949.96	0.014737	1E-09	0.420080846	1E-09	0.579919
	99	1047.971	0.020039	1E-09	0.495272293	1E-09	0.504728
	91	1149.81	0.03131	1E-09	0.907236848	1E-09	0.092763
	115	1247.641	0.024847	1E-09	0.267745289	0.322738	0.409517
	179	1351.756	0.024413	1E-09	0.308406251	1E-09	0.691594
	96	1447.58	0.008981	1E-09	0.52552536	1E-09	0.474475
	98	1550.08	0.009032	1E-09	0.886851001	1E-09	0.113149
	121	1642.04	0.020706	1E-09	0.9998782	0.000122	1E-09
	187	1748.086	0.026887	1E-09	0.321608891	0.124311	0.55408
S.korea	101	1844.571	0.020601	1E-09	0.883739905	1E-09	0.11626

	187	1949.24	0.020521	0.038702	0.341584412	1E-09	0.619713
	155	2051.32	0.01755	0.381808	0.32458612	1E-09	0.293606
	187	2150.81	0.028826	1E-09	0.764716549	1E-09	0.235283
	192	2255.96	0.02039	1E-09	0.683420805	0.269384	0.047195
	213	2345.44	0.020892	0.032165	0.252856607	0.244496	0.470483
	189	2447.52	0.018386	0.320001	0.242310584	0.234298	0.20339
	237	2548.18	0.016482	0.307361	0.455501574	1E-09	0.237138
	287	2648.92	0.022273	1E-09	0.71436661	0.267158	0.018475
	260	2731.21	0.019039	0.027621	0.568348827	1E-09	0.40403
	194	2839.66	0.014791	0.185149	0.650658882	0.012125	0.152068
	259	2956.04	0.020974	1E-09	0.938035345	0.045409	0.016556
	215	3062.64	0.016326	0.171669	0.828331113	1E-09	1E-09
	197	3151.221	0.018088	0.166843	0.714786745	1E-09	0.11837
	286	3250.61	0.016612	0.240942	0.374046717	1E-09	0.385011
	271	3353.811	0.017294	0.022494	0.733846063	1E-09	0.24366
	235	3538.231	0.016392	0.148594	0.745983233	1E-09	0.105423
	276	3637.961	0.019791	1E-09	0.811201934	1E-09	0.188798
	234	3746.451	0.019218	1E-09	0.998337093	0.001663	1E-09
	241	3971.541	0.014352	0.132382	0.867618136	1E-09	1E-09

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
	4	77.65	0.025757	1E-09	0.000000001	1	1E-09
	21	155.3	0.025757	1E-09	0.000000001	1	1E-09
	42	247.56	0.060591	1	0.000000001	1E-09	1E-09
	40	366.66	0.049092	1E-09	1	1E-09	1E-09
	57	450.613	0.039946	0.119215	0.000000001	0.880785	1E-09
	73	542.77	0.055272	1E-09	0.855721576	0.144278	1E-09
Tokyo	142	639.96	0.039065	1E-09	0.426854803	0.573145	1E-09

	89	749.21	0.05072	1E-09	1	1E-09	1E-09
	98	848.03	0.061319	0.477	0.367498791	0.155502	1E-09
	138	951.586	0.062002	0.295224	0.000000001	0.704776	1E-09
	123	1059.13	0.044376	1E-09	1	1E-09	1E-09
	129	1149.598	0.053062	0.693751	0.000000001	0.251499	0.05475
	300	1249.225	0.052032	0.958534	0.005651504	0.035814	1E-09
	153	1336.155	0.03293	1E-09	0.000000001	1	1E-09
	92	1452.071	0.029613	0.668025	0.000000001	0.277081	0.054894
	112	1537.93	0.033812	0.576678	0.004740138	0.418582	1E-09
	158	1653.211	0.046576	0.311896	0.254946283	0.433158	1E-09
	136	1755.881	0.032462	0.696881	0.000000001	0.303119	1E-09
	142	1847.461	0.041138	0.063444	0.597073497	0.339483	1E-09
	156	1944.291	0.041146	0.663265	0.000000001	0.336735	1E-09
	115	2051.855	0.031191	1	0.000000001	1E-09	1E-09
	241	2149.263	0.050715	0.129133	0.535248595	0.335619	1E-09
	161	2241.748	0.03524	1	0.000000001	1E-09	1E-09
	184	2364.325	0.031299	0.718884	0.000000001	0.281116	1E-09
	239	2468.37	0.03322	1E-09	0.497105377	0.502895	1E-09
	129	2556.471	0.025035	1	0.000000001	1E-09	1E-09
	230	2631.951	0.030776	0.429362	0.021941898	0.548696	1E-09
	170	2768.693	0.029256	0.672816	0.155065946	0.172118	1E-09
	256	2927.988	0.034495	0.645196	0.055201729	0.299603	1E-09

