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The Accessibility of Public Transportation Stops: Istanbul Case

Toplu Taşıma Duraklarının Erişilebilirliği: İstanbul Örneği

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Abstract

The study emphasizes the importance of creating a sustainable public transportation system that people can use comfortably. This sustainable transportation approach aims to deliver transportation plans focused on people, society and space. Developing public transportation systems that contribute to social equality by appealing to all segments of society and reducing traffic density has become one of the main objectives of transportation plans. Ensuring the accessibility of public transportation stops is a crucial aspect of achieving this objective. In this context, the study examines the accessibility of public transportation stops in Istanbul. For the accessibility measurements of public transportation stops, the study uses the Service Areas Analysis tool in the ArcGIS program's Network Analyst extension, a geographical information system-based software program. The analysis results indicate that approximately 90% of the population can reach the stops of rubber-tyred public transportation types (one of the public transportation types in Istanbul) within a five-minute walking distance. However, the ratio of the population that can reach rail system stations and maritime transportation piers within a five-minute walking distance is only approximately 3%. Accordingly, it can be seen that the Istanbul transportation system depends heavily on the rubber-tyred public transportation system.

Keywords: *Transportation planning, Public transportation, Accessibility, GIS, Network analyst, Service area analysis*

Özet

Çalışma, insanların rahatlıkla erişebileceği, sürdürülebilir bir toplu taşıma sistemi oluşturmanın önemini vurgulamaktadır. İnsan, toplum ve mekân odaklı ulaşım planlarının üretilmesi ancak sürdürülebilir ulaşım yaklaşımının benimsenmesiyle mümkün olacaktır. Toplumun tüm kesimlerine hitap ederek, toplumsal eşitliğin sağlanmasına katkıda bulunan ve trafik yoğunluğunu önemli ölçüde azaltan toplu taşıma sistemlerini geliştirmek, kamu yararı adına ulaşım ana planlarının temel amaçlarından biri haline gelmiştir. İnsanların rahatça kullanabildiği sürdürülebilir bir toplu taşıma sistemi oluşturmanın da temel önceliği toplu taşıma duraklarına insanların erişilebilirliğini sağlamaktır. Bu bağlamda, çalışmanın amacı İstanbul'daki toplu taşıma duraklarının erişilebilirliğini incelemektedir. Toplu taşıma duraklarının erişilebilirliğini sayısal bulgular ile değerlendirmek için çalışma, coğrafi bilgi sistemi tabanlı bir yazılım olan ArcGIS programının Ağ Analizi uzantısında bulunan Servis Alanı Analizi aracını kullanmaktadır. Analiz sonuçları, İstanbul'daki lastik tekerlekli toplu taşıma sisteminin duraklarına nüfusun yaklaşık %90'ının beş dakikalık yürüme mesafesinde erişebildiğini göstermektedir. Ancak raylı sistem istasyonlarına ve deniz yolu ulaşım iskelelerine beş dakikalık yürüme mesafesinde erişebilen nüfusun oranı yaklaşık olarak sadece %3'tür. Bu değerler İstanbul ulaşım sisteminin, lastik tekerlekli toplu taşıma sistemine olan bağımlılığını ortaya koymaktadır.

Anahtar kelimeler: *Ulaşım planlaması, Toplu taşıma, Erişilebilirlik, CBS, Ağ analizi, Servis alanı analizi*

1. Introduction

Urban areas are currently facing transportation issues due to population growth and the increasing use of individual vehicles. The convenience and comfort of automobiles have determined the transportation systems in cities and caused an enormous increase in the number of motor vehicles on the road. As a result, urban centres are experiencing problems such as traffic congestion, air and noise pollution, and traffic accidents due to the high demand for transportation. An automobile-centric transportation approach is unsustainable as it negatively impacts the environment, the economy, and the social structure (Greene, 1997; Newman and Kenworthy, 2006). Therefore, developed countries are adopting sustainable policies, including reducing automobile use and greenhouse gas emissions, promoting more efficient and equitable forms of transportation, encouraging non-motorized transportation types, creating pedestrian zones, and improving public transportation systems (Newman and Kenworthy, 2015; Pojani and Stead, 2015).

