Cartography M.Sc.

Master Thesis

Getting There is Half the Fun:
Intermodal Transport Comparison of Two Dissimilar Cities of AMS and BLR.

POORNIMA BADRINATH
September, 2023

SUPERVISORS:
Prof. Dr. M.-J. Kraak (Chair)

Technical University of Munich

TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology

TECHNISCHE UNIVERSITÄT DRESDEN

ITC UNIVERSITY OF TWENTE.

UNIVERSITY OF TWENTE.

STATEMENT OF AUTHORSHIP

I, Poornima Badrinath, solemnly affirm that the Master's thesis titled "Getting there is half the fun: Intermodal transport comparison and cartographic analysis of two dissimilar cities of Amsterdam and Bengaluru" presented herewith is the product of my own scholarly endeavour and intellectual exploration.

Enschede, 07.09.2023.

GETTING THERE IS HALF THE FUN:

Intermodal Transport Comparison of Two Dissimilar Cities of Amsterdam and Bengaluru.

POORNIMA BADRINATH

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.

University of Twente's Faculty of Geo-Information Science and Earth Observation Department of Geo-Information Processing.

SUPERVISORS:
Prof. Dr. M.-J. Kraak (Chair)

THESIS ASSESSMENT BOARD:
Prof. Dr. M.-J. Kraak (Chair)
Sagnik Mukherjee (Reviewer, TU Dresden)

ITC UNIVERSITY OF TWENTE.

STATEMENT OF AUTHORSHIP

I, Poornima Badrinath, solemnly affirm that the Master's thesis titled "**Getting there is half the fun: Intermodal transport comparison and cartographic analysis of two dissimilar cities of Amsterdam and Bengaluru**" presented herewith is the product of my own scholarly endeavour and intellectual exploration.

Throughout the course of this research, I have diligently undertaken the task of conceptualising, designing, and executing this study in its entirety. As the sole author, I take full responsibility for the originality, integrity, and authenticity of the content contained within this thesis.

In accordance with the principles of academic integrity and scholarly rigour, all sources, whether drawn from published works or unpublished materials, have been duly acknowledged and appropriately referenced. The contributions of fellow scholars, educators, and researchers have been diligently attributed through meticulous citation and acknowledgment. Any guidance, insights, or support received during the research and composition phases have been openly acknowledged, thereby recognising the collaborative and collective nature of scholarly pursuits.

I am keenly aware of the implications of academic misconduct and plagiarism, and I affirm that no part of this thesis has been copied, paraphrased, or borrowed without appropriate citation. I recognise the significance of upholding the highest standards of scholarly ethics and take pride in my commitment to the academic community.

Signed: Date:

________________________ ________________________

Poornima Badrinath

Getting there is half the fun: Intermodal transport comparison and cartographic analysis of two dissimilar cities of Amsterdam and Bengaluru.

Master Thesis

Poornima Badrinath
April-September, 2023

Thesis submitted to the Faculty of Geo-Information Science and EarthObservation of the University of Twente in partial fulfilment of the requirements for the joint Master of Science in Cartography.

Supervisor
Prof. Dr. M.-J. Kraak (Chair)

Thesis Assessment Board (TAB)
Prof. Dr. M.-J. Kraak (Chair)
Sagnik Mukherjee (Reviewer, TU Dresden)
Drs. B. Köbben

DISCLAIMER

ABSTRACT

The significance of comparing two seemingly dissimilar elements lies in its potential to uncover hidden similarities and identify areas for improvement. This research aims to explore the extent of similarity between two distinctly built cities, which, at a superficial level, appear to lack any common ground. By conducting a cartographic comparative analysis of their pervasive and ubiquitous transport networks, this study endeavours to elucidate the points of intersection, the ease of understanding the complexity of transport models with maps that helps visualise it dynamically and assess the potential for leveraging one city's navigation system to enhance the other. Through a comprehensive cartographic examination of the multimodal transport systems in Bengaluru and Amsterdam, this research aims to contribute to our understanding of urban mobility and highlight opportunities for optimisation. By delving into the complexities of these diverse cities, we seek to establish a framework for knowledge exchange and explore strategies to improve the efficiency and effectiveness of their transport infrastructures. The findings of this research have the potential to guide future urban planning initiatives and inform policymakers, enabling them to create more resilient, sustainable, and user-centric transport systems in cities worldwide.

Keywords: Navigation, Last Mile Connectivity, Pattern analysis, Comparative analysis urban transport, Cartographic multimodal networks, Urban mobility optimisation, City navigation systems leverage, Transport infrastructure efficiency strategies, Sustainable user-centric transport systems.

ACKNOWLEDGEMENTS

This Master's thesis and the concomitant research endeavour owe their existence and quality to the unwavering support and invaluable contributions of several individuals, whom I wish to acknowledge with deep appreciation.

First and foremost, I extend my heartfelt gratitude to Prof. Dr. Menno Jan Kraak, whose steadfast guidance and critical insights have been instrumental throughout this academic journey. His mentorship has enriched both the scope and depth of this work.

I extend my sincere thanks to Sagnik Mukherjee, an esteemed external reviewer, and Barend Kobben, members of the Thesis Assessment Board, for their meticulous evaluation and invaluable feedback, which significantly enhanced the rigour and robustness of this study.

I am profoundly indebted to Dr. H.S. Sudhira, whose expertise in transport systems and urban planning provided an essential foundation for comprehending the intricacies of transport networks. His insights have been pivotal in shaping the analytical framework of this research.

I wish to thank Yuhang Gu, for his help in understanding the workings of the space-time cube.

I wish to acknowledge my colleagues in the realm of cartography, whose invaluable discussions and perspectives have lent valuable dimensions to my work. Their camaraderie has fostered an environment of intellectual growth and exchange.

Lastly, I express my gratitude to all the participants, and friends who generously contributed their time and insights by participating in the user study questionnaire. Their perspectives have added depth and authenticity to the exploration of transport challenges.

There were many mapping inspirations used for this study and each of the mapping examples and instagram posts have been appropriately referenced and credited.

Finally, I thank everyone who has been my wise soundboards, offline editors and a great support during the entirety of the course. Your support has been invaluable in the successful completion of this thesis.

Poornima Badrinath

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF TERMS

1. Accessibility: Accessibility refers to the ease with which people can reach and use various facilities, services, and opportunities in a physical or social environment.
2. Data comics: A graphic novel-style representation of data or design graphic visualisation.
3. Data visualisation: The representation of data in a visual format, such as charts, graphs, and maps.
4. GIS: Geographic Information Systems.
5. Gaps: Gaps refer to the deficiencies or shortcomings in the transport infrastructure that impede or hinder effective and efficient movement of people and goods within a city or region.
6. Infrastructure: The physical structures and systems that support a society, such as roads, bridges, and power grids.
7. Intuitive design: Intuitive design refers to the process of designing products or systems that are easy to use and require minimal instruction or training.
8. Last-mile connectivity: Last mile connectivity refers to the final leg of the transportation network that connects people to their final destination, such as their home or workplace, and is often the most challenging and expensive part of the journey due to the need for short-distance transportation modes and infrastructure.
9. Mobility: The ability of people and goods to move from one place to another.
10. Multimodal transport systems: Transportation systems that involve the use of multiple modes of transportation, such as buses, trains, and bikes.
11. NMT: Non Motorised Transport
12. Navigation patterns: The ways in which people move through and interact with urban environments.
13. Navigation system: A system that provides information and directions to help a user navigate from one location to another.
14. Smart cities program: Launched by Govt. of India in 2015, The program focuses on using technology and data-driven solutions to improve the quality of life for residents, promote sustainable urban development, and enhance economic growth.
15. Spatiotemporal data: Spatiotemporal data refers to data that contains both spatial and temporal components, meaning it includes information about both the location and time of events or phenomena being observed.
16. Spatial analysis: The process of examining and understanding patterns in geographic data.
17. Temporal analysis: The process of examining and understanding patterns in time-based data.

18. Transport index: A city's metric of how effective the infrastructure for navigation is.
19. Transport Infrastructure: Physical facilities, structures, and systems designed to support the movement of people and goods from one location to another, including roads, railways, airports, seaports, and related facilities for various modes of transportation.
20. Transport Systems: A transport system refers to the network of physical infrastructure, modes of transportation, and operations that enable the movement of people and goods from one location to another within a geographic region.
21. Urban planning: The process of designing and managing the physical and social development of cities, towns, and other urban areas.
22. Urban structure: The physical layout and organisation of a city or urban area, including its buildings, streets, and public spaces.

1. INTRODUCTION

Navigation, despite its deceptively simple appearance, embodies a complex and multi-faceted system that amalgamates numerous elements. Since time immemorial, humankind's inherent drive to traverse from one location to another has been fuelled by curiosity, exploration, and the pursuit of resources. Navigation, as an essential aspect of human existence, has evolved over centuries, seeking to expedite and optimise the process of movement (O'Conner, 2020; Hofmann-Wellenhof et al., 2016). Navigation defines the process of determining and following a specific route or course to reach an intended destination. It involves utilising various tools, techniques, and sources of information to guide the movement of individuals, vehicles, or vessels through known or unknown territories (Parkinson, B. W., & Spilker, J. J., 2007).

Comprehending navigation, in its entirety, presents a challenging endeavour given its multifaceted and intricate nature. The intricacies of navigation encompass a web of interconnected elements that impact daily life and the overall ecosystem of a place, whether it be a village, town, or city. The effectiveness of a transportation network depends on critical components such as infrastructure, timeliness, accessibility, frequency, and their interplay. Any deficiency in these elements can significantly diminish the efficiency of the entire system.

To enhance efficiency, urban authorities often derive inspiration from effective networks implemented in other cities or towns, both nationally and internationally (Griffiths, 2021). Developing nations, in particular, exhibit a keen interest in adopting concepts from more developed countries to improve their own transport networks. India, with its rich cultural and historical tapestry, exemplifies the interplay between indigenous architecture and influences from around the world.

One noteworthy aspect of this evolution is the interplay between architectural styles and navigation networks. In the Indian context, numerous cities bear witness to the fusion of indigenous architectural traditions and influences from around the world, particularly from European colonial powers (Dutta et.al, 2017). These architectural resemblances serve as tangible reminders of the historically significant connections between India and Europe. For instance, Mumbai's colonial-era buildings evoke architectural similarities to those found in London and Manchester, while Panaji in Goa has a charming resemblance to the streetscapes of Lisbon and other Portuguese cities. Additionally, cities such as Kolkata, Pondicherry, Chennai, Shimla, and New Delhi exhibit fascinating blends of indigenous and European architectural styles, reflecting cultural exchange and colonial legacies. Understanding the influence of European architecture on these Indian cities is crucial for comprehending the interplay between urban design and navigation networks (Mehrotra, 2016). By exploring this intricate relationship, researchers can gain insights into the historical, cultural, and practical factors that have shaped the transport networks in these cities.

However, it is vital to recognise that, while these architectural resemblances exist, the transportation needs and challenges of each city are unique. Implementing a transport system that works effectively in one city may not yield the same results in another. Inefficient systems and wasteful infrastructure often emerge when solutions are replicated without considering the specific context and needs of each city.

In conclusion, navigation, as a fundamental aspect of human existence, has undergone significant modifications over time. Historical, cultural, and practical elements have all impacted the development of navigation networks. The interplay between indigenous and foreign architecture has also shaped the design of transport networks in Indian cities. Designers and planners must consider the unique characteristics of each city while drawing inspiration from other models when developing new transportation systems. Research in this area should continue to explore the interrelated domains of navigation and architecture to improve urban design.

1.1. Research Identification

The crux of this research endeavours to undertake a focused exploration by extensively scrutinising comparative maps of two ostensibly different cities, namely Bengaluru in India and Amsterdam in the Netherlands, thereby seeking to unravel the intricate interplay between their transportation systems and city designs. Despite distinct differences such as Bengaluru's topography, disjointed lakes, and Amsterdam's intricate canals, this study aims to shed light on the conjoined challenges of navigating urban regions while taking into account the influence of European architectural designs in an Indian context. Through meticulous analysis and examination of these cities, this investigation aims to unravel the complexities inherent in urban transportation systems, enabling us to arrive at better decisions and improve transportation systems globally, while also acknowledging the crucial role of maps in articulating these complexities.

1.1.1. Research Aim

The primary aim of this study is to investigate the potential of cartographic design in visually representing the complexities of transportation and navigation systems, along with their attendant challenges, in a manner that is engaging, aesthetically pleasing, and easily comprehensible to a diverse audience. Although the urban infrastructure domain is expansive, the study seeks to narrow down key concepts and present them in a simplified form, thus providing a stepping stone for further research and facilitating the development of more optimal public and private transportation infrastructure, particularly in smaller urban centres. This approach holds significant ramifications for policymaking, particularly for influential stakeholders with limited comprehension of navigation infrastructure (Bertolini et al., 2015).

1.1.2. Why is it Important?

Maps are an essential tool for analysing traffic, public transport infrastructure, and urban planning (Mehaffy et.al, 2020). By comparing the transport systems of two dissimilar cities and identifying the variations in their infrastructure, in the transport network like lack of public transport, or lack of connectivity in certain areas, and the time difference taken to commute the same distance in different peak hours, it is possible to highlight areas for potential improvement.

The study seeks to understand the commonalities that exist between two vastly different cities, and how those commonalities can be used to address the challenges posed by multi-modal transport. The aim is to utilise cartographic and design techniques to understand the gaps in the transport of these cities, and to identify the factors that differentiate them.

Ultimately, this research aims to contribute to the development of strategies that can be used to improve the efficiency and effectiveness of multimodal transport systems in both cities, and shed light on how maps can help with that study. Previous studies have also highlighted the importance of cartography and data visualisation in analysing transport systems and urban planning (Giaoutzi, 2021; Cao et al., 2020, Scheurer & Curtis, 2016, 2018;).

1.1.3. Elucidating Research Objectives

Main Research Objective

The main research objective is to understand what kinds of comparison can be done with perspective data, that is using user centric points selected and compared with the available public transport data and driving data to identify the gaps. Defining the gaps visualised with the data and understanding the patterns that the analysis yield.

The key aspect of this research objective is to verify how much of one city's transport model can be applied to another city and if it is even possible to do that, considering the dynamically different ways cities are usually built, no matter the similarities that appear.

The detailed objective of this research is defined in the next section.

Sub Research Objectives:

SRO1: Analysing Commute Disparities: Investigate the underlying reasons why the time taken to travel the same distance in Bengaluru is nearly double that of Amsterdam. This involves understanding whether the inefficiency is attributable to the transport system's efficiency, urban sprawl, population density, or other contributing factors.

SRO2: Development of Spacetime Cube Environment: Create a spacetime cube environment integrated with linked map visualisations to facilitate a comparative examination of the transportation systems of the two cities. This aims to highlight both commonalities and discrepancies, offering insights into the current transport structures and the potential for introducing new transportation modes seamlessly.

SRO3: Interactive Comparative Web Map: Construct an interactive web map featuring diverse data visualisations. The map will portray the temporal and spatial dimensions of the two cities' transport systems for equivalent distances. The interactive nature of the visualisations will empower users to explore and manipulate the data representations for enhanced comprehension.

SRO4: Time as a Key Factor: Focus on time as a pivotal factor for interpreting spatial information regarding transport infrastructure in the compared cities. The objective is to identify patterns that shed light on the factors contributing to inefficient transit systems. This involves using time and space to visually illustrate issues and recognise patterns that can be considered as potential solutions, rather than providing definitive solutions outright.

By delineating the main and sub research objectives, this study strives to shed light on the dynamics of urban transport systems, drawing on cartographic tools to elucidate complexities and provide meaningful insights for urban planning and transportation optimisation.

1.1.3.1. Possible Outcomes

- Illustrate time and space dimensions of both cities' transport systems for equivalent distances.
- Develop an interactive web map featuring diverse map data visualisations and enable users to explore and manipulate the visualisation.

1.1.4. Research Challenges

Transport encompasses a very wide array of elements and a detailed comparison requires a massive amounts of data and a very intense processing to understand every aspect and modes of transport and their efficiencies and inefficiencies. The main challenges regarding this particular field of study is:

Diverse Transport Elements and Metrics:

It's broad spectrum of elements, including modes, infrastructure, and services, each with distinct performance metrics that defy uniform comparison. Metrics such as speed, capacity, accessibility, and cost vary across modes, further adding to the intricate nature of assessment.

Intricate Data Collection and Integration:

Gathering data from diverse sources—surveys, sensors, government records, and private databases—across various transport elements poses a significant challenge. Ensuring data accuracy, consistency, and comparability demands meticulous integration, a process prone to complications.

Complex Interaction and Contextual Factors:

Transport elements interact dynamically, with changes in one facet influencing the entire system. Additionally, geographic variations, socioeconomic dynamics, and policy influences introduce localised complexities that affect system performance in unique ways.

Evolving Nature and Stakeholder Dynamics:

Transport systems are in a constant state of evolution due to technological advancements, urban development, and shifting user behaviours. The multifaceted involvement of public and private stakeholders introduces further complexity, necessitating careful consideration of their respective roles.

The main challenge faced in this research was determining which aspect to include and investigate for the comparison of transport systems in two different cities. To streamline the process and specifically analyse the cartographic significance of these systems, the study focused primarily on the element of time and how its changes affect transit in both cities. This approach enabled a thorough understanding of similarities and differences in the cities' transport methods and how time plays a crucial role in their functionality.

To carry out this research, the established City's mobility indicators index was utilised to compare the relationship between the identified elements and time, exploring potential gaps and assessing the efficacy of each city's approach. Furthermore, the study aims to determine if one city's more efficient approach could be used to inform the transport model for the other city.

To address these challenges, a focused approach was employed, emphasising time as the central factor for comparison and utilising established indices. The results of this study provide significant insights into the intricacies of transport systems while acknowledging the multifaceted nature of the subject.

1.2. Thesis Structure

Introduction:
The first chapter is about introducing the concept of navigation and intermodal transport, and elucidating what this research tries to achieve in its objectives, research questions and the subsequent challenges.

Background and Related Work:
This chapter highlights the fundamentals of public transport, the related transport research conducted and understanding the basics needed to optimally analyse the complexities of transit models. It also draws parallels from the previous works done in this regard, in comparison studies and in space time cubes symbolising the relationship between the space a route covers to the time it takes.

Methods and Findings
This chapter highlights the work done and the methods used to collect the data, filter the data to the required format and zeroing in on the visualisation techniques that highlight choosing the concepts based on how simple the concepts could be for normal users to understand the complexities of transport systems gaps in a simple way, and summarises the analysis and highlighting the gaps that were elucidating in introduction and the methods. Understanding the concept of gaps is drawn from the findings, and the main gaps visualised is highlighted and explained.

Results and Discussion:
The main part of this research is to highlight how and where the patterns emerge to understand how similar or different the two chosen cities are from each other, how or if the patterns emerged from one city can be helped in designing or translating to the development of another city's transport systems. The discussion is to further highlight how the patterns have been identified, and what insights the user survey gathered.

Conclusion:
In conclusion, the research is summarised with the work done, the challenges faced and the results obtained. Also, highlighting the future work and the potential prospects in this line of navigation research.

2. BACKGROUND AND RELATED WORK

2.1. Influence of European Cities on Indian cities

The impact of European cities on Indian urban development has been a substantial issue, shaping various aspects of architecture, infrastructure, culture, governance, and lifestyle (Smailes, 1969). The British, Dutch, French, and Portuguese colonial powers established settlements and trading posts across India, leaving a lasting imprint on the urban landscape (Mukherjee, 2008). These influences have resulted in positive and challenging transformations in Indian cities.

Architecturally, European colonial powers disseminated styles that integrated European designs with regional features. As a result, iconic buildings, government structures, churches, and monuments were constructed that still stand today as reminders of colonial past (Jørgensen, 2019). Cities like Mumbai, Kolkata, and Chennai feature architectural influences that reflect the grandeur of the colonial era. Urban planning and infrastructure development were also strongly influenced by European models. Cities shaped by colonial powers often had organised layouts, well-defined streets, and public spaces. Concepts of sanitation, water supply, and transportation systems were introduced initially to cater to the needs of colonial rulers (Madakkam, S., & R. Ramaswamy, 2013). These systems later laid the groundwork for modern urban development.

Culturally, European influences impacted art, education, and lifestyle. The establishment of educational institutions, libraries, and cultural centres by colonial powers significantly influenced intellectual and cultural exchanges. Western education systems were introduced, shaping the social fabric and intellectual pursuits of Indian cities (Kamerkar, M. P., 2000).

However, European influence also had negative implications. Colonial rule led to socio-economic disparities, with certain areas of cities developed at the expense of others. The transformation of urban landscapes often disrupted local communities and cultural practices forcefully. Moreover, the introduction of European systems sometimes overshadowed indigenous methods, leading to a detachment from traditional practices (Beverley, E. L. 2011).

In modern times, European cities continue to influence Indian urban development through concepts like sustainable urban planning, heritage conservation, and smart city initiatives (Beverley, E. L. 2011). Exchange programmes, tourism, and globalisation have fostered continued interactions between European and Indian cities. In conclusion, European cities had a significant influence on Indian urban development, shaping various aspects of Indian cities' architecture, infrastructure, culture, governance, and lifestyle. The impact has both positive and challenging elements. Nevertheless, the legacy of European influence still reverberates in contemporary Indian urban development, and the transport infrastructure is one area where this influence is visibly seen.

2.2. Defining Navigation, Intermodal Transport and Transport Network Efficiency

Navigation often encompasses understanding geographic positions, calculating distances, considering obstacles, and making decisions to ensure efficient and safe travel from one point to another. Whether on land, sea, or air, navigation involves the use of maps, charts, instruments, and technology to ensure accurate and successful journeys.

Urban mobility, in the context of navigation, refers to the movement of individuals and goods within urban environments using various transportation modes and networks. It encompasses the intricate web of transportation options available within cities, including public transit systems, private vehicles, cycling, walking, and emerging mobility solutions. Urban mobility also considers the challenges associated with navigating through densely populated areas, congested streets, diverse transportation options, and varying infrastructure.

Effective urban mobility involves not only providing viable transportation choices but also optimising the coordination, accessibility, and efficiency of these options. Navigation within urban mobility entails guiding individuals and goods seamlessly through a city's complex network of routes, pathways, and transportation modes. It often involves using navigation technologies, maps, real-time data, and route planning to ensure efficient, convenient, and sustainable movement within urban environments. There are three main stakeholders involved in the urban mobility problem: the users of urban infrastructure (passengers), transportation service providers, and public municipal authorities (PMAs), as elucidated by Carvalho et al. (2015), in understanding the efficiency versus satisfaction in public transport systems.

Public transport systems are one of the finest examples of intermodal or multimodal transport. Intermodal transport, also known as multimodal transport, refers to the movement of goods or passengers using multiple modes of transportation within a single journey. This approach involves seamlessly transitioning between different transportation modes, such as trains, trucks, ships, and planes, to optimise the efficiency, convenience, and overall effectiveness of the transportation process.

In the context of intermodal transport, navigation plays a pivotal role in ensuring the smooth coordination and successful execution of these complex journeys. Navigation technologies and systems guide each mode of transport through its designated route, enabling accurate tracking, real-time updates, and precise timing for mode transitions. Effective navigation ensures that intermodal journeys are seamless and synchronised, minimising delays, enhancing reliability, and maximising the benefits of combining various modes of transportation. It enables the efficient movement of goods and passengers across diverse transportation networks, making intermodal transport a powerful solution for addressing the challenges of modern logistics and travel.

Intermodal transport, when defined in the context of public transport, is the efficient way to connect between two modes of transport to reduce the time to reach your destination from the point of your origin. Simply put, if you take a bicycle to reach a bus stop, which in turns leads you to an interchange in the nearest metro station or a tram stop before you reach you destination, it becomes multimodal or intermodal transit. It is the relationship between the smooth transitions in these modes of public transport that analyses the patterns and tries to measure the efficiency in this research.

There are several compelling research studies conducted in the field of measuring the efficiency of multimodal or intermodal transit systems. According to SteadieSeifi et al. (2014), their literature review on multimodal freight transportation planning illustrates the variety of models being used. In practical applications, diverse transportation network topologies exist, including direct link, corridor, hub-and-spoke, connected hubs, static routes, and dynamic routes. Notably, consolidation systems are frequently configured as hub-and-spoke networks, where the hub functions as a freight handling (consolidation) facility. The determination of hub locations and the allocation of spoke nodes to these hubs are key considerations in this network configuration (Woxenius, 2007). This approach integrates the reference to the research by SteadieSeifi et al. (2014) and seamlessly connects their findings with the discussion on transportation network topologies and consolidation systems. These network hubs play a key role in understanding the efficiency is defined and where the additional transit routes can be defined or applied. Similar pattern identification is what this research is aiming to achieve or identify to further the research in applications of efficiency methods in public transport. SteadieSeifi et al. (2014) also highlight the possibility of a feasible service plan, feasible service routes, using neural/space-time networks to efficiently connect the nodes in a manner that offers the best way to reach it.

In a broader context, the concept of Public Transport System (PTS) encompasses more than just the physical movement of passengers; it inherently creates value across both spatial and temporal dimensions. Hamid Saeedi, Behzad Behdani et al. (2019), elucidate the concept of multimodal transit from the perspective of freight trains and highlight these transport networks are crucial for the goods to move around with the time stipulated to reach the users. Also highlighted by Brkljač et al. (2013), this value synthesis arises from the intricate interplay between spatial and time factors. Spatial value manifests through the dynamic adjustment of transit routes and stops, aligning with passengers' preferences for accessible and well-connected locations. Simultaneously, time value emerges by guaranteeing that transportation services are available precisely when and where required by

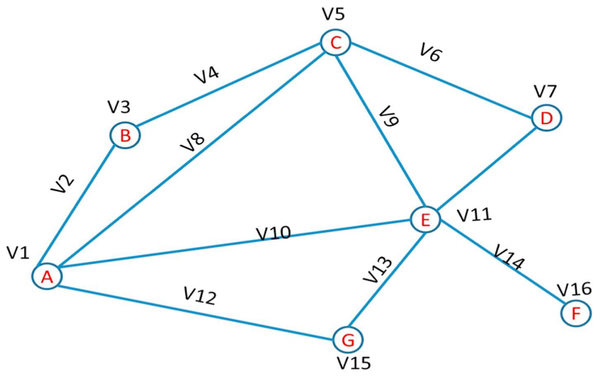


Fig 2.3.1: Transport Network Movement
Source: Saeedi et al., 2019

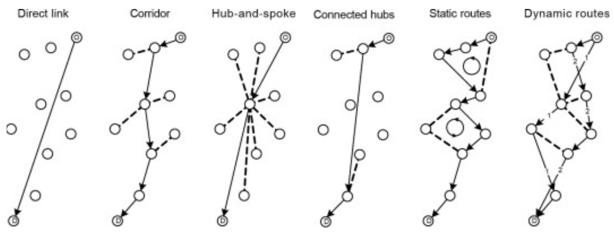


Fig 2.3.2: Transport Hubs and their types.
Source: Woxenius, 2007

passengers. This interdependent relationship between spatial and temporal aspects forms the cornerstone of an effective PTS. When passengers experience timely and convenient transit services that align with their intended destinations, the practical value of the service becomes palpable. This conceptual framework accentuates the pivotal role of synchronised spatial and temporal coordination in unlocking the potential of a PTS to deliver enriched user value and streamline transport operations.

Just as it holds for urban mobility, where the interplay of space and time enhances transportation efficiency, this notion resonates profoundly within the realm of navigation networks. Just as passengers derive value from being at the right place at the right time, navigation networks ensure that information flows seamlessly across space and time, enabling users to navigate optimally through interconnected routes, pathways, and transportation modes. By aligning spatial understanding with temporal considerations, navigation networks empower users to navigate efficiently, make informed decisions, and experience the value of streamlined transport operations firsthand. In essence, the synchronisation of space and time in navigation networks mirrors the core essence of enhanced user value and operational optimisation that the conceptual framework underscores in the context of a PTS.

2.3. Complexities of Transit Networks

Understanding transit systems encompasses navigating a multitude of complexities arising from the intricate interplay of various factors. Transit systems comprise networks, vehicles, infrastructure, operations, and user behaviours that collectively enable people's movement within urban and suburban areas. Transit networks feature routes, stops, and transfer points that require meticulous planning to ensure efficient operations. The network of transit systems is complex, and its understanding and analysis involve intricate calculations to analyse massive amounts of data and understand the evolving patterns.

The complexity of transit systems arises from the multifaceted infrastructure, including roads, railways, airports, and more, which require meticulous planning, construction, and coordination. Integration of different modes of transport like cars, buses, trains, planes, and ships compounds the challenge. Rapid urbanisation strains existing systems, causing congestion and increasing demand for public transit. Human behaviour, influenced by culture and socioeconomic factors, adds unpredictability. Technology like autonomous vehicles reshapes systems but necessitates safety measures. Environmental concerns mandate balancing mobility with sustainability. Stakeholders range from government agencies to the public, making effective coordination necessary.
Stringent policies address safety, environmental impact, and operations. Crisis readiness, economic impact, cultural nuances, and long-term planning add layers. Transportation's global reach, interdisciplinary nature, and economic significance amplify the intricacy.

Each mode of transport presents unique operational characteristics, infrastructure needs, and regulations, necessitating seamless coordination. Transit systems' complexity can be explained by the theory of complex networks, which classifies them into public transportation route networks, public transportation transfer networks, and bus station networks. The network parameters' practical significance was analysed, (Lu Huapu et al. 2007).

Small-world networks and scale-free networks are two well-known and much-studied classes of complex networks considered in network analysis. Small-world networks are characterised by a high degree of local clustering (nodes being interconnected) and short average path lengths between nodes. These networks offer a balance between local connectivity and global reach, making them more relevant to the structure of public transit systems (Newman & Watts, 1999; Watts & Strogatz, 1998).

Relevance to Public Transit Complexity:
Public transit systems exhibit characteristics that align more closely with small-world networks:

- **Local Clustering:** In public transit systems, local clustering is evident through routes that connect nearby stops and facilitate movement within neighbourhoods

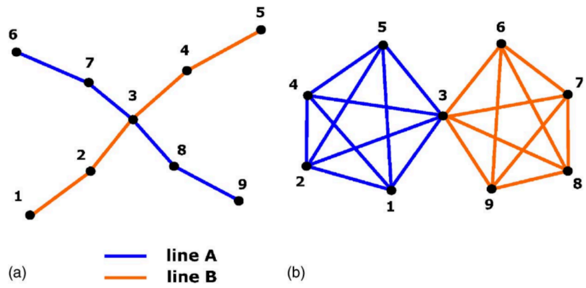


Fig 2.3.3: Explanation of the space L and the space
Source: P. Sienkiewicz. Et al. 2005

or regions. Passengers tend to travel between neighbouring stops, creating clusters of activity.

•**Short Average Path Lengths:** Public transit systems aim to provide efficient connections between different parts of a city or region. The goal is to minimise travel times and ensure that passengers can reach their destinations relatively quickly.

•**Efficient Connections:** Just as small-world networks optimise global reach through short paths, public transit systems aim to efficiently connect different areas to provide accessibility for passengers across the network.

- **Integration of Modes:** Public transit networks often involve various modes of transportation, such as buses, trains, trams, and metro lines. Small-world networks' characteristic of integrating different types of connections aligns with the multimodal nature of public transit.
- **Navigability:** Small-world networks are known for their navigability, allowing for efficient movement between nodes. This concept relates to the ease with which passengers can navigate public transit routes and transfer points.

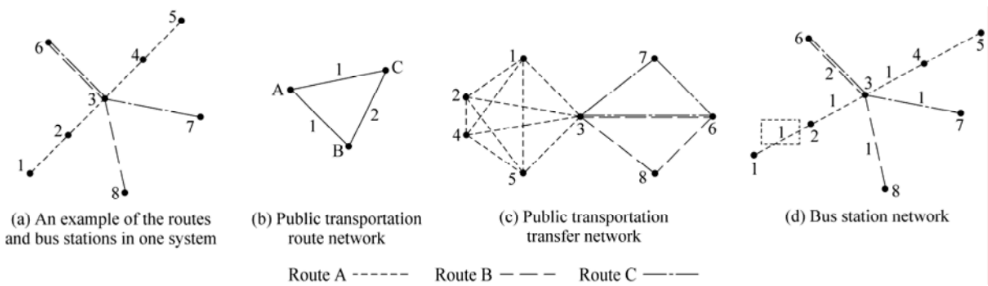


Fig 2.3.4: Sketch of public transportation networks.
Source: Lu Huapu et al. 2007

While both scale-free and small-world network concepts are extensively studied in network science, the small-world network concept appears to better capture the structure and operational dynamics of public transit systems. Small-world networks offer a balance between local connectivity, allowing for efficient travels between nearby stops, and global reach, allowing for easy access to more distant locations, making them more relevant to the structure of public transit systems (Newman &

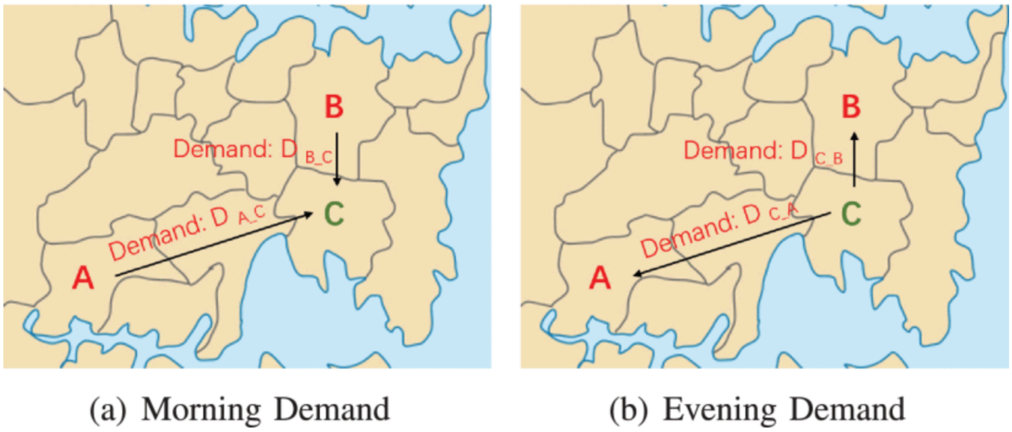


Fig 2.4.1: Areas and demands: peak hour and non peak hour traffic flows.
Source: C. Li. et al. (2022)

Watts, 1999). However, it is essential to note that public transit networks can exhibit a mix of characteristics from both types and involve additional complexities beyond network structure, such as scheduling, user behaviour, and operational management, making transit networks a unique case of complex networks.

The realm of small-world networks is exceptional for understanding the intricate patterns involved in making transport systems transparent, efficient and identifying where elements might not be functioning optimally. For instance, the small-world network approach can help identify important transit hubs and optimise their utilisation by analysing connectivity between different transit modes (Chen et al., 2022).

2.4. Patterns in Driving versus Public Transport Systems

The behaviour that emerges in complex network analysis of transportation systems is commonly referred to as patterns. These patterns provide insight into a variety of factors, including travel time between points, preferred modes of transportation, peak hours, changes in travel direction or user preferences, footfall in certain areas over time, and the need for new transportation infrastructure based on current usage patterns. (Batty, 2013)

Driving is not exempt from this pattern behaviour and is influenced by the urban infrastructure and public transportation behaviour. Factors such as traffic flow, delays due to construction or incidents, peak and non-peak hours, traffic signals, turn restrictions and one-ways, all present opportunities for potential inefficiencies or gaps in the system. (Currie, 2004)

Understanding these patterns is crucial in identifying areas for further research and potential improvements in transportation systems. Common behaviours that can be identified as patterns include travel time, usage of transportation modes, congestion, and spatial-temporal distribution. (Li et al., 2022)

Therefore, to understand where this research is heading, identifying patterns is paramount. The subsequent analysis and identification of potential gaps in the system will enable policymakers and stakeholders to address inefficiencies and work towards more optimal transportation networks. (Avelar et al., 2019), and below highlighted are some of the common behaviours that can be identified as patterns.

Patterns in Driving:

- Driving patterns can be defined as a set of behaviours and decisions made by individual drivers in different driving situations. These patterns reflect habits, personal preferences, driving experience, and responses to various road and traffic conditions. (Bouhsissin et al., 2022)
- Driver characteristics are also reflected in driving patterns, such as age, gender. For instance, younger drivers tend to take more risks while driving and have a higher involvement in car crashes, while older drivers tend to drive more slowly and carefully. (Fernández, Susel & Ito, Takayuki., 2015)
- Driving patterns are not static but can adapt to different driving situations, such as the level of congestion, speed limits, and road infrastructure. Some drivers might adopt a more aggressive driving behaviour when encountered with heavy congestion, while others might drive more cautiously. (Keyvanfar et al., 2018)
- These individual driving patterns ultimately impact traffic flow and congestion, contributing to driving behaviour that can create additional delays and traffic issues such as sudden braking, abrupt lane changes, and following too closely. (Zhang et al., 2011)
- Studying driving patterns often involves collecting data from different sources such as GPS devices, traffic cameras, and sensors. By analysing this data, insights into how drivers navigate the road environment can be gained. (Chen et al., 2022)

Patterns in Public Transport Systems:

- Patterns in public transport systems can be defined as the collective behaviours and dynamics of the entire transportation network. These patterns reflect service frequencies, passenger demand, route structures, transfer points, and interactions with traffic patterns. (Ma et al., 2013)
- Public transport patterns are influenced by a variety of factors, including socioeconomic indicators such as income, density and level of development of the surrounding area, urban planning, and shifts in employment centres. The collective influence of these factors can create patterns of usage that can be studied and optimised. (Ma et al., 2013)

- Public transport systems operate along predetermined routes and schedules that may be continuously adjusted based on passenger demand, peak hours, and special events. These shifts can create new patterns of passenger behaviour, which need to be understood and incorporated into the transportation system. (Jenelius, 2018)
- The reliability of public transport services is affected by traffic patterns as buses and trains share the road space with individual vehicles. Congestion and road conditions can impact the operational efficiency and reliability of public transport services, creating patterns of usage and feedback loops. (Jenelius, 2018)
- Studying public transport patterns requires analysing data on ridership, schedules, service interruptions, and operational efficiency. This data can come from sources such as fare collection systems, passenger surveys, and real-time tracking, providing valuable insights and opportunities for improvement in the transportation system. (Ma et al., 2013)

Intersections and Overlaps:

While driving patterns and public transport patterns are distinct, there are intersections between the two domains. Traffic congestion can impact the reliability of public transport, while public transport usage patterns can influence road traffic demand. Urban planners and transportation officials consider both sets of patterns to optimise transportation networks, alleviate congestion, and provide efficient and accessible mobility options for individuals and communities.

Patterns in driving refer to individual driver behaviours in the road environment, including speed choices, lane changes, turning manoeuvres, adherence to road rules, and covering distances. Individual driver characteristics such as age, gender, and driving experience also influence driving patterns and impact traffic flow and congestion dynamics. Such patterns are analysed using GPS devices, traffic cameras, and sensors placed on vehicles, providing insights into driver navigation processes (Lemonde, C. et al, 2021; Thomson, 1977).

Patterns in public transport systems focus on the collective behaviours and dynamics of transportation networks providing mobility solutions for larger populations. These patterns include service frequencies, passenger demand, route structures, transfer points, and interactions with traffic patterns, such as congestion and road conditions. Various factors influence public transport patterns, including population density, urban planning, socioeconomic factors, and shifts in employment centres. Data sources such as fare collection systems, passenger surveys, and real-time tracking provide valuable insights for optimising transportation systems (Zhang et al., 2011.

Efficient urban mobility requires considering aspects of both types of patterns. Optimising driving and public transport patterns are necessary to provide a solid foundation for sustainable urban transportation infrastructures, curb traffic congestion, and facilitate efficient transportation (Zhang et al., 2011).

2.5. Cartographic Influences on Transport Models and How Best to Visualise Them

Cartographic influences on transport models entail the application of map-making principles to enhance the representation, analysis, and communication of transportation-related data. It involves contextualising data spatially, allowing transport models to incorporate geographical components such as road networks and transit routes. By transforming data into visual forms, cartography facilitates the intuitive representation of complex information, making it comprehensible to a wide audience (Wilson 2011).

One significant aspect is the creation of maps that illustrate various transportation scenarios, enabling decision-makers to assess the potential outcomes of different choices and make informed decisions about transportation infrastructure and policies (Miller, 2013). Moreover, Geographic Information Systems (GIS), an integral component of cartography, enables accessibility analysis, visualising the ease of reaching vital destinations like schools and healthcare facilities, aiding in identifying underserved areas and crafting equitable transportation solutions

Cartography uncovers spatial patterns and relationships that may remain obscured in tabular data, such as the proximity of transit stops to residential areas, aiding planners in understanding potential transit ridership (Liu et al., 2022). Furthermore, cartography serves as a powerful communication tool, bridging the gap between technical analysis and practical decision-making. By visualising complex concepts in map format, it simplifies conveying insights, trends, and potential impacts of diverse transportation strategies.

In essence, cartographic influences on transport models empower stakeholders, including policymakers, planners, and researchers, to engage effectively with transportation challenges. By leveraging map-making principles, cartography enhances the clarity, comprehensibility, and usability of transportation-related data, fostering informed decision-making and addressing the intricacies of transportation planning and policy.

2.6. The Visualisation Methods for Understanding Time and Space in a User-Friendly Way

Visualising time and space in a user-friendly manner involves employing techniques that enable intuitive comprehension of complex data. One approach is the use of time-series charts, such as line or area graphs, to illustrate data trends over time. Heat maps, characterised by colour intensity to represent values on a grid, effectively showcase spatial patterns, such as traffic congestion or population density. Animated maps bring together time and space, allowing for dynamic visualisation of changes over time. Additionally, flow maps demonstrate movement between locations, facilitating the understanding of transportation flows. These methods aid in conveying temporal and spatial relationships in a manner accessible to a broad audience.

Among these methods, the space-time cube stands out as a comprehensive approach. The space-time cube, a 3D representation where two dimensions denote space, and the third represents time, offers an unparalleled perspective. It allows for the visualisation of data changes over time within specific geographic locations. This method is particularly effective for analysing transportation systems, where temporal and spatial dimensions are intricately linked (Kraak et al., 2017; Kang et al., 2018). The cube's dynamic representation enables viewers to observe trends, spot anomalies, and discern patterns that might otherwise go unnoticed, providing a powerful tool for deciphering complex transportation data and enhancing decision-making processes in the realm of transportation planning and analysis (Farooq et al., 2018).

Space-time cubes find application in a variety of transportation-related fields (Leduc et al., 2018) For instance, in public transit planning, space-time cubes facilitate the identification of high-demand areas and key routes, aiding in optimised transit service provision. In traffic analysis, space-time cubes enable the construction of spatiotemporal traffic models, offering an understanding of the spatiotemporal dynamics of congestion. This information can be used to develop effective traffic management policies.

In essence, visualising time and space through space-time cubes and other visualisation methods enables stakeholders to engage effectively with transportation challenges. By leveraging visualisation principles, these methods enhance the clarity, comprehensibility, and usability of transportation-related data, fostering informed decision-making and addressing the intricacies of transportation planning and policy.

2.7. Case Studies

A comparative analysis is a useful tool to highlight similarities and differences between two or more elements and identify patterns that help us understand how systems work and where they can be improved. Comparing different aspects, whether similar or different, enables us to gain insights into what works well and identify areas for improvement.

By piecing together a puzzle of individual cities, we can see the bigger picture of how each city functions and determine if there are shared features (Eaton et al., 1997, Quah, 1993). Comparing the similarities and differences between cities allows us to understand their strengths and weaknesses while identifying factors contributing to their successes and struggles. Comparative analysis provides valuable insights into urban systems. By examining and understanding the factors that make each city efficient and the challenges they face, we can gain a deeper understanding of each city's individual workings and explore opportunities for betterment (Li et al., 2013).

The literature review conducted aimed to identify similar research on comparative analysis of cities and their transport systems, as well as the use of visualisation methods like the space-time cube to explain problems such as transport delays (Wagner et al., 2019). Some of the papers reviewed included Wu et al., (2021, 2022); Song et al., (2018); Keler et al, (2023); Rastogi et al., (2023).

To gain a better understanding of comparative analysis, three similar papers were selected for a thorough case study analysis. The aim was to closely examine their elemental functionalities and identify emerging similarities that could lead to mutual learning and the identification of potential areas for improvement.

The ultimate goal of comparative analysis is to understand the underlying patterns of a complex system and create user-effective explanations (Háznagy et al., 2015). By performing a comparative analysis of Amsterdam and Bengaluru, I sought to identify similar research and experimentation previously carried out and identified three potential case studies that have similar approaches to my research, allowing me to define possible learnings from them.

Comparative analysis is a crucial tool for identifying similarities and differences among variables and data sets to gain a deeper understanding of a complex system. By comparing different elements such as urban mobility, we can identify factors contributing to their successes and struggles and explore opportunities for improvement.

Case 1: The Comparative Chrono-Urbanism of Brno and Bratislava Public Transport Systems (Osman, R., Ira, V., & Trojan, J. (2020)

This case study investigates the concept of comparative chrono-urbanism in the public transportation systems of Brno and Bratislava. The study aims to understand the historical evolution of these cities' transportation infrastructures, considering their unique urban characteristics and socioeconomic factors. As a researcher interested in conducting a comparative study of Amsterdam and Bengaluru's public transport systems, this paper holds significant value for several reasons.

The study employs a mixed-method approach, combining qualitative and quantitative methods to collect data on the efficiency, accessibility, and integration of public transport in Brno and Bratislava (Parkes and Thrift, 1980; Harmoinen, 2003). This approach enables a comprehensive analysis of various key factors, such as service frequency, punctuality, network coverage, fare structures, and user satisfaction.

The study focuses on the temporal and urban aspects of the transportation networks, providing valuable insights into how these systems have evolved over time, adapting to changing urban landscapes and commuting patterns. Through contextualising the historical development of Brno and Bratislava's public transport systems, a better understanding can be gained of the underlying factors that have shaped their current state. This historical context would assist in comprehending the trajectory of Amsterdam and Bengaluru's public transport systems and identifying any parallels or disparities.

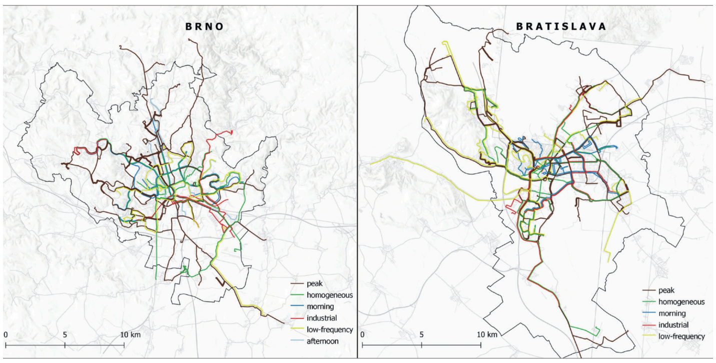


Fig 2.7.1: Spatial synthesis of public transport lines according to rhythmic profiles of connections
Source: Osman et.al, 2020

Furthermore, the study examines the impact of technological advancements on the public transport systems of Brno and Bratislava. This presents a contemporary lens to assess the role of smart technologies, ticketing systems, and real-time tracking in modern urban transportation (Mulíček, Osman and Seidenglanz, 2015, 2016). Since Amsterdam and Bengaluru are likely to have adopted technological solutions to varying degrees, comprehending the successes and challenges faced by Brno and Bratislava's transportation systems could enrich my analysis of the adoption and implementation of similar innovations in the two Indian cities.

The identification of strengths and weaknesses in the public transportation systems of Brno and Bratislava could offer potential solutions for enhancing efficiency and user experience. Hence, learning from the experiences of these two cities can provide useful lessons and insights for researchers studying transport systems across different regions.

Case 2: Why do People Refrain from Cycling in Indian Cities? A Comparative Case Study between Indian Cities of Chandigarh and Noida and European Cities of Copenhagen and Amsterdam (Biswas, A., Mittal, S., & Padmakar, S. 2019)

This research paper aims to unravel the underlying reasons behind the limited uptake of cycling as a mode of transport in Indian cities, drawing insightful comparisons between two Indian cities, Chandigarh and Noida, and two European counterparts, Copenhagen and Amsterdam.

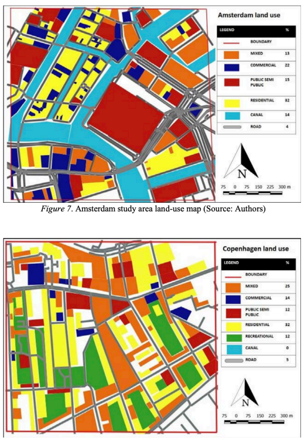


Fig 2.7.2: study area land-use map for understanding the build for Amsterdam and Copenhagen
Source: Biswas et.al, 2019

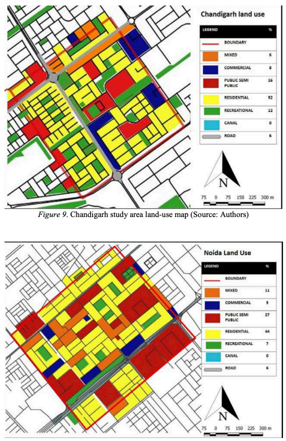


Fig 2.7.3: study area land-use map for understanding the build for Chandigarh and Noida
Source: Biswas et.al, 2019

The paper employs a meticulous comparative approach, delving deep into the multifaceted aspects of urban mobility in the four cities. The study juxtaposes the cultural, infrastructural, and socioeconomic disparities that shape people's cycling behaviours, identifying the distinct challenges and enablers influencing cycling adoption in each city. This approach offers a comprehensive understanding of the prevailing dynamics that impact cycling culture.

The study focuses on the importance of cycling infrastructure and facilities available in Chandigarh, Noida, Copenhagen, and Amsterdam, and analyses the differences between the various cycling lanes, parking facilities, and safety measures. The paper discusses the impact of a well-planned infrastructure on promoting cycling culture and its importance in advocating for sustainable urban planning that prioritises non-motorised transportation.

Moreover, the study delves into the cultural norms and societal perceptions surrounding cycling as a mode of transport in these cities. It highlights the intricate interplay between culture and mode choice, drawing attention to the sociocultural factors influencing cycling habits that are crucial for policymakers to devise contextually appropriate strategies to promote cycling in Indian cities.

The case study's most valuable contribution is its comparative analysis of European cities known for their cycling-friendly environments. By benchmarking Chandigarh and Noida against Copenhagen and Amsterdam, the research offers valuable insights into best practices and policies that boost cycling as a viable transport option. This perspective serves as a source of inspiration for crafting tailored interventions to enhance cycling in Indian cities.

The findings and recommendations of the paper hold immense significance for fostering sustainable and resilient cities in India. By uncovering the complexities surrounding cycling adoption in Chandigarh and Noida in comparison to Copenhagen and Amsterdam, this research provides valuable insights for guiding urban planners, policymakers, and transportation authorities towards creating bike-friendly cities that prioritise the wellbeing of their inhabitants and the environment.

Case 3: Moving Around in Indian Cities. The Transport around the Cities and How They are Built. (Mohan, D. 2013)

This research paper provides a comprehensive exploration of the intricate web of factors that underpins urban transportation networks in Indian cities. The paper focuses on the designing and development of transportation infrastructure and its implications for urban planning.

The study examines the modes of transportation available in Indian cities, unravelling the interplay between public transport, private vehicles, walking, and cycling and comparing it with the European build. By scrutinising the transportation choices available to city residents, the paper aims to draw attention to the factors influencing mode selection and their implications for urban planning.

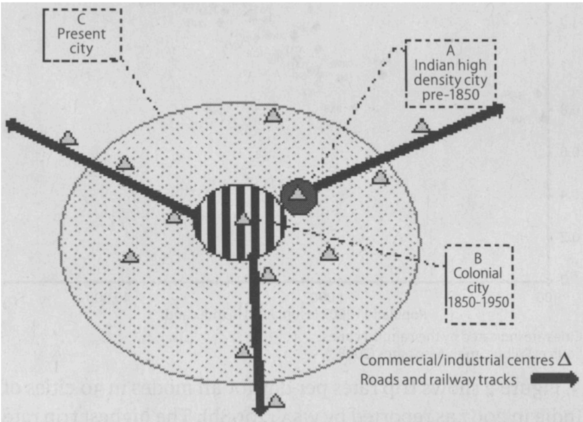


Fig 2.7.4: Transport model: Development of the Indian City, 19 century to present. Source: Mohan, D. (2013)

The research presents an exhaustive analysis of the transportation infrastructure of various cities across India, assessing the effectiveness of public transit systems, the accessibility of transportation hubs, and the quality of road networks. The study draws attention to the complexities of these infrastructural elements and their importance in creating efficient and sustainable urban transportation systems.

Moreover, the paper also delves into the challenges and opportunities faced by urban planners in creating transportation infrastructure that caters to the evolving needs of city dwellers. By analysing case studies across Indian cities, the paper highlights the importance of context-specific solutions in developing sustainable, efficient, and inclusive transportation systems.

The study's emphasis on the relationship between urban development and transportation is particularly noteworthy. By identifying the synergies between urban growth and transportation networks, the research offers valuable insights into the dynamics that determine the urban landscape. This understanding is pivotal in creating integrated and future-ready urban development plans that prioritise efficient, eco-friendly transportation solutions.

The paper's exploration of potential solutions to transportation challenges in Indian cities is compelling. By presenting innovative ideas and successful interventions, the research serves as a catalyst for transformative policy measures that can mitigate traffic congestion, improve air quality, and promote sustainable urban environments.

2.8. Mobility Indicators

Mobility is a complex system within urban areas characterised by several effective interactions (Cervero, 2002). In the past, increasing the number of transport supplies such as new roads and facilities had been desirable, leading to unsustainable transportation systems characterised by problems such as high car usage and congestion (Gallotti et al., 2015; Litman, 2014, 2023).

Mobility indicators encompass a wide range of metrics that reflect various aspects of urban mobility. These include indicators related to congestion and travel time, mode share, accessibility, environmental impact, public transit usage, equity and social inclusion, infrastructure utilisation, and multimodal integration (Here Technologies, 2020; World Bank, 2019).

- **Congestion and Travel Time:** Indicators related to congestion levels and travel time provide insights into the efficiency of transportation systems. High congestion and extended travel times can lead to decreased productivity, increased fuel consumption, and air pollution.
- **Mode Share:** Mobility indicators assess the distribution of trips across different modes of transportation, such as private cars, public transit, cycling, and walking. A balanced mode share promotes a shift towards sustainable transportation options.
- **Accessibility:** These indicators evaluate how easily people can access essential services, workplaces, and recreational areas. Improved accessibility can reduce the need for long commutes and promote more localised travel patterns.
- **Environmental Impact:** Indicators related to carbon emissions, air quality, and energy consumption offer insights into the environmental sustainability of transportation systems. Monitoring these indicators helps cities work towards reducing their carbon footprint.
- **Public Transit Usage:** Metrics related to public transit ridership provide an understanding of the effectiveness of public transportation systems. Higher public transit usage can lead to reduced traffic congestion and lower emissions.
- **Equity and Social Inclusion:** Mobility indicators can also consider equity by assessing transportation options available to different socioeconomic groups. Ensuring that all segments of the population have access to reliable and affordable transportation is a key consideration.
- **Infrastructure Utilisation:** These indicators assess the efficiency of existing infrastructure. For example, optimal usage of public transit networks and roadways can contribute to reduced congestion and smoother traffic flow.

- **Multimodal Integration:** Indicators that measure the integration of various transportation modes encourage seamless connectivity between different modes of travel, making it easier for individuals to switch between modes during their journey.

By utilising mobility indicators, urban planners and policymakers can better understand the dynamics of urban transportation systems and design interventions that address specific challenges. Instead of solely focusing on expanding infrastructure, cities can adopt a holistic approach that encourages sustainable modes of transportation, reduces congestion, and minimises environmental impacts.

The major mobility indicators used for this research come from the DULT mobility indicators for Bengaluru, conducted by the Directorate of Urban Land Transport (DULT) with Namma Metro (BMRCL), and HERE Maps' extensive mobility indicators list conducted for more than 200 cities.

Through conducting a thorough review of academic literature in the field related to the research objective, the present study aims to provide insights into existing research trends and patterns. By posing carefully curated research questions, this study aims to offer answers to critical questions regarding the observed patterns, as well as the underlying rationales. Given the inherent complexity of the subject matter, a comprehensive understanding of the academic discourse on the topic is vital. A rigorous and informed analysis of available research on related fields and topics will ensure that the study's research objectives are well-informed and evidence-based.

An important objective of this literature review is to identify how learning from previous studies can inform future research and identify the next set of steps to be taken in the field. The central idea behind this research effort is to produce simplified and easily interpretable visualisations and analyses that can provide insights into the inefficiencies and efficiencies present in transport systems, and furthermore, how these simplifications can help identify areas where future research can refine the current understanding of transport system complexities.

2.9. Defining the Research Questions

After a thorough literature review and understanding the related work and the background of the transit systems and the network of the patterns, the following research questions are defined:

RQ1. How might data visualisations such as space-time cubes be used to compare and map the transport infrastructure of two cities?

- **RQ1.1.** What insights might be gained from this analysis for both cartography and transport?
- **RQ1.2.** How can space-time cubes be used to identify differences in urban infrastructure, such as traffic delays, travel times, and transportation accessibility, including last-mile connectivity?
- **RQ1.3.** What implications do these differences have for each city's transport system?

RQ2. To what extent do the gaps explained in the Gaps section exist in cities of India like Bengaluru, and to what extent do the observed changes in the systems persist in more developed cities like Amsterdam?

- **RQ2.1.** What are the impacts evident in the multimodal transport systems of the two cities under study, and how might these be related to the urban structure of each city?
- **RQ2.2**. How do time and space factors differ between the two cities, and what implications might these differences have for the design and improvement of transport systems?
- **RQ2.3.** How can a comparative analysis of transport systems between cities be used to assess the potential for improvement of those cities?
- **RQ2.4.** What factors are likely to influence success in implementing changes?

RQ3. What further research is needed to address any outstanding questions or issues that arise from this analysis?

- **RQ3.1.** Finally, can one city's navigation system be used to help build or improve another city's transport network?
- **RQ3.2.** To what extent can the implementation of one city's ideas onto another city's developments be successful, and what challenges might arise in the process?

By structuring the research questions and sub-questions in this format, the investigation aims to methodically delve into the intricacies of cartographic comparative analysis, transport infrastructure disparities, urban structure influences, and the potential for mutual enhancement among distinct urban environments.

3. IDEOLOGY, REASONING AND DEFINITIONS

Comparing dissimilar cities offers a valuable opportunity for cross-learning, innovation, and identifying adaptable strategies for urban planning and transportation policy. This topic has been extensively researched in academic literature, highlighting the benefits of learning from diverse cities to promote sustainable, efficient, and safe transportation in urban areas.

1. Contextual Adaptation: Comparing dissimilar cities emphasises the importance of contextual adaptation in urban planning, as each city has unique geographical, cultural, historical, and demographic characteristics that influence the design and implementation of multimodal transport systems. Research has highlighted the significance of context-specific approaches to sustainable mobility planning (Liu et al., 2021).

2. Diverse Approaches to Mobility: Dissimilar cities often adopt diverse approaches to mobility based on their priorities and challenges. Research has shown that examining shared mobility services in different cities can provide new insights into the shared mobility landscape (Grindrod et al., 2016).

3. Problem-Solving Innovation: Comparing dissimilar cities allows for identifying innovative solutions to transportation challenges that may not be immediately evident in a single city analysis. A study by Shaheen et al. (2018) highlights the importance of context-specific solutions to meet the specific requirements of each city.

4. Lessons in Success and Failure: Learning from cities with different levels of success in implementing multimodal transport systems can provide insights into what works and what doesn't work. Pojani et al., (2015); Stolte Bezerra et al., 2019 demonstrated that understanding good governance practices among small and medium-sized cities can promote sustainable urban mobility.

5. Cultural and Behavioural Factors: Dissimilar cities often have diverse cultural norms and behavioural patterns related to transportation. Research has advocated examining different cultural perceptions and social practices that influence travel behaviour to promote sustainable and inclusive mobility (Banister & Hickman, 2013).

6. Policy and Governance: Comparing cities with different governance structures and policy frameworks can shed light on how political decisions impact transportation planning and implementation. Understanding the role of leadership and governance in shaping transportation policies encourages the formulation of

comprehensive and sustainable transportation plans that consider the needs of future generations.

7. Long-term Vision: Analysing dissimilar cities provides a broader perspective on long-term vision and planning for transportation infrastructure that considers context-specific factors, challenges, and successes. Shaheen et al. (2018) emphasise the need for transport planning to keep pace with evolving urban contexts.

In summary, comparing dissimilar cities provides a rich opportunity for cross-learning, innovation, and identifying adaptable strategies to address transportation challenges in diverse urban contexts. Research has demonstrated that understanding the context-specific needs, challenges, and successes of different cities can promote sustainable, efficient, and safe transportation systems in urban areas.

3.1.1. The cities chosen:

- Bengaluru, India
- Amsterdam, Netherlands

3.2. Why these Two Cities?

The choice of cities for comparison is an important aspect of this research. Navigation is one of the primary applications of cartography (Krygier, 2011), and understanding navigation patterns can inform policy changes and infrastructure improvements for cities. European cities have historically influenced the structure and development of cities in India, particularly in terms of urban transport systems (Basu.S et al.,2013; Basu et al., 2018).

European cities are often considered good examples of well integrated transport systems, which can serve as a benchmark for Indian cities. Comparing a European city with an Indian city can help identify why certain methods are more effective than others and can inform strategies to make Indian cities more public transport friendly and reduce reliance on private vehicles.

This research is on two specific cities of Bengaluru, India and Amsterdam, Netherlands. Since this is a multimodal transport comparison, these two cities were chosen, because Amsterdam has all modes of transport metro, trams, buses, ferries, suburban rail, and bicycles used regularly and Bengaluru is now in the process of making the city more multimodal and less reliant on private transport and comparing these two cities will give a clear understanding of where cities like Bengaluru, Delhi, Mumbai, Chennai, Hyderabad, Lucknow, Kolkata or other Indian cities chosen for smart cities program, can be benefited with this research.

3.3. How Similar or Different these Cities are?

Comparative analysis of dissimilar cities offers an opportunity to gain insights into the unique factors that shape their urban contexts, while also identifying shared strengths and commonalities in addressing transportation challenges. Academic research in this area highlights the importance of understanding the diverse factors that influence city-specific transportation needs, as well as identifying strategies and best practices that can be adapted to suit different urban contexts.

The similarities and differences between Bengaluru and Amsterdam provide an interesting case for comparative analysis. Both cities have a strong commitment to technological innovation in developing smart and efficient transportation systems. Bengaluru's reputation as a centre of technology development has contributed to the adoption of innovative approaches to meet the transportation needs of its diverse population, while Amsterdam's status as a technology hub has driven the city to implement cutting-edge strategies for managing its transport networks.

Cultural diversity plays a crucial role in shaping transportation demands in both cities. Bengaluru's multicultural influx has resulted in a diverse range of public and private transport options to accommodate varying commuting patterns and preferences. Similarly, Amsterdam's international appeal has necessitated the development of an intricate transport network that can connect people from different cultural backgrounds.

Both cities share a commitment to sustainable urban development, albeit with differing challenges and strategies. Amsterdam has adopted a focus on cycling and eco-friendly infrastructure to reflect its commitment to environmental stewardship, while Bengaluru grapples with the environmental impact of rapid urbanisation, prompting initiatives to promote sustainable transport choices and greener infrastructure.

Education and research are essential contributors to transportation planning and innovation in both cities. Bengaluru's research organisations and educational establishments contribute to developing transportation solutions uniquely suited to the city's needs, while Amsterdam’s renowned universities provide valuable insights to shape the city's transportation policies and governance.

Art and culture also play an essential role in shaping transportation preferences in both cities. Amsterdam's rich cultural heritage translates to an environment conducive to walking and cycling, while Bengaluru's evolving arts and music scene may influence the choice of transportation modes, with a potential emphasis on public transport to accommodate cultural events and gatherings.

Tourism also serves as a key factor that shapes transportation infrastructure in both cities. In Amsterdam, a well-connected transportation network that navigates visitors through picturesque canals and historical landmarks is essential, while in Bengaluru, a comprehensive transport system that caters to the travel needs of domestic and international tourists is necessary.

Connectivity is a shared strength, with both cities investing in comprehensive transport networks. Amsterdam's efficient trams, buses, and trains interconnect the diverse neighbourhoods of the city, while Bengaluru's growing metro system coupled with a variety of public transport options addresses the increasing transportation needs of its expanding urban landscape.

In conclusion, a comparative analysis of Bengaluru and Amsterdam highlights several unique aspects of their transportation systems, while also identifying shared strengths and commonalities. The insights gained from examining these distinct urban contexts can promote cross-learning and collaborative efforts, fostering a unified approach to urban mobility in diverse global cities.

Similarities:

1. Public Transit Systems: Both cities have well developed public transit systems. Bengaluru has a network of buses operated by Bangalore Metropolitan Transport Corporation (BMTC) that serves the city and its suburbs. Amsterdam has an extensive public transport network that includes trams, buses, and metros, operated by Gemeente Vervoerbedrijf (GVB-Municipal Transport Company) and, Nederlandse Spoorwegen (NS-Dutch Railways).

2. Cycling Infrastructure: Both cities prioritise cycling as a sustainable mode of transportation. Bengaluru has been making efforts to improve cycling infrastructure, including dedicated bike lanes and bike-sharing initiatives. Amsterdam is renowned for being a bicycle friendly city, with an extensive network of bike paths and facilities for cyclists.

3. Traffic Congestion: Both Bengaluru and Amsterdam face traffic congestion due to the increasing number of vehicles on the road. As a result, both cities have been exploring measures to manage congestion and promote the use of public transport and cycling to alleviate traffic related issues.

4. Focus on Sustainability: Both cities have a focus on sustainability and reducing their carbon footprint. Bengaluru has been implementing initiatives to improve air quality and reduce pollution, while Amsterdam has been at the forefront of sustainable urban development, emphasising eco friendly transportation options.

Differences:

1. Transport Modes: While both cities have buses and cycling infrastructure, Amsterdam has a more extensive public transport network that includes trams and metros, providing comprehensive coverage across the city. Bengaluru's metro system is still expanding and not as extensive as Amsterdam's.

2. Public Transport Usage: Public transport usage differs significantly between the two cities. In Amsterdam, a considerable portion of the population relies on public transport for daily commuting, with a high percentage of residents using bicycles. In contrast, public transport usage in Bengaluru is not as widespread, and private vehicles dominate the transportation landscape.

3. Transport Culture: The transport culture in Amsterdam is deeply rooted in cycling and using public transport, with a strong emphasis on sustainable mobility. In contrast, Bengaluru has a stronger car/motor-vehicle centric culture, with a significant portion of the population depending on private vehicles for daily commuting.

4. Urban Density: Amsterdam is a compact city with a higher urban density, which makes public transport and cycling more feasible and convenient for daily travel. Bengaluru, being a sprawling city with lower urban density but significantly higher population, faces challenges in providing efficient and accessible public transport options across all realms of the city sprawl.

Overall, while Bengaluru and Amsterdam share certain transport similarities, they also exhibit significant differences in terms of transport infrastructure, modes of transportation, public transport usage, and transport culture. The two cities have unique challenges and opportunities in developing and enhancing their transport systems based on their respective urban contexts and transportation needs.

3.4. Defining the "Gap"

A gap can be defined as a significant disparity, deficiency, or lack in understanding, performance, or capability between two points, concepts, or entities. It represents a space or distance between what is currently present and what is desired or expected, highlighting an area where improvement, alignment, or resolution is needed (Bach, 2004). Gaps can manifest in various contexts, such as knowledge, skills, infrastructure, performance, or outcomes, and identifying and addressing gaps is often crucial for progress and development.

In the context of transport, a gap refers to a discernible disparity or inadequacy in the efficiency, accessibility, or performance of transportation systems or infrastructure. It signifies a notable difference between the current state of transport services and the desired or optimal state. These gaps can encompass various aspects, including but not limited to time efficiency, connectivity, accessibility for diverse user groups, safety measures, infrastructure maintenance, and the alignment of transportation options with the evolving needs of a community or region. Identifying and addressing such gaps is vital for enhancing the overall effectiveness, sustainability, and convenience of transportation systems.In the realm of transportation, the term gap is closely connected to the concept of "last mile connectivity." Last mile connectivity refers to the final leg of a journey, often the most critical and challenging part, where passengers or goods reach their ultimate destination from a transportation hub or network. Various reasons can cause the last mile connectivity to be non optimal, which means, there might be a slew of reasons that prevent you to ideally reach the destination or move from the origin.

The connection between these two concepts lies in addressing the gap that exists between the larger transportation system and the actual destination. This gap can be a physical, logistical, or efficiency-related disparity that makes it difficult for individuals to smoothly complete their journeys. Last mile connectivity seeks to bridge this gap by establishing efficient and accessible modes of transport, whether through local transit, walking, cycling, or innovative solutions like ride-sharing or micro-mobility services. The goal is to provide seamless integration between the main transportation network and the final destination, effectively closing the gap in accessibility and enhancing the overall transportation experience (Kanuria et al., 2019).

This gap is very essential when it comes to measuring the efficiency of public transport. Because when it comes to last mile connectivity, nothing is more ideal than to drive to and from to your origin or destination but that defines the extreme dependency of private vehicles, which in turn puts a lot of pressure on various aspects of daily life causing climate change, inflation in fuel prices, extreme duress on the fossil fuels and just added pollution that hinders the quality of life. While the public transport system cannot completely bridge the last mile connectivity gap, it can help in improving the distance between performance and its resulting efficiency and make the entire system more inclusive, appropriate, efficient and eco-friendly. When the city's public transport system works in order, the dependency on private vehicles reduces drastically and invariably aids in increasing the quality of life.

Defining the gap and understanding it is one of the key concepts of this research, to visualise them in a cartographic way that ties in making these crucially complex concepts easy to understand and helps in analysing the impact it has on these systems.

3.5. Understanding the Gap

Navigation has been an intrinsic part of our daily lives, and commuters ask for efficient methods that will allow them to reach their destinations faster through highly developed transport network. (Zhu et al., 2019) When it comes to improving the city's transport network, public transport gets a huge importance because improving the public transport system improves the whole city's infrastructure.

But sometimes, certain areas do not have necessary footfall to build a whole new station or an underground line and certain transport methods like private cars or auto rickshaws (in case of Bengaluru) and bicycles (in the case of Amsterdam) come into play. Analysing the multimodal transport system for improvement requires the understanding of the gaps, like:

- Lack of integration between different modes of transport, such as buses, trains, and metros.
- Lack of efficient transport methods that do not require a lot of infrastructure changes.
- Poor last mile connectivity, making it difficult for commuters to reach their final destinations from transport hubs.
- Insufficient infrastructure for pedestrians and cyclists, making it dangerous and difficult for them to navigate city roads.
- Limited accessibility for people with disabilities, with many public transport systems lacking appropriate facilities.
- Lack of realtime information about transport schedules and delays, which makes it difficult for commuters to plan their journeys.
- Public transport can be crowded and delays can occur due to maintenance or unexpected events.
- The narrow streets and historic architecture in cities like Amsterdam can create challenges for accommodating large vehicles such as buses or trucks.

The word gap is a ambiguous in nature. However, when visualising the data, its meaning becomes clearer as the analysis progresses. The gap analysis is split into two parts in this thesis.

- What the maps can visualise or perceive as the gaps in the transport systems.
- What the users perceive as gaps in the transport systems, for which the results are being taken from the user survey conducted.

The patterns where both the map visualisations and the user study coincide in values are considered to be priority gaps as in where the transport systems need to address them first in order to improve efficiency. By that definition and perspective, this research is trying to understand how to simplify complex transport issues by visualising them and understanding better for the policy makers to analyse the level of impact an inefficient transport system might have.

The focus of gap analysis in this research is Time and understanding how much of a time difference an efficient transport can system can make when certain inefficiencies can be removed. That's where the comparative analysis with Amsterdam can help in understanding where growing cities like Bengaluru can be benefited from.

3.6. Study Area

The cities chosen:

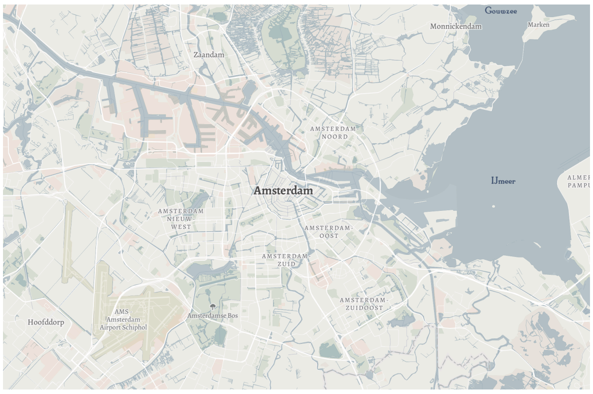


Fig 3.6.1: Amsterdam Urban Area.
Map Scale: 1:500,000 - 76.437 meters/pixel
Style: Mapbox @bepoorni

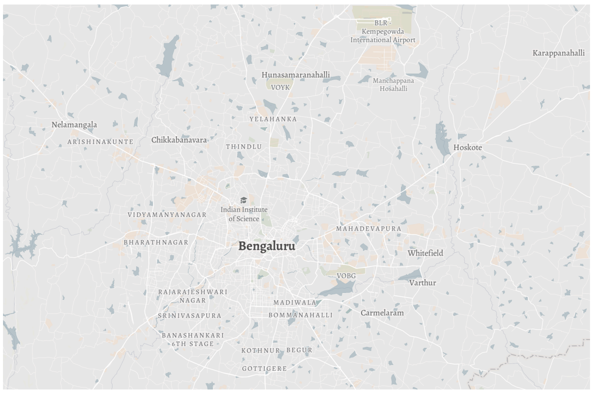


Fig 3.6.2: Bengaluru Urban Area
Map Scale: 1:500,000 - 76.437 meters/pixel
Style: Mapbox @bepoorni

- Bengaluru, Karnataka, India
- Amsterdam, Noord Holland, Netherlands

4. UBIQUITOUS TRANSPORT SYSTEM OF AMSTERDAM AND BENGALURU AND THEIR CURRENT STATE

The cities of Bengaluru and Amsterdam are well known for their beauty, technological capabilities and their reach towards other important cities of their respective countries. Amsterdam is the capital of Netherlands, while Bengaluru serves as the state capital of one of the biggest Indian states, Karnataka. In a comparative analysis, it is important to understand how the cities that are being compared are structured and how the lay of the land is.

This comparative analysis's main question is how much time does it usually take to commute in cities and whether one city's transport can help better another city's network. To start with, we understand the city's road and infrastructure network that is existing before we analyse what is missing.

Table 4.1. Overview of the cities and their urban transport elements and their influences. Statistics from government.nl, bbmp.gov.in.

Element	Amsterdam	Bengaluru
Area	219.32 sq km	709 sq km
Population	1,174,000	13,608,000
Road Network in Km	~1,800	~10,600
Pedestrian Network in Km	~1500	~6782
Bicycle Lane Network in Km	~1781	No specific lanes for bicycles
Accessibility in %	97	92
Available modes of public transport	4	2
Train Network in Km	91	148
Registered No of Vehicles (as of 2022)	~2,70,000	~8,563,863
No of Modes of NMT	2	2
Average % of users driving daily	19%	65%
Average % of users using PT/bicycles daily	81%	35%
Vehicles per household on average (Cars and 2 Wheelers)	2	4

The maps added in this section are a visual representation of the cities's transport network, to reiterate the research question of how visualising these networks helps in ease of understanding the complexities of transport network. Simplifying the understanding of the networks can help in making informed decisions about improving the efficiency of the network and that's what this thesis is trying to achieve.

4.1. BENGALURU'S TRANSIT NETWORK

Bengaluru has two major transport networks: Bangalore Metropolitan Transport Corporation (**BMTC**) and Bangalore Metro Rail Corporation Limited (**BMRCL**) that cater to the 13 million population of the city. With an area of 747 sq km, Bengaluru is divided into Urban Bangalore and Rural Bangalore, and is very well connected to major Indian cities of Mysore, Hubli-Dharwad, Davanagere, Belagavi,

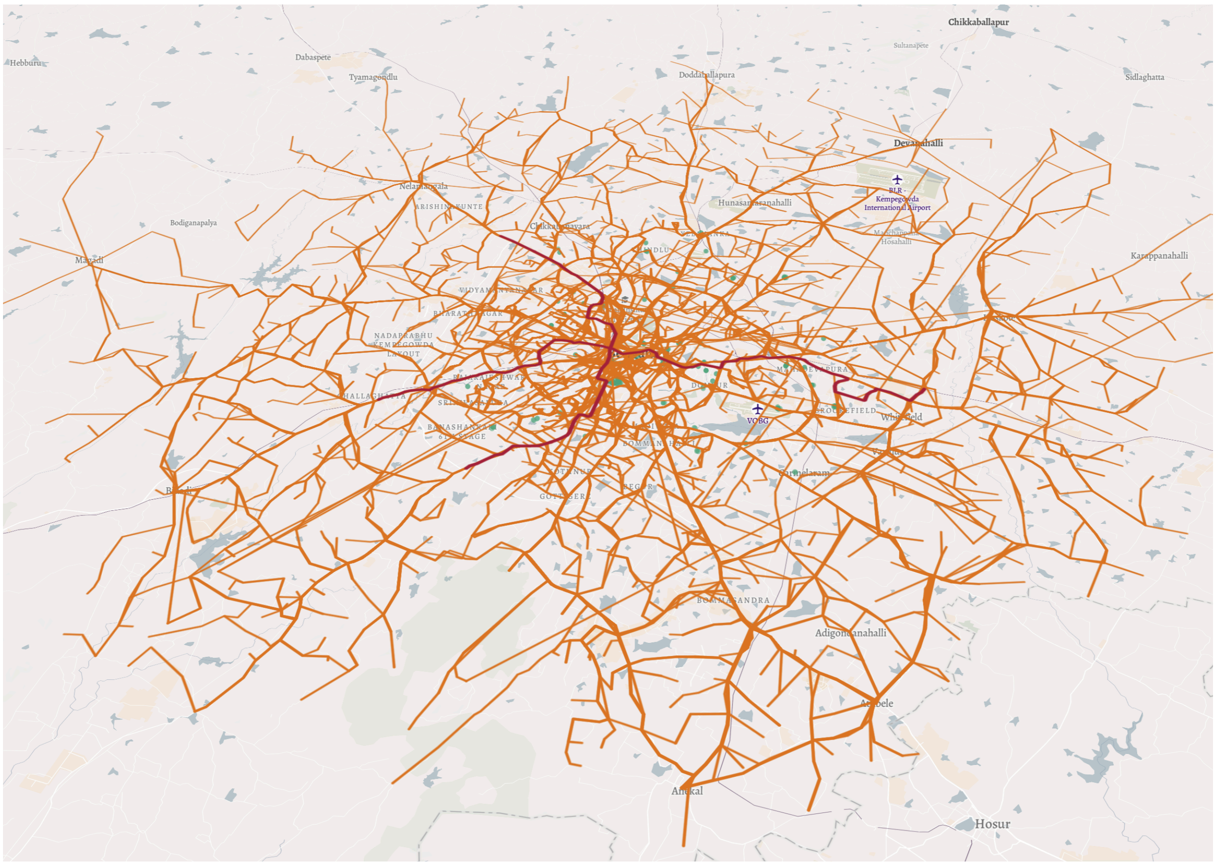


Fig 4.1.1: Bengaluru's massive transport network visualised with routes in orange: BMTC and routes in pink: BMRCL

Mangaluru, Ballary (Karnataka), Chennai (Tamil Nadu) and Hyderabad (Telangana), Mumbai (Maharashtra) and Ernakulam (Kerala) which furthers the highway network to other states and cities of India.

BMTC currently has 2004 routes running all over the city of Bengaluru, with the fleet of buses including the city plying J.N.Nurm, electric, and normal buses and the airport plying Vayu Vajra that connects different parts of the city to the Kempegowda International Airport, Devanahalli. In 2021, the city introduced a network of Metro Feeder Buses that connect some of the major hubs of metro stations to other important bus stands that are not accessible by walk.

BMTC

Table 4.1.1. Overview of the Bengaluru Metropolitan Transport Corporation (BMTC) fleet and their current plying routes. Data (BMTC and Moovit)

Element	Bengaluru
Bus network in Km	1238 km
No of Bus Stops	8649
No of Vayu Vajra Routes	20
No of Metro Feeder Routes	29
No of Vehicles in the Fleet	6798

BMRCL

Table 4.1.2. Overview of the Bengaluru Metro Rail Corporation Limited (BMRCL) lines and their current and proposed plying routes

Element	Bengaluru
Metro network in Km	154
No of Metro Stops	112
No of Running Routes	2
No of Proposed Routes	3
Suburban Rail Network in km	145 km
No of Stations within Bengaluru	18

BMRCL is the underground and elevated tracks Metro Train System connecting the important and heavy footfall areas of Bengaluru with each other.

Currently there are two major lines running:

- **North to South of Bengaluru, Silk Institute to Nagasandra:** The Green Line
- **East to West of Bengaluru, Kengeri to Baiyappanahalli:** The Purple Line - Operational **(Whitefield to Chalaghatta - Operational by End of September, 2023)**

Three more lines of Metro: The Blue, Yellow and Pink Line are proposed and under construction, aiming to form a ring around the city and connecting all major neighbourhoods of Bengaluru with each other.

The other modes of transport frequently used in Bengaluru:

- Autos
- Ola/Uber (Taxi)
- Rapido (Shared motorbikes)
- Yulu (Shared Bicycles)

4.2. AMSTERDAM'S TRANSIT NETWORK

The city of Amsterdam's major transit network is Gemeente Vervoerbedrijf (**GVB**) and currently has four modes of transports: Buses, Trams, Metro and Ferries, catering to its 1.5 million population. With an area of 232 sq km, Amsterdam is the coastal canal city, that is the capital of Netherlands, and well connected to the other cities of Netherlands like Utrecht, Arnhem, and Frankfurt, Germany.

With an area three times smaller than Bengaluru, Amsterdam's city network is already completely well established and connects all the major neighbourhoods of Amsterdam to the centre and the other towns and cities around it.

GVB

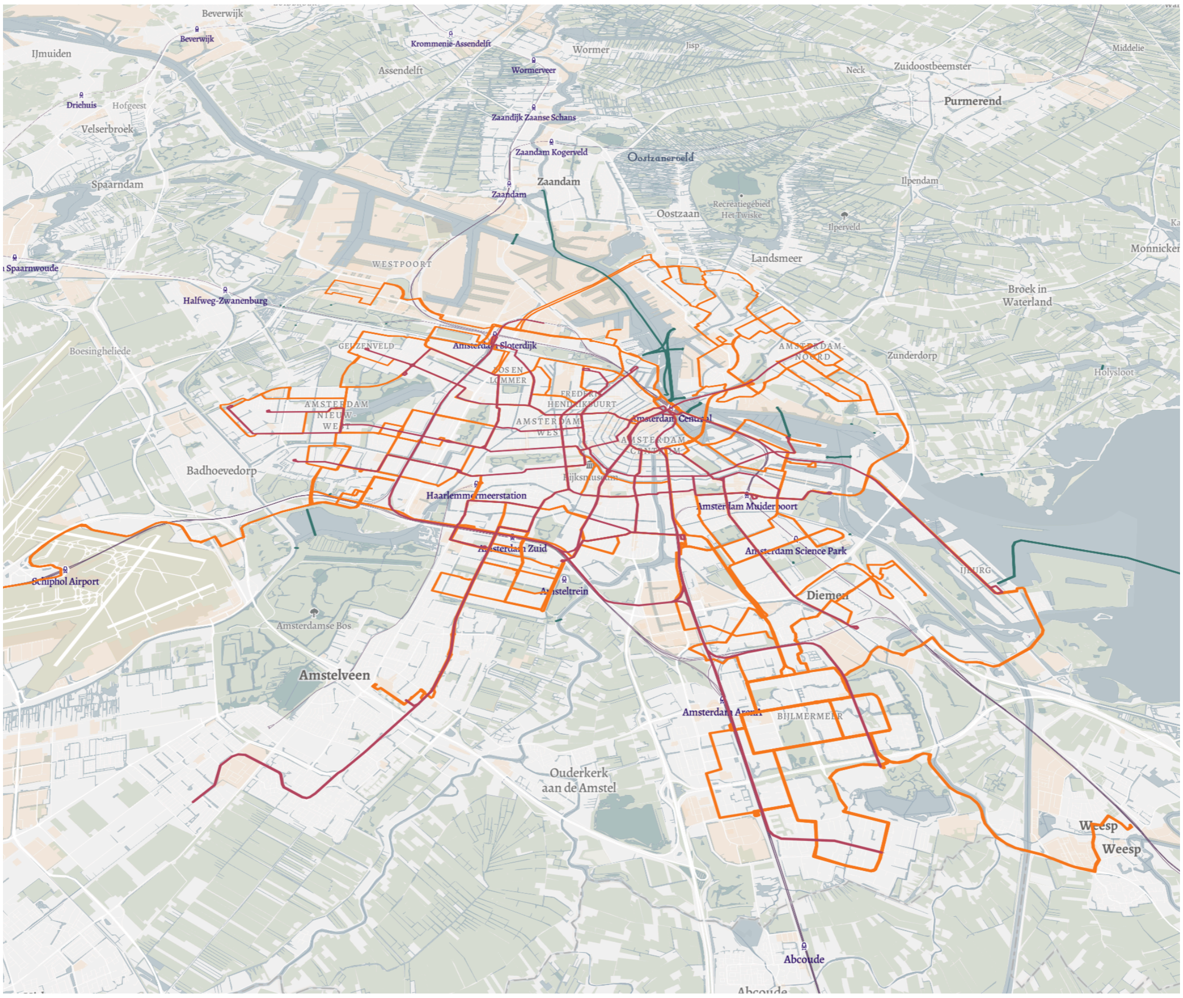


Fig 4.2.1: Amsterdam's wide transport GVB network visualised with routes in orange: Bus and routes in pink: Train/Tram, and routes in green: ferry

Table 4.2.1. Overview of the Amsterdam's GVB network and their current plying routes of trams, trains and buses. (Data: GVB and amsterdam.nl)

Element	Amsterdam
Bus network in Km	152
No of Bus Stops	536
Metro network in Km	42.7
No of Metro Stops	39
Tram Network in Km	80.5
No of Tram Stops	500
Ferry Network in Km	34
No of Ferry Ports	11

The other modes of transport frequently used in Amsterdam:

- Scooters (Lime, Tier)
- Bolt/Uber (Taxi)
- AMS (Shared Bicycles)

4.3. THE CITY MOBILITY INDEX

The City Mobility Index is a quantitative measure used to assess the efficiency, accessibility, and overall effectiveness of a city's transportation and mobility systems. It takes into account various factors that contribute to urban mobility, including transportation infrastructure, connectivity, modes of transportation, travel times, congestion levels, public transportation availability, pedestrian and cyclist friendliness, and more. The index provides a comprehensive snapshot of how well a city's transportation network meets the needs of its residents and visitors.

Typically, the City Mobility Index involves collecting and analysing data related to transportation networks, traffic flows, public transportation usage, environmental impact, and user satisfaction. This data is often standardised, normalised, and weighted to provide a numerical value that reflects the city's performance in terms of mobility and transportation quality. Higher values on the index generally indicate better mobility and more efficient transportation systems, while lower values may suggest areas for improvement.

The City Mobility Index is a valuable tool for urban planners, policymakers, and researchers to assess the strengths and weaknesses of transportation systems, identify trends, and make informed decisions to enhance urban mobility and sustainable transportation solutions.

In any analysis of a city's transit system, mobility indexes are used to maintain the uniformity of the analysis and to highlight the factors which are used to understand the city's health and performance of various aspects. As defined in the section mobility indicators, the extended research on mobility indicators have seen researches defining and redefining the mobility indicators based on different transport and urban systems. For this research, mobility indicators act as indicators to identify the patterns that exist in both cities that could be construed as gaps.

Urban mobility indicators are exhaustive and all the indicators that are considered in UMI is defined in the section 3.6. The UMI indicators are redefined here to adhere to the limitations of this research and also maintain the uniformity for both the cities and making sure the comparative factors in both the cities.

Urban Mobility Indicators used for this comparison are:

- **Public Transportation**
  - Public transportation ridership (e.g., total passengers, modal split)
  - Coverage and density of public transportation routes and stops
  - Frequency and reliability of public transit services
- **Cycling Infrastructure**
  - Length and quality of dedicated cycling lanes and paths
  - Number of bike sharing stations and usage
  - Cycling safety measures (e.g., bike friendly intersections, traffic calming)
- **Road Networks and Traffic**
  - Total road length and road density
  - Congestion levels and average travel time during peak hours
  - Number of registered vehicles and vehicle ownership per capita
- **Pedestrian Infrastructure**
  - Accessibility and safety of sidewalks and pedestrian crossings
  - Availability of pedestrian only zones or pedestrian friendly areas
- **Accessibility to Key Destinations**
  - Distance and travel time to schools, hospitals, commercial centres, and recreational areas via different transportation modes.
- **Transportation Equity**
  - Accessibility of transportation options in different neighbourhoods and income groups
  - Affordability of public transportation for diverse socioeconomic groups
- **Smart Mobility Solutions**
  - Adoption of smart technologies for realtime transport tracking and information dissemination
  - Integration of digital payment systems for seamless transit options

The specific approach this research is trying to take is to visualise these through maps rather than assign the mathematical metrics to it. Transport as a concept is very complex and visualising these in a simple, aesthetic manner for even the normal users, and not just transport experts, urban planners, cartographers to understand. These visualisations make it simple for policy makers to highlight the impact for people unaware of these complexities and appropriately maximise the difference it could make when the concepts are properly understood.

Table 4.3.1. Overview of the Mobility Indicators and how they exist in both cities.

Element	**Amsterdam**	**Bengaluru**
Availability of night transport	Yes	No
One single ticket for all modes of public transport	Yes	No
Affordable means of public transport	Yes	Yes
Availability of open and clear schedules at transit stops	Yes	Only at metro stations
Availability of smart travel options	Yes	Yes
Good frequency of public transport	Yes	Yes
Great frequency of public transport at night	Every half hour	Every hour-only airport routes
Optimum routes	Yes	Yes
Good accessibility	Yes	Yes
Crowded	During Peak Hours	Overcrowded during Peak hours

The presented maps aim to visualise various mobility indicators for the specific cities under consideration. These indicators are evaluated to understand their existence or non-existence in these cities. The process of understanding these mobility indicators involves redefining them in their elemental form, which is essential for proper evaluation and analysis. Prior to visualisation, the table above is presented to explain the elemental forms of these mobility indicators in detail. This approach aids in presenting a comprehensive understanding of the nature and significance of these indicators, thus facilitating their visualisation and enabling policymakers to address them effectively.

4.4. DATA COLLECTION

This research tries to combine two perspectives. The researcher perspective and the user perspective. The analysis is done slightly different from the already available data. The already available data such as bus routes, tram and train networks are used to visualise the existing transport networks while the data collected personally is used to analyse the time factor, by physically checking the gaps present in these routes.

Bengaluru's data:

Route network data is procured from:

- BMTC
- BMRCL
- OpenStreetMap-Overpass
- Bangalore OpenCity
- Geohacker's BMTC Visualisation

The present study utilises 50 routes for pattern analysis to evaluate the transport system efficiency in different areas of Bengaluru. These routes were collected through personal experience and surveys conducted by various individuals living in Bangalore. The routes involve various modes of transportation such as driving, taxis, and public transport, and include travel between important destinations, including office to home, malls, and other significant places. These routes were selected to cover different areas of the city and reflect the various transportation options available within Bengaluru. By analysing these routes, the present study aims to provide insights into the efficiency of the transport system in the city and potentially identify areas where improvements can be made. The inclusion of various transportation options in the analysed routes adds further depth to the analyses and presents a more comprehensive evaluation of the city's transport infrastructure.

Amsterdam's data:

Route network data is procured from:

- GVB
- OpenStreetMap-Overpass
- Netherlands OpenData

The present study utilises a sample of 50 routes for pattern analysis, which were collected from various sources in Amsterdam, The Netherlands. The routes were collected through personal experience and surveys conducted by the researcher from individuals living in the city. The routes include different modes of transport such as driving, bicycles, scooters, taxis and public transport, and involve travel between important destinations including office to home, malls, and other significant places. These routes were selected based on neighbourhoods from and to which regular commuting occurred and no personal addresses were used. This approach aims to provide a comprehensive evaluation of the city's transport infrastructure and reflect the various transportation options available in Amsterdam. By analysing these routes, the study aims to identify patterns in transportation usage and provide insights for improving the city's transport system. The inclusion of various transportation options in the analysed routes adds further depth to the analyses and presents a more comprehensive evaluation of the city's transport infrastructure.

4.5. CRITERIA USED IN THE COLLECTION OF THE ROUTES

Assessing the efficiency of urban transport networks is a complex and crucial task as it involves various dynamic factors, underlying mobility patterns, and individual travel motivations. The data analysis process can be influenced by various biases, shaping the interpretation of the results and outcomes. Therefore, this research study aimed to intentionally introduce biases into the data analysis to overcome these limitations and offer a more robust evaluation criterion.

The study chose specific data points that represented diverse categories and travel motivations to introduce biases, leading to a more encompassing view of the city's transportation efficiency. The selected categories include transit hubs, entertainment centres, institutional centres, places of worship, cultural and landmark sites, and varied access points, covering the most critical aspects of travel within the city. Each category was assigned equal importance, reflecting the varied travel motivations and purposes individuals have. Some individuals may be commuting for work, while others may be tourists exploring the city, residents attending religious services, or individuals facing unexpected circumstances. This balanced weighting ensured a comprehensive assessment of the entire transportation network's efficiency, eliminating the chances of an overemphasis on major points while neglecting other aspects of the network.

The study acknowledged that the efficiency of a city's transport network was not solely determined by its central or prominent locations, and network efficiencies also depend on how well-connected even the farthest neighbourhoods are to all the city's offerings. Therefore, this study adopted a holistic approach to efficiency assessment, which was rated on a scale from 1 to 5, aligned with the user study's scale, ensuring consistency in the analysis. These data points are chosen to provide an encompassing view of the city's transportation efficiency. The following categories of data points are included:

1. Transit Hubs: Locations such as bus interchanges and major train stations, serving as key mobility nodes for daily commuters.

2. Entertainment Centres: Places like malls, cinemas, and entertainment venues, catering to leisure and recreational activities.

3. Institutional Centres: Hospitals and universities, essential for various services and education.

4. Places of Worship: Acknowledging the significance of religious and spiritual activities in mobility patterns.

5. Cultural and Landmark Sites: Museums, landmarks, and notable attractions contributing to both local and tourist mobility.

6. Varied Access Points: A selection of anonymised addresses representing a broad spectrum of origins, reflecting different purposes and journeys.

The study acknowledged that the efficiency of a city's transport network was not solely determined by its central or prominent locations, and network efficiencies also depend on how well-connected even the farthest neighbourhoods are to all the city's offerings. Therefore, this study adopted a holistic approach to efficiency assessment, which was rated on a scale from 1 to 5, aligned with the user study's scale, ensuring consistency in the analysis.

Introducing biases into data analysis for a good analysis has been supported by several research practices. Several research endeavours, such as Guiot (2011), Podsakoff(2003), and Spring(1997), GhislainVieilledentG (2009) argue and acknowledge the importance of selecting diverse data points that are representative of various scenarios to assess the transportation network's efficiency. Similarly, Litman (2003) highlights the significance of understanding and acknowledging biases to ensure a rational and reliable analysis. Sánchez-Díaz (2018) emphasises the role of systematic bias in shaping planning processes and suggests that addressing the biases related to transportation planning can lead to better decision-making.

In conclusion, introducing proper biases in analysing the transportation network's efficiency was a crucial step in this research study. By selecting diverse data points from different travel motivations, the study ensured a holistic approach to efficiency assessment. The data's availability further enables other researchers to replicate the study or conduct further analysis, providing valuable insights into transportation planning and policymaking.

5. MODES OF COMPARISON WHAT VISUALISATION TECHNIQUES ARE USED AND WHY

5.1 Understanding the Concept of Ideal Time Taken

The "ideal time taken" in the context of transit refers to the optimal or expected duration it would take to travel between two points using the most efficient and timely means of transportation available. It represents the hypothetical travel time under ideal conditions, assuming no traffic congestion, delays, or disruptions along the route.

The concept of ideal time taken is often used as a benchmark to assess the efficiency of transit systems and compare actual travel times against the best-case scenario. It serves as a reference point for evaluating the performance of transportation networks and identifying areas where improvements can be made to reduce travel times and enhance the overall transit experience.

In practical terms, ideal time taken is a theoretical measure that helps set expectations for how long a trip would ideally take if all conditions were optimal, without considering real-world constraints and variations.

Visually understanding the ideal distance and comparing it with actual distance, helps narrow down the elements that can be considered gaps. The mode here is driving, because the same average distance is covered by public transport as well in order to maintain the uniformity for comparison.

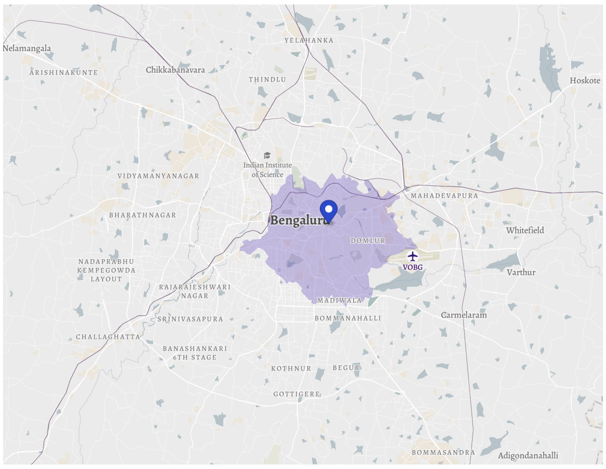


Fig 5.1.1: Bengaluru's ideal coverage within 20 minutes, driving. Map by Mapbox GL.

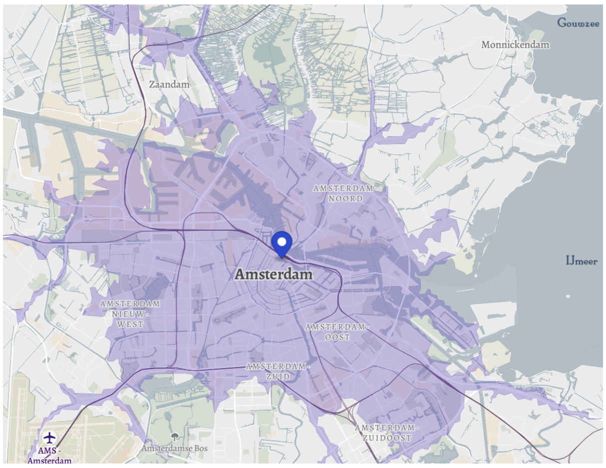


Fig 5.1.2: Amsterdam's ideal coverage within 20 minutes, driving. Map by Mapbox GL.

5.2 The Visualisation Techniques used for Gap Analysis and Why.

Visualisation 1:

Space time Cube
Understanding the Lay of the Land with respect to Time

The space time shows the relationship between the space and the time to understand how the cities are structured in a 3 Dimension format to visualise their form in space and the time in axis. Space time cube's advantage is the ease of visualising the relationship of time taken against the space built and to understand the cities' transport performance, it is very crucial to visualise how the patterns emerge and how they change. The analysis is compared with the distance proximity of the ideal distance it should cover within a time period.

There are several works that highlight the usage of space time cubes in cartographically understanding how the locations are spread over time and this visualisation helps in analysing the impact the time creates on the space (Gatalsky et al., 2004).

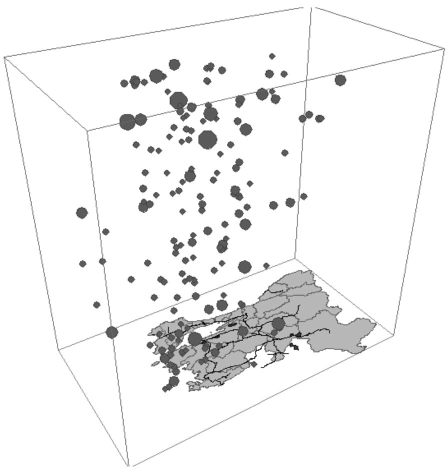


Fig 5.2.1: Representation of object movement in a space-time cube. Source: Gatalsky et al., 2004, Fig2

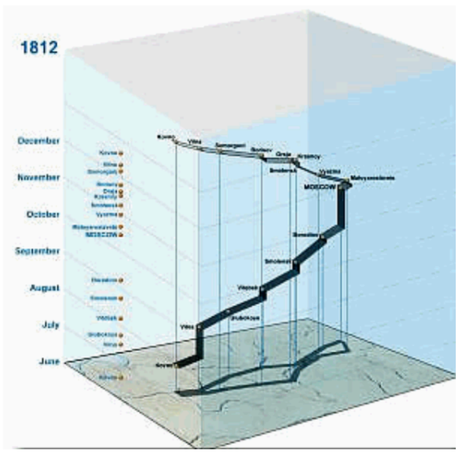


Fig 5.2.2: Representation of route movement in a space-time cube Source: Gatalsky et al., 2004, Fig1

Visualisation 2:

Scatter Plot
Understanding the Gaps

Scatter plots show the relationship of distance with respect to proximity and when combined with the analysis of SpaceTime cubes, can help understand how the proximity to a certain element can change the efficiency of a route. For example, when a public transport stop is in walking distance to an area the user is, how quickly one can reach their destination.

While there are a lot of visualisation techniques like isolines, heat maps and chloropleth maps that help visualise the gaps, the main aim of this research was to visualise transport complexities in an easier way for the normal people, one who are not cartographers, to understand. The scatter plot is very simple to understand, because it deals with a simple concept of measuring distances and measuring the proximity and visualising them on the map based on size. The bigger the point, the higher the distance and the smaller the point, lower the distance. The simplicity manages to reach more people without much explanation and that is the main reason why this visualisation method was chosen for the analysis

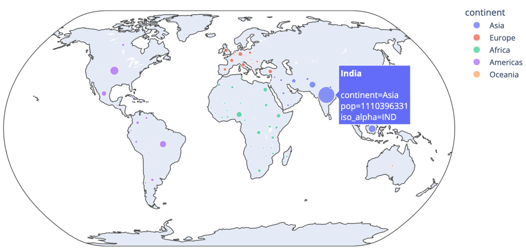


Fig 5.2.3: Scatter Plots being effective examples in showing the size, by Plotly.js

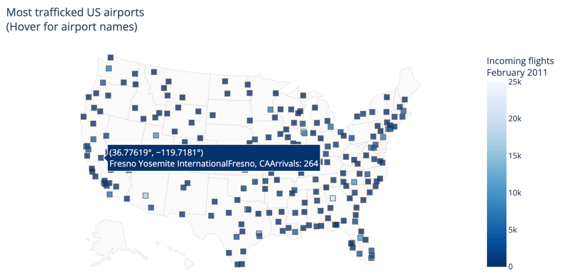


Fig 5.2.4: Scatter Plots being effective examples in showing the density, by Plotly.js

Visualisation 3:

Bar Graphs, Radial Graphs and Line Graphs
Understanding the User Perspective of the Gaps

To compare the understanding the gaps from a researcher point of view to a user point of view, a combination of scatter plots and the bar graphs are used. While the scatter plots are used in visualisation 2, to analyse the user responses from the survey, the simple bar graphs and line graphs are used, adhering to maintaining the simplicity to visualise complex transit issues. Understanding the relationship between good public transit performance to traffic intensity is the first step in the gap analysis done.

To compare the understanding the gaps from a researcher point of view to a user point of view, a combination of scatter plots and the bar graphs are used. While the scatter plots are used in visualisation 2, to analyse the user responses from the survey, the simple bar graphs and line graphs are used, adhering to maintaining the simplicity to visualise complex transit issues. Understanding the relationship between good public transit performance to traffic intensity is the first step in the gap analysis done.

The procedure used is detailed in the section, methods and the user perspectives.

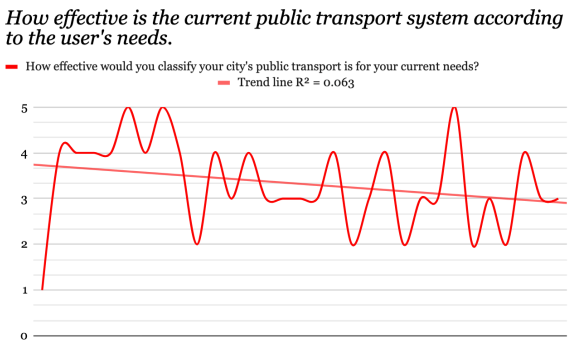


Fig 5.2.5: User understanding of public transport in the two cities being compared. Lower dips point to Bengaluru, vs higher peaks are learning currently towards Amsterdam.

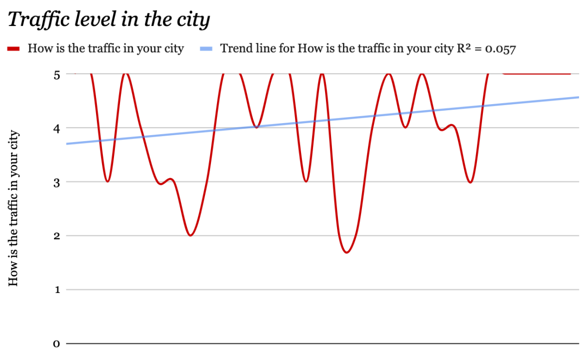


Fig 5.2.6: User understanding of traffic density in the two cities being compared. higher dips point to Amsterdam, vs higher peaks are learning currently towards Bengaluru.

Languages Used

The visualisation techniques use two major programming languages:

- Javascript: D3.Js, Three.Js
- Python

The references are shown in methodology, highlighting which visualisations are written with which language.

6. METHODS

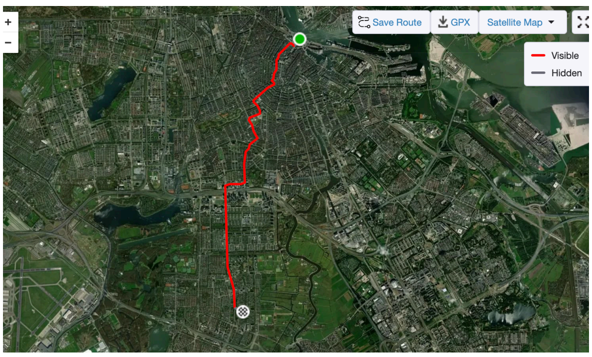
For this research, there are three phases in which the visualisation take place and the methodology follows the 6 steps iterated below. Starting with literature review, the methodology highlights the process of experimenting, choosing, filtering and then finalising the data visualisations used to categorically analyse the data collected and to be able to answer the research questions posed.

Step 1: Literature Review

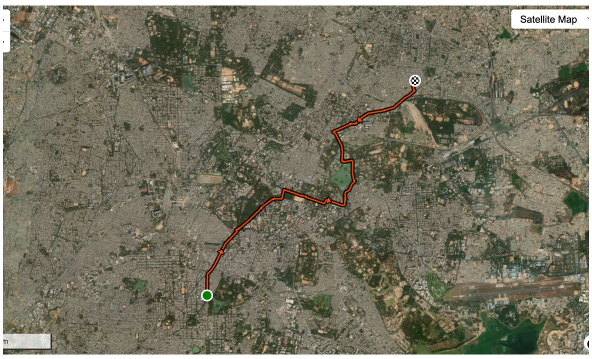
To begin with, this topic was specifically chosen for the research as navigation and transport form one of the major use cases of maps and highlight the importance of maps very specifically in this field when it comes to understanding the efficiency of the available systems and dynamically identifying the zones of the inefficiencies through locations and markers. The major interest was to understand how maps can help bridge the gap in understanding complexities of the world and these research questions provided an ample opportunity to do that. With that began the first step of literature review to understand what works have been done in transport and navigation with the help of cartography and how they can be translated in to this research. Detailed literature review is already presented in the section: Background and related work.

Step 2: Data Collection

First step was to understand how to go about this research, to leverage on the already available data and clinically present gaps in form of numbers and percentages or to physically collect the data and use the knowledge of the cities as an advantage to check and visualise the gaps personally. Hence the routes were personally collected from both the places using a variety of transport methods used to reach either one of them. The notes taken during the route collection also is presented as an explanation in the gap analysis to understand what the users think are a problem when it comes to efficient transport systems.



6.2.1: Route Collection in Amsterdam: Amstelveen to Central



6.2.2: Route Collection in Bengaluru: Lalbagh to Kammanhalli

Modes of transport used in data collection. Buses, Trams, Trains and Ferries in Amsterdam. Buses, trains, autos and cabs in Bengaluru. Wherever possible, the help of other users commuting daily was also leveraged and they have shared their daily commute routes and time.

Second step of the data collection was to understand the already available transport routes and this data was scraped from the official websites of GVB, BMTC and BMRCL.

The entire dataset and the filtered ones used for analysis can be found here.

Step 3: Data Filtration

With the numerous points collected from personal data collection and users commuting everyday, the category bias was applied to select 50 routes in each city that traversed between 50 location pairs or around 100 individual locations mostly travelled. The routes were selected based on the frequent trips made to these places from the locations, to identify the gaps present in that location, highlighted by the frequency of usage from people.

These 50 routes are shown in the space time cube to understand the relationship of space vs time and how efficiency matters when compared with driving vs the public transport. The availability of good modes of public transport is a major to select the combination on routes seen in the space time cube to show the difference between modes of transport and their efficiency.

The same approach can be further applied to other combination of location pairs, where more modes of transport available, but that approach is more suited to do for one city rather than a comparative analysis where the uniformity is necessary to identify patterns in both of the cities.

The 50 routes are ideal in this case to show all the necessary patterns, yet keep the sample small enough to be comfortably visualised using the space time cube.

The individual points collected are more than a 100, exact numbers highlighted in the visualisation for a proper understanding and relating to the map, and is used in proximity analysis of how close or far a public transport stop is.

Step 4: Identifying the Libraries Needed

With three phases of visualisation done in this research, this step was necessary to identify the easiest ways the above data could be visualised that didn't add to the complexity of the research in terms of time, as only 6 months were available to come to proper conclusion. The libraries were chosen based on ease or comfort of working with the languages, thereby eliminating the need to learn something from scratch and to effectively utilise the time available to make the visualisations as aesthetically pleasing and easy as possible for the masses to understand.

There the Python libraries of Matplotlib, JavaScript libraries of D3.Js and Three.js where chosen to visualise the space time cube for showcasing the route and the Python libraries of Geopy and Numpy were used to analyse the routes and come to the conclusion.

Step 5: Building the Base Code for all the Visualisations

1. SpaceTime Cube: While the data collection and filtration was in progress, simultaneously building a base code was also started. To be able to have a place holder to visualise a small sample of data helped in removing the kinks in the process and understanding how the data needs to be filtered in order to visualise it accurately for the necessary analysis.

The libraries of D3.Js and Three.js was used to visualise a space time cube to show the exact route between two points, a route that was collected, to visualise how the route spread over the space in time. This visualisation helps in understanding how the route progresses in time and how one route compares to another in two different modes and two different places.

2. Scatter Plot: Various methods like heatmaps, cloropleth maps and bar graphs were checked with a small sample data to understand which visualisation would meet the criteria of effectively showcasing the proximity analysis while being easy to understand. After trials and errors, the scatter plot made with Python, with proximity analysis done with Haversine Formula was chosen to visualise the distance between the chosen location points to its nearest public transport stops. This visualisation is necessary to understand why driving or taking their own mode of transport is still sometimes preferred over using the public transport, and the scatter plot makes for a very simple way of visualising a complex problem of understanding distance.

Understanding Haversine Formula:

The Haversine formula is a mathematical equation used to calculate the shortest distance between two points on a sphere, given their latitudes and longitudes. It is commonly applied in navigation and geolocation where distances on the surface of the Earth are required.

The Haversine formula is preferred over the Euclidean formula when calculating distances between latitude-longitude pairs because it takes into account the curvature of the Earth's surface, resulting in a more accurate representation of the distance. This is especially important when dealing with long distances or larger areas. Even at the scale of a city, the Earth's curvature is significant, so the Haversine formula is still better suited for calculating distances between latitude-longitude pairs in kilometres. The Haversine formula gives results within 0.3% of their actual value, whereas the Euclidean formula could result in significant errors calculating distances for the kind of analysis done in this research (C. C. Robusto, 1957; Rezania Agramanisti Azdy 2020).

3. User survey: A questionnaire was created to understand what the general users think of as gaps, and to analyse whether it was possible to effectively visualise these gaps cartographically, thereby checking for patterns emerging from the similar visualisations using two different samples of data.

Step 6: Design

Finalising the visualisation techniques led to the final step of completing the design and colour schemes to effectively visualise the necessary data in the way needed to analyse it. For the scatter plot: the colour scheme chosen was Greens, to effectively highlight the nearest to farthest points and for the space time cube, the colour scheme in the space time cube maintained the same colours of the traffic that the users are used to seeing to make them understand how much time in general is taken for these routes to be traversed. The maps used here to highlight the city patterns are created using Illustrator, based on the reference of existing transit maps of the city, which have been referenced in the image captions and in the design inspirations section of the References.

7. VISUALISATIONS FOR TRANSIT PATTERNS BASED ON TIME

The research is split into four visualisations, each having a specific purpose of why they have been visualised and the patterns they demonstrate. The visualisations are built for understanding the spread of the route in the dimension of the time; understanding the patterns the routes convey based on the time and the performance; understanding the distance from the user perspective and the user preferences. The four types of visualisations built are:

1. Space Time Cube of Public Transport Route vs Driving Routes
2. Space Time Cube of Locations spread over time period
3. Understanding Gaps based on Time factor
4. What users perceive as Gaps

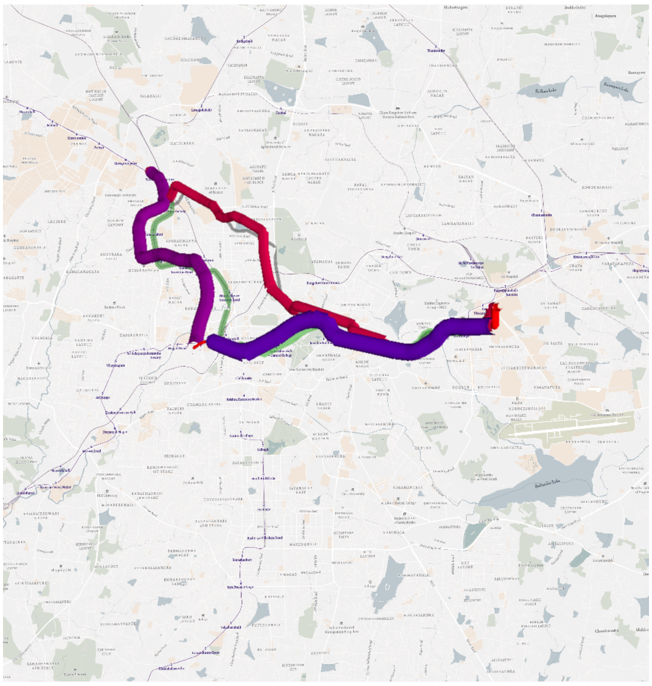
7.1. SPACE TIME CUBE OF PUBLIC TRANSPORT ROUTE VS DRIVING ROUTES

The first analysis in this research aims to understand the spread of the space-time cube in each city and how the route is distributed within the spatial extent of the city, with the time factor being a crucial variable in analysing the differences between the transport systems. The analysis objective is to identify the variation in travel time on similar routes with comparable distances in the two different transport systems (public transport and driving) to gain insight into the complexity of inefficiencies in transport systems.

The original and final destinations of the route remain the same, while the mode of transportation changes between the two systems under analysis. The comparison of the major transport modes in each city is necessary to provide a consistent platform for analysis.

Peak hours are selected for analysis, comprising relevant commute hours of people in both cities. Specifically, the hours chosen are in the morning from 07:30 to 10:30, and in the evening from 06:30 to 10:30, representing the hours when efficiency is of paramount importance.

The resulting pattern shows the visualisation of the same route, with the average time taken for each mode of transport represented, to enable comparison between the two modes. Analysis of the space-time cube provides insights into how similar routes can have widely differing travel times due to differing transport modes in use.



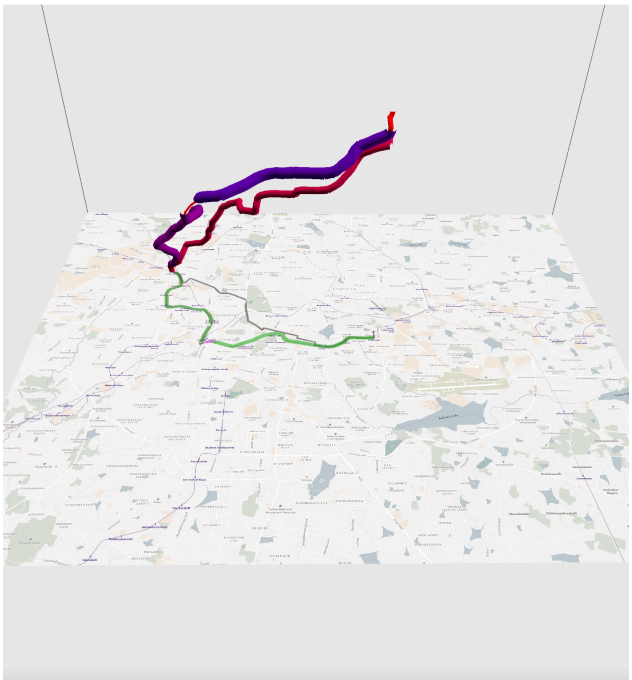
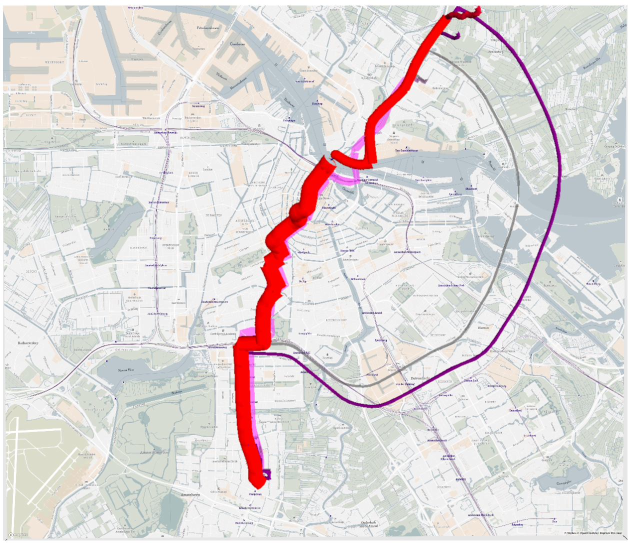


Fig: 7.1.1: Driving vs public transport spread: Bengaluru. The public transport taking less time than driving.

Fig: 7.1.2: Driving vs public transport spread: Bengaluru. The public transport taking less time than driving.



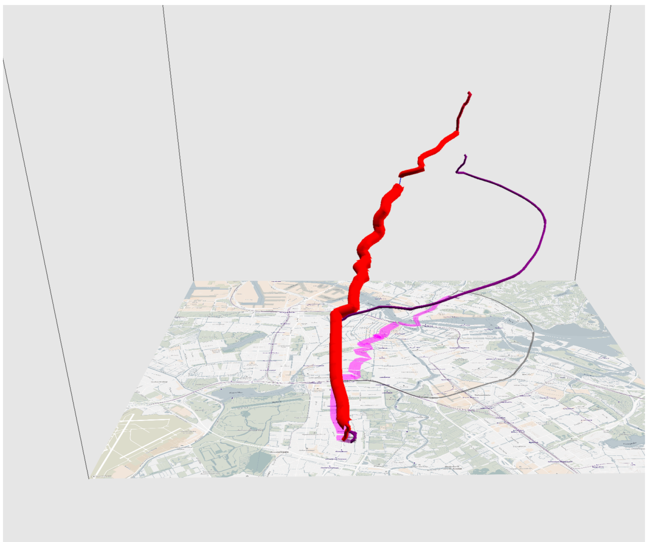


Fig: 7.1.3: Driving vs public transport spread: Amsterdam. The public transport taking more time than driving.

Fig: 7.1.4: Driving vs public transport spread: Amsterdam. The public transport taking more time than driving.

Low time/less delay

Higher time/more delay

This cube highlights the way the routes of both driving and public transport are spread over the time. The time scale is from 10 minutes to 120 minutes. The purple route highlights the lower time or delay, and, the red route highlights higher time or delay. Likewise, the thickness of the cylindrical tube movement of the route shows more time, or delay.

The pattern visible here shows while in Bengaluru, both public transport and driving pretty much have the same routes followed, including kilometre level, and Amsterdam has the driving route longer.

The highlight of Amsterdam is that even though the driving route is longer, the time taken is half of what it takes for public transport route to be traversed.

For Bengaluru however, the driving time is double that that of the public transport. Owing to the factors of how Bengaluru traffic is, the driving time is very inefficient compared to the public transport time. This could indicate three important features in the pattern (RQ1):

- Bengaluru's heavy population with a significantly heavier dependency on driving makes driving time higher.
- Bengaluru's public transport system is not as efficient yet that users would prefer using public transport over driving.
- The usage of roads infrastructure the same way for both public transport and driving can prove to be the choking factor when it comes to time because it doesn't assign different weights to both the systems, unlike Amsterdam which has specific streets and highways modified to accommodate both public transport and driving in their own way.

7.2. SPACE TIME CUBE OF LOCATIONS SPREAD OVER TIME PERIOD

The second analysis talks about the time factor spread over entire locations. There are 50 routes taken in each city, spread across the entire city, comprising the main modes of public transport, and any transport mode that is used to connect to the mode of public transport. On an average more than 70 percent of routes in Amsterdam fall within the time bracket of 40 mins. But on the other hand, more than 70 percent of routes in Bangalore are between 40 to 120 mins.

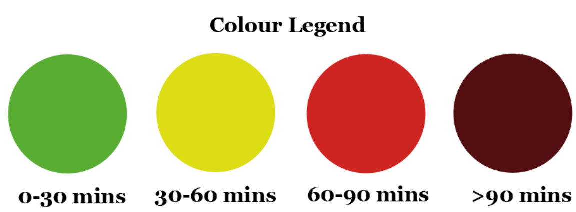
The key factor here, the spread of Bangalore is in more km level than Amsterdam, with an area that is three times bigger than Amsterdam, making it absolutely necessary for a robust transport system to have already been built that connects all the neighbourhoods of Bangalore efficiently.

The main aim of this space time cube is to understand the average performances of the routes, and highlighting similar areas with a similar commercial or industrial aspect and how this can change the behaviours in both of the cities, especially the difference being having a good public transport infrastructure versus the ones where it is still not complete. This pattern of performances helps in analysing where cities like Bengaluru can benefit from cities like Amsterdam.

The routes are in the format of connectors, with origin and destination points and lines connecting each pair of points colour coded in the same format as the traffic colours. The space time cube shows the locations in a 3d cube, with latitude/ longitude serving as the x and y axis, and the time marking the z axis.

The cube shows the spread of the routes, based on how much time each route takes: depending on whether it is driving during peak hours versus non peak hours and using public transport during peak hours versus non peak hours. The gradation shows the pattern of how the routes perform. This is the average time taken, recorded for over a week, for the same route pairings.

Legend:



Colours used show traffic density

Bengaluru

Peak Hour - Driving

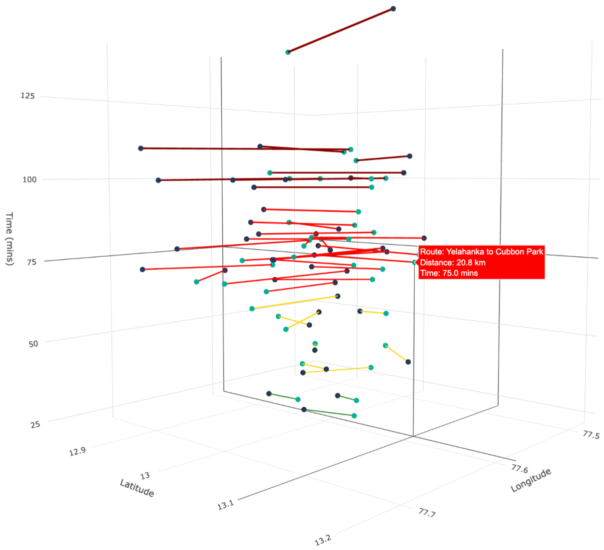


Fig 7.2.1: Driving during peak hours in Bengaluru usually takes more than 1 hour.

Peak Hour - Public Transit

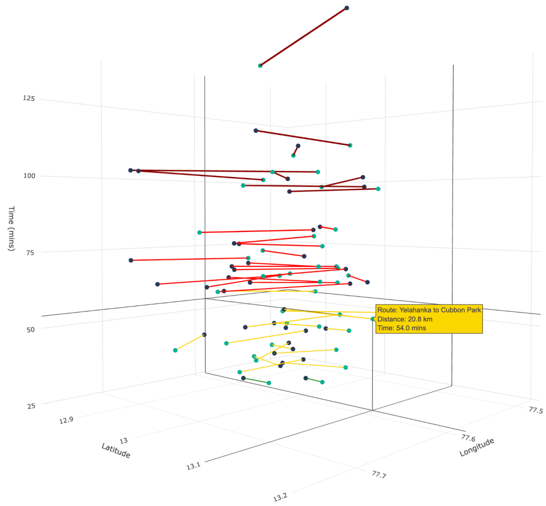


Fig 7.2.2: Using public transport during peak hours in Bengaluru usually takes less time than driving.

Non Peak Hour - Driving

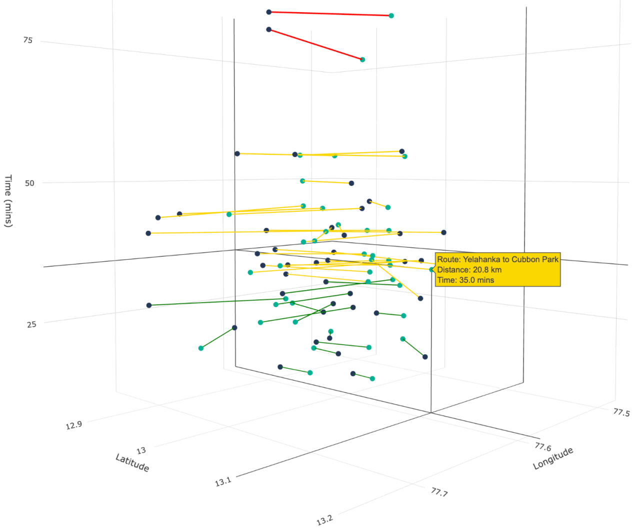


Fig 7.2.3: Driving during non peak hours in Bengaluru usually takes less time than using public transit

Non Peak Hour - Public Transit

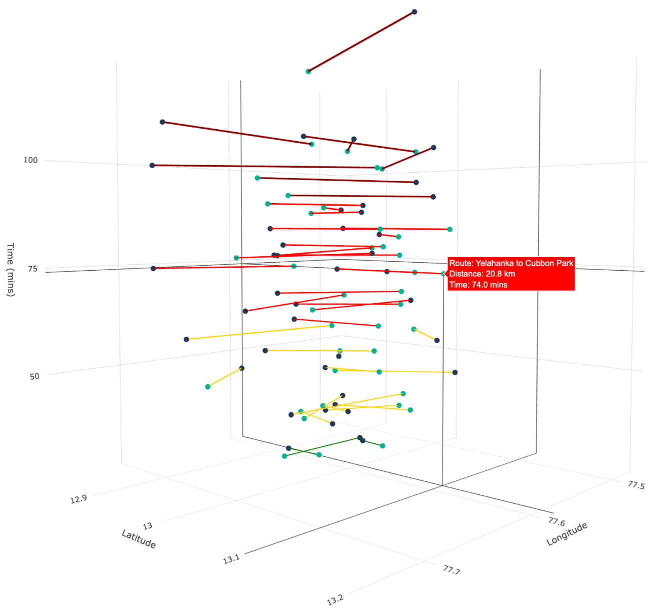


Fig 7.2.4: Public transit during non peak hours in Bengaluru usually takes more time than driving

Amsterdam

Peak Hour - Driving

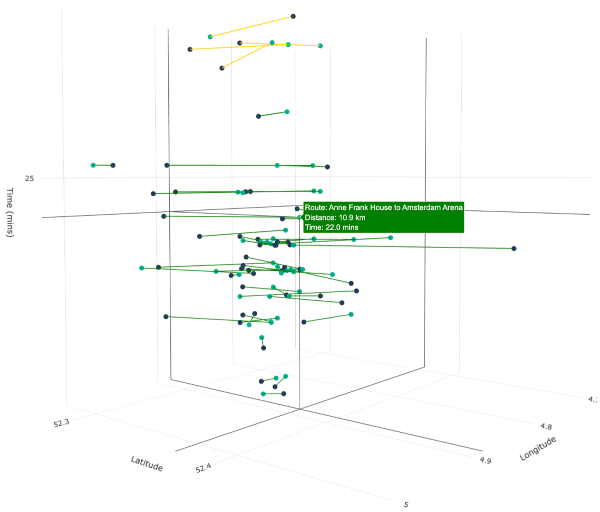


Fig 7.2.5: Driving during peak hours in Amsterdam takes less time than public transit

Peak Hour - Public Transit

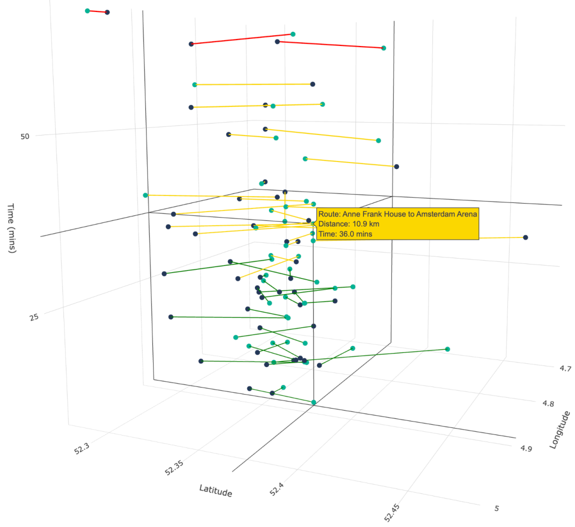


Fig 7.2.6: Public transit during peak hours in Amsterdam takes more time than driving but still less time due to good frequency

Non Peak Hour - Driving

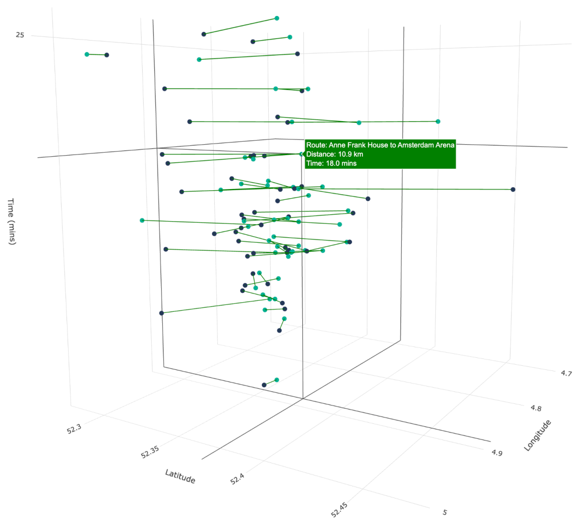


Fig 7.2.7: Driving during non peak hours in Amsterdam takes way less time than public transit

Non Peak Hour - Public Transit

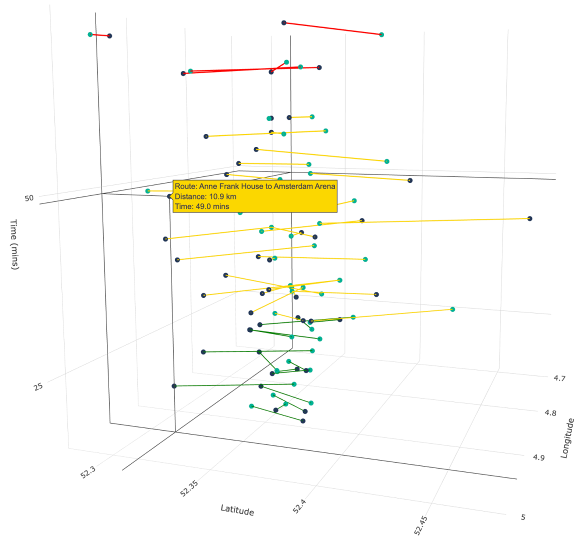


Fig 7.2.8: Public transit during non peak hours in Amsterdam takes slightly more time than driving due to lesser frequency

7.3. UNDERSTANDING PATTERNS

The second analysis in this research aims to investigate the impact of different factors on the travel times of public transport and driving modes during peak and non-peak hours through the use of space-time cubes. The objective is to identify the underlying factors that contribute to the observed patterns in transport behaviour and to assess their role in shaping travel times.

In general, the trend of public transport requiring more time than driving can be attributed to the additional time spent commuting to and from public transport stops and waiting for the transport. On the other hand, driving eliminates these delays by allowing passengers to travel directly from their origin to their destination, with traffic or other incidents being the primary factor influencing travel times.

However, the analysis reveals that Bengaluru exhibits a radically different pattern during peak hour traffic, where public transport takes less time than driving when the routes are connected via the metro. This substantial reduction in travel time emphasises the importance of efficient and accessible public transport systems, which can reduce the time lost due to congestion on crowded streets. Conversely, Amsterdam shows a similar trend to other urban areas, where public transport takes more time than driving, demonstrating the city's continued reliance on a strong and established public transport framework.

The patterns are derived from a dataset of 50 routes spread throughout the cities, with varying modes of transport for public transport, where the average time taken to commute between the origin and destination points of each route was recorded over a week. Subsequent comparison with the overall time taken for each route demonstrates that the time patterns are consistent with the average time taken for each route, revealing crucial insights into the impact of various factors on travel times.

In conclusion, the analysis reveals that the patterns observed in travel times between public transport and driving modes are shaped by various factors, including access to public transport systems and congestion on crowded roads. Therefore, it highlights the significance of efficient and well-designed transport systems that provide easy accessibility and promote smooth travel. These findings lay the foundation for future investigations into improving the transport system while identifying the key factors influencing travel behaviours in urban regions.

- **70%** of the routes in Bengaluru take 60 minutes or more during peak hour driving. The average kilometre level of 10-20.
- During peak hour, the public transport usage for the same routes average less than hour, with a significant average kilometre level of 10-20 km.
- During non peak hours, **100%** of the routes take an average time of 30-60 minutes with an average kilometre level of 10-20.
- During non peak hours, **73%** of the routes take an average time of 60-90 minutes with an average kilometre level of 10-20.

However, when compared with Amsterdam, the pattern changes significantly with:
- **80%** of the routes in Amsterdam take 30 minutes during peak hour driving. The average kilometre level of 10-20.
- During peak hour, **65%** the public transport usage for the same routes average more than 30 minutes but below 45 minutes, with a significant average kilometre level of 10-20 km.
- During non peak hours, **65%** of the routes take an average time of 20-30 minutes with an average kilometre level of 10-20.
- During non peak hours, **76%** of the routes take an average time of 30-60 minutes with an average kilometre level of 10-20. This is due to longer waiting time of the public transport.

The analysis section provides a detailed examination of what the observed patterns in the data could signify, offering insights into the underlying factors that contribute to the behaviour of travel times between public transport and driving modes in both cities (RQ1 and RQ2).

8. UNDERSTANDING AND VISUALISING GAPS

Gaps or inefficiencies are a lack of a service that could be used efficiently or lack of infrastructure that makes the service un-rendered. The lack of infrastructure is a time consuming gap to eliminate while lack of a service that could be used could be repaired easily by introducing more modes of available transport. To understand that gap (RQ3), the datasets are divided into two classes:

- Bus stops the mode of public transport that uses the existing road infrastructure.
- Train, Tram Stops and ferry stops the mode of public transport that has a separate infrastructure needed to work.

Gap 1.
Lack of proximity

One of the major reasons why people prefer to drive or use their own transport over public transport is the lack of a transit option near to them, that is easily accessible. The proximity analysis is analysing the proximity of any of the available public transit stops, in any direction, to the locations collected in both the cities and this distance of the public transit points to the neighbourhoods in priority is visualised as a simple scatter plot.

The scatter plot highlights the distance of the transit stop from anywhere in the average location collected from the neighbourhood as a circle. The nearer the transit point from any direction, the smaller the circle and as the distance increases, the radius becomes bigger, to highlight the gap.

- Map scale used in the below presented maps: **Scale: 1:450,000**
- Map design by the author, unless stated and referenced otherwise.

Bengaluru Bus Stops

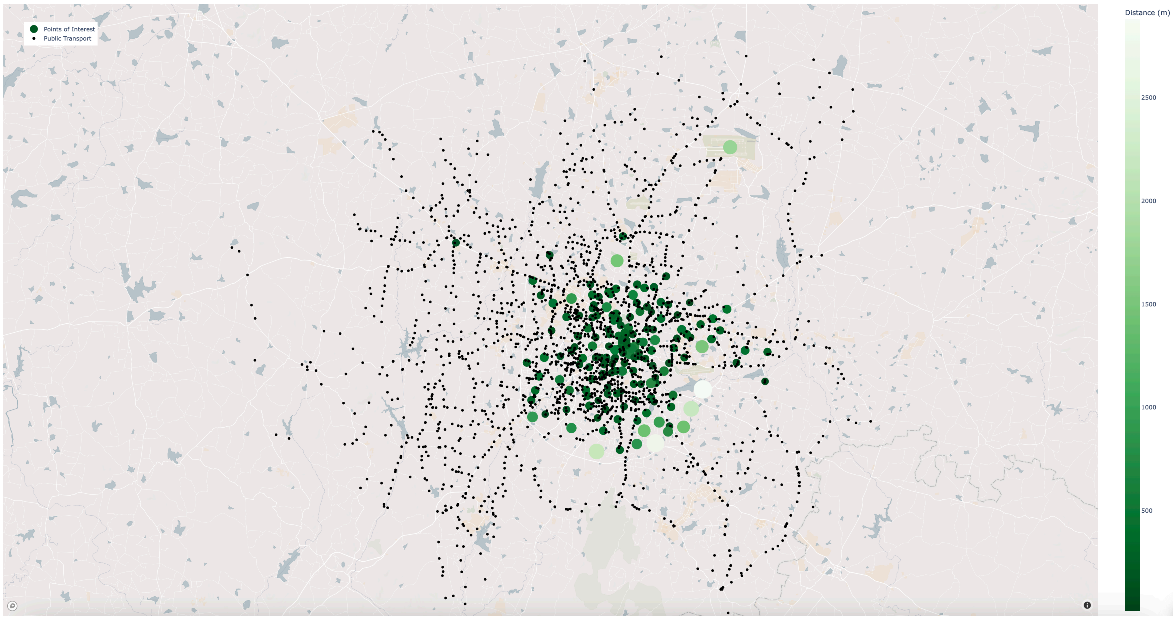


Fig 8.1: Proximity of bus stops from the selected key addresses of Bengaluru. The outliers here are a part of BMTC service area.

Amsterdam Bus Stops

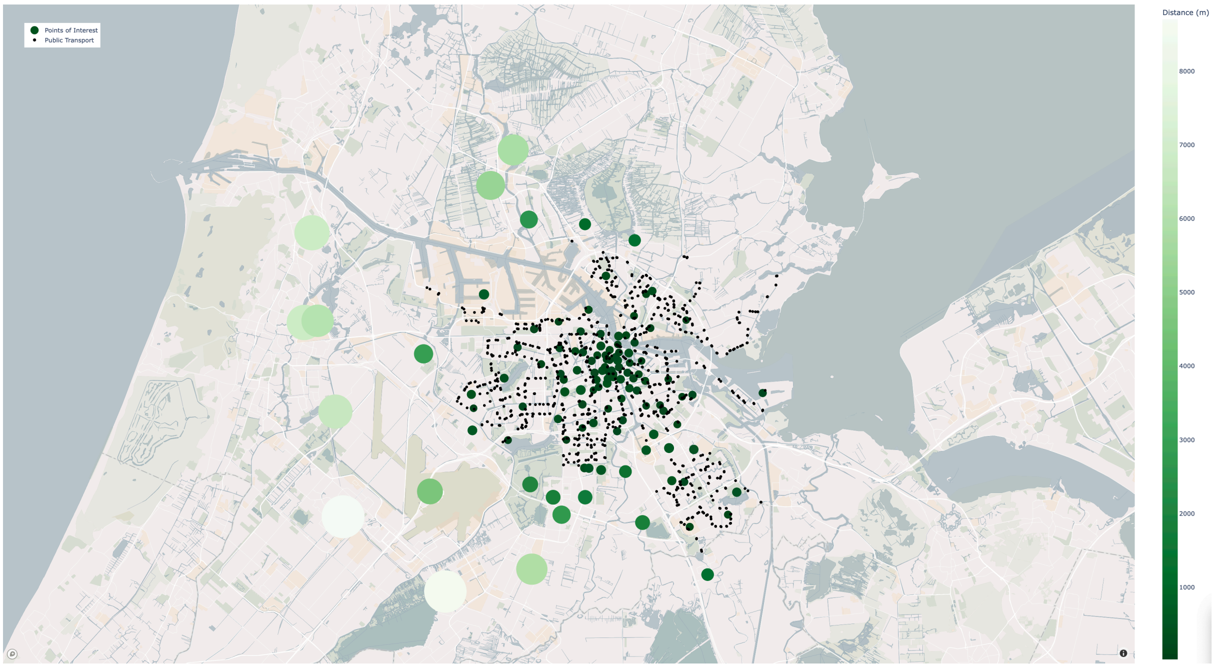


Fig 8.2: Proximity of bus stops from the selected key addresses of Amsterdam. The outliers here are not a part of GVB service area.

Bengaluru Metro Stops

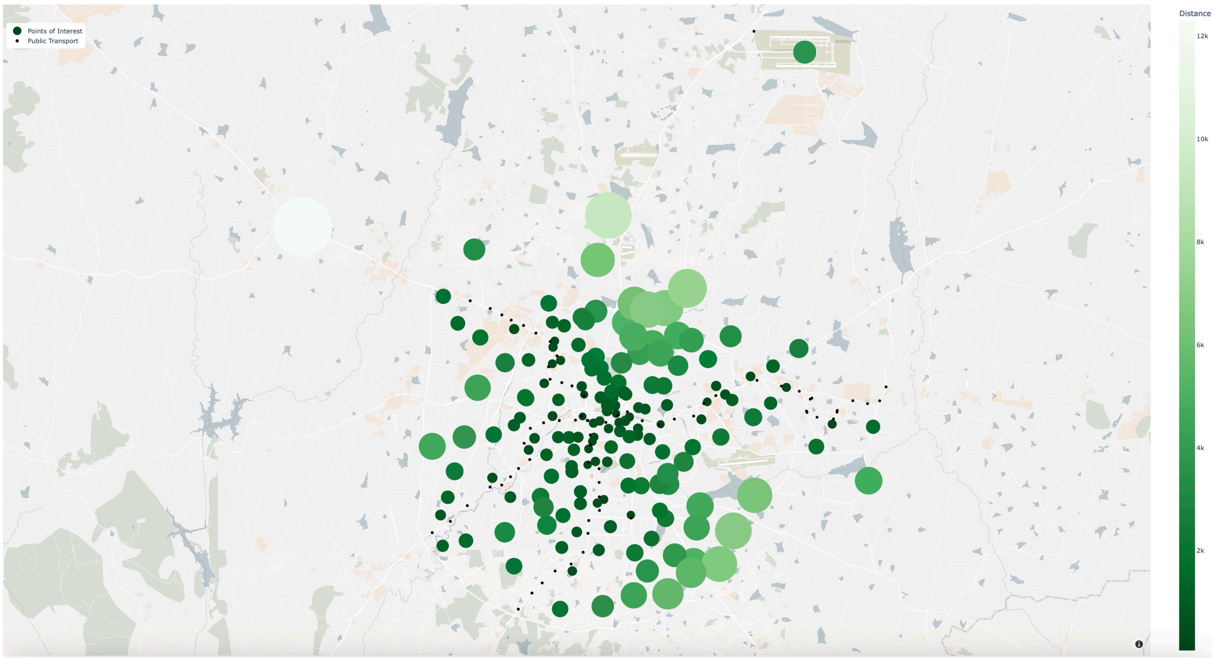


Fig 8.3: Proximity of metro stops from the selected key addresses of Bengaluru. The outliers here are a part BMRCL service area.

Amsterdam Tram and Metro Stops

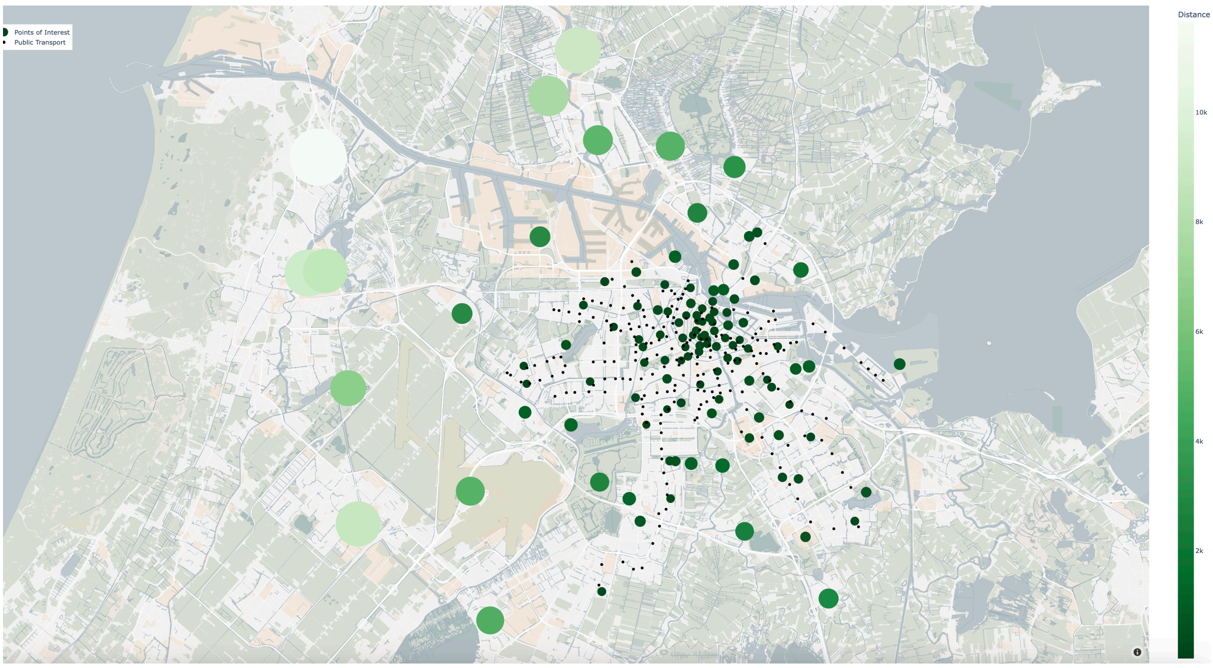


Fig 8.4: Proximity of metro stops from the selected key addresses of Amsterdam. The outliers here are not a part of GVB service area.

The scatter plot visualisation helps with simplifying the complexity of the concept of proximity gaps and visualising them in a way that the user understands the magnitude of how it could spread and the impact it has.

Analysis

While the scatter plots visualise gaps, the graphs below shows how much percentage of stops are in the proximity of a walking distance for every mode of transport and when the transport network is improved, how that gap percentage change, and how the proximity changes.

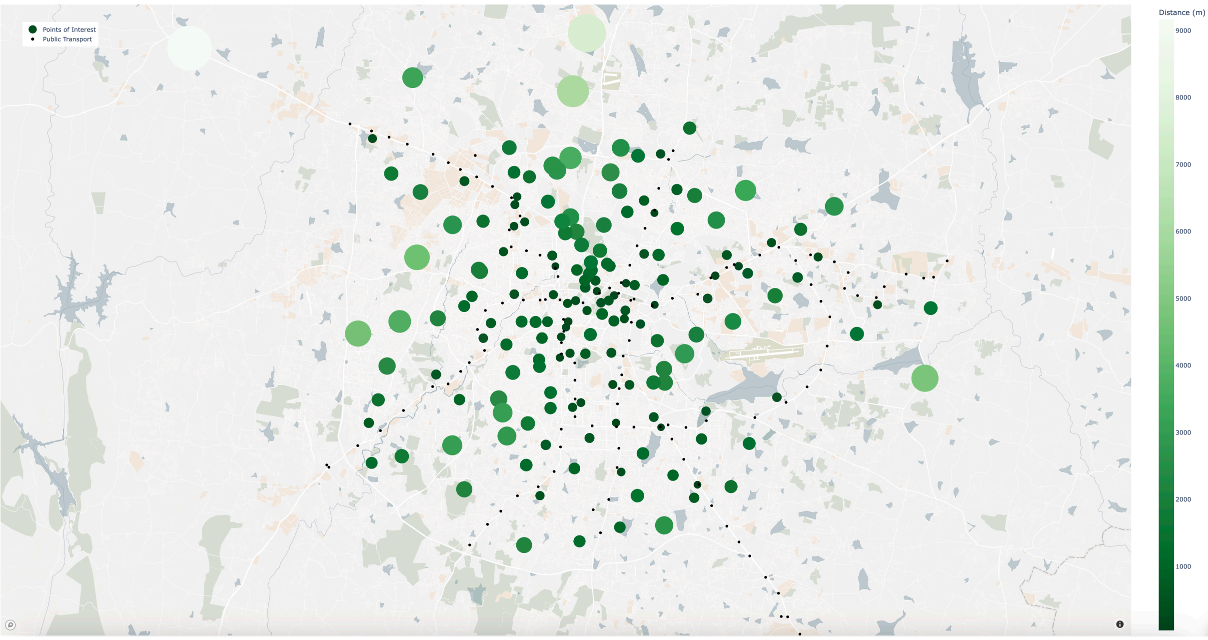


Fig 8.5: Proximity of metro stops from the selected key addresses of Bengaluru after the proposed lines are operational.

Bengaluru:

Bengaluru has a massive, robust bus network with 2682 routes currently running and over 2900 bus stops spread across the entire city. With this analysis, the routes collected plays the datapoints spread over every important area of Bengaluru and analysing their proximity to the bus stop, and how many are less than 500 metres to walk to more than a kilometre to walk.

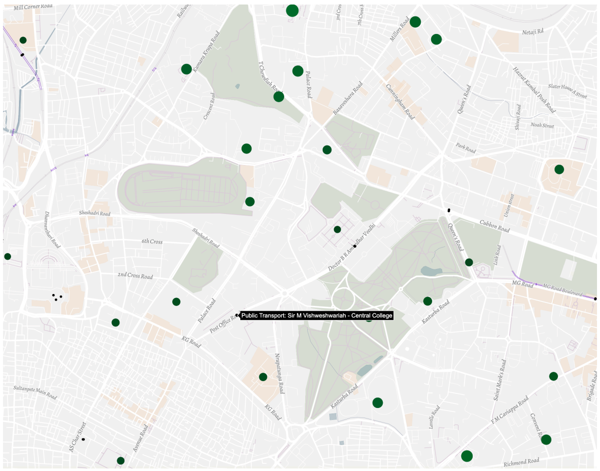


Fig 8.6: The difference is distance from one public transport point in Bangalore, where the distance is between 150-500 meters.

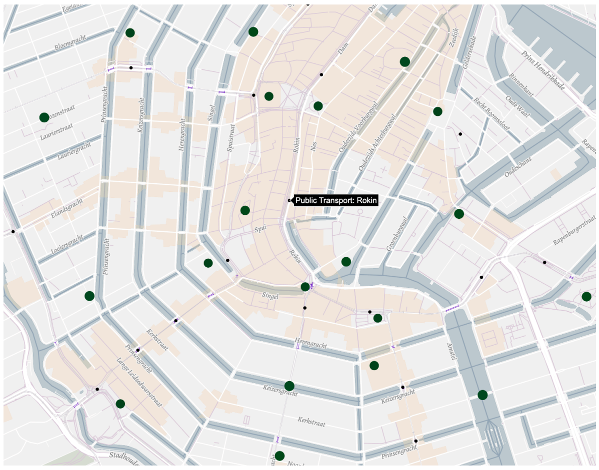


Fig 8.7: The difference is distance from one public transport point in Amsterdam, where the distance is between 50-250 meters.

BMTC network is extensive and services all neighbourhoods of urban and rural Bengaluru. However, the metro train network in Bengaluru is not complete across all the neighbourhoods, and is a significantly higher distance to access from the other neighbourhoods in comparison to where the metro lines runs.

Amsterdam:

Amsterdam, in comparison, has both a robust bus network, and train, tram and ferry network that is quite accessible just walking without having to access another mode of transport to reach a public transit stop.

The combination of having a complete bus, metro, tram network, along with the usages of ferries that can access any neighbourhood with a combination of public transit modes. The outliers here, in orange and red, are the points that are outside of Amsterdam area and is not serviced by GVB’s Amsterdam Network but still accessible by suburban buses and trains. Similar distances in Bengaluru is still well within the city’s serviceable limits and is not considered suburban.

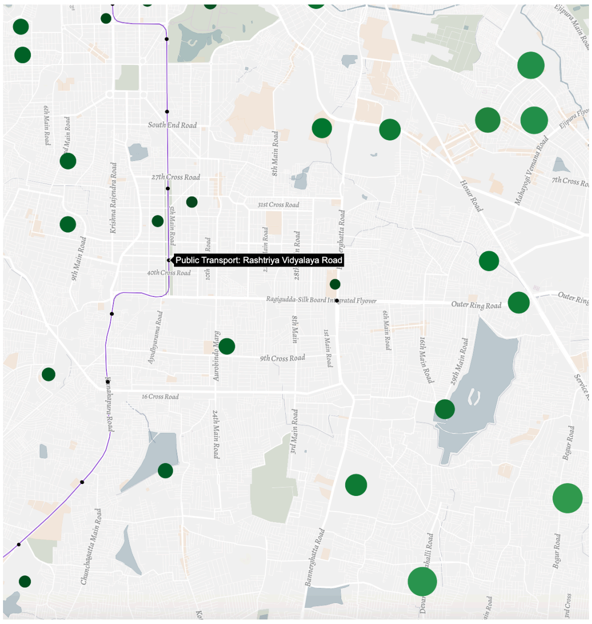


Fig 8.8: The current distances of the key addresses from the Green Line Metro Line.

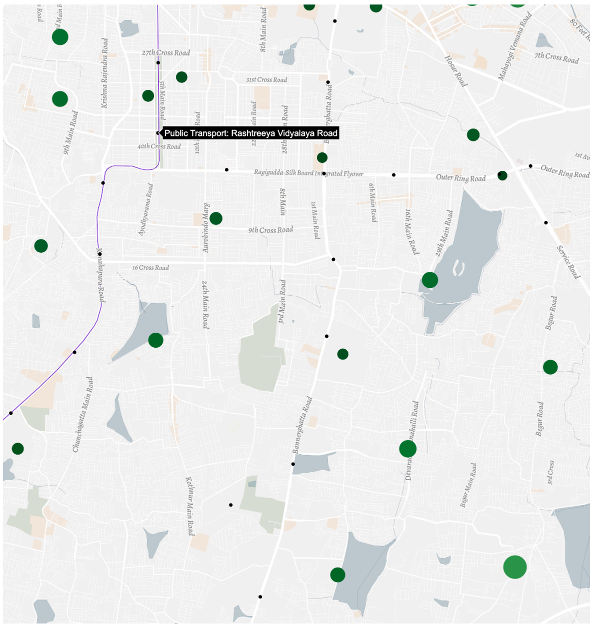


Fig 8.9: The change in distances of the key addresses once the current proposed line is open.

Gap 2.
Lack of connectivity

Another major reason why people prefer to drive or use their own transport over public transport is the lack of a faster transit option near to them, that is easily accessible by walking or a non motorised transport and without having to use their private vehicle.

Bengaluru:

While the bus routes are well routed and connected all over the major neighbourhoods of Bengaluru, the exponential traffic problem and the lack of specific bus lanes hinders the buses' easy and faster movement and the travel time increases remarkably. Even if the metro lines are running, and there are feeder buses running to majority of the metro stations, it is not running to all of them which is the lack of connectivity. Invariably in Bengaluru, users end up using one of their private vehicles to connect to a metro station that is more than a kilometre away, or use private vehicles all the way.

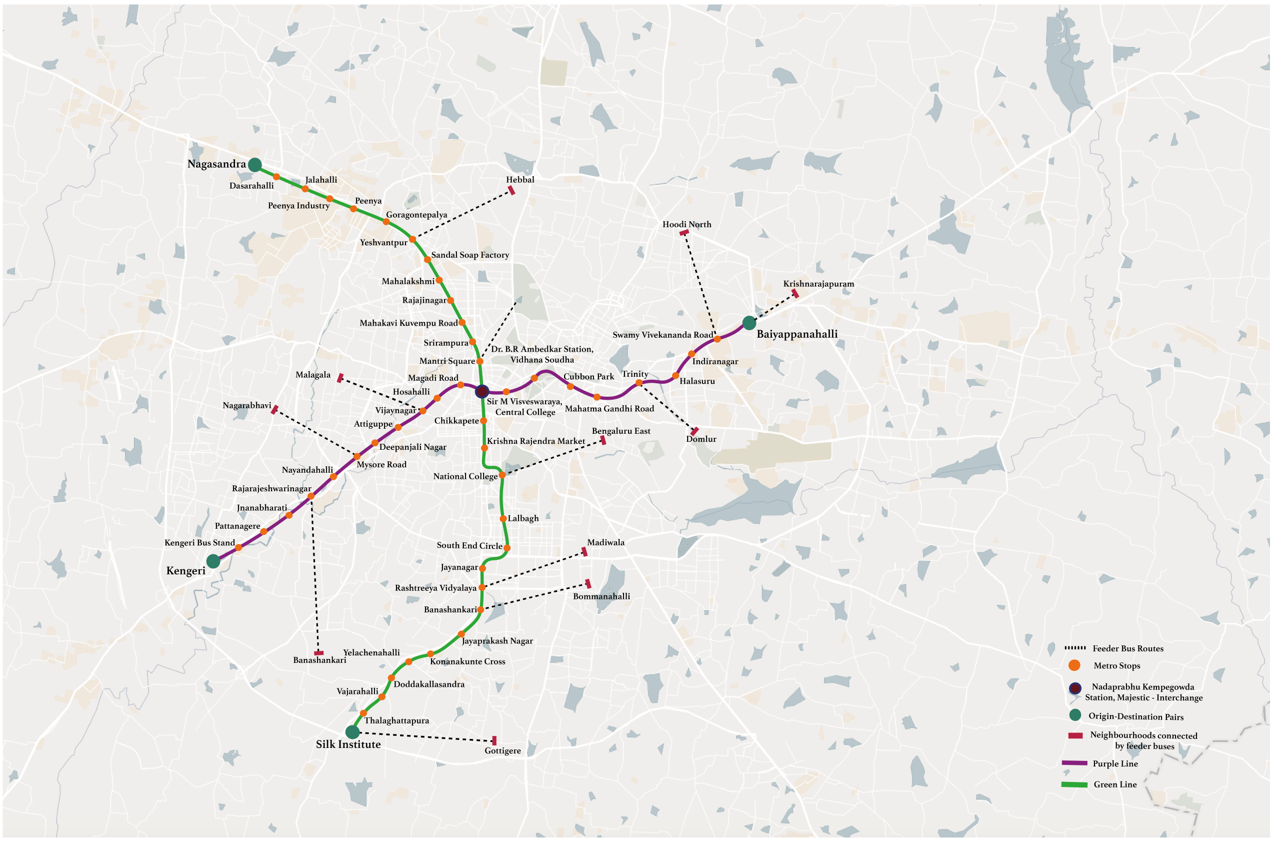


Fig 8.10: Bengaluru feeder buses connecting certain high footfall areas to key metro stations.

The lack of connectivity also applies to the availability of a fantastic suburban train network, with the twenty major railway stations within Bengaluru with a possibility of connecting every one of them through various routes and utilise the network with a slew of suburban trains, that decreases the time factor by commuting through the robust network of the trains. However, currently the major railway stations are only being used for intercity rails with minimum passenger trains running without a good and frequent schedule and that lack of connectivity is one of the major gaps of efficient use of available transport modes. The Bengaluru Suburban Rail Project is under works, and would include extra infrastructure make it feasible and efficient.

Amsterdam:

Amsterdam, in comparison, has a great suburban trains network, that has separate lines for the local trains to connect to to farther neighbourhoods from the city and has a good frequency of 10 to 30 minutes. That enables the users to take complete advantage of the well connected network and plan the routes in an efficient way that doesn't require the usage of private vehicles and reduce the traffic in general.

Fig 8.11.1 The existing suburban rail network in Bengaluru.

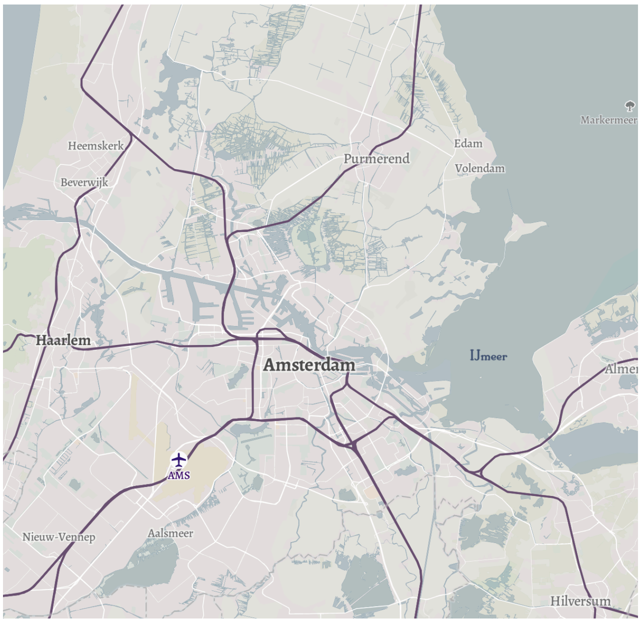


Fig 8.11.1 The existing suburban rail network in Amsterdam.

Fig 8.12: Bengaluru's Suburban Rail Project Proposal to connect the major neighbourhoods in Bengaluru

Table 8.1.1. Overview of Feeder Buses and Suburban Rail Frequency

Element	Bengaluru	Amsterdam
Metro Feeder Buses	Yes	No
Frequency	30 mins	NA
Suburban Rail Network	No-under proposal stage	Yes
Frequency	Follows the intercity time table. No regular trains for interconnections within the city	10 to 15 minutes

Gap 3.
Lack of availability

One of the biggest concerns of efficient transit systems is safety, which is the availability of transport modes at all hours of the day. When public transport is available throughout the day, the dependency on private vehicles reduces drastically.

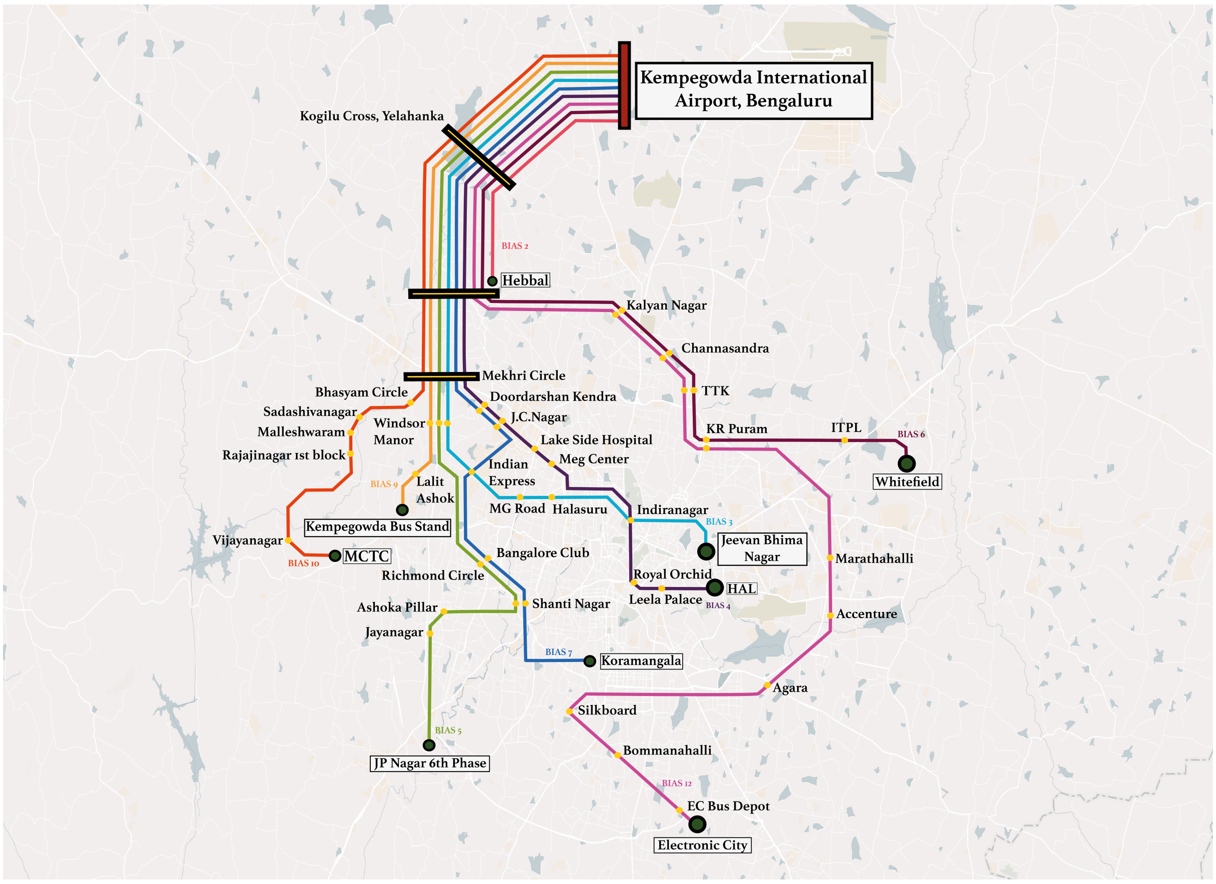


Fig 8.13: The night routes in Bengaluru, focussed on the destination: Airport, and only key neighbourhoods

Bengaluru:

Bengaluru public transit times starts at **5 AM** ends at **11:15 PM** on all days with little to no service in the hours in between **11:15 PM-4:59 AM**

The major routes that run throughout the night are only the ones that go to airport and the wait time for the Vayu Vajra routes are between 1 to 2 hours, depending on the neighbourhood.

Amsterdam:

Amsterdam, in comparison, has 24 hours transport during the entire week with a frequency differing between 15 minutes to 1 hour, depending on the lines' popularity or greater usage.

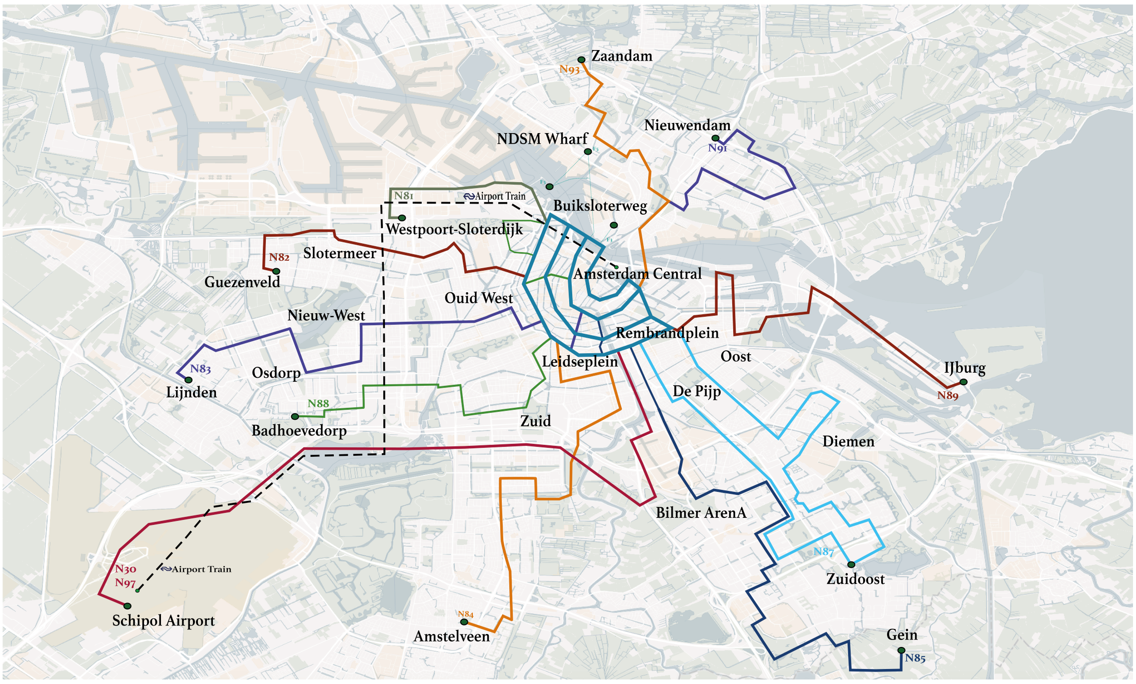


Fig 8.14: In comparison, the night routes in Amsterdam, focussed on the centre and the neighbourhoods, with a line specifically focussed to Airport.

- Weekdays: 6 lines run nightly, with a frequency of 1 hour between **12:30 AM** to **05:30 AM**
- During Saturdays and Sundays: 6 lines running with a frequency of 20 minutes to 30 minutes from **12:30 AM** to **07:30 AM**.

The combination of having good frequency night transport is also a way to bridging the gap of having an efficient transport system.

Data about frequency:

- Amsterdam: **GVB**
- Bengaluru: **BMTC** and **BMRCL**

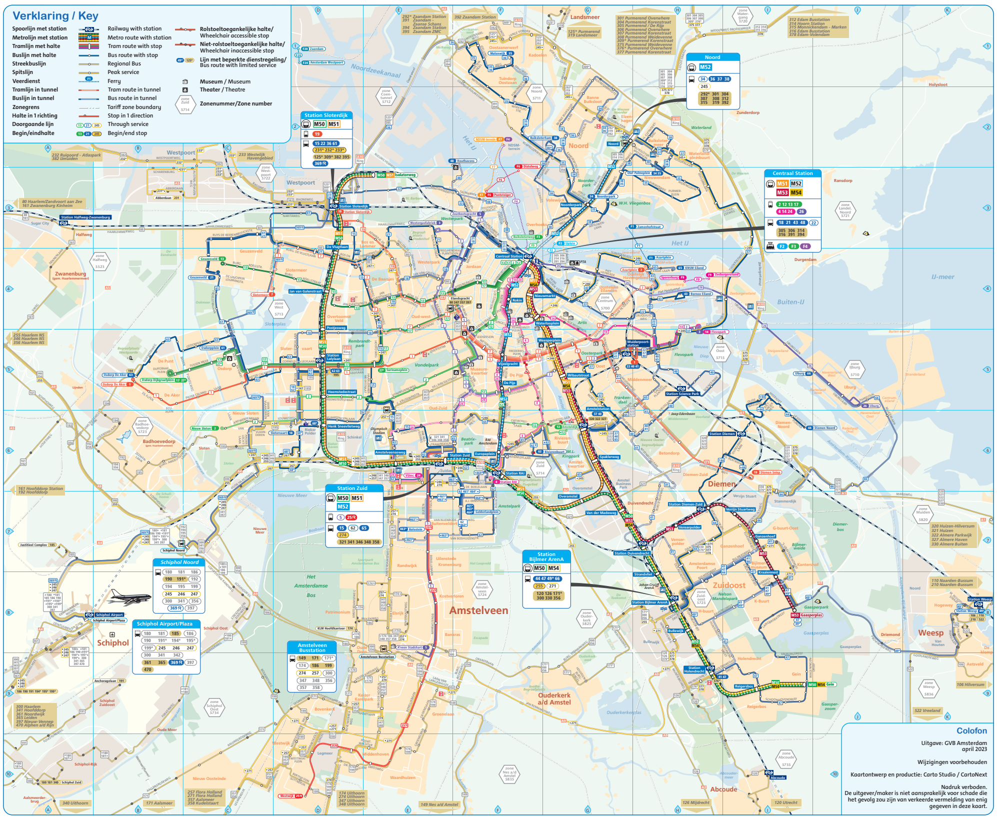


Fig 8.15: Amsterdam's extensive transport map. Source: [reisinfo.gvb]

9. ANALYSING GAPS

Gap 1.
Lack of proximity

Bengaluru Public Transport Proximity Range

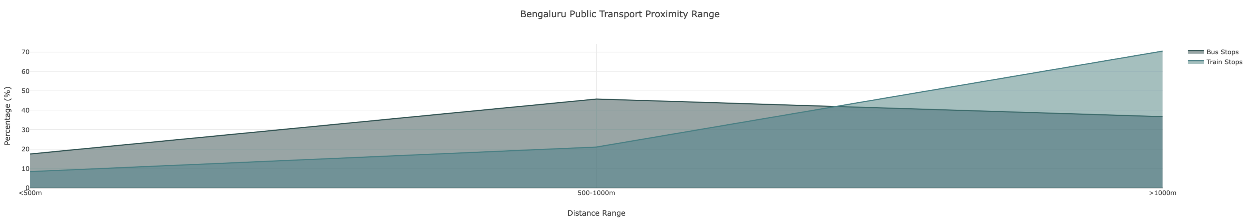


Fig 9.1: Bengaluru: Proximity of bus stops vs train stations from the selected key addresses.

Amsterdam Public Transport Proximity Range

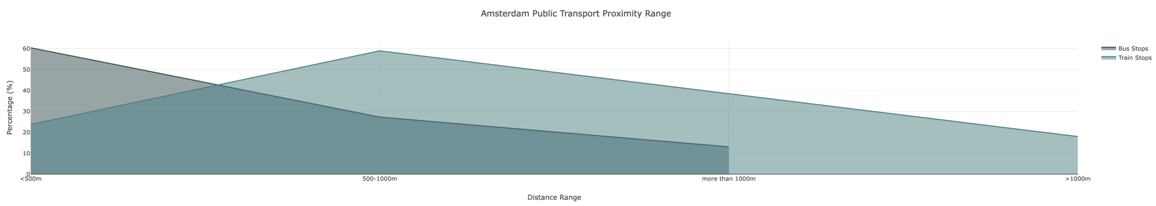


Fig 9.2: Amsterdam: Proximity of bus stops vs train stations from the selected key addresses.

Table 9.1.1 Overview of Percentages of Transit Stops within a distance

Element	Bengaluru	Amsterdam
Bus stops <500 m	15%	60%
Bus Stops within 500-1000 m	45%	27%
Bus stops > 1 km	40%	13%
Train/Tram or Ferry Stops <500 m	9%	24%
Train/Tram or Ferry Stops 500-1000 m	21%	59%
Train/Tram or Ferry Stops > 1 km	70%	17%

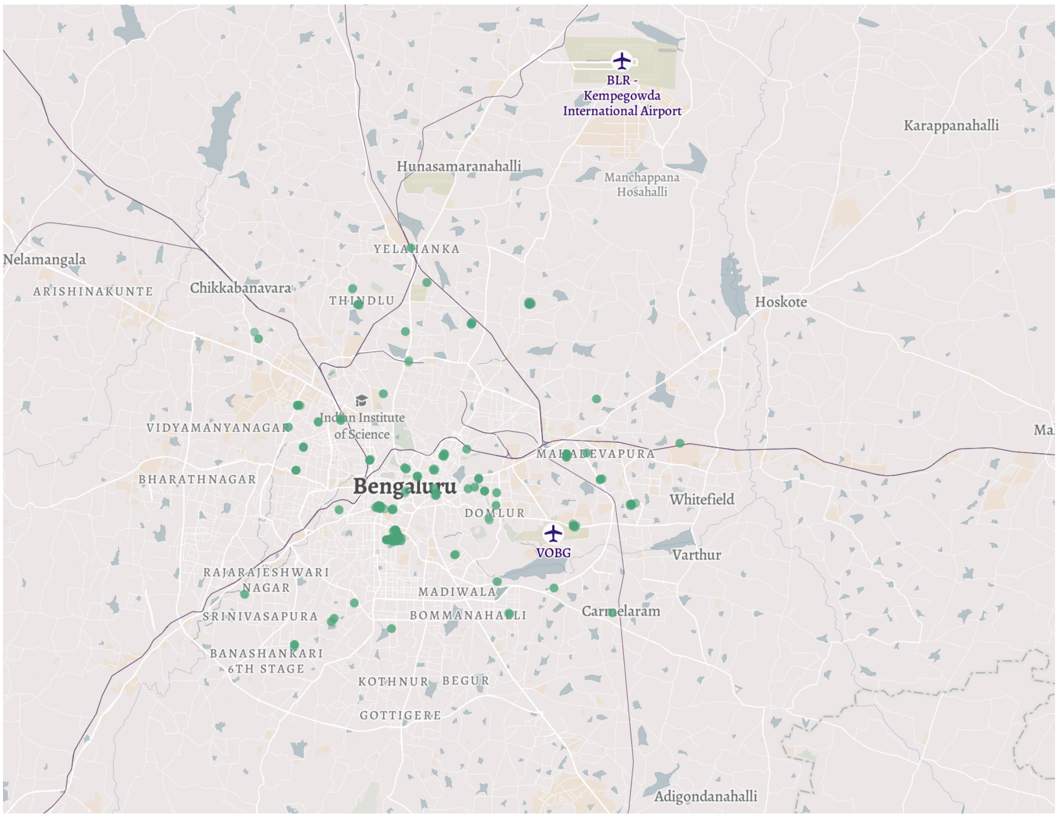


Fig 9.3: Bengaluru's focussed pedestrian highways or areas

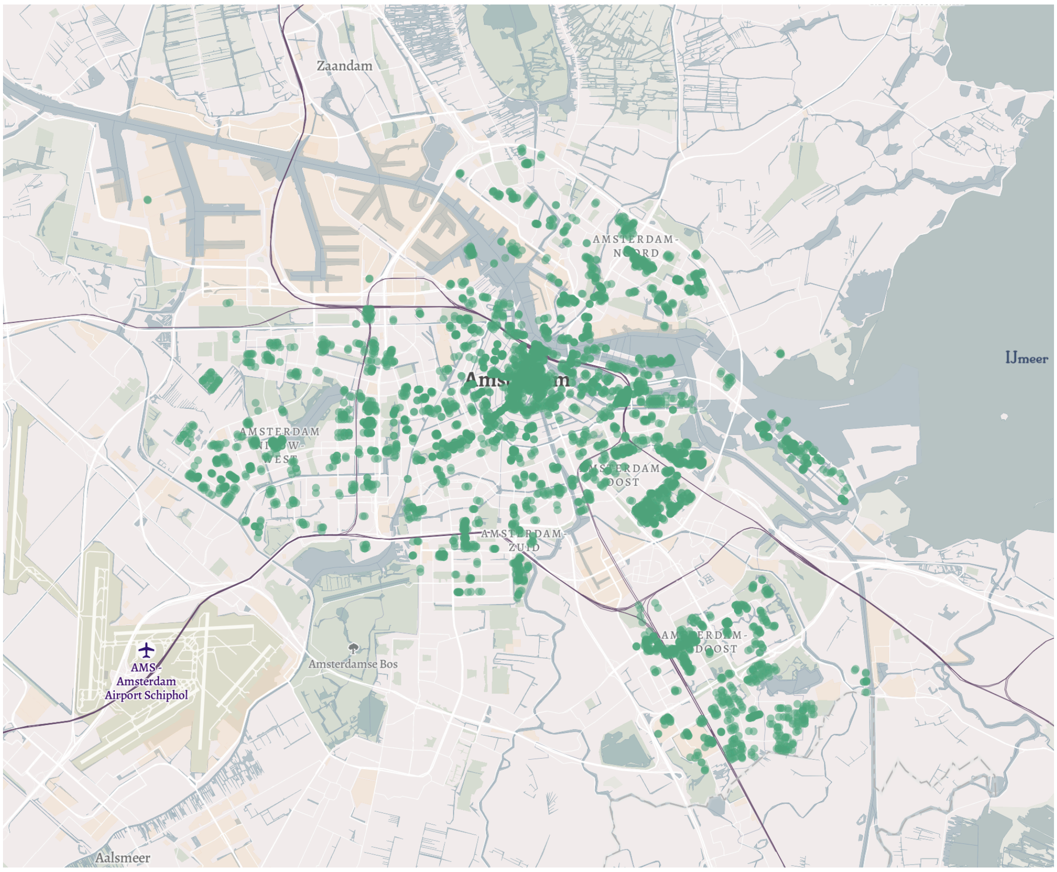


Fig 9.4: Amsterdam's focussed pedestrian highways or areas

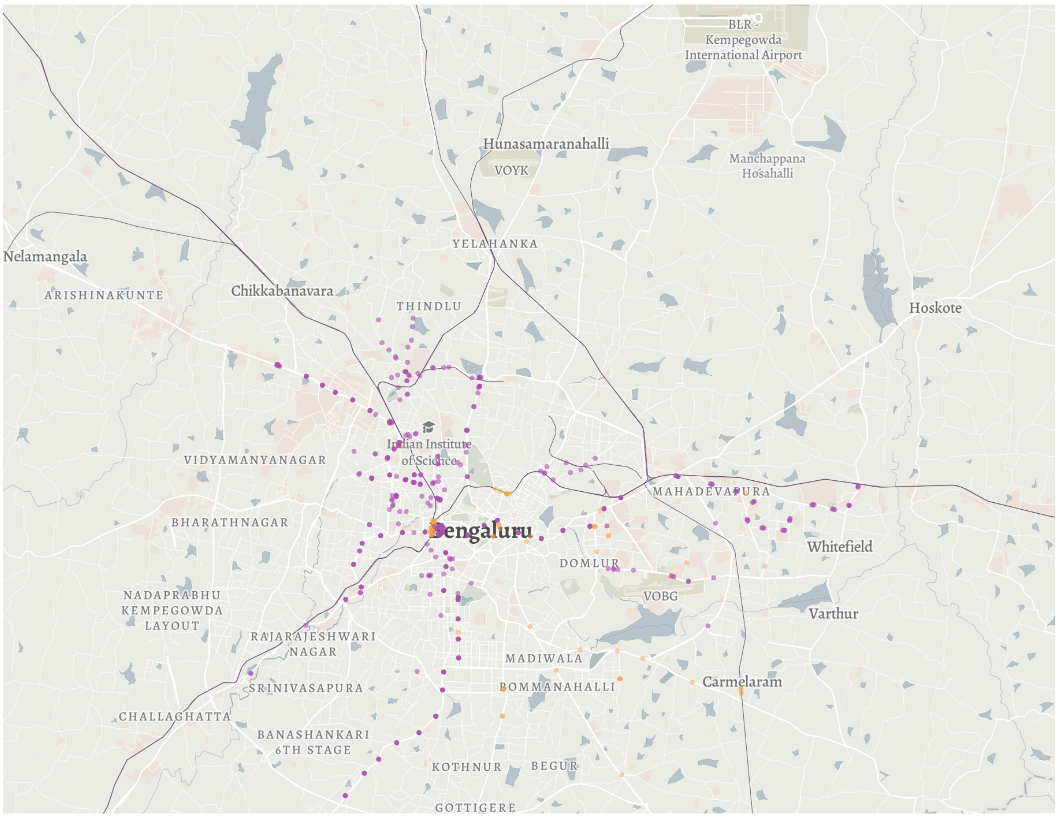


Fig 9.5: Public transit stops in Bengaluru that are completely accessible by everyone (purple dots) and lit at night (orange dots)

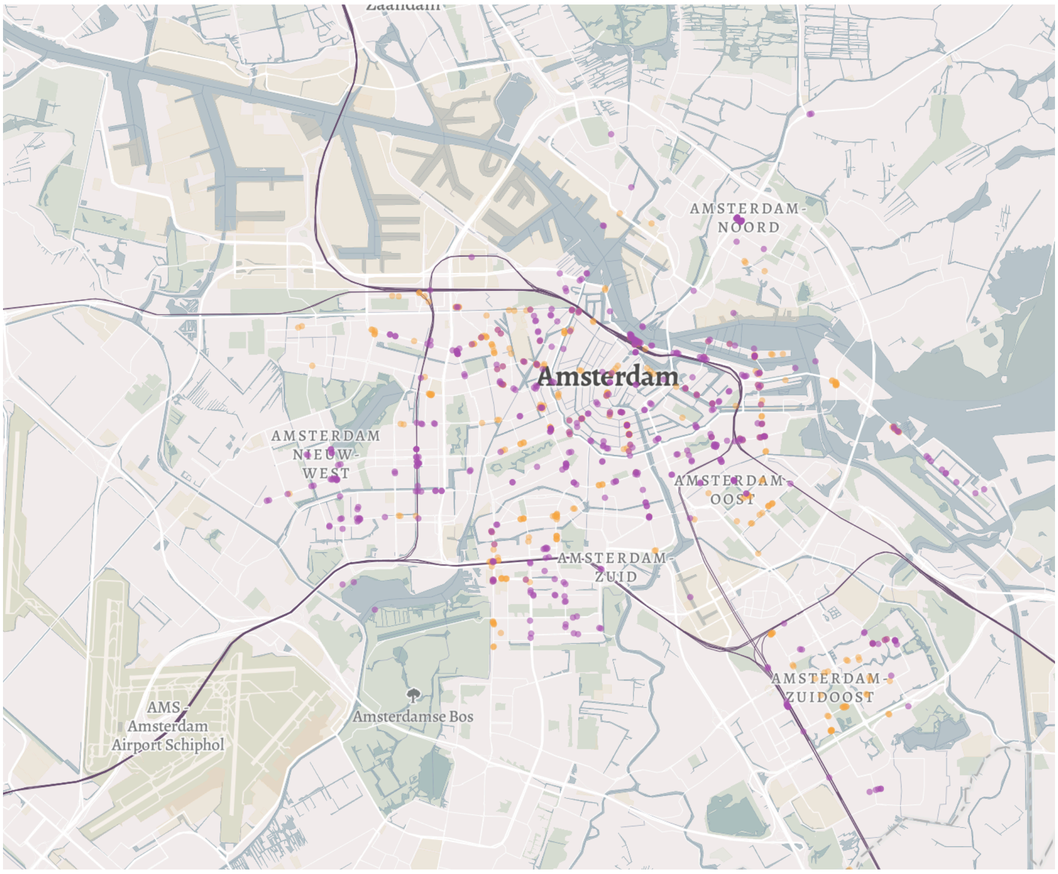


Fig 9.6: Public transit stops in Amsterdam that are completely accessible by everyone (purple dots) and lit at night (orange dots)

- Bengaluru: Only **15%** of the bus stops are within 500m or the ideal walking distance to reach a public transport mode, and only **9%** of the train stops are within walking distance.
- More than **70%** of the train stops are more than a kilometre, needing the usage of another transport mode to connect for faster transit.
- Meanwhile more than **60%** of the bus stops are within 500m or the ideal walking distance in Amsterdam and around **24%** of the train stations are within 500 m, while **59%** of them are within a kilometre, making it very easy to access without another mode of transport, or using bicycles.

Gap 2.
Lack of connectivity

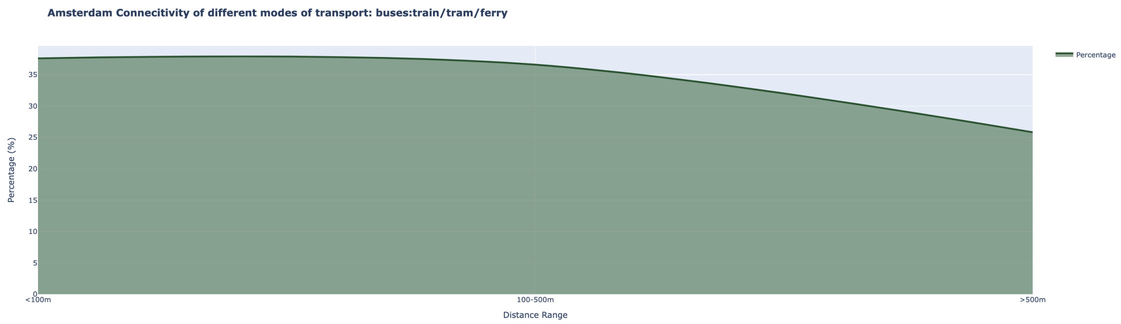


Fig 9.7: Amsterdam connectivity: percentage of different transit stops near to each other.

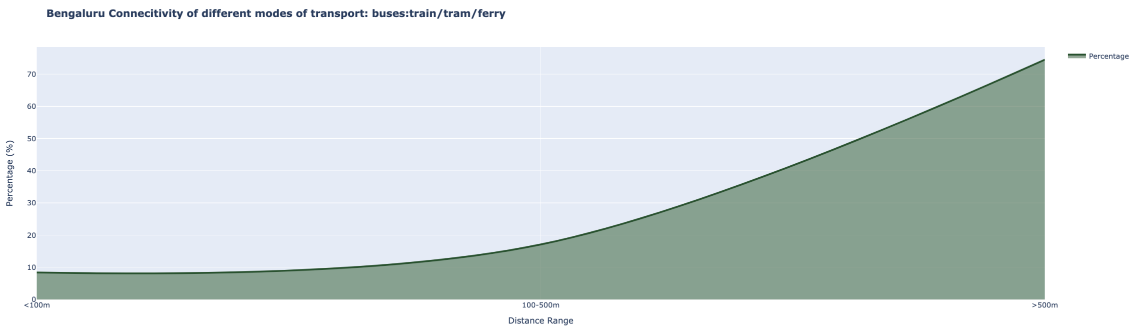


Fig 9.8: Bengaluru connectivity: percentage of different transit stops near to each other

The advent of multimodal transport poses a unique challenge as it often necessitates the development of new infrastructure to facilitate faster modes of travel. However, the creation of such infrastructure is often not feasible due to logistical and financial constraints. In such situations, the most practical approach is to leverage the existing transport options as feeders or fillers to connect to faster modes of travel.

Among existing transport options, buses present the most convenient option for expansion as they do not require extensive infrastructure modifications. Consequently, buses serve as a primary mode of transport for connecting between transport modes in many cases. The efficacy of such connections is measured by the proximity of bus stops to other modes of transport's stop platforms. Therefore, buses play a critical role in facilitating multimodal transportation, connecting people from diverse areas and destinations, and ensuring prompt and efficient travel experiences.

Table 9.1.2 Overview of Percentages of Transit Stops within a Connectivity Metric.

Element	Bengaluru	Amsterdam
Connectivity within 100m	9%	38%
Connectivity within 100-500m	18%	36%
Connectivity within >500m	73%	26%

When to comes to Bengaluru:

- Only **9%** of the bus stops are near to a train station, within 100m.
- **18%** of them are within 100-500m.
- **73%** of them are more than 500m, which makes them not ideal for efficient connectivity. This increases travel time exponentially.

However, in Amsterdam:

- **38%** of them are within 100m, making it very easy to get down from one mode of transport and connect it to another.
- **36%** of them are within 100-500m
- And only **26%** of them are more than 500m.

Efficiency in the context of transportation systems is often measured by the extent to which they can bridge gaps in transportation access, particularly in under-resourced and isolated communities. In this regard, efficient transportation systems are those that effectively bridge the divide between neighbourhoods lacking adequate transportation options and commercial or more frequently-visited areas. By doing so, they increase mobility and accessibility, enabling greater economic participation and social inclusion for these communities. Thus, an efficient transportation system must prioritise equitable access to transport and connectivity, acting as a critical enabler for communities with lesser reach or commercial viability.

Gap 3.
Lack of availability

Table 9.1.3 Overview of Elements used in Mobility indicators and its current state

Element	Amsterdam	Bengaluru
Availability of night transport	Yes	No
One single ticket for all modes of public transport	Yes	No
Affordable means of public transport	Yes	Yes
Availability of open and clear schedules at transit stops	Yes	Only at metro stations
Availability of smart travel options	Yes	Only for Namma Metro
Good frequency of public transport	Yes	Yes
Great frequency of public transport at night	Every half hour	Every hour only airport routes
Optimum routes	Yes	Yes
Good accessibility	Yes	No
Crowded	During Peak Hours	Overcrowded during Peak Hours
Enough number of vehicles in the fleet for the current needs of the population	Yes	No
Safety	Yes	Relatively unsafe at night times

Pedestrian access:

To facilitate accessibility and ease of use of public transportation, it is critical to establish pedestrian zones in the vicinity of bus stops and train/tram stations. These zones are areas designated specifically for pedestrian use, with restricted access to vehicles to enhance safety. Ideally, the areas around public transit must feature dedicated footpaths or pedestrian access areas that are sufficiently removed from major vehicular traffic. The difference in the efficiency of bus stops and train/tram stations concerning pedestrian access, access to essential services, and safety can be visualised through a comparison of the two cities:

Table 9.1.4 Overview of Percentages of Accessibility indicators

Element	Bengaluru	Amsterdam
No of focussed pedestrian access points	138	3120
Total public transit stops	2955	2692
Accessibility	349	2422
Safety at night at public transit stops (lit)	312	1513

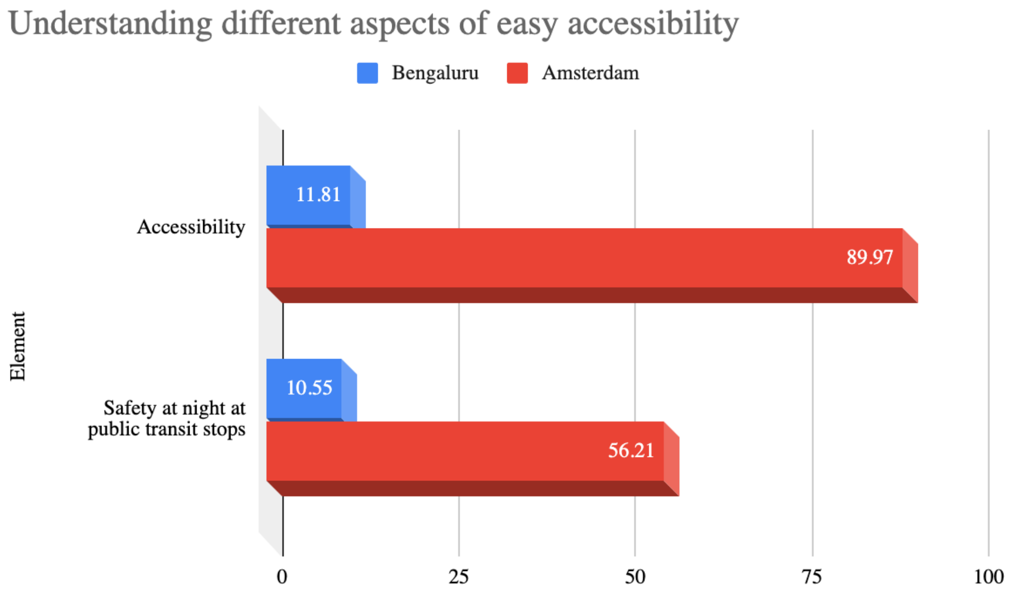


Fig 9.9: Comparing how easily accessible and safe are public transit stops in both the cities currently (percentage) This is entirely based on available data for both cities

The disparity in pedestrian infrastructure between Bengaluru and Amsterdam is vast. In Bengaluru, only **10%** of highways are dedicated to pedestrian use, with most having incomplete footpaths and sharing space with motor vehicles. The 138 streets classified as pedestrian zones represent the only areas that are entirely inaccessible to vehicular traffic.

In contrast, Amsterdam has developed a comprehensive infrastructure for pedestrians that is independent of highway infrastructure for motor vehicles. Pedestrian zones line the main highways and are separated from bicycle lanes and motor vehicles to provide exclusive access for pedestrians. This infrastructure is extensive and well-developed, enabling safe and efficient pedestrian traffic throughout the city.

10. USER PERSPECTIVES

To gain a complete understanding of the gaps in transportation infrastructure, it is essential to consider the perspective of users and their perceptions of inefficiencies. This approach enables more prominent identification of patterns when cross-referenced and analysed with conducted analyses and perspectives thought of. The user perspectives was collected through this elaborate yet simple questionnaire.

To this end, a questionnaire was designed to determine the various modes of transportation used in both cities, the average commute time, and the reasons for choosing a specific mode of transport. This analysis is connected to the previous gap analysis to highlight where the gaps are most prominent and where even minor changes could be made to improve the system. This user-centric approach to gap analysis enables a deeper understanding of the issues faced by commuters and can help identify potential solutions to problems.

10.1 Average time taken

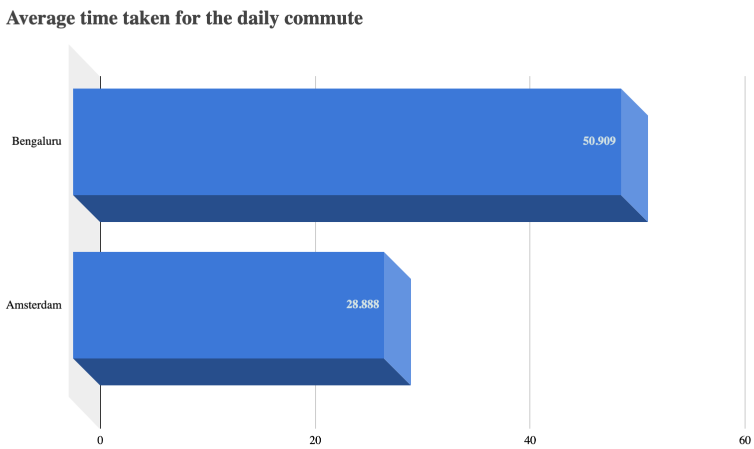


Fig 10.1.1: Average time taken (in minutes) for daily commute in both cities.

The significant increase in average commute time for a similar distance of 10-20 km in Bengaluru compared to Amsterdam indicates widespread inefficiencies in the transportation system of Bengaluru. These inefficiencies contribute to delays and lengthy commutes for every single trip, affecting individuals' productivity, quality of life, and the economy as a whole. Addressing these inefficiencies is critical to developing a more efficient and sustainable transport system for Bengaluru, reducing commute times, and improving the overall quality of life for individuals and the city's economic productivity.

The increase in the trip time is due to the following reasons:

- Lack of transit stops being nearby
- Lack of connectivity options
- Traffic delays
- Lack of infrastructure

The inefficiency trend is the focus on how well the users use public transport over other modes.

10.2 Modes of transport used

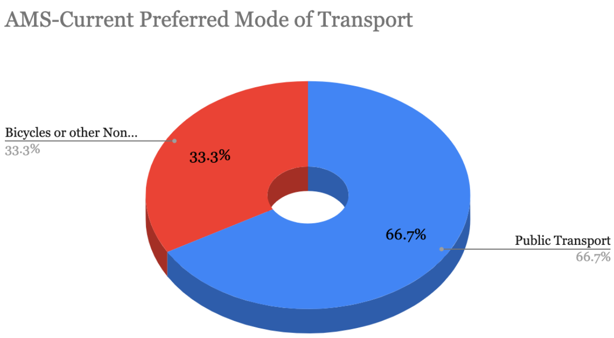


Fig 10.2.1: Amsterdam's Preferred Modes of Transport used

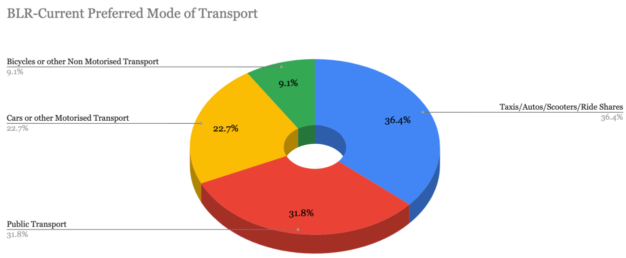


Fig 10.2.2: Bengaluru's Preferred Modes of Transport used

- Currently, **67%** of the users in Amsterdam use public transport and only **31.8%** of the users in Bengaluru use public transport.
- While **33%** of the users prefer to bike all the way to their preferred destination, that is an NMT mode of transport, supported by fantastic cycling infrastructure while only **9%** of the users in Bengaluru use bicycles.
- The majority of users in Bengaluru, **60%** of the users use motorised transport in the form of personal driving or using taxis and other ride sharing like autos.

10.3 Preference of public transport connections used

- **78%** of the users in Amsterdam walk to connect to a public transport while **73%** of the users in Bengaluru use Autos, 2 wheelers and cars to connect to a public transport mode, which indicates that the efficient public transport modes are not easily accessible to people in Bengaluru.

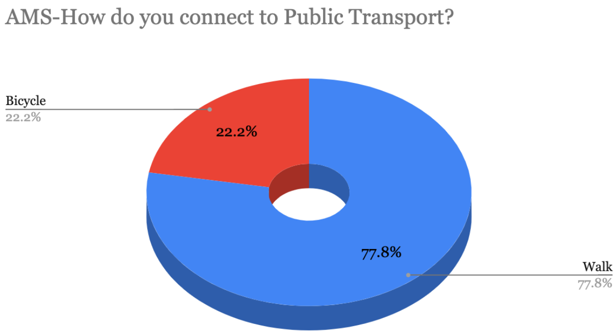


Fig 10.3.1: Amsterdam's connectivity modes to a public transport

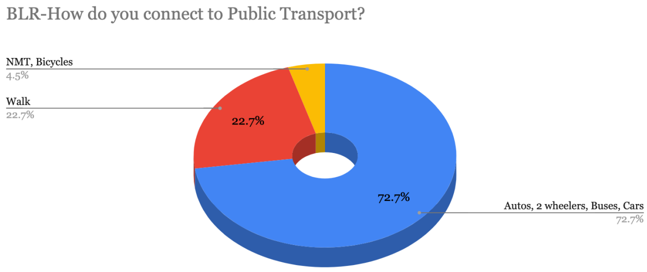


Fig 10.3.1: Bengaluru's connectivity modes to a public transport

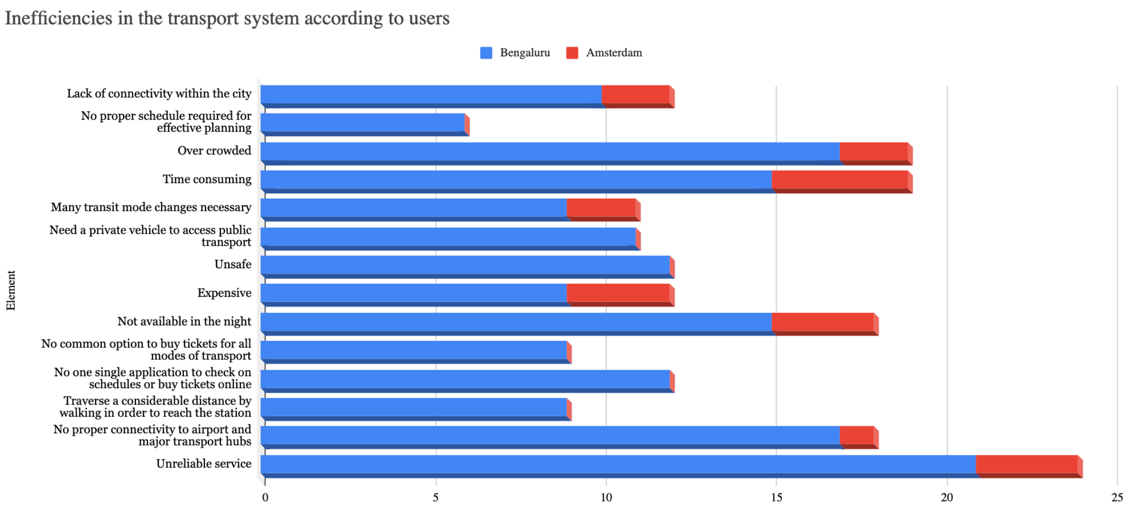


Fig 10.4.1: What the users perceive mainly as existing gaps in each city (percentage of users measured for each element)

10.4 Where do the gaps occur prominently?

Understanding user perspectives on transport inefficiencies is crucial to addressing the gaps identified in the gap analysis. The user study questionnaire provides insight into the specific issues that users face and their perceptions of the transport system's inefficiencies. Here are some examples of inefficiencies identified in the user study questionnaire, along with the percentage of users who chose that particular inefficiency:

- Traffic congestion (**74%**)
- Unreliable public transport (**67.7%**)
- Lack of proper transport infrastructure (**54%**)
- Safety concerns while using public transport (**58%**)

These user perspectives complement the results of the gap analysis, highlighting similar issues that commuters face on a daily basis. These insights can help policymakers and city planners develop effective solutions to address the inefficiencies in the transport system, such as improving the public transport system, building more adequate transport infrastructure, and addressing traffic congestion through better traffic management policies.

11. RESULTS

Based on the gap visualisation and analysis, the efficiencies and the inefficiencies are highlighted for each city.

Amsterdam's Efficiency

- Availability of good transport: Amsterdam has a well developed and comprehensive transport network, including buses, trams, trains, and ferries. This availability contributes to efficient mobility options for residents and visitors.
- Good accessibility: The city's well-connected layout and integrated transport system make it easy to access various parts of the city quickly.
- Public Transport method that is very effective: All modes of public transport in Amsterdam, including buses, trams, and trains, are known for their efficiency and reliability, contributing to effective mobility.
- Availability of smart travel options: Amsterdam offers smart travel options like contactless payment methods and integrated ticketing, enhancing convenience for travellers.
- Easy accessibility of public transit stops through walk: Public transit stops are designed to be easily accessible by walking, contributing to the overall efficiency of the transport system.
- Availability of open and clear schedules at transit stops: Clear schedules at transit stops help passengers plan their journeys effectively and minimise waiting times.
- Availability of all modes of transport: Amsterdam provides a diverse range of transport modes, offering residents multiple choices for their daily commutes.
- Good frequency of public transport: Frequent services of buses, trams, and trains ensure that passengers don't have to wait long for their next ride.
- Great frequency of public transport at night: The availability of public transport at night with a high frequency provides efficient mobility options for night owls.
- Optimum routes: The transport network is well designed with optimised routes, minimising travel times.
- Effective usage of existing infrastructure: Amsterdam has effectively integrated its various transport modes and infrastructure to create a cohesive and efficient system.
- Enough number of vehicles in the fleet for the current needs of the population: Adequate fleet size ensures that transport services are available to meet the demand of the population.

Amsterdam's Inefficiency:

- Crowded during Peak Hours: Amsterdam experiences crowding on public transport during peak hours, which can lead to discomfort for passengers.
- Delays: Amsterdam experiences train delays and extended waiting times that increases the time taken to commute within the city.

Bengaluru's Efficiency:

- Good frequency of public transport: Public transport in Bengaluru offers good frequency in certain routes, allowing passengers to travel without extended waiting times in core areas of Bengaluru.
- Effective routes: Public transport, especially metro currently runs on one of the highest congested corridors of both north and south, and east and west Bengaluru, and is contributing to cutting down the travel time exponentially.
- The added parking space under the metro stations are encouraging users to commute minimum distance from their addresses to the nearest metro station and opt for the train for the longer commute.
- Smart Mobility: There are several apps for live updates for metro (Namma Metro App, Tummoc) and bus schedules enabling passengers to plan their routes.

Bengaluru's Inefficiency:

- Public Transport System that is not very effective: While Bengaluru has an extensive bus network, it is often criticised for inefficiencies such as irregular schedules in certain routes, unreliable services during non peak hours, and overcrowding.
- Limited accessibility of public transit stops by walk: Limited pedestrian infrastructure can hinder easy access to public transit stops, impacting the overall efficiency of the system.
- Non-availability of open and clear schedules at transit stops: Schedules are only available at metro stations, potentially causing uncertainty for bus users.
- Non-availability of all modes of transport: The availability of different modes of transport is limited in Bengaluru compared to a diverse range of options in Amsterdam that uses the full potential the city's potential.
- Limited frequency of public transport at night: The frequency of public transport at night is limited to hourly services on specific routes like airport routes, making it less efficient for nighttime mobility.
- Ineffective usage of existing infrastructure: Bengaluru struggles with effectively using its existing infrastructure due to various challenges, leading to inefficiencies in the transport system.

- Limited number of vehicles in the fleet for the current needs of the population: The inadequate number of vehicles in the fleet impacts the ability to meet the transportation needs of Bengaluru's growing population.
- Inefficient Smart Mobility: Multiple applications are causing confusions among passengers. Multiple modes of transport under different corporate or government umbrellas make it inefficient and unable to be seamless and effective.
- Unregulated fares for auto rickshaws: Unregulated metered fares for auto rickshaws between metro stations and other transit stops provide a cost-effective commuting option.
- Bicycle friendly lanes: Bicycle friendly lanes were introduced in a few major neighbourhoods of Bengaluru, but were enforced properly for effective usage.

In summary, Amsterdam is efficient in terms of its well developed and diverse transport options, effective infrastructure usage, and comprehensive services. Bengaluru faces challenges related to irregular services, limited modes of transport, and infrastructure constraints, leading to inefficiencies in its current public transport system. The impact of these elements of efficiencies and inefficiencies visualised cartographically help in the ease of understanding of how big of a change or how small a change it is.

11.1. DISCUSSION

When understanding the transport comparison done between two or more cities, the first question that comes to mind is how can comparative analysis of transport systems between cities be used to assess potential for improvement of those cities?

Comparative analysis helps in understanding the strong and weak points of any city's navigation system and how they were built or how they work. By comparing the two cities' transport systems, it was possible to identify the currently running infrastructure of transport and visualise them. With the help of visualisations, it is possible to understand the extent of the transport network and how much infrastructure is already available to consider for effective usage.

While Amsterdam has a smaller area compared to Bengaluru, which might be one of the reasons for the relatively easy maintenance of the transport system, it also has a very widely built network that has been existing and being used from several years now. The biggest advantage of that is the availability of enough space to build the required infrastructure without having to compromise on people's needs. The existing transit network of buses, trams, metros and ferries work seamlessly for the daily commute and connectivity, albeit with certain time delays and mechanical failures that are always expected.

One major advantage of Amsterdam's transit network is the entire public transport modes is handled by one company, GVB, which makes it easier to build, maintain and interconnect all the modes of transport.

Bengaluru however has a fantastic bus coverage and suburban train infrastructure but it is not effectively used. Metro trains are effectively running but are not covering all the neighbourhoods to be considered an effective mode of transport. In a few years, the existing infrastructure will be better with new modes of transport available for the users needs. But, the efficiency can be increased by tweaking the existing infrastructure and making certain non demanding improvements that can help elevate the way people commute daily.

One major disadvantage is the fact the buses network BMTC and the metro train network BMRCL are two different organisations, which leads to an added barrier between seamless connectivity between the two modes of transport.

Given its threefold larger size compared to Amsterdam and a population nearly ten times greater, Bengaluru faces significant challenges in catering to a larger area with a more substantial population density. Consequently, the magnitude of time delays and infrastructure gaps becomes more apparent. Comparative analysis aids in comprehending the challenges a city may encounter when attempting to adopt transit solutions from other urban areas.

With the comparative analysis, one question that comes up is: can we use one city's navigation system to help build or improve another city's transport network and to what extent can we implement one city's ideas on another city's developments.

Finding a concrete solution to massive transport problems of any city is a task that has a lot of hoops to go through. For any major infrastructure change, including introducing new trains of buses, there is a lot of steps involved. The major infrastructure changes are already being considered to be done in Bengaluru:

- Three new metro lines are being built that connect the network of neighbourhoods in a ring and also have an exclusive line that connects the airport which is roughly 35 kilometres away from the main city.
- The suburban train network is being built that connects the twenty major stations like Hebbal, Malleshwaram, Bengaluru Cantonment, Bengaluru East etc within Bengaluru city and the other areas that are in within the radius of urban and rural Bengaluru, Bidadi, Hoodi, Kengeri, Devanahalli, Nelamangala, Whitefield and Electronic City.
- The Demu train is being introduced to ply between the city centre (KSR City Station) to the KIAL, with a ticket price of 10-35 rupees and a frequency of about one to two hours.

However a few tweaks can make the transport seem much more seamless.

- Introducing the smart announcements that show the bus schedules at the bus stops like at the metro stations helps users in knowing when their transport will arrive.
- Adding the schedules of all the connections available at that particular transit stops in trains, buses and their respective stops.
- Creating one single app like GVB for both BMTC and BMRCL travel routes and times helps in planning the schedules much better. The app can also be a way to purchase tickets and passes for easier commute.
- Introducing more metro feeder buses to all the nearby stations and increasing the frequency of the buses to 10 minutes rather than 30 minutes is more efficient and makes the transport less crowded. This is also an area where the electric buses can play a much better role than diesel and petrol locomotives.
- Introducing and enforcing bus specific lanes help in giving the importance to the public transport network, make the buses less stuck in traffic and also encourage users to not use their private vehicles as the bus lanes can decrease the road width by a significant level increasing traffic density.
- Introducing the night routes for both metro and buses for every night and increasing the commute time from 5AM to 1AM instead of just on days with major sporting events and cricket matches.
- Until the suburban train infrastructure is built, increasing the frequency of the passenger trains that go to the major stations of Kempegowda International Airport, Hebbal, Malleshwaram, Hoodi, Bengaluru Cantonment and East can help with increasing efficiency and using the existing infrastructure in an effective way.

The cartographic comparative analysis has highlighted the small tweaks that Amsterdam has in its transit system that can be applied to Bengaluru without needing to make major changes to the infrastructure, and this has also visually highlighted how maps make it simpler to visualise complex concepts

11.2. TO WHAT EXTENT ONE CITY'S NAVIGATION MODEL CAN BE USED ON ANOTHER CITY(RQ3) ?

Amsterdam has a robust transport system in place, that is a result of years of planning and modifying the infrastructure based on the focus on making public transport system better and more used. Other than major infrastructure changes like train stations and underground lines, the other rules in play in Amsterdam that makes users use public transit more than driving for their daily commute is:

- Enforcing pedestrian only zones in the city's commercial zones.
- One ways and longer routes for driving modes.
- The streets infrastructure having focussed lanes of buses, pedestrians and bicycles and all of them being separate entities, that effectively cuts down the space and importance given only for driving.
- Focus on non motorised transport like scooters, and proper parking spaces.

While Bengaluru has a great transport system in place, the infrastructure changes are currently being implemented for the public transport system to be more robust and well connected. The Terminal 2 of Bengaluru International Airport has been inaugurated and is yet to be operational on the international fleet, and the new train lines connecting from the city to the airport is being introduced. The transit model seen in cities like Amsterdam, Copenhagen, Vienna is already put in place in developing cities like Bengaluru, Chennai, Hyderabad, Mumbai - focussing on infrastructure building for public transport.

However, the effective city transport system is not only based on building new infrastructure but to use the existing one in an effective way. By understanding the focus that cities like Amsterdam put in the development of overall transport system, can improve other cities's navigation system effectively and this modal could be very efficiently implemented in cities like Bengaluru by:

- Assigning bus lanes in the existing road and street network that makes the public transport less susceptible to traffic delays.
- Implementing the odd even date system for parking spaces to free up one side of the road from vehicle parking and increasing the space for free flowing traffic.
- Assigning the space for bicycles and creating them as separate lanes to increase the usage of bicycles.
- Enforcing oneways and turn restrictions in major roads that makes the driving routes longer, and in turn ineffective to cut down time.
- Enforcing pedestrian only zones in severe commercial areas, and assigning no parking spaces near by except for specific accessibility needs.
- Increasing the night transit, and in turn contributing to safer public transport for everyone, with better stop platform infrastructure.

- Making the ticket system common and introducing smart travel for the buses, which makes the use of chip card like OV chip card in Amsterdam, or partnering with Namma Metro's electronic chip card and make it usable in buses.
- Increasing the frequency of buses and trains, adding an electronic schedule board that shows the frequency of the routes on all bus routes and stops.
- Increasing the frequency of passenger trains and use them for suburban commute in the existing infrastructure currently in operation.
- Making a government mandated application, like GVB is for Amsterdam, that maps the all of the cities' transit routes and lines, the live schedules and the ability to purchase tickets and passes online.
- Encouraging carpooling and other alternative modes of transport - Amsterdam has implemented several initiatives to encourage carpooling and other alternative modes of transport, such as bike sharing and car sharing, which are helping to reduce traffic congestion and encourage more sustainable mobility habits.

When applying another city's model, it is important to understand the workings and the gaps and then choosing what can be effectively implemented. By understanding and analysing the patterns and the gaps, these were some of the learnings that are inferred from Amsterdam's transit model that can be effectively applied to Bengaluru's existing transit model to make it more efficient and easily accessible.

11.3. CHALLENGES

The transport analysis is an intensive process that requires a vast amount of data and processing. However, this research encountered certain limitations with the lack of effective mechanisms that would have facilitated the processing of large datasets. Within the given timeframe of six months, conducting a comprehensive comparison of every aspect of the mobility index was not possible. Therefore, the focus was limited to cartographically visualising and analysing 50 routes and 100 points across the cities to identify the existing transportation networks and the possible gaps.

Despite the small dataset, strategically chosen from significant neighbourhoods and key places, the analysis yielded valuable insights into the patterns and trends of the transportation systems. By cartographically comparing these two diametrically opposite cities, it became possible to identify different learnings and potential areas of improvement that could be further explored.

The primary objective of this research was to identify the possibility of conducting cartographic comparisons of two cities and the learning outcomes that could be gained from them. In this regard, the study was successful in identifying specific patterns and performances that can serve as a basis for further research. With detailed analysis and larger datasets, it is possible to uncover more concrete findings.

One of the challenges faced in this research was the working with different sets of codes, which added a layer of complexity to the project. Despite these challenges, the analysis and visualisation of the data provide a solid foundation for further research that can help improve the transportation systems of different cities. The python space time cubes in particular was challenging, as the incompatibility of the format of images to the system used proved inefficient to display images as the base of the cube. But as that space-time cube works on a pattern level more than an understanding of the map, the cube was retained without an image to help perform the analysis needed to understand the time scale. The actual 3D Space-time uses Three.js to show the unique spread of the routes over the area.

11.4. FUTURE STUDIES

The field of transportation analysis is a complex and dynamic field, offering numerous research opportunities for those seeking to understand the intricacies of urban mobility dynamics. In pursuing ongoing academic studies, my primary goal is to gain a deeper scientific understanding of transportation trends and issues.

Transport systems consist of multifaceted networks, influenced by a range of variables spanning spatial, temporal, and sociopolitical dimensions. Despite the depth of existing analyses, many uncharted territories remain in the field. To comprehensively capture these territories, my research interests lie in conducting exhaustive analyses of transportation systems in major cities.

By conducting such thorough investigations, key operational components yielding exemplary outcomes can be identified. The identification of these optimal elements makes possible the establishment of a valuable repository of best practices for the transportation sector. By discerning best practices that exhibit optimal functionality within major urban centres, these elements can be adapted to suit diverse contexts.

To facilitate continued research, the GitHub repository initially established for the current research project will remain an active platform for continuous updates. The repository will serve as a repository for newly acquired and analysed data from diverse cities, contributing to the field of knowledge concerning urban mobility and transport systems.

The culmination of these efforts holds significant promise for advancing urban mobility and shaping the cities of tomorrow. Addressing emerging questions and challenges in the field of transportation analysis requires a continuous commitment to innovative transport analysis and data-driven solutions. In conclusion, the ongoing research in transportation will aim to uncover best practices, build a knowledge repository, and analyse transportation systems in major cities. This journey will help gain valuable insights into urban mobility dynamics and contributes to improved city planning and development in the future.

12. IMPLEMENTING THE INTERACTIVE VISUALISATIONS: WORKING PAGES

This research was done not just to do a comparison of two cities but to build a portal that would facilitate further research on other cities as well. This GitHub page is now hosted with the interactive space-time cube and the maps of the two cities that users can interact with, to understand the build and the spread of the space with respect to time. This repository, Getting There is Half the Fun, will be further updated with more research insights of more cities across the world that would enable pattern analysis and deeper, impactful insights of how the cities are built and where their transport could be improved further.

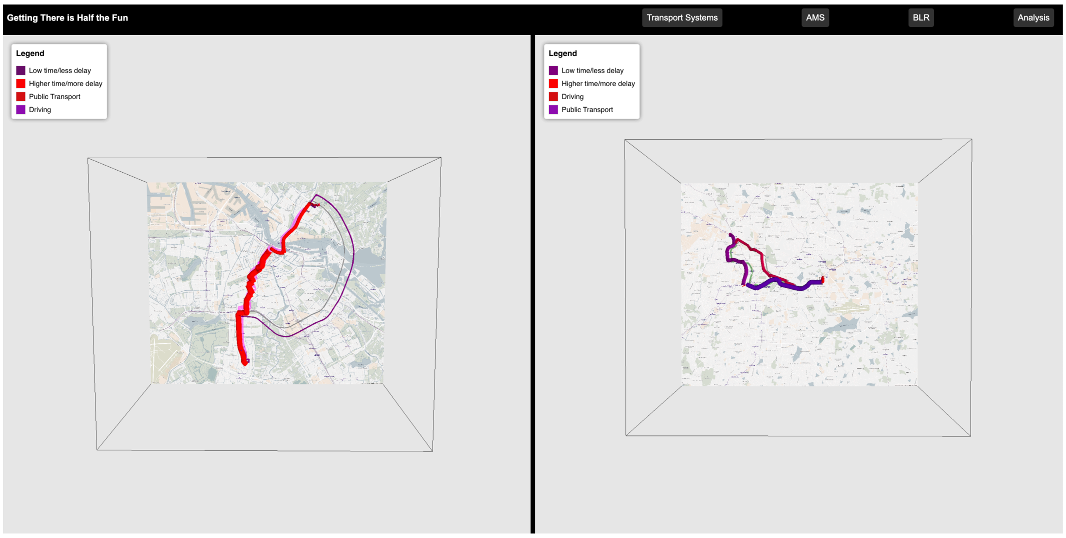


Fig 12.1: Interactive workings of the space-time cubes for the cities, shown side by side for comparison

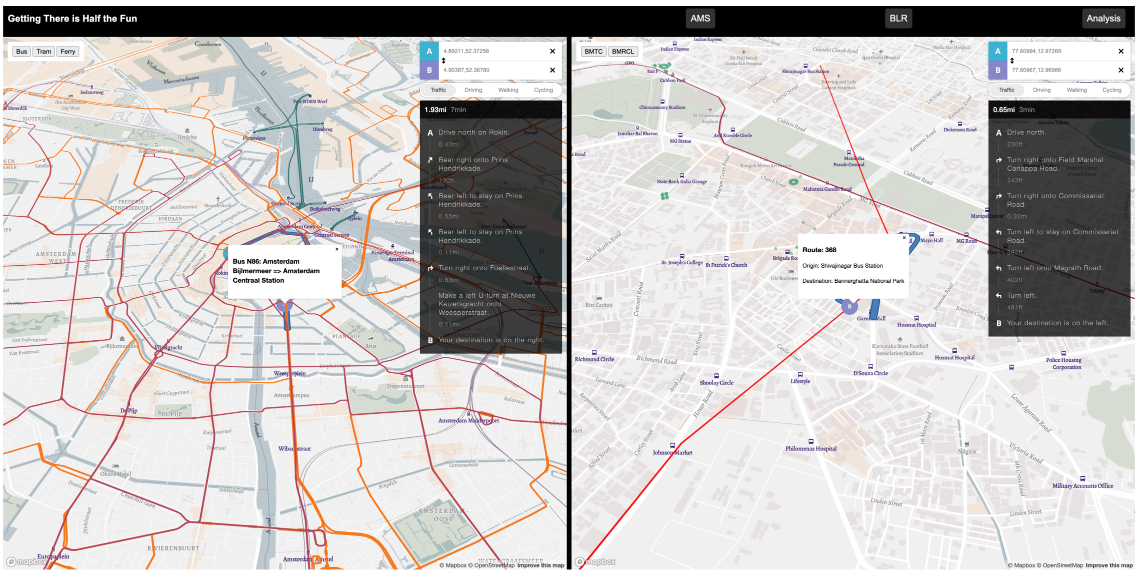


Fig 12.2: Interactive visualisation of the current modes of transport, along with the directions, for the cities, shown side by side for comparison.

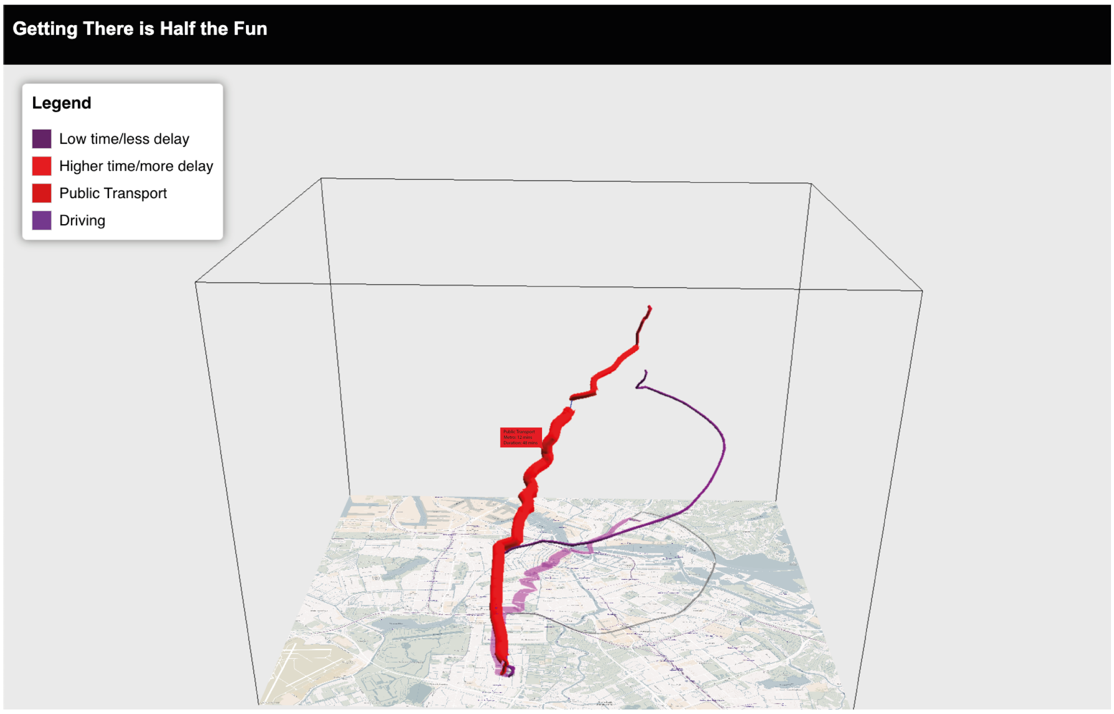


Fig 12.3: Amsterdam's space time cube spread in a close up for clearer understanding

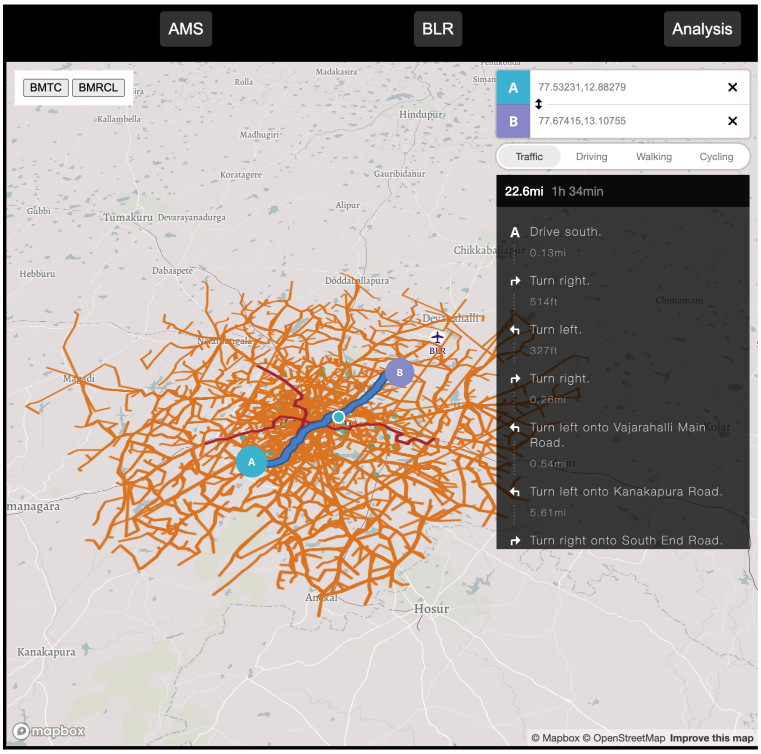


Fig 12.4: Bengaluru's BMTC and BMRCL Spread along with driving routes for comparison.

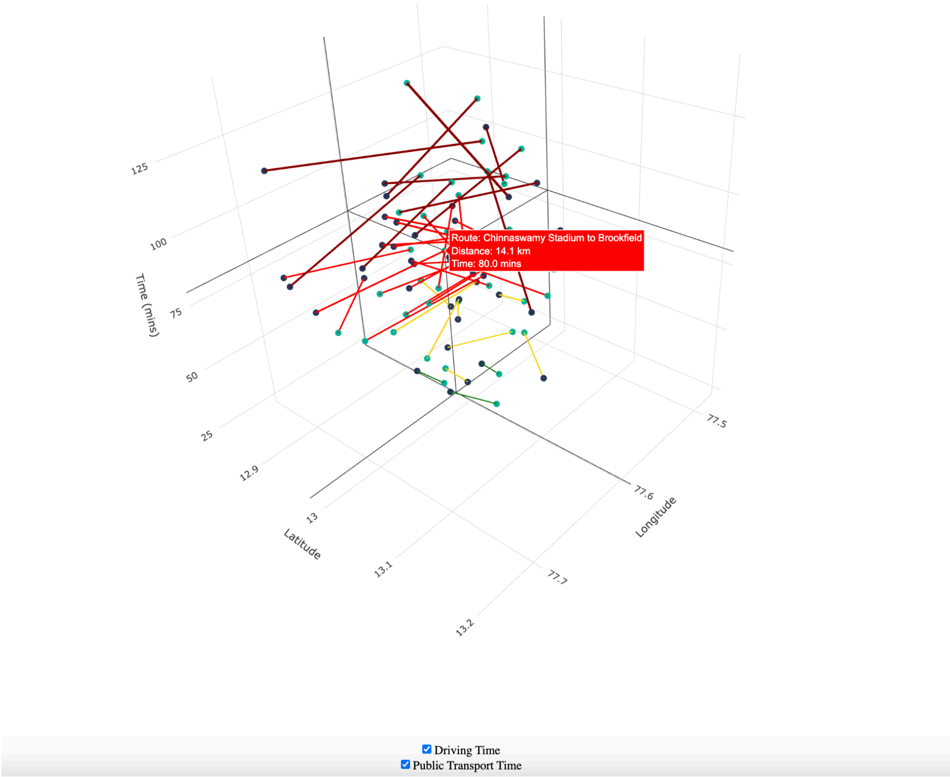


Fig 12.5: The pattern space time cube for time analysis

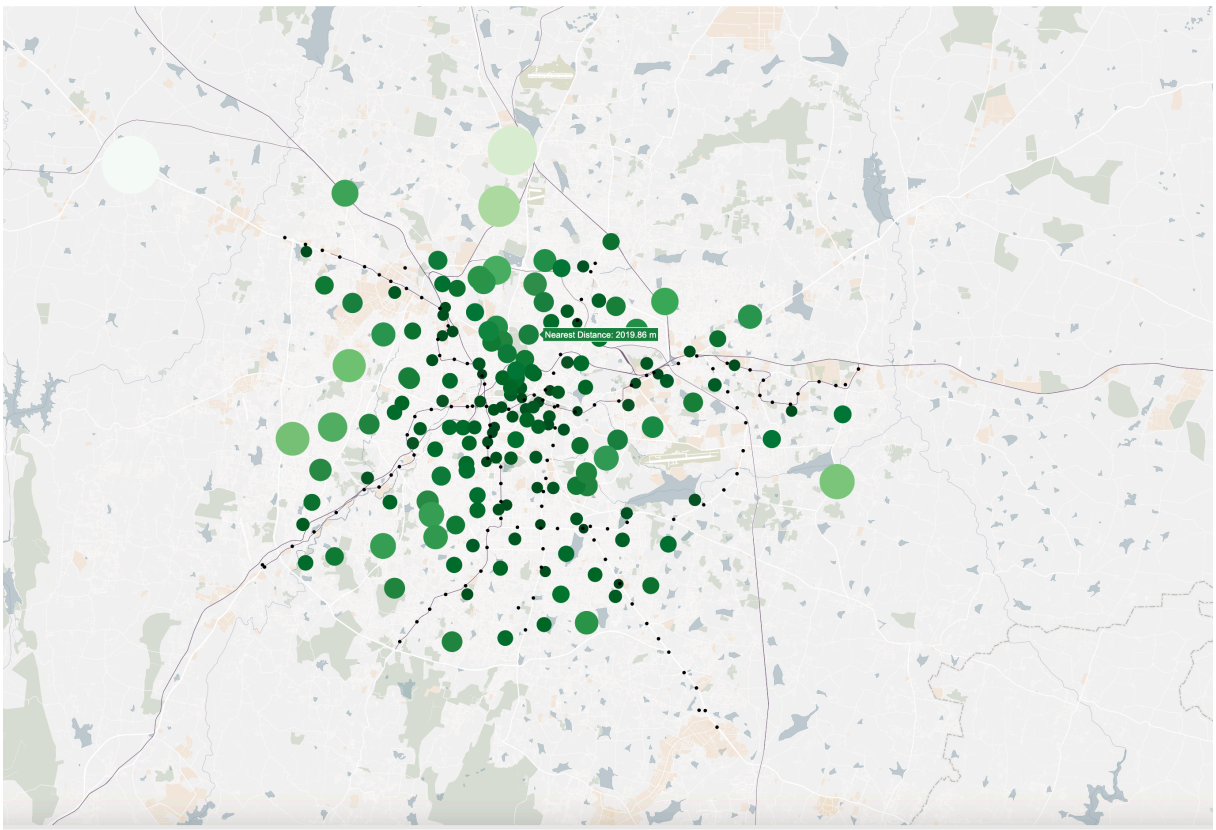


Fig 12.6: Interactive data analysis visualisation for distance monitoring

Bengaluru Public Transport Proximity Range

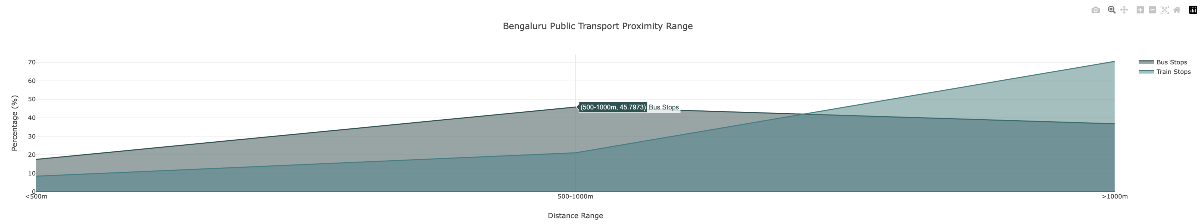


Fig 12.7: Interactive data visualisation for the gap analysis: Example of Bengaluru

13. REFERENCES

1. Avelar, E. , Simon, R. , &, & Gaus, H. (2019). Sustainable Urban Transport in Latin America Assessment and recommendations for mobility policies. [SUTP]
2. Banister, D., & Hickman, R. (2012). Transport futures: Thinking the unthinkable. [ScienceDirect]
3. Basu, D., Saha, A., & Chattopadhyay, S. (2018). Urban morphology and public transport: Case studies of Kolkata and Delhi. International Journal of Urban Sciences, 22(1), 60-75. [cprindia]
4. Basu, S., & Vasudevan, V. (2013). Effect of Bicycle Friendly Roadway Infrastructure on Bicycling Activities in Urban India. Procedia - Social and Behavioral Sciences, 104. [ScienceDirect]
5. Batty, Michael. (2016). Big Data and the City. Built Environment. 42. 321-337(17). 10.2148/benv.42.3.321. [DOI]
6. Bertolini, Luca & Dijst, Martin. (2003). Mobility Environments and Network Cities. Journal of Urban Design. 8. 10.1080/1357480032000064755. [DOI]
7. Beverley, E. L. (2011). Colonial urbanism and South Asian cities. Social History, 36(4), 482–497. [JSTOR]
8. Bianchi, C., & Bach, K. (2004). Minding the Gap. [Citeseer]
9. Biswas, Arindam & Mittal, Sumedha & Padmakar, Sanya. (2019). Why People Refrain from Cycling in Indian Cities:: A Comparative Investigation. 7. 111130. 10.14246/irspsda.7.3_111. [DOI]
10. Bouhsissin, S., Sael, N., & Benabbou, F. (2022). Classification and Modelling of Driver Behaviour During Yellow Intervals at Intersections. [ISPRS]
11. C. Li, L. Bai, W. Liu, L. Yao and S. T. Waller, "Graph Neural Network for Robust Public Transit Demand Prediction," in IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 5, pp. 4086-4098, May 2022, doi: 10.1109/TITS.2020.3041234 [IEEE]
12. Carvalho, Marcius & Syguiy, Takao & Silva, Daniel. (2015). Efficiency and Effectiveness Analysis of Public Transport of Brazilian Cities. Journal of Transport Literature. 9. 40-44. 10.1590/2238-1031.jtl.v9n3a8 [DOI]
13. Cervero, R., Ferrell, C., & Murphy, S. (2002). Transit Cooperative Research Program Sponsored by the Federal Transit Administration Transit-Oriented Development and Joint Development in the United States: A Literature Review
14. Chaitanya Kanuria, Krithi Venkata, Sudeept Maitia, & Pawan Mulukutlaa. (2019). Leveraging innovation for last-mile connectivity to mass transit. [ScienceDirect]
15. Chen, B. Y., Teng, W., Jia, T., Chen, H. P., & Liu, X. (2022). Transit Voronoi diagrams in multi-mode public transport networks. Computers, Environment and Urban Systems, 96. [ScienceDirect]
16. Currie, G. (2004). Gap analysis of public transport needs: Measuring spatial distribution of public transport needs and identifying gaps in the quality of public transport provision. Transportation Research Record, 1895, 137–146. [SageJournals]
17. Dutta, M., Banerjee, S., & Husain, Z. (2005). Economics of Conservation of Built Heritage A CV Study of Some Heritage Sites of Calcutta. Indian Economic Review, 40(2), 221–243.[JSTOR]
18. Eaton, J., & Eckstein, Z. (1997). Cities and growth: Theory and evidence from France and Japan. J. Eaton, 2. Eckstein / Regional Science and Urban Economics, 27, 44–51. [ScienceDirect]

19. Eaton, J., & Eckstein, Z. (1997). Cities and growth: Theory and evidence from France and Japan. J. Eaton, 2. Eckstein / Regional Science and Urban Economics, 27, 44–51. [ScienceDirect]
20. Fernández, Susel & Ito, Takayuki. (2015). Driver Behavior Model Based on Ontology for Intelligent Transportation Systems. 227-231. 10.1109/SOCA.2015.44. [DOI]
21. Fernández, Susel & Ito, Takayuki. (2015). Driver Behavior Model Based on Ontology for Intelligent Transportation Systems. 227-231. 10.1109/SOCA.2015.44. [DOI]
22. Gallotti, R., & Barthelemy, M. (2015). The multilayer temporal network of public transport in Great Britain. Scientific Data, 2. [Nature]
23. Gatalsky, P. & Andrienko, N. & Andrienko, Gennady. (2004). Interactive analysis of event data using space-time cube. Proceedings of 8th International Conference on Information Visualization. 145- 152. 10.1109/IV.2004.1320137 [IEEE]
24. GhislainVieilledentG. Vieilledent, BenoîtCourbaudB. Courbaud, GeorgesKunstlerG. Kunstler, Jean-FrançoisDhôteJ.-F. Dhôte, and James S.ClarkJ.S. Clark. 2009. Biases in the estimation of size-dependent mortality models: advantages of a semiparametric approach. Canadian Journal of Forest Research. 39(8): 1430-1443. [CSN]
25. Giaoutzi, Maria & Papadopoulou, Chrysais-Aliki. (2021). The Role of Visualisation in Spatial Planning: A GIS-based Approach. 10.1007/978-981-33-4098-5_15.[DOI]
26. Griffith H. (2021). Smart City Demonstrators: A global review of challenges and lessons learned.[FutureCities]
27. Grindrod, P., & Lee, T. E. (2016). Comparison of social structures within cities of very different sizes. Royal Society Open Science, 3(2). [RoyalSociety]
28. Guiot, J., & de Vernal, A. (2011). Is spatial autocorrelation introducing biases in the apparent accuracy of paleoclimatic reconstructions? [ScienceDirect]
29. Háznagy, A., Fi, I., London, A., & Németh, T. (2015). Complex network analysis of public transportation networks: A comprehensive study. 2015 International Conference on Models and Technologies for Intelligent Transportation Systems, MT-ITS 2015, 371–378. [IEEE]
30. Hofmann-Wellenhof, B., Legat, K., & Wieser, M. (2003). Navigation. [Springer]
31. Jenelius, E. (2018). Public transport experienced service reliability: Integrating travel time and travel conditions. Transportation Research Part A: Policy and Practice, 117, 275–291. [ScienceDirect]
32. Jørgensen, H. (2019). Postcolonial perspectives on colonial heritage tourism: The domestic tourist consumption of French heritage in Puducherry, India. Annals of Tourism Research, 77, 117–127. [ScienceDirect]
33. Kamerkar, M. P. (2000). Impact of British Colonial Policy on Society relating to Education in Western India during the 19th Century. Bulletin of the Deccan College Research Institute, 60/61, 373–382. [JSTOR]
34. Keyvanfar, Ali & Shafaghat, Arezou & Muhammad, Nasiru & Ferwati, M Salim. (2018). Driving Behaviour and Sustainable Mobility—Policies and Approaches Revisited. Sustainability. 10. 1152. 10.3390/su10041152. [ResearchGate]
35. Kraak, M. J., & Ormeling, F. J. (2019). Cartography: visualisation of geospatial data. [Routledge]
36. Krygier, John & Wood, Denis. (2011). Making maps : a visual guide to map design for GIS / John Krygier, Denis Wood. [ResearchGate]
37. Leduc, T., Tourre, V., & Servières, M. (n.d.). The space-time cube as an effective way of representing and analysing the streetscape along a pedestrian route in an urban environment. [SHS]

38. Lemonde, C., Arsenio, E. & Henriques, R. Integrative analysis of multimodal traffic data: addressing open challenges using big data analytics in the city of Lisbon. Eur. Transp. Res. Rev. 13, 64 (2021). [Springer]
39. Litman, T. A., & Litman, T. (2023). www.vtpi.org Info@vtpi.org 250-508-5150 Evaluating Public Transit Benefits and Costs Best Practices Guidebook. www.vtpi.org
40. Liu, X., & Dijk, M. (2022). The role of data in sustainability assessment of urban mobility policies. Data & Policy, 4, E2. doi:10.1017/dap.2021.32 [Cambridge]
41. Lu, Huapu & Shi, Ye. (2007). Complexity of Public Transport Networks. Tsinghua Science & Technology. 12. 204-213. 10.1016/S1007-0214(07)70029-9. [DOI]
42. Ma, X., Wu, Y.-J., Wang, Y., Chen, F., & Liu, J. (2013). Mining smart card data for transit riders' travel patterns. [ScienceDirect]
43. Madakkam, S., & R. Ramaswamy. (2013). The State of Art: Smart Cities in India: A Literature Review Report. [ResearchGate]
44. Mehaffy, Michael & Kryazheva, Yulia & Rudd, Andrew & Salingaros, Nikos. (2020). A New Pattern Language for Growing Regions: Places, Networks, Processes. [Patterns Digital Library]
45. Mehrotra, R. (2016). Spatial Organization and Ritual. In Mehrotra, R. (Ed.), The Kumbh Mela: Mapping the Ephemeral Mega City (pp. 39-54). [Harvard University Press]
46. Menno-Jan Kraak & Irma Kveladze (2017) Narrative of the annotated Space–Time Cube – revisiting a historical event, Journal of Maps, 13:1, 56-61, DOI: 10.1080/17445647.2017.1323034 [TaylorandFrancis]
47. Miller, H. J., Witlox, F., & Tribby, C. P. (2013). Developing context-sensitive livability indicators for transportation planning: a measurement framework. [ScienceDirect]
48. Milorad J. Kilibarda, Brkljač, M., & Gajic, S. (2013). Gaining a Competitive Advantage By Integration of Marketing and Logistics. [DOI]
49. Mohan, Dinesh. (2013). Moving around in Indian cities. Economic and Political Weekly. 48. 4048. [ResearchGate]
50. Mukherjee, A. (2008). The Return of the Colonial in Indian Economic History: The Last Phase of Colonialism in India. Social Scientist, 36(3/4), 3–44. [JSTOR]
51. Mulíček, Ondřej & Osman, Robert. (2018). Rhythm of urban retail landscapes: Shopping hours and the urban chronotopes. Moravian Geographical Reports. 26. 10.2478/mgr-2018-0001 [ScienceDirect]
52. Newman, M. & Watts, Duncan. (2000). Scaling and percolation in the small-world network model. Physical review. E, Statistical physics, plasmas, fluids, and related interdisciplinary topics. 60. 7332-42. 10.1103/PhysRevE.60.7332. [Cornell]
53. O'Connor, M. R. (2019). Wayfinding: The science and mystery of how humans navigate the world. St. Martin's Press. pp. 6-7. [Book]
54. Osman, Robert & Ira, Vladimír & Trojan, Jakub. (2021). A tale of two cities: The comparative chronourbanism of Brno and Bratislava public transport systems. Moravian Geographical Reports. 28. 269 282. 10.2478/mgr20200020. [DOI]
55. Parkinson, B. W., & Spilker, J. J. (Eds.). (2007). Position, Navigation and Timing Technologies in the 21st Century: Integrated Satellite Navigation, Sensor Systems, and Civil Applications, Volume 1.(pp. 3-5) [Book]
56. Peijie Wu, Xianghai Meng & Li Song (2022) Identification and spatiotemporal evolution analysis of high-risk crash spots in urban roads at the microzone-level: Using the space-time cube method, Journal of Transportation Safety & Security, 14:9, 1510-1530, DOI: [TaylorandFrancis]

57. Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. Journal of Applied Psychology, 88(5), 879–903. [APAPsyc]
58. Pojani, D., & Stead, D. (2015). Sustainable urban transport in the developing world: Beyond megacities. Sustainability (Switzerland), 7(6), 7784–7805 [ScienceDirect]
59. Quah, D., 1993, Empirical cross-section dynamics in economic growth, European Economic Review 31, 426-434.[ScienceDirect]
60. Rastogi, T., & Björkman, M. (2023). Automated Construction of Time-Space Diagrams for Traffic Analysis Using Street-View Video Sequences (Under review for IEEE ISTC 2023). [DOI]
61. Robusto, C. C. (1957). The Cosine-Haversine Formula. The American Mathematical Monthly, 64(1), 38–40. [JSTOR]
62. Saeedi, H., Behdani, B., Wiegmans, B., & Zuidwijk, R. (2019). Assessing the Technical Efficiency of Intermodal Freight Transport Chains using a Modified Network DEA Approach. [ScienceDirect]
63. Sánchez-Díaz, I. (2018). Potential of Implementing Urban Freight Strategies in the Accommodation and Food Services Sector. Transportation Research Record, 2672(9), 194–203. [SageJournals]
64. Scheurer, Jan & Curtis, Carey. (2016). Planning for Public Transport Accessibility: An International Sourcebook. 10.4324/9781315600758. [DOI]
65. Shaheen, Susan, Chan, Nelson, Bansal, Apaar, Cohen, Adam, Shaheen, S, Chan, N, Bansal, A, Cohen, A, Berkeley, U., Alm, E., Grimes, A., Huckabay, L., Iacobucci, L., Morneau, J., Longoria, N., Schermer, F., Srivastava, R., Williams, S., 2015. Definitions, Industry Developments, and Early Understanding, in: Transportation Sustainability Research Center. Berkeley, CA, USA, pp. 5–20.[InnovativeMobility]
66. Smailes, Arthur E. "The Indian City: A Descriptive Model." Geographische Zeitschrift, vol. 57, no. 3, 1969, pp. 177–90. [JSTOR]
67. SteadieSeifi, M. & Dellaert, Nico & Nuijten, Wim & Van Woensel, Tom & Raoufi, R.. (2014). Multimodal freight transportation planning: A literature review. European Journal of Operational Research. 233. 1–15. 10.1016/j.ejor.2013.06.055. [DOI]
68. Stolte Bezerra, B., Laura Lordelo dos Santos, A., & Delmonico, D. V. (2019). Unfolding barriers for urban mobility plan in small and medium municipalities-A case study in Brazil. [ScienceDirect]
69. Wagner, Jorge & Stuerzlinger, Wolfgang & Nedel, Luciana. (2019). Evaluating an Immersive Space-Time Cube Geovisualization for Intuitive Trajectory Data Exploration. IEEE Transactions on Visualization and Computer Graphics. PP. 1-1. 10.1109/TVCG.2019.2934415 [IEEE]
70. Wilson, Matthew. (2011). 'Training the eye': Formation of the geocoding subject. Social & Cultural Geography. 12. 357-376. 10.1080/14649365.2010.521856. [DOI]
71. Woxenius, J. (2007). Generic framework for transport network designs: Applications and treatment in intermodal freight transport literature. Transport Reviews, 27(6), 733–749. [TaylorandFrancis]
72. Xinhui Cao et al 2020 IOP Conf. Ser.: Earth Environ. Sci. 440 042066, [IOPScience]
73. Zhang, Junping & Wang, Kunfeng & Lin, Wei-Hua & Xu, Xin & Chen, Cheng. (2011). Data-Driven Intelligent Transportation Systems: A Survey. IEEE Transactions on Intelligent Transportation Systems. 12. 1624-1639. 10.1109/TITS.2011.2158001. [IEEE]

74. Zhu, L., Yu, F.R., Wang, Y., Ning, B., & Tang, T. (2019). Big Data Analytics in Intelligent Transportation Systems: A Survey. IEEE Transactions on Intelligent Transportation Systems, 20, 383-398. [SemanticScholar]

Design Inspirations

75. Space & Narrative (@space_and_narrative). (2021, April 28). Instagram.
76. KIAL: KIAL Airport Map
77. Dayaa Wordpress - BIAL
78. https://www.ewebbuddy.com/bangalore-airport-bus-vayu-vajra-bial/
79. Railkaart Amsterdam
80. Amsterdam Transit
81. Amsterdam Night Transit

Getting There is Half the Fun:

Intermodal Transport Comparison of Two Dissimilar Cities of Amsterdam and Bengaluru.