	57	130.53	0.06895	1	0.000000001	1E-09	1E-09
	22	242.11	0.008261	0.548965	0.000000001	1E-09	0.451035
	161	350.86	0.057003	1E-09	0.000000001	0.686456	0.313544
	83	436.15	0.029806	1E-09	0.358317093	0.282816	0.358867
	77	547.84	0.02373	1E-09	0.000000001	0.09908	0.90092
	63	657.5	0.031939	0.155909	0.676471483	0.000304	0.167316
	113	748.01	0.045454	0.196267	0.497867676	0.289488	0.016377
	62	852.59	0.009383	1	0.000000001	1E-09	1E-09
	109	946.46	0.010566	0.118389	0.211535617	0.424149	0.245927
	212	1050.31	0.025707	1E-09	0.57446849	1E-09	0.425532
	221	1157.13	0.020741	0.205794	0.219551822	1E-09	0.574655
	170	1257.6	0.015903	1E-09	0.730931934	1E-09	0.269068
	134	1340.45	0.009698	0.182745	0.000000001	0.117028	0.700228
	150	1451.146	0.011026	1E-09	0.24699789	0.276503	0.476499
	136	1549.09	0.016139	1E-09	1	1E-09	1E-09
	248	1652.13	0.023001	0.310139	0.144928063	0.131067	0.413866
	175	1742.7	0.017215	1E-09	0.730624892	0.070781	0.198594
	170	1842.88	0.014651	0.549661	0.15692286	0.270191	0.023225
	206	1954.42	0.024048	0.610125	0.067569918	0.24222	0.080085
	292	2035.91	0.027506	0.069694	0.627272325	0.240197	0.062837
	266	2187.37	0.022401	0.866579	0.015370056	1E-09	0.11805
B.Aires	214	2243.73	0.015599	0.271557	0.297388723	1E-09	0.431055

	230	2318.63	0.020702	0.817177	0.071455989	1E-09	0.111367
	230	2452.14	0.015497	0.248477	0.357104407	1E-09	0.394419
	216	2571.53	0.015944	0.841075	0.097502265	1E-09	0.061423
	224	2676.61	0.016812	0.467367	0.289620079	0.046084	0.196928
	261	2762.98	0.017373	0.326094	0.491205148	0.041488	0.141213
	225	2806.19	0.016392	0.445786	0.366379326	1E-09	0.187835
	236	3013.03	0.017922	0.311378	0.479557124	0.157118	0.051948
	354	3163.02	0.01644	0.566787	0.212322401	0.157422	0.063468

Cities	Duration	Length	Junt_density	Primary	Secondary	tertiary	Residential
	7	75.45	0.026508	1E-09	0.000000001	1E-09	1
	16	128.06	0.023427	1E-09	0.000000001	1E-09	1
	34	290.48	0.034426	1E-09	0.000000001	0.153849	0.846151
	48	369.67	0.035166	1E-09	0.000000001	0.220792	0.779208
	116	454.42	0.039611	1E-09	0.703534175	0.00044	0.296026
	145	550.09	0.02545	1E-09	0.000000001	1E-09	1
	103	652.33	0.022994	1E-09	0.000000001	1E-09	1
	68	750.33	0.023989	1E-09	0.456505804	0.187504	0.35599
	86	854.68	0.024571	0.205574	0.000000001	0.044379	0.750047
	84	948.48	0.025304	1E-09	0.000000001	0.597187	0.402813
	202	1050.79	0.029502	1E-09	0.483445788	0.09136	0.425194
	189	1148.97	0.017407	0.064797	0.024178177	0.431247	0.479778
	158	1247.41	0.028058	1E-09	0.407243809	0.389271	0.203486
	128	1346.56	0.028963	0.047625	0.310457759	0.471839	0.170078
	154	1446.36	0.026273	1E-09	0.400564175	0.408951	0.190485
	201	1545.05	0.016181	1E-09	0.000000001	0.420284	0.579716
	188	1652.34	0.031471	1E-09	0.560550492	0.000121	0.439328
	166	1748.91	0.021156	1E-09	0.103195705	0.306071	0.590734
	128	1850.34	0.021618	1E-09	0.504701839	0.350941	0.144357
	272	1947.081	0.025679	1E-09	0.036202911	0.343792	0.620005
	216	2045.22	0.021514	1E-09	0.214949981	0.311399	0.473651
	246	2147.22	0.031203	0.035232	0.621529233	1E-09	0.343239
	197	2252.53	0.017314	0.201152	0.000000001	0.332093	0.466755
	223	2345.271	0.029847	0.19744	0.232646888	0.330495	0.239418
Perth	201	2445.221	0.028627	0.375348	0.223137295	0.316986	0.084528

	227	2551.9	0.032133	0.359658	0.420729652	1E-09	0.219613
	216	2659.82	0.022558	0.122813	0.246486604	0.381842	0.248859
	189	2723.47	0.022031	0.357849	0.2410234	0.233291	0.167837
	203	2851.05	0.024202	0.209488	0.414184248	0.325568	0.05076
	217	3140.78	0.022606	0.05911	0.380427792	0.47344	0.087023
	209	2854.77	0.01226	0.214823	0.000000001	0.785177	1E-09
	60	469.38	0.021305	1E-09	0.000000001	1E-09	1
	69	469.38	0.021305	1E-09	0.000000001	1E-09	1
	75	557.08	0.019746	1E-09	0.000000001	1E-09	1
	158	1359.69	0.013974	1E-09	0.000000001	1E-09	1
	98	175.92	0.017053	1	0.000000001	1E-09	1E-09
	121	175.92	0.017053	1	0.000000001	1E-09	1E-09
	96	175.92	0.017053	1	0.000000001	1E-09	1E-09
	155	744.698	0.055056	1	0.000000001	1E-09	1E-09
	89	1251.04	0.019184	1E-09	0.250487594	0.486283	0.263229
	284	1666.6	0.026401	0.105556	0.109036361	1E-09	0.785407
	173	2154.25	0.007427	1E-09	0.000000001	0.282595	0.717405
	311	3033.09	0.02209	1E-09	0.281805024	0.343587	0.374608
	195	2640.862	0.012496	1E-09	0.000000001	0.783968	0.216032
	276	3154.36	0.013315	1E-09	0.15939525	0.084911	0.755694
	366	3842.45	0.013793	0.126942	0.000000001	0.341878	0.531179
	367	3842.45	0.013793	0.126942	0.000000001	0.341878	0.531179
	168	2462.98	0.010556	0.01661	0.000000001	0.844782	0.138609
	151	2462.98	0.010556	0.01661	0.000000001	0.844782	0.138609
	250	3552.2	0.013794	0.137315	0.000000001	0.631074	0.231611
	262	3552.2	0.013794	0.137315	0.000000001	0.631074	0.231611
	217	2349.613	0.016598	1E-09	0.124582218	0.646176	0.229242
	270	2741.658	0.024438	0.321629	0.000000001	0.116138	0.562233
	278	2741.658	0.024438	0.321629	0.000000001	0.116138	0.562233
	317	3753.933	0.015184	1E-09	0.13393686	0.404446	0.461617
	270	3753.933	0.015184	1E-09	0.13393686	0.404446	0.461617
	351	3957.963	0.015412	1E-09	0.127032516	0.383597	0.48937
	362	3957.963	0.015412	1E-09	0.127032516	0.383597	0.48937
	199	2530.23	0.015809	0.242377	0.000000001	0.437174	0.320449
	22	241.96	0.012399	1E-09	0.000000001	1E-09	1
	35	20.766	0.192623	1E-09	0.000000001	1E-09	1
	61	469.38	0.021305	1E-09	0.000000001	1E-09	1
	74	469.38	0.021305	1E-09	0.000000001	1E-09	1
	73	469.38	0.021305	1E-09	0.000000001	1E-09	1
	142	1359.69	0.013974	1E-09	0.000000001	1E-09	1
	158	1359.69	0.013974	1E-09	0.000000001	1E-09	1
	198	1756.63	0.01594	0.225853	0.000000001	1E-09	0.774147
	199	1756.63	0.01594	0.225853	0.000000001	1E-09	0.774147
Sydney	41	396.94	0.022673	0.999496	0.000000001	1E-09	0.000504

	41	396.94	0.022673	0.999496	0.000000001	1E-09	0.000504
	39	396.94	0.022673	0.999496	0.000000001	1E-09	0.000504
	77	670.468	0.058168	1	0.000000001	1E-09	1E-09
	193	946.192	0.032763	0.64708	0.000000001	1E-09	0.35292
	274	3245.922	0.017252	0.036708	0.130850341	0.633518	0.198923
	130	1556.219	0.025061	0.176489	0.000000001	0.608933	0.214578
	153	1556.219	0.025061	0.176489	0.000000001	0.608933	0.214578
	215	2243.963	0.020054	0.051057	0.130447784	0.818495	1E-09
	218	2243.963	0.020054	0.051057	0.130447784	0.818495	1E-09
	189	2243.963	0.020054	0.051057	0.130447784	0.818495	1E-09
	91	838.443	0.022661	0.136646	0.000000001	0.379763	0.48359
	125	1455.603	0.019923	0.157364	0.000000001	0.521532	0.321104
	136	1455.603	0.019923	0.157364	0.000000001	0.521532	0.321104
	160	1948.603	0.014369	0.117551	0.000000001	0.767336	0.115113
	150	1051.918	0.04373	0.522387	0.000000001	0.153073	0.324541
	110	1051.918	0.04373	0.522387	0.000000001	0.153073	0.324541
	127	1051.918	0.04373	0.522387	0.000000001	0.153073	0.324541
	118	1149.876	0.02435	0.438252	0.000000001	1E-09	0.561748
	193	1852.538	0.031308	0.662674	0.000000001	1E-09	0.337326
	298	3448.47	0.015369	1E-09	0.132186158	0.077785	0.790029
	273	2965.804	0.018882	1E-09	0.153698626	0.37137	0.474932
	204	2047.59	0.014651	0.371363	0.000000001	1E-09	0.628637
	271	4026.12	0.013661	1E-09	0.256251677	0.25876	0.484988
	318	4639.87	0.010561	1E-09	0.130816165	0.057769	0.811415
	302	4377.08	0.012794	1E-09	0.138670072	0.415229	0.446101
	354	4841.05	0.011774	1E-09	0.125379825	0.471274	0.403346
	294	4377.08	0.012794	1E-09	0.138670072	0.415229	0.446101
	260	3651.423	0.01698	1E-09	0.166228344	0.41588	0.417892
	335	4184.863	0.015054	1E-09	0.145039396	0.362868	0.492093
	261	3338.78	0.014676	1E-09	0.181793949	0.102325	0.715881
	343	4452.302	0.015498	0.024851	0.13632723	0.325198	0.513624
	390	4452.302	0.015498	0.024851	0.13632723	0.325198	0.513624
	370	4511.043	0.015296	0.02538	0.134552032	0.407215	0.432853
	66	51.61	0.019376	1E-09	0.000000001	1E-09	1
	88	151.72	0.006591	1E-09	0.000000001	1E-09	1
	203	224.11	0.004462	1E-09	1	1E-09	1E-09
	92	348.46	0.011479	1E-09	0.000000001	1E-09	1
	121	469.62	0.008518	1E-09	0.614709765	0.38529	1E-09
	115	555.859	0.026985	1E-09	0.000000001	0.231946	0.768054
	104	650.346	0.023065	1E-09	0.000000001	0.167151	0.832849
	69	746.89	0.021422	1E-09	0.646159408	1E-09	0.353841
	116	849.38	0.018837	1E-09	0.619722621	0.380277	1E-09
	172	952.84	0.012594	1E-09	1	1E-09	1E-09
Mumbai	221	1051.429	0.025679	0.706429	0.000000001	0.293571	1E-09

	71	1153.91	0.014733	1E-09	0.721373417	0.057231	0.221395
	153	1249.55	0.010404	1E-09	0.000000001	0.687928	0.312072
	199	1343.81	0.015627	0.256629	0.383067547	0.134498	0.225806
	138	1449.921	0.018622	0.256545	0.429699963	1E-09	0.313755
	213	1552.9	0.009015	1E-09	0.000000001	0.553545	0.446455
	97	1652.696	0.019967	0.544553	0.000000001	0.219657	0.23579
	176	1749.19	0.022296	1E-09	0.134342181	0.393628	0.47203
	136	1850.67	0.014049	0.387562	0.285248045	0.32719	1E-09
	87	1942.489	0.020077	0.623329	0.218029549	0.158641	1E-09
	89	2049.5	0.018053	0.685035	0.184967065	1E-09	0.129998
	123	2151.15	0.01813	1E-09	0.368616786	0.559324	0.072059
	104	2246.84	0.018693	0.231352	0.460455573	0.308193	1E-09
	216	2352.957	0.020825	1E-09	0.816562734	1E-09	0.183437
	214	2450.11	0.01755	0.436503	0.533527066	0.02997	1E-09
	113	2553.58	0.017231	0.434171	0.101641617	0.403485	0.060703
	175	2641.42	0.014008	0.545896	0.159247677	0.032274	0.262582
	98	2751.18	0.017084	0.188941	0.170984814	0.498335	0.141739
	144	2865.15	0.017102	0.508357	0.090588625	0.241045	0.160009
	117	2954.24	0.015571	0.711719	0.142385182	0.145895	1E-09
	81	3054.53	0.015714	0.170177	0.154004053	0.448845	0.226974
	123	3129.96	0.014697	0.737195	0.114311365	0.023991	0.124503
	229	3341.06	0.013469	0.535237	0.231737832	0.025516	0.207509
	113	3433.17	0.01369	0.672087	0.104215637	0.021872	0.201825