In Türkiye, Istanbul has been dramatically affected by the negative consequences of an automobile-focused transportation approach. The city's population has grown from 3.3 million in 1970 to 15.9 million today (TÜİK, 2023), making it the world's most densely populated European city and the thirteenth most. The city has invested in expanding its urban road network to accommodate the growing population. However, this approach has ultimately increased the dependence on cars and created traffic congestion, leading to a complex and difficult transportation system. As a result, city officials face numerous challenges, including accidents, decreased public transportation usage, environmental problems, climate change, energy consumption, and visual/auditory pollution.

To solve transportation-based problems, studies have been carried out for sustainable transportation planning in Istanbul. Previous transportation master plans for the city have focused on policies to meet travel demand through various public transportation options such as Metrobus, minibus, bus, rail system, and maritime transportation. Unfortunately, some policies have not been implemented (Öztürk, 2021). As a result, the city's transportation system still fails to comply with sustainable principles due to the increase in motor vehicles and inadequate investments in public transportation (İBB, 2022). In this context, this study considers the main reason why Istanbul does not have a sustainable transportation system is that the city's public transportation system is insufficient and inaccessible. The city's public transportation systems are not meeting the desired level of accessibility and have resulted in long travel times for individuals and encouraging them to rely on automobiles.

The sustainable transportation approach prioritizes public transportation systems and emphasizes the importance of accessibility. Studies show that access to public transport stops and stations significantly changes travel demands and that passengers often choose accessible travel options (Cirit, 2014). The concept of accessibility has been included in Türkiye's planning legislation with the Spatial Plans Construction Regulation (Resmi Gazete, 2014). However, the explanations regarding accessibility in this legislation do not cover all the principles concerning accessibility. Additionally, there are limited scientific studies on accessibility practices in Türkiye. About this, the study examines the accessibility of public transportation stops in Istanbul. The study used geographic information systems (GIS) to analyze the service areas of stops, stations, and piers in Istanbul's rubber-tyred, rail, and maritime public transportation systems (in this study, the term "stop" may also refer to stations and piers at times). The service areas analysis tool in the network analysis module of ArcGIS software was used to analyze the data. The accessibility analysis reveals the percentage of the population that can reach stops within 5, 10, and 15 minutes on foot.

2. Material and Method

The study employs a mixed methodology that analyses both qualitative and quantitative data about the transportation system of Istanbul. The analysis focuses on the general structure of the transportation system. It includes an accessibility assessment of all public transportation (rubber-tyred, rail, and maritime) options available in the city.

2.1 Case Area: Istanbul

The study is focused on Istanbul (Figure 1), a global metropolis and Türkiye's most populous and densely populated city. Istanbul is the most populous city in Europe and the thirteenth most in the world. Based on data from the Turkish Statistical Institute (TUIK), Istanbul's population in 2022 was 15.9 million, with an average population density of approximately 2912 persons/km^2 (TÜİK, 2023). One of the reasons why the population of Istanbul is so high is its level of economic development.

According to 2020 data, Istanbul ranks first in Türkiye in terms of per capita income, and has approximately 4.9 million employees (İBB, 2022). There are 39 districts in the city with a surface area of 5461 km^2. Since Istanbul is a rapidly growing city, the sustainability and accessibility of the public transportation system are essential for people's quality of life.

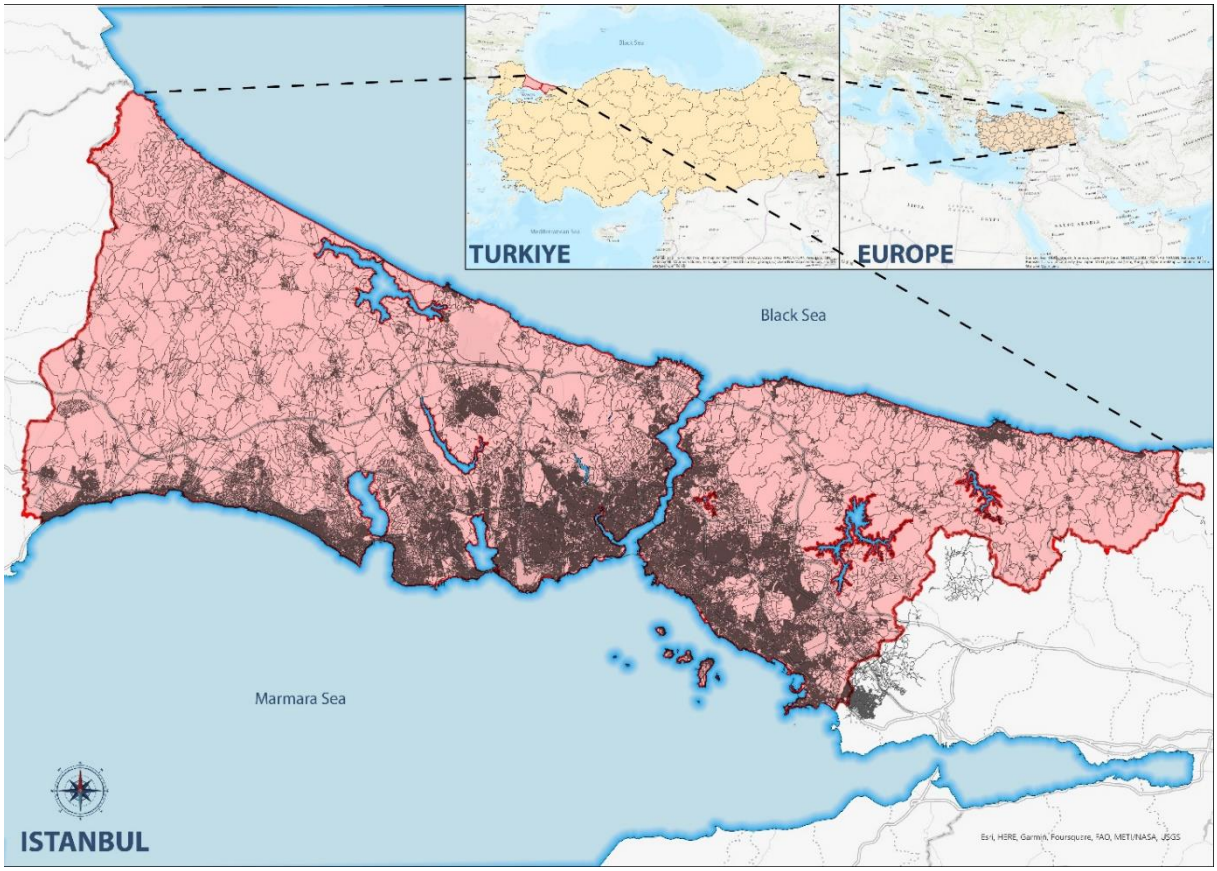

Figure 1. Location of Istanbul

One of the most significant issues that the city faces is the problems arising from the increase in automobile ownership. Traffic density in Istanbul ranks fourth in the world, following Bogota, Rio de Janeiro, and Mexico, with each driver losing 153 hours per year due to traffic congestion (İBB, 2022). With this in mind, it is imperative to devise policies and strategies that decrease car usage and establish a sustainable and accessible public transportation system.

Istanbul's public transport system (Figure 2) offers a variety of options, including buses, trains, metros, trams, and ferries. Public or private organizations manage these modes of transport and follow specific routes, schedules, and fares. The system is divided into three types: rubber-tyred, rail, and maritime (Figure 3). Each type provides different speeds and comfort features. The rubber-tyred public transport system is serviced by four vehicles: IETT bus, taxi-dolmus, taxi and minibus. The municipal IETT service has a fleet of 3457 vehicles and approximately 15000 stops (İETT, 2022). Rail public transportation includes metro, tram, suburban trains (Marmaray), funicular, and cable car lines. The metro line, 185.69 km long, and the Marmaray Line, 73.6 km long, are the backbone of Istanbul's rail system. Additionally, a 172.7 km long rail system project is currently being constructed in Istanbul (Metro İstanbul, 2022). Sehir Hatlari, a subsidiary company of Istanbul Metropolitan Municipality (IMM), is the most important institution in Istanbul's maritime transportation. Sehir Hatlari offers a range of transportation options, including ferries, sea buses, passenger ferries, car ferries, and sea taxis. In addition to Sehir Hatlari, private companies like Turyol and Dentur provide passenger transportation services using small and medium-sized motor vehicles in Istanbul (İBB, 2022).

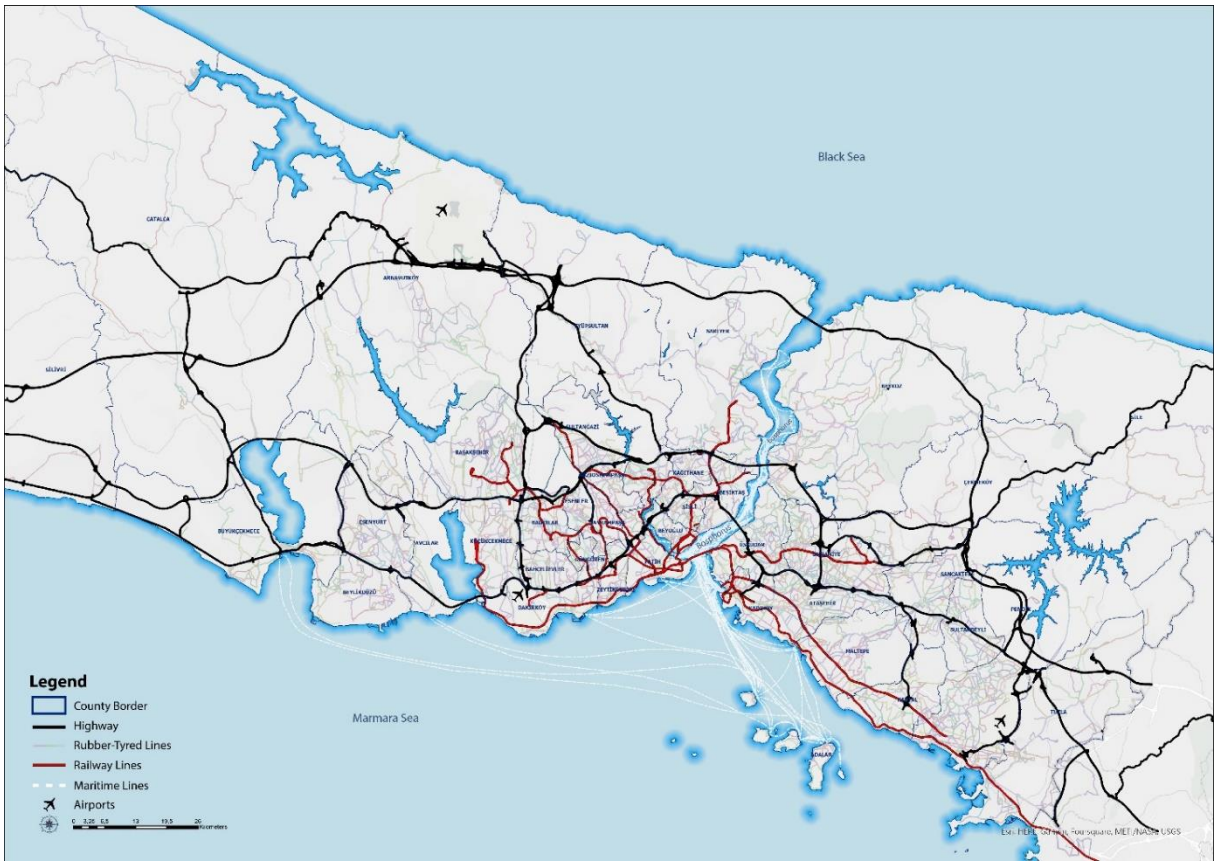

Figure 2. Istanbul public transport system

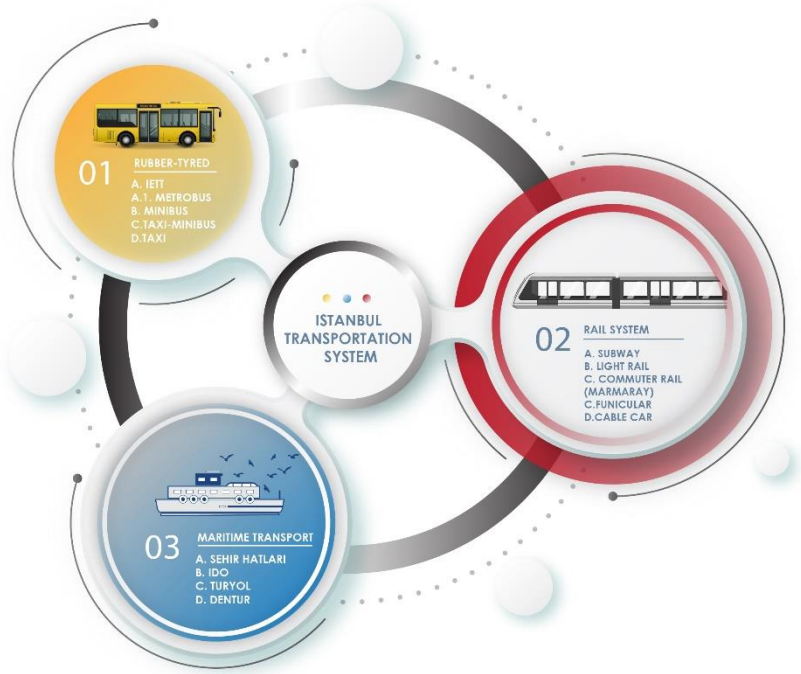

Figure 3. Istanbul public transport types

Among the public transportation types in Istanbul, the rubber-tyred public transportation system has the highest daily passenger usage at 69.28%. On the other hand, although there are approximately 500 kilometers of coastline, maritime transportation has the lowest average daily passenger number among public transportation types at 1.91. Table 1 shows the distribution and rates of daily journeys made by public transport types in December 2020 (İBB, 2020).

Table 1. Distribution of trips made in December 2020 by public transport types

Public Transport Types	Daily Passenger Number	Percentage (%)
Rubber-tyred	3.070.121	69,28
Rail	1.276.632	28,81
Maritime	84.639	1,91
TOTAL	**4.422.605**	**100,0**

Although investments have been made in the Istanbul public transportation system in recent years, it still lacks sustainability. Insufficient accessibility to transportation stops is one of the primary reasons for this. Hence, within the scope of the study, the accessibility of the Istanbul public transportation system stops was analyzed, and the population that could reach the stops in 5, 10 and 15 minutes of walking time was determined. Based on the findings, recommendations are made to enhance the accessibility and sustainability of Istanbul's public transportation system.

2.2 Material

The accessibility of Istanbul's public transportation stops was analyzed using the service areas tool in the ArcGIS software's network analyst module. For accessibility analysis, line and stop data of all public transportation types (rubber-tyred, rail, and maritime systems) in the city were utilized as the primary data set. In addition, a spatial data set from 2020 that includes all the buildings in Istanbul was used to determine the population with access to public transportation stops. The attribute table of the building data contains information about the number of people residing in each building. These data sets were acquired from the Istanbul Metropolitan Municipality Department of Transportation.

2.3 Method: Accessibility Analysis

Accessibility is a fundamental concept for transportation planning as it measures the ease and comfort of people to reach a desired destination. Accessibility often means physical access to services or an intended destination. Hansen (1959) first defined accessibility as a criterion for determining a person's level of interaction with others in a particular location. However, due to its relevance to various professions, accessibility can be defined and interpreted differently. Essentially, accessibility refers to the ease of accessing a destination where different activities can take place via a specific mode of transportation, serving a particular purpose (Dalvi, 1976; Hess, 2012; Güray and Kemeç, 2016). Another definition emphasizes that accessibility is the capacity to travel along a predetermined route from the starting point to the endpoint (Bhat et al. 2001; Simon, 2016). Furthermore, accessibility should be measured beyond the ease of transportation but should also consider factors such as the suitability of the vehicle used, journey distance, and safety and comfort levels (Ross, 2000). Therefore, accessibility is a crucial element of the planning process and a component that contributes to the overall welfare of communities.

Accessibility analysis allows for measuring the quality and efficiency of transport services in terms of their accessibility to essential facilities such as work, education, health and other vital uses (Miller, 2018). This analysis enables transportation planners to evaluate how well the transportation system caters to the needs of people, particularly those with limited mobility or transportation options (Straatemeier and Bertolini, 2020). By examining accessibility, planners can pinpoint areas of the transport infrastructure that require improvement to enhance mobility and connectivity and ensure equal access to transport services for all members of society. Accessibility analysis also plays a crucial role in identifying and addressing issues related to social equity, environmental sustainability, and economic development (Morris et al. 1979; Todd, 2008). In addition, it can assist in identifying areas that lack adequate public transport services and determine investments and policies for new routes or services to support sustainable transport opportunities (Afacan, 2015).

In 2014, the Turkish planning legislation incorporated the concept of accessibility in the Spatial Plans Construction Regulation. This regulation highlights the need for decisions to prioritize accessibility in urban planning, transportation planning, and urban design processes (Resmi Gazete, 2014).

The regulation aims to ensure that individuals can quickly and safely access essential urban services (such as residential and commercial areas) and social/technical infrastructure (such as health, education, and stations) and sets out the criteria to be complied with in the zoning plