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Metropolitan Rail Transit Improvement: The Baltimore Study

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Abstract

In urban areas across the United States (US), private vehicle use dominates transportation, causing congestion, economic loss, and environmental damage. This paper examines transportation planning strategies to strengthen public transport networks, particularly focusing on rail transit, as a way to reduce reliance on private cars. Using the Baltimore area as a case study, the research explores the challenges and opportunities of promoting shifts to rail transit in sprawling American cities. Unlike densely populated cities where rail excels, the dispersed nature of US cities requires careful planning of access points, walking distances, and travel times. Baltimore's case reveals the need for targeted rail transit investments and measures to discourage car use, emphasizing improved accessibility, connectivity, and user experience. Drawing on successful models from Europe and Asia, the study highlights the importance of integrated planning, where rail systems are seamlessly connected to feeder networks and supported by land use policies. The success of such initiatives depends on collaboration among stakeholders, including government agencies, urban planners, and the community. By leveraging global best practices and strategic investments, cities like Baltimore can work towards reducing private vehicle use and developing sustainable transportation systems. This paper aims to guide future transportation planning in US cities, advancing metropolitan rail transit.

Keywords

American, Urban Transit Systems, Sustainable Transportation, Baltimore Rail Transit, Sustainable Mobility Solutions

1. Introduction

Urban transportation systems in the United States face significant challenges due to heavy reliance on private vehicles, leading to traffic congestion, economic losses, and environmental pollution. Rail transport, while efficient in densely populated areas, struggles to serve dispersed populations effectively. This paper focuses on transportation planning, aiming to explore strategies to increase the modal share of rail transport, with a specific focus on the Baltimore conurbation as a representative American urban area. Drawing insights from successful transit systems in cities like Madrid, Paris, London, Tokyo, and Seoul, this study seeks to propose recommendations applicable to American cities.

1.1. Objectives of Study

The primary objective of this study is to analyze the transportation planning dynamics within the Baltimore conurbation and identify opportunities to enhance rail transport modal share. Specific objectives include:

- Compilation of relevant data on Baltimore's transportation system and comparative analysis with efficient transit systems worldwide.
- Examination of the current state and expansion plans of Baltimore's rail network.
- Identification of key passenger generation and reception points within the Baltimore area.
- Evaluation of the effectiveness of the existing transportation network concerning population distribution.
- Identification of bottlenecks in transportation planning and proposing strategies to overcome them.

1.2. Scope and Limitations

The scope of this study focuses on transportation planning within the Baltimore conurbation, with comparisons to international best practices in urban rail systems. However, the study does not address broader urban planning issues beyond transportation. Limitations include potential challenges related to data availability, especially in comparative analyses with international cities, and constraints in forecasting future transportation trends. For the comparative study of rail networks in various cities, data was collected from academic sources and online databases. The data includes geo-population statistics and rail network information. For geo-population data, urban areas were defined as contiguous urbanized zones, independent of political boundaries, allowing for consistent comparisons across different cities. Surface area and population data were collected to calculate population density, providing a meaningful metric for comparison.

Collecting rail network data for each city proved more complex, as many urban areas have multiple overlapping rail systems that often extend beyond the immediate city limits. In cities like Baltimore, New York, Paris, and Madrid, only local transit rail networks were considered, excluding long-distance services that, while occasionally used by commuters, are primarily intended for intercity travel. Although this approach may not capture every detail, it provides a reasonable basis for comparing the scale and scope of urban rail systems (Roy, 2017).

In Tokyo, obtaining comprehensive rail data posed the greatest difficulty. Not all private rail operators have publicly available data in English, which may result in an underestimation of Tokyo's total rail network size. Consequently, the figures for Tokyo should be interpreted with caution, as they might not fully reflect the city's extensive rail infrastructure.

1.3. Significance of the Study

This study is significant in addressing critical issues related to urban transportation in the United States. By focusing on rail transport, it seeks to provide valuable insights into reducing reliance on private vehicles, alleviating traffic congestion, mitigating economic losses, and promoting environmentally sustainable modes of transportation.

Urban areas in the US face numerous challenges, such as traffic congestion, pollution, and inefficient public transportation systems. Rail transport represents a key solution to these issues. By enhancing rail transit, the study aims to promote a shift from private vehicle usage to more sustainable transportation alternatives. This shift is expected to reduce traffic congestion, improve air quality, and decrease greenhouse gas emissions (Gudmundsson et al., 2015; Rodrigue, 2024).

Alleviating traffic congestion is another major objective, as congestion leads to wasted time, increased fuel consumption, and decreased productivity (Singleton & Clifton, 2017). Furthermore, congestion not only affects daily commuters but also imposes significant economic costs. Businesses face increased transportation costs, reduced productivity, and lost revenue due to delays. By advancing rail transit infrastructure, this study seeks to mitigate these economic losses and provide a more efficient and reliable means of moving people and goods within urban areas (Schrank et al., 2024; Buba & Lee, 2016).

Promoting environmental sustainability is a central concern, given that transportation is a major contributor to greenhouse gas emissions and air pollution, with adverse effects on public health and the environment. Rail transport, particularly when powered by clean energy sources, is generally considered more environmentally sustainable than private vehicles. The study aims to support environmental sustainability efforts by reducing emissions and promoting cleaner modes of transportation (European Environment Agency, 2019; Perfetto & Lamacchia, 2016).

Additionally, the findings of this study are expected to provide valuable guidance for policymakers, urban planners, and transit authorities involved in urban transportation planning. By identifying strategies for improving rail systems, the study aims to inform decision-making processes and help allocate resources to enhance public transportation infrastructure and services (Gudmundsson et al., 2015). Ultimately, improving rail transport will contribute to a better quality of life for residents in Baltimore and other similar American cities by providing more efficient, reliable, and sustainable transportation options. This will enhance accessibility, mobility, and the overall well-being of urban populations, leading to more vibrant and livable urban environments (Geels, 2012).

2. Literature

2.1. Historical Development of Metropolitan Rail Transit

The evolution of metropolitan rail transit systems spans over a century, reflecting the dynamic interplay between urbanization, technological advancements, and socio-economic factors. The genesis of modern urban rail can be traced back to the late 19th century, notably with the inauguration of the London Underground in 1863, marking the advent of electrified rapid transit. Subsequent developments, such as the New York City Subway in 1904 and the Paris Métro in 1900, underscored the global proliferation of subway systems as emblematic symbols of modern urbanism (Vuchic, 2007).

The mid-20th century witnessed a zenith in rail transit expansion, fueled by post-war urbanization and federal investments in infrastructure. Metropolitan areas across the United States experienced a surge in subway and light rail construction, epitomized by the extensive networks of New York, Chicago, and Philadelphia. Concurrently, European cities like Berlin and Madrid embarked on ambitious metro projects, integrating rail transit as a cornerstone of urban development (Cervero, 1998).

However, the latter half of the 20th century witnessed a decline in rail transit investment amid the ascendancy of automobile-centric planning paradigms. The proliferation of highways, coupled with suburbanization trends, led to disinvestment in urban rail and the marginalization of public transportation (Lewyn, 2000). This era of neglect culminated in the 1970s and 1980s, characterized by deferred maintenance, service cuts, and ridership declines across many American transit systems (Gleeson & Low, 2000).

2.2. Current State of Metropolitan Rail Transit Systems

Contemporary metropolitan rail transit systems exhibit a diverse spectrum of characteristics, shaped by regional demographics, policy frameworks, and infrastructural legacies. Major global cities boast extensive and sophisticated rail networks, providing seamless connectivity and high-frequency service. For instance, Tokyo's integrated rail system, comprising the JR East, Tokyo Metro, and Toei Subway, stands as a paragon of efficiency and reliability, serving millions of passengers daily (Banister, 2008).

In contrast, the state of rail transit in many American cities reflects a patchwork of successes and shortcomings. While cities like New York and Boston boast venerable subway systems with robust ridership, others, including Los Angeles and Atlanta, grapple with nascent rail networks hampered by funding constraints and low ridership (Schuyler, 1997; Freemark, 2023). Moreover, the proliferation of commuter rail and light rail systems in cities like Denver and Minneapolis underscores a renewed interest in rail transit as a catalyst for urban revitalization and mobility equity (Solís et al., 2023).

2.3. Challenges and Issues Facing Metropolitan Rail Transit

Despite its potential benefits, metropolitan rail transit faces numerous challenges that hinder its expansion and effectiveness. One of the primary obstacles is securing adequate funding and financing. Rail projects require substantial capital investments and long lead times, often extending over several years or even decades. Sustainable funding sources are difficult to secure, as cities and states must navigate competing priorities, budget constraints, and shifting political landscapes. The competition for public funds between rail transit and other infrastructure projects, such as roads and highways, further complicates the issue (Xuto et al., 2023).

Another key challenge is the spatial mismatch between rail infrastructure and population centers, particularly in the context of sprawling American cities. The "last-mile problem" persists, where commuters face difficulties in reaching transit stations due to inadequate access or connections. This issue diminishes the appeal of rail transit, encouraging continued reliance on private vehicles. The limited accessibility to stations is a significant deterrent for prospective riders, especially in areas with poor pedestrian infrastructure or limited feeder services such as buses and bike-sharing systems (Peng et al., 2023). Additionally, concerns about safety, security, and comfort on public transit—especially in cities with higher crime rates or social disorder—further dissuade potential users (Loukaitou-Sideris et al., 2007).

The imperative of addressing environmental sustainability underscores the urgency of expanding rail transit as a low-carbon transportation option. Rail systems, especially when electrified, offer significant environmental benefits compared to car-based transportation. However, the transition to emissions-free rail requires large-scale infrastructural upgrades, which are expensive and complex to implement. Policy interventions supporting sustainable rail transit must be accompanied by strong political will and widespread public support to ensure successful implementation (Litman, 2009). Integrating renewable energy sources into rail systems and developing efficient, electrified networks are essential for mitigating the environmental impact of urban transportation (Sims et al., 2011).

In summary, the historical trajectory, current state, and prospects of metropolitan rail transit systems are contingent upon a myriad of factors, including historical legacies, policy choices, and societal preferences. Addressing the multifaceted challenges facing rail transit requires concerted efforts from policymakers, transit agencies, and the broader community to realize its potential as a sustainable and equitable mode of urban transportation.

3. Methods and Materials

3.1. Data Collection and Analysis Methods

To achieve the objectives outlined in this study, a comprehensive and multifaceted approach to data collection and analysis was employed. The methodology combined both qualitative and quantitative techniques, drawing upon existing literature, statistical data, and comparative analyses of rail transit systems in various urban settings. This blend of methods provided a holistic understanding of the challenges and opportunities associated with rail transit expansion, particularly in the context of the Baltimore conurbation.

A key aspect of the study involved a comparative analysis of rail transit systems in international cities such as Madrid, Paris, and Tokyo. The analysis focused on network coverage, ridership patterns, infrastructure investments, and policy frameworks to identify best practices and strategies that could be applied to the Baltimore metropolitan area. Data from these cities were collected and analyzed to provide insight into how different urban contexts approach rail transit planning and what lessons can be learned.

Primary data collection efforts concentrated on gathering information specific to Baltimore's transportation system, including the current state of its rail network and any future expansion plans. This involved accessing publicly available data from transportation agencies, urban planning departments, and transit authorities. Geographic Information System (GIS) tools were utilized to map rail infrastructure and assess its alignment with population distribution, offering a detailed spatial analysis of where improvements or expansions might be most effective.

However, the predictive models and analyses conducted in this study are subject to certain limitations and inherent uncertainties, particularly in relation to future projections. Variables such as demographic shifts, technological advancements, and policy changes introduce complexities that could affect the accuracy and reliability of predictions. Despite these uncertainties, the study provides valuable insights to guide decision-making, while acknowledging that future developments may necessitate adjustments to the proposed strategies.

3.2. Baltimore Metropolitan Rail Transit System Overview

Baltimore's rail transportation system currently consists of one main light rail (LRT) line with two branch lines, one heavy rail (HRT) metro line, and two longer distance commuter rail lines serving Central Maryland and Washington DC in addition to general intercity Amtrak service at Pennsylvania Station.

3.2.1. Light Rail

Main Line light rail service begins in Hunt Valley, and travels south to the downtown area, and continues south to Glen Burnie. Branch lines serve Pennsylvania Station and BWI Airport. Baltimore's light rail uses a combination of dedicated right of way track outside of the downtown area, and in roadway track on city streets. Much of the system utilises at grade crossings with crossing gates, and a transit priority signal timing system was implemented along its shared right-of-way corridor in the downtown district. Much of the line is a two-track facility, but operations are reduced to single tracking between the Pepper Road and Gilroy Road stations towards the northern end of the line.

3.2.2. Heavy Rail

Baltimore's metro line runs east-west for 15 miles, beginning in Owings Mills and terminating at Johns Hopkins Hospital. Track on this route runs in the median of I-795 near its northwest terminus in Owings Mills and continues at grade before running on an elevated structure further east. From there the track finally runs underground for the remaining six miles of the line within the city. All tracks on the line operate within dedicated right of way, and trains are powered by an electrified third rail.

3.2.3. Commuter Rail

Baltimore is served by two commuter rail lines, both operated by MARC (Maryland Area Rail Commuter), as shown in Figure 1. The first line is the Penn Line (shown in yellow). This line originates at Washington DC's Union Station before heading north towards Baltimore's Penn Station with intermediate stops along the way at locations such as Baltimore/Washington International Airport and West Baltimore. After Baltimore Penn Station, the Penn Line continues north to its current terminus at Perryville Station with additional intermediate stops at locations such as Martin State Airport and Aberdeen. The entirety of the Penn Line operates on Amtrak's Northeast Corridor. The second commuter line that serves Baltimore is the Camden Line (shown in green). This line also originates at Union Station, before heading north towards Baltimore with intermediate stops at locations such as Laurel and Jessup before terminating at Camden Station which is located adjacent to Baltimore's Inner Harbor with connections to the Light Rail. This line does not run-on Amtrak's Northeast Corridor and does not serve Baltimore's Penn Station.

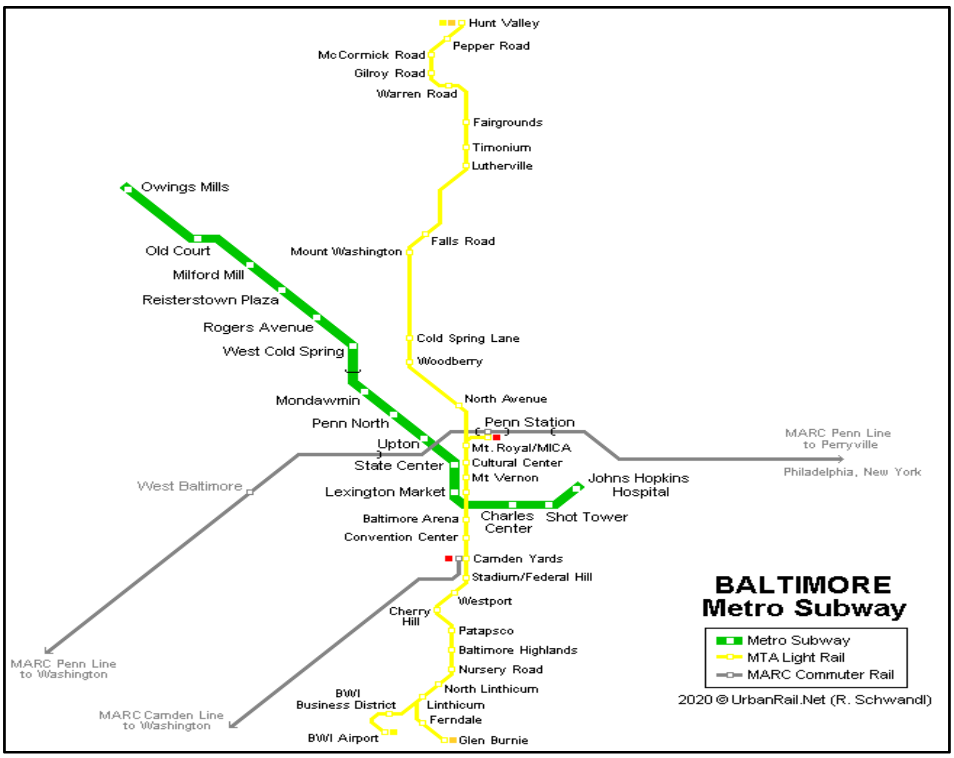

Figure 1. Commuter Green and Yellow rails (https://www.urbanrail.net/).

3.3. Case Studies of Successful Metropolitan Rail Transit

3.3.1. Madrid Urban Rail Network

The urban area of Madrid is relatively compact compared to other major cities, covering approximately slightly less than 650 square kilometers. Despite its smaller geographical size, Madrid has a notably high population density, exceeding 10,000 inhabitants per square mile. This makes it one of the densest urban areas in Europe, which supports the high ridership on its public transportation systems.

Madrid's urban rail network primarily consists of two major systems: the Madrid Metro and the Renfe Cercanías commuter rail network. The Madrid Metro serves as the city's primary subway system, with numerous lines that extend across the city and into its suburbs (Figure 2). It is one of the largest and most extensive subway systems in Europe, playing a critical role in Madrid's public transportation infrastructure. The network connects key areas, including major train stations, the airport, shopping centers, universities, and residential districts. The continuous expansion of the Metro has added new lines and stations over the years, ensuring that it remains an essential component of the city's urban mobility strategy (Rodriguez, 2011).

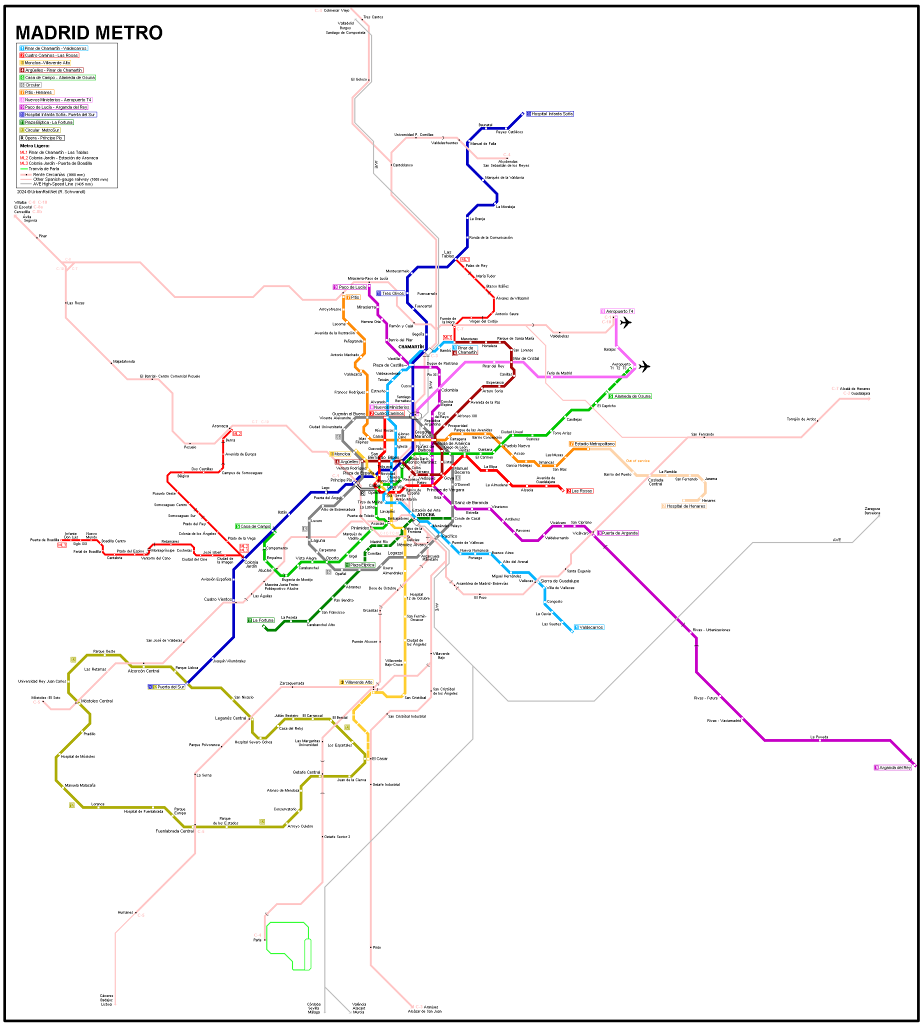

Figure 2. Madrid rail network (https://www.urbanrail.net/).

The total length of the Madrid Metro network is approximately 294 kilometers, encompassing all lines and branches throughout the metropolitan area. The system currently includes 12 primary lines, numbered from 1 to 12, and one light rail line (ML-1), which connects Pinar de Chamartín with Las Tablas. The Metro network has over 300 stations, strategically distributed to provide extensive coverage across various parts of the city, as well as important destinations such as the airport and major commercial hubs. Before the COVID-19 pandemic, the Madrid Metro recorded over 600 million trips annually. To accommodate the city's growth and improve connectivity, the system has undergone significant expansions, with the addition of new lines and modernization projects aimed at enhancing service efficiency and safety. Metro de Madrid's fare system is distance-based, with pricing varying depending on the zone and ticket type. Accessibility improvements, such as elevators and barrier-free designs, have been implemented to ensure inclusivity across the system (Metro de Madrid, 2019).

The Renfe Cercanías commuter rail network complements the Metro by connecting Madrid with its suburbs and nearby cities. This network is essential for daily commuters who live outside the city but work or study in Madrid, as well as for passengers traveling from other parts of the region. The Cercanías network spans approximately 370 kilometers, consisting of 10 main lines: C-1, C-2, C-3, C-4, C-5, C-7, C-8, C-8a, C-9, and C-10. These lines provide access to numerous suburban towns and cities, with over 90 stations across the system (Renfe Cercanías Madrid, n.d.).

Cercanías trains operate frequently, particularly during peak hours when trains run every few minutes. Service is available throughout most of the day, with schedules extending from early morning until late evening. Like the Metro, the Cercanías network was heavily utilized before the COVID-19 pandemic, with over 200 million trips annually. The network is fully integrated with other public transportation options in Madrid, including the Metro and the city's bus system, offering seamless connectivity for passengers traveling within Madrid and its surrounding areas.

3.3.2. Paris Urban Rail Network

The urban area of Paris is the densest among the cities considered, with a population density of over 14,000 inhabitants per square mile, covering an area of approximately 1100 square miles and home to around 14.7 million people. Madrid, by contrast, is a smaller, concentrated area of 656 square miles.

Paris's urban rail system is one of the most extensive and complex in the world, comprising the Paris Métro, the RER (Réseau Express Régional), a tramway network, and the Transilient regional trains. Each system plays a vital role in connecting the city with its suburbs and the broader Île-de-France region (**Figure 3**).

The Paris Métro is the city's primary subway system, consisting of 16 lines (1 to 14, plus 3bis and 7bis) that cover approximately 214 kilometers of track. With more than 300 stations, the Métro provides extensive coverage of Paris, linking key areas such as major landmarks, shopping districts, universities, and residential zones. Before the COVID-19 pandemic, the Métro carried over 4.5 million passengers daily. Trains operate frequently, running every 2 to 5 minutes during peak hours. Service typically begins at 5:30 a.m. and ends at midnight, with slight variations depending on the line. The system is integrated with other transport modes in the Île-de-France region under a unified fare structure, and accessibility improvements, such as elevators and ramps, have been added to many stations (Île-de-France Mobilités, 2022).

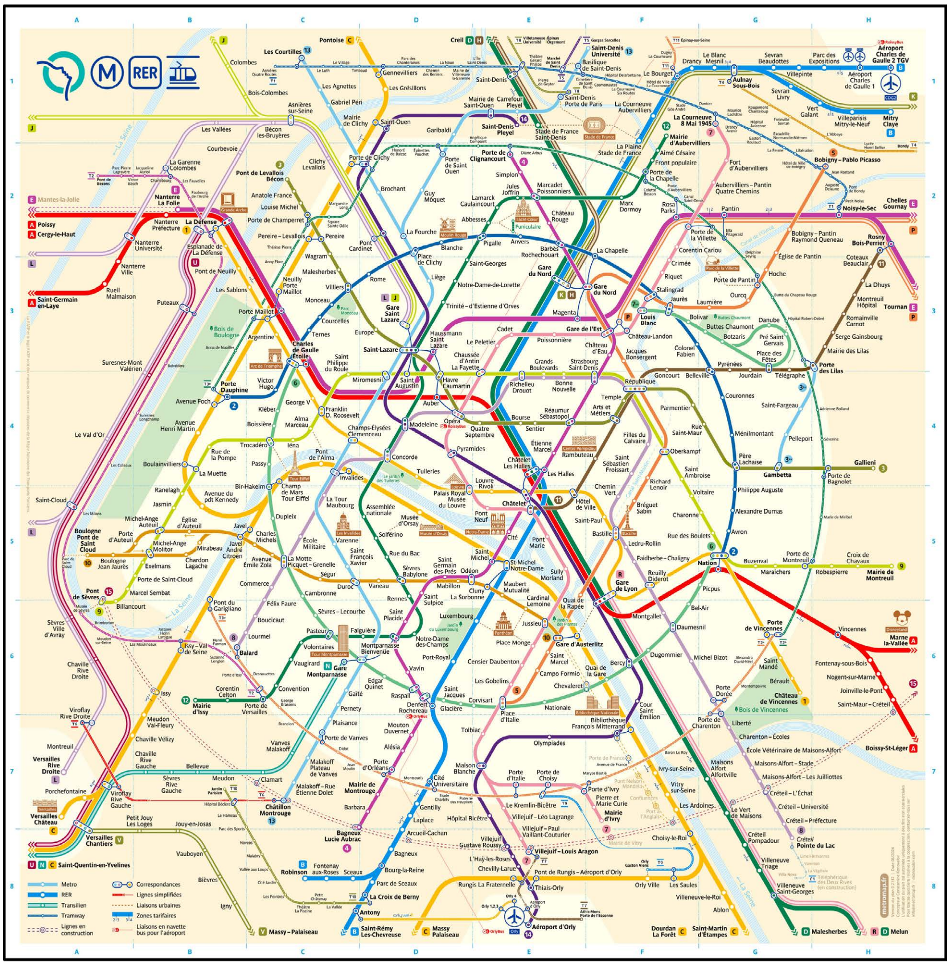

Figure 3. Paris rail network (source: https://metromap.fr/).

The RER is a regional rail network that complements the Métro, connecting Paris to its suburbs and surrounding regions. The RER system spans 587 kilometers and includes five main lines (A, B, C, D, and E), with over 250 stations. It connects to key destinations, including Charles de Gaulle and Orly airports, and serves millions of passengers daily, particularly commuters from the suburbs. RER trains operate with higher frequencies during rush hours, with a less frequent service during off-peak times. The RER is also part of the Île-de-France integrated fare system and includes accessibility features at major stations.

Paris also has an extensive tramway network, which serves as an additional transportation option, especially for areas not covered by the Métro and RER. The tram system consists of several lines (T1, T2, T3a, T3b, T5, T6, T7, T8, and T11 Express) covering approximately 100 kilometers of track. These lines connect various parts of the city and its suburbs, serving over 130 stations. The tram network is particularly useful for connecting suburban areas to key urban locations, such as shopping centers, hospitals, and universities. The tram system operates with high frequency during peak hours, and like the other public transport modes, is integrated into the regional fare system (Île-de-France Mobilités, 2022).

The Transilient network, operated by SNCF, is a regional train service that connects Paris with more distant suburbs and towns in the Île-de-France region. It covers over 1700 kilometers of rail and serves more than 400 stations. Transilient lines (e.g., H, J, K, L, N, P, R, U, and T4) complement the RER and provide critical transport services to areas beyond the immediate reach of the Paris Métro. The network handles millions of passengers annually and offers high-frequency services during peak hours. The Transilient network is also integrated into the broader public transport system and includes accessibility accommodations at most stations (Le Bras, 2022).

3.3.3. London Urban Rail Network

Public rail transport in Greater London consists of a well-integrated and extensive network of services connecting London to its surrounding areas. This system includes the London Underground, London Overground, National Rail services, Docklands Light Railway (DLR), and Tramlink, providing comprehensive coverage across the capital.

The London Underground, or "the Tube", is one of the oldest and most extensive rapid transit systems in the world. Serving Greater London and parts of adjacent counties such as Buckinghamshire, Essex, and Hertfordshire, the Tube consists of 11 lines and over 270 stations (**Figure 4**). The network spans approximately 402 kilometers of track, making it a critical component of London's public transport infrastructure. Its reach extends to central London and the suburbs, with millions of passengers using the system daily for commuting and travel across the city (Transport for London, 2021b).

The London Overground is a suburban rail network that supplements the Underground by connecting more outlying areas of London. It operates on several key routes, including the North London, East London, West London, and South London lines. This network provides vital links between different parts of the city, particularly in areas not served by the Underground. The Overground operates over 167 kilometers of track and serves more than 100 stations, enhancing connectivity for passengers traveling within and outside London (Transport for London, 2021b).

In addition to the Underground and Overground, National Rail services operate throughout Greater London, providing essential connections to destinations across the UK. London is home to major railway terminals like Paddington, Victoria, Liverpool Street, King's Cross, Waterloo, and London Bridge. These stations serve as hubs for national rail services, linking London to other cities and regions. As of recent updates, Greater London has over 100 National Rail stations, further expanding the reach of public rail transport within the capital (National Rail, 2022).

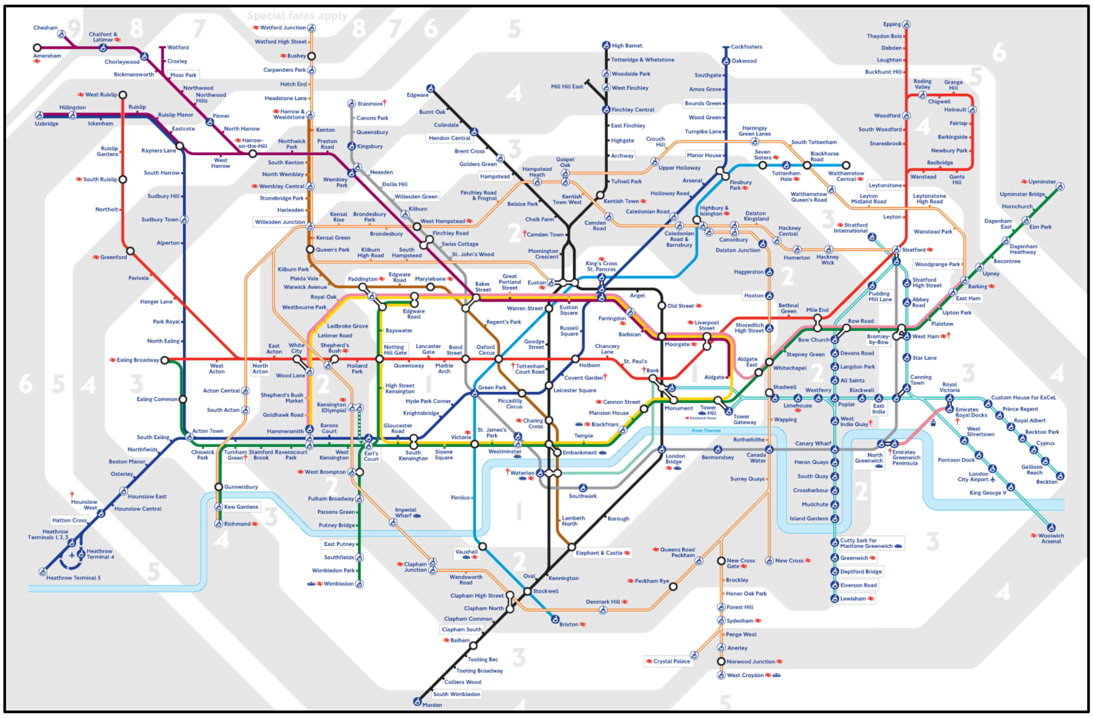

Figure 4. London rail network (source: https://tfl.gov.uk/maps/track).

The Docklands Light Railway (DLR) is an automated light metro system serving East London, particularly the Docklands area. It operates on elevated viaducts and through tunnels, providing seamless connections between residential areas and major business districts such as Canary Wharf. The DLR comprises 45 stations across its network, which spans approximately 34 kilometers of track (Transport for London, 2021a).

Tramlink, a tram system primarily serving South London, operates across the boroughs of Croydon, Merton, and Sutton. Tramlink provides essential connections between residential neighborhoods, commercial areas, and other public transport modes. The network covers approximately 28 kilometers of track, with three main lines serving 39 stations. Tramlink complements the broader public transport system by offering reliable, frequent services in areas with limited rail infrastructure (Transport for London, 2021c).

3.3.4. Tokyo Urban Rail Network

The urban area of Tokyo is the most populated urban area in the world with 37.9 million in a surface of 5200 mi^2. The density is 7300 inhabitants per square mile. The public rail transport system in Greater Tokyo is one of the most extensive and efficient in the world. It includes a combination of commuter trains, subways, and high-speed rail services, all interconnected to provide seamless travel within the Greater Tokyo area and beyond. The total number of rail stations in Greater Tokyo is well over 2000. As of my last update, the total length of the railway network in Greater Tokyo, including all lines operated by JR East, private railways, and other operators, is estimated to be well over 3000 kilometers (**Figure 5**).

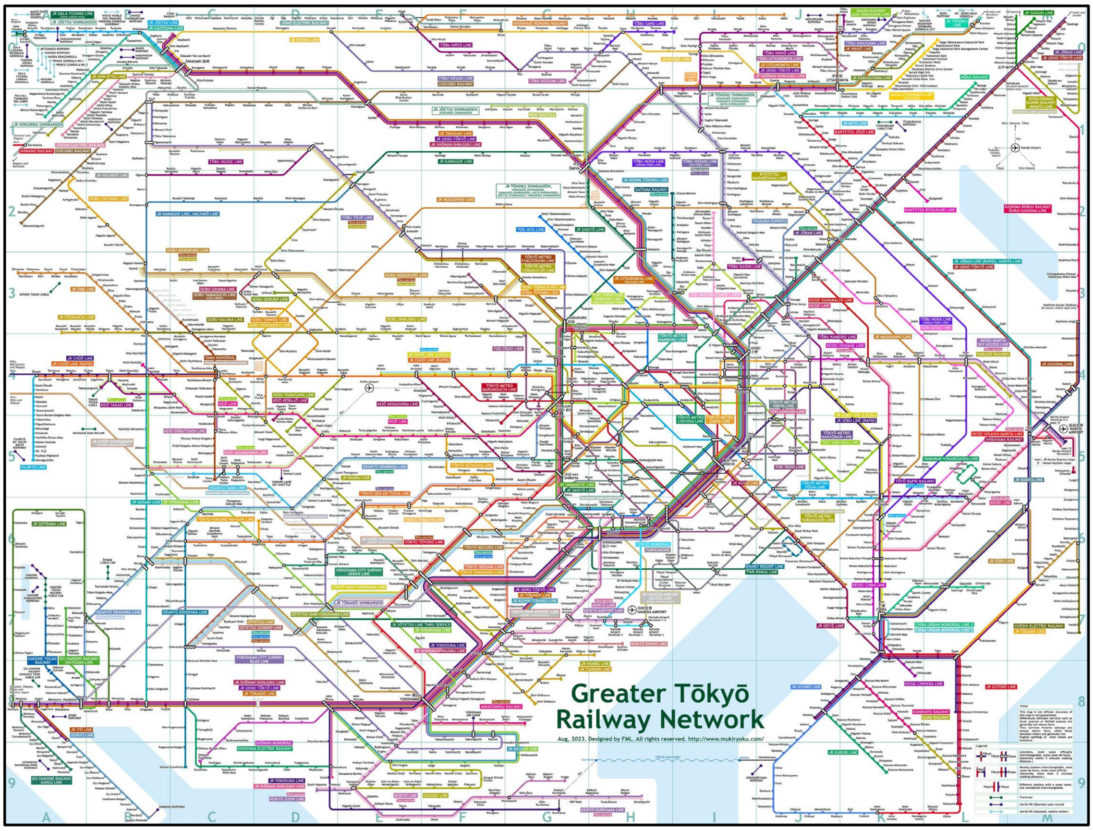

Figure 5. Greater Tokyo rail network (source: Flickr/Kzaral).

Here are some key features of the rail public transport system in Greater Tokyo:

Tokyo has an extensive subway network operated by two main entities: Tokyo Metro and Toei Subway. These subways serve the central and suburban areas of Tokyo, with multiple lines covering different parts of the city. Tokyo Metro operates a comprehensive subway network consisting of 9 lines, designated by different colors, covering various parts of Tokyo and neighbouring areas. The total number of stations on the Tokyo Metro network is around 179. The total length of the Tokyo Metro network, including all lines operated by Tokyo Metro, is approximately 195 kilometers. The total length of the Toei Subway network, including all lines operated by Toei Subway, is approximately 109 kilometers.

Japan Railways (JR) East operates several commuter lines, including the Yamanote Line, which loops around central Tokyo, and the Chuo Line, which connects Tokyo with western suburbs such as Shinjuku and Tachikawa. JR East also operates regional and high-speed Shinkansen (bullet train) services connecting Tokyo with other major cities across Japan.

Tokyo is also served by numerous private railway companies, such as Keio Corporation, Seibu Railway, and Odakyu Electric Railway, which operate commuter and suburban lines connecting Tokyo with surrounding cities and towns.

3.3.5. New York Urban Rail Network

The urban area of New York with 8300 mi^2 is the biggest of the selected cities where there is a population of 20.1 million people. The density is 2400 inhabitants per square mile.

The rail public transport system in the New York City metropolitan area is one of the largest and most comprehensive in the United States. It consists of several key components, including commuter rail, subway, and light rail services. Here's an overview:

The New York City Subway is one of the world's oldest and busiest rapid transit systems, serving the five boroughs of New York City. It consists of 27 subway lines in Figure 6, with over 400 stations and approximately 394 kilometers of track. The subway system operates 24/7 and serves millions of passengers daily.

Figure 6. New York rail network (Mader, n.d.).

The Long Island Railroad (LIRR) is the busiest commuter rail system in North America, serving Long Island and connecting it to Manhattan. It operates 11 branches and serves over 120 stations. The LIRR has approximately 1127 kilometers of track and carries hundreds of thousands of commuters daily.

MTA Metro-North operates commuter rail service between New York City and its northern suburbs in New York State and Connecticut. It consists of three main lines: the Hudson Line, Harlem Line, and New Haven Line. Metro-North has over 120 stations and approximately 620 kilometers of track, serving hundreds of thousands of commuters daily. New Jersey Transit NJT operates commuter rail services connecting New Jersey with New York City and its suburbs. It operates several lines, including the Northeast Corridor Line, North Jersey Coast Line, and Morris & Essex Lines. NJT also operates the Hudson-Bergen Light Rail and Newark Light Rail systems. New Jersey Transit operates over 160 rail stations across its network. New Jersey Transit's rail network spans approximately 1560 kilometers of track.

The Port Authority Trans-Hudson (PATH) is a rapid transit system connecting Manhattan with several cities in New Jersey, including Newark, Jersey City, and Hoboken. It operates four lines and operates a total of 13 stations across its network. The PATH network spans approximately 22.5 kilometers of track.

The Staten Island Railway (SIR) is a rapid transit line connecting Staten Island with the Staten Island Ferry terminal in St. George. It operates a single line with 22 stations. The Staten Island Railway has approximately 22.5 kilometers of track.

3.3.6. Comparison

Table 1 presents data for the cities analyzed, along with a comparison of current and projected figures for Baltimore City. This table provides a clear overview of how Baltimore's transportation metrics align with those of other major cities, both in the present and looking toward future developments.

Table 1. Cities and corresponding selected rail transit parameters.

City	Population (in million)	Area (sq. mile)	Density (hab./sq. mile)	Rail Length (miles)	Number of Stations
Paris	14.7	1100	13,364	1488	1147
Madrid	7.0	700	10,000	239	698
Tokyo	37.9	5200	7288	1864	2000
London	14.8	3400	4353	1013	712
New York	20.1	8300	2422	2361	864
Baltimore	2.8	2600	1077	45	47
Baltimore (future)	2.8	2600	1077	109	122

From these data, we can draw some ratios that allow us to compare the analyzed urban rail networks with each other. The ratios that have been established are the number of stations per square mile, the length of railroad tracks per square mile as well as the number of stations per 100,000 inhabitants. The ratios are shown in the following Table 2.

Table 2. Cities and corresponding ratios for selected rail transit parameters.

Cities	Stations (per sq. mile)	Rail Length (per sq. mile)	Stations (per 100,000 hab.)
Paris	1.04	1.35	7.8
Madrid	1.00	0.34	10.0
Tokyo	0.38	0.36	5.3
London	0.21	0.30	4.8
New York	0.10	0.28	4.3
Baltimore	0.02	0.02	1.7
Baltimore (future)	0.05	0.04	4.4

4. Results and Discussion

4.1. Improvement Strategies for the Baltimore Metropolitan Rail Transit System

After evaluating existing conditions within Baltimore, utilizing social-economic evaluation tools to understand which areas and connections are at the greatest need for the city, and studying existing successful and efficient transit systems, the team drafted a series of 4 new proposed lines in detail, including the mode of transportation, proposed route, stations and connections. A summary of each proposal is included in the following sections.

4.1.1. Red Line

The team considered the ongoing developments with the Baltimore Red Line (Figure 7) when deciding which routes to create, where they would go, and which modes of train vehicle they would use. The Red Line was originally proposed in the early 2000's and a preferred alternative was selected, approved, and received federal funding in the 2010's. However, in 2015, the project was cancelled due to financial concerns. In the spring of 2023, the state of Maryland decided to revive talks of building the Red Line, and public outreach took place during the summer and fall of 2023. The outreach campaign was used to determine whether the public preferred BRT or LRT, tunnels through the downtown, and other project aspects such as route alignment. In May of 2024, MDOT MTA published a report summarizing the results of the public outreach, with LRT being the overwhelming favorite among the public. For this reason, the team elected to design the rest of the Baltimore transit system improvements on the basis that the Red Line would be an LRT line using the southern alignment alternative with tunnels under downtown.

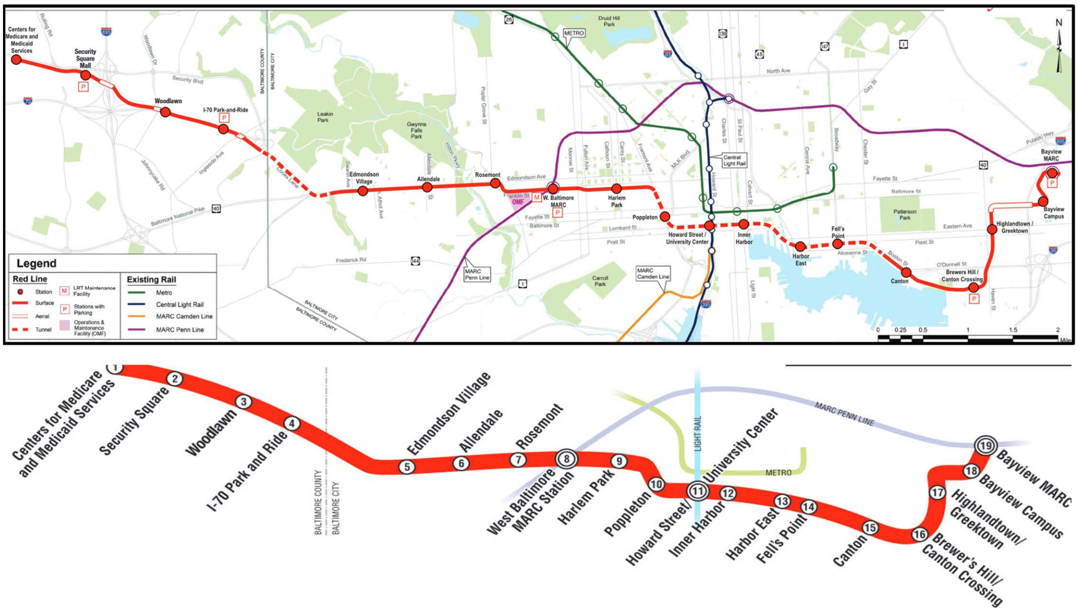

Figure 7. Baltimore metropolitan rail (MDOT, n.d.).

The Red Line begins west of the city limits, serving the Social Security Administration and the Security community. The line then continues eastward, serving Edmondson Village and other West Baltimore Communities, before connecting with the MARC Penn Line at the existing West Baltimore MARC station. The line then continues in the median of the existing Mulberry Street Expressway (Informally known as the "Highway to Nowhere") before entering a tunnel to traverse downtown Baltimore. The Red Line continues past the Inner Harbor, with a proposed pedestrian tunnel connecting the Inner Harbor station to the Green Line's existing Charles Center Station, and eventually resurfaces in the Fells Point neighbourhood. The line eventually turns to the north to serve Johns Hopkins Bayview Hospital and terminates at the proposed Bayview station with a new connection to the MARC Penn Line.

4.1.2. Green Line

The team is proposing the extension of the existing Green metro (heavy rail) line in **Figure 8** an additional 8 miles north from the current eastern terminus at Johns Hopkins Hospital. The line will include 9 new stations and be completely underground. The extension will connect to the proposed Orange LRT line at the proposed Broadway station, as well as the proposed Purple Line at York Road station. Towson University will be accessible from the St. Joseph's Hospital and Courthouse stations, and the line will terminate at the Towson station which will serve Towson Town Center (Statista, 2022). The line will also bring service to Morgan State University.

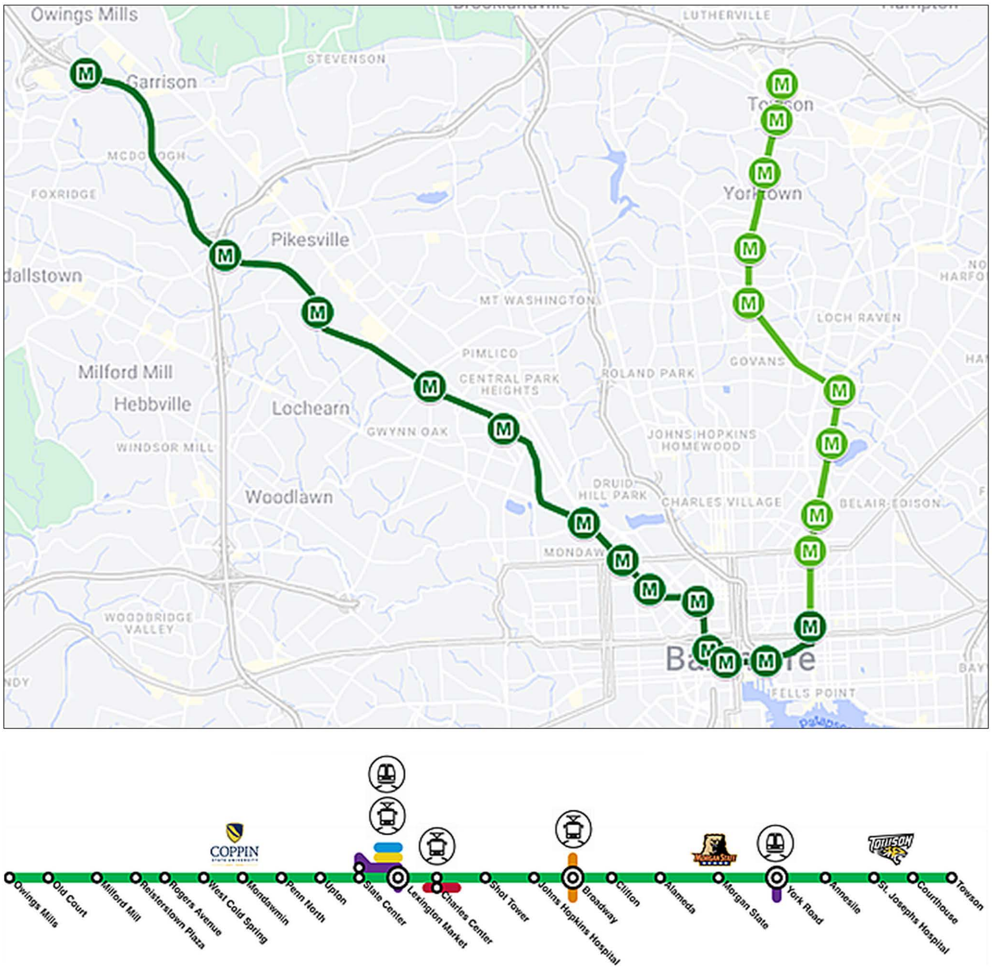

Figure 8. Baltimore metropolitan Green rail line (MDOT, n.d.).

4.1.3. Silver Line

The Silver Line will be a 19 mile long east-west LRT line from UMBC (University of Maryland Baltimore county) to the Edgemere community in **Figure 9**. It will consist of 19 stations, with 12 being newly constructed and 7 being concurrent with the currently proposed and in impact studies in real life Red Line. The line will begin in dedicated right of way on the surface at UMBC before entering a tunnel underneath I-695 and following Wilkens Avenue (MD 372) on a north-easterly path towards downtown. The line will join the proposed Red Line in a tunnel at the proposed Poppleton Station, and run concurrently through the Inner Harbor, Fells Point and Canton before splitting off and briefly running on an elevated structure through the Point Breeze and Holabird industrial areas. The line will then run down the median of Dundalk Avenue and adjacent to Broening highway, before crossing the Bear Creek on an elevated structure adjacent to I-695 to reach Tradepoint Atlantic. The Silver Line will have two stops serving Tradepoint Atlantic, and its massive Amazon, FedEx and Under Armour warehouses which are home to over 12,000 jobs. The line will then continue east for one more stop, serving the Edgemere community.

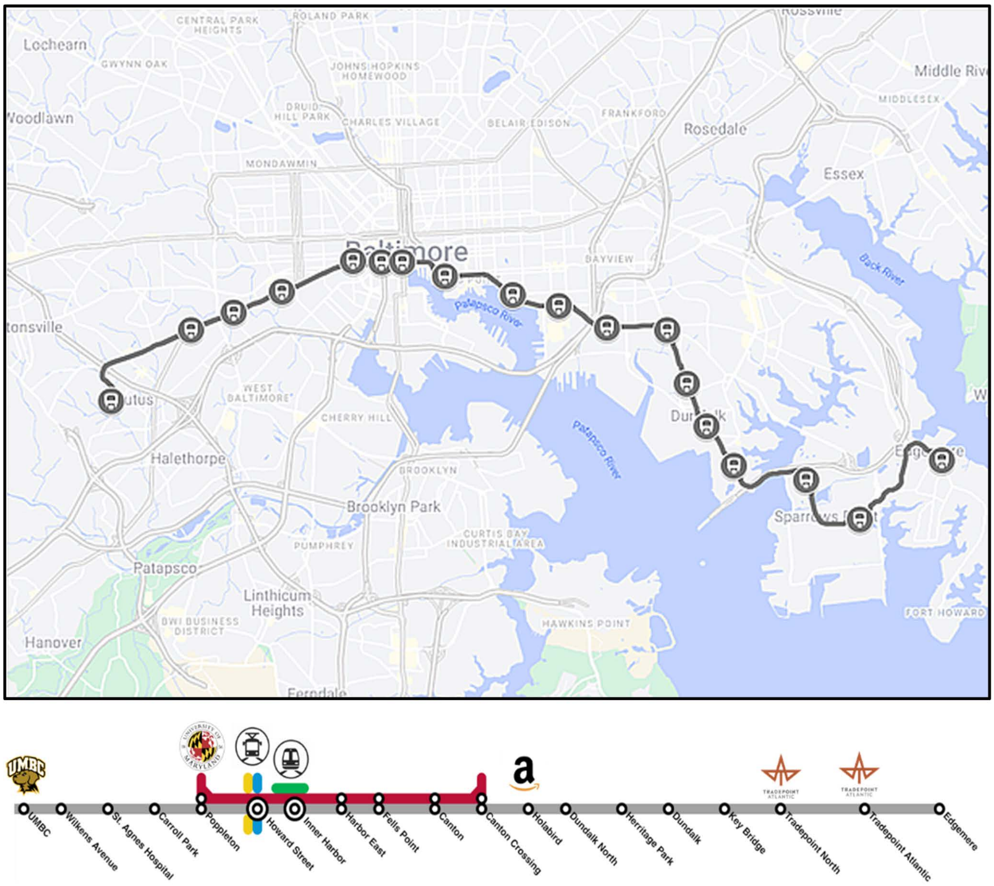

Figure 9. Baltimore metropolitan Silver rail line (MDOT, n.d.).

4.1.4. Orange Line

The orange line will be a 13-mile-long LRT line from Penn Station to White Marsh in Figure 10. The line will consist of 9 new stations and utilize a mix of tunnels and at grade track. The Line will begin at Penn Station with connections to the existing light rail shuttle, the proposed purple line, and existing MARC and Amtrak services. The line will continue east in a tunnel until it reaches the proposed broadways station, which will offer connecting service to the proposed green line extension. The line will continue east to Clifton-Edison Station before surfacing and running northeast in the median of a redesigned and road-dieted Belair Road for two stops. The line will then return to tunnel and turn west to serve Parkville before crossing under I-695 and surfacing as an at grade, dedicated right of way track past carney and terminating in White Marsh at White Marsh Mall. The line will close a major gap in transit for the north-eastern half of the region and serve the rapidly growing White Marsh/Nottingham region.

4.1.5. Purple Line

The Purple Line will be a 6-mile-long heavy rail transit line from the existing Camden Station at the Inner Harbor to the proposed Green Line Extension York Road station in the northern section of the city in Figure 11. This line will have 9 stations, with 4 existing stations and 5 newly constructed stations. The Purple Line will be fully underground, being in a newly constructed tunnel from Camden Station until Lexington Market, before running concurrent with the existing Green Line metro tunnel from Lexington Market to State Center station. The line will then follow an alignment within a new tunnel towards Penn Station, before continuing north in the new tunnel to meet the proposed extension of the Green Line at York Road Station. The line will provide connections to MARC service at Camden and Penn stations to the Camden and Penn lines respectively, as well as the existing light rail, existing green line metro, Amtrak, and the proposed orange line light rail. The station will also serve Johns Hopkins, Notre Dame and Loyola Universities (Maryland Transit Administration, n.d.).

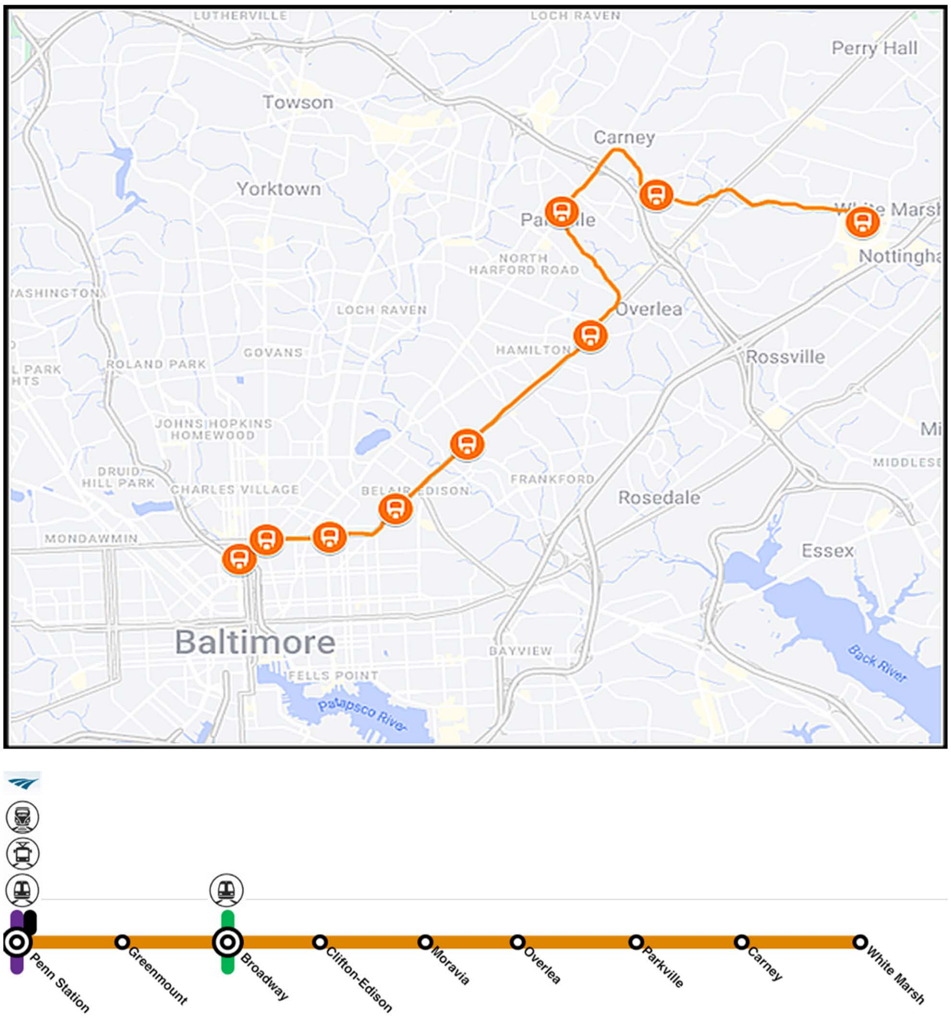

Figure 10. Baltimore metropolitan Orange rail line (MDOT, n.d.).

In all the proposed improvements would effectively double Baltimore's rail transit mileage and number of stations and give the city a much larger overall coverage by rail transit. The improvements will also emphasize creating connections between lines, to allow for exponentially more possible destinations from a given origin. Finally, the line makes use of concurrencies to allow for a wide variety of services on minimal infrastructure, reducing costs while increasing connections. With the high number of concurrencies, Baltimore would be able to move away from the line coloured based system operation, and instead opt for a system operation similar to New York with lettered and numbered services that operate on different patterns on the varying concurrencies of infrastructure. Operations could shift to heavy rail using numbered lines, and light rail using lettered lines. Each letter/number could also be matched with the color of the line that the service pattern most closely resembles in the overall proposed system map Figure 12.

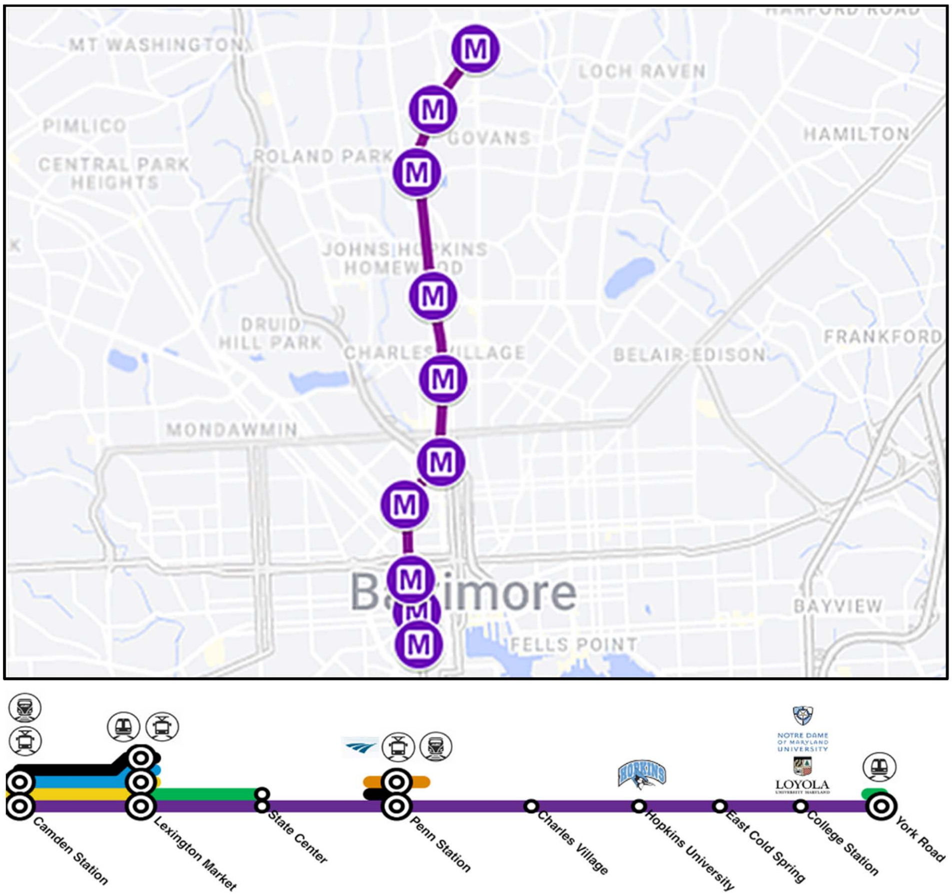

Figure 11. Baltimore metropolitan Purple rail line (MDOT, n.d.).

5. Conclusion

The data analysis reveals three distinct typologies of cities based on population density and transit accessibility. First, cities like Paris and Madrid, with high population densities concentrated in their urban cores, exhibit station densities close to one station per square mile. This means that most of the population is within walking distance of a station. In both cities, the population per station aligns with their overall density, which exceeds 10,000 inhabitants per square mile.

Next, we have cities with moderate population densities, such as Tokyo, London, and New York. These cities have more spread-out populations, leading to lower station densities per square mile and per 100,000 inhabitants. In these cases, not all residents are within walking distance of a station. To encourage greater use of public rail transport, cities in this category often need to implement measures like reducing parking availability in downtown areas, building park-and-ride facilities near stations, and integrating fares across different modes of urban transport.

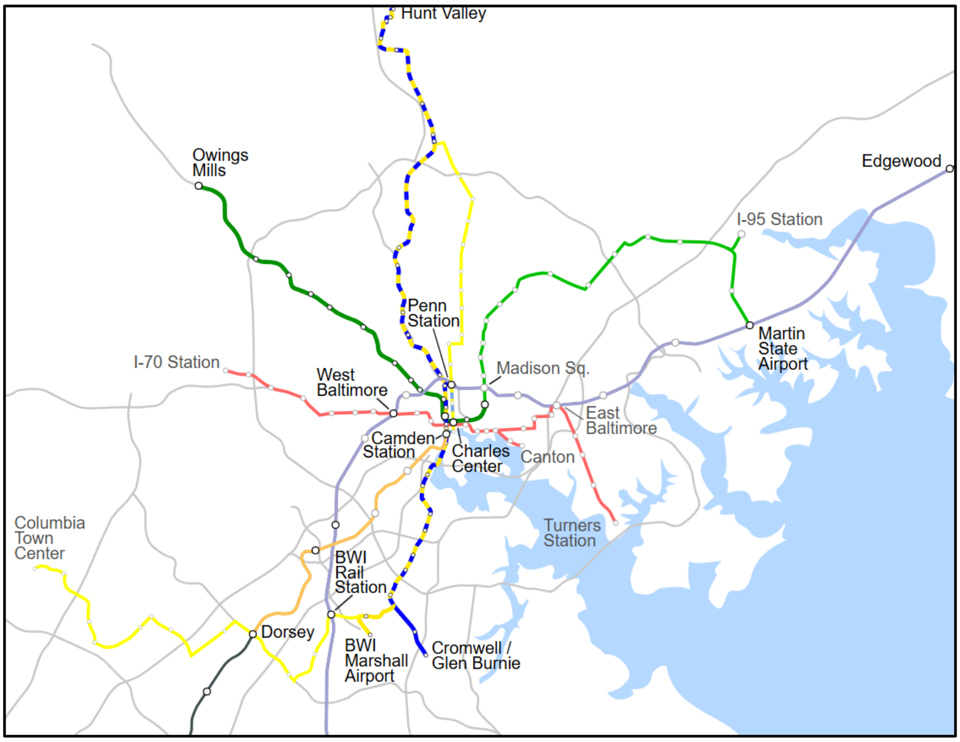

Figure 12. Baltimore metropolitan rail network (https://upload.wikimedia.org/).

Finally, Baltimore represents a third category of cities characterized by low population density, a common trait in North American cities. Here, the ratios of stations per square mile and per 100,000 inhabitants are significantly lower. Even with planned expansions in Baltimore's transit network, the city will achieve station densities typical of medium-density cities, but a relatively small percentage of the population will be within walking distance of a station. As a result, similar measures recommended for medium-density cities—such as park-and-ride facilities and integrated fare systems—will be necessary to boost public transit usage.

6. General Recommendations

To develop an effective urban transit system, several key principles must be followed. First, new rail lines should be aligned along high-density corridors. This ensures that the system serves areas with the greatest potential ridership, maximizing efficiency and utility. By focusing on densely populated regions, transit can offer frequent service, reduce wait times, and make rail travel a more attractive option for commuters.

The placement of stations is equally critical. Stations should be strategically located at key points where large numbers of people either start (trip origins) or end their journeys (trip destinations), such as residential areas, business districts, shopping centers, and entertainment hubs. Properly positioned stations make public transit a more convenient and viable alternative to driving, enhancing accessibility and usage.

In addition to infrastructure planning, policies that disincentivize private car usage in city centers are essential. These policies could include measures like congestion pricing, restricted parking, and pedestrian-only zones, which encourage more people to switch to public transit. By reducing the convenience of driving, such policies help alleviate traffic congestion and contribute to lowering urban pollution levels.

Another crucial aspect is increasing the overall efficiency of transit services. This can be achieved by implementing dedicated bus lanes, granting signal priority for transit vehicles, and introducing streamlined fare collection systems. By improving speed and reliability, these measures make public transport more competitive with private cars, thereby increasing its appeal to commuters.

Offering free parking at rail stations, especially in suburban areas, can further incentivize the use of public transportation. This measure can encourage commuters to drive to nearby rail stations and then take public transit into the city, making the journey more cost-effective and reducing the number of cars entering urban centers.

Lastly, integrating bus and rail services is essential for creating a cohesive transit network. Seamless transfers between buses and trains, supported by synchronized schedules, unified fare systems, and shared information platforms, minimize wait times and improve the overall user experience. When buses and trains complement each other, the transit system becomes more efficient and accessible.

In summary, the success of an urban transit system depends on strategic rail alignment along high-density corridors, careful station placement, policies that discourage private car use, enhanced transit efficiency, free parking for transit users, and the integration of bus and rail services. Together, these measures create a more accessible, efficient, and sustainable urban transportation network.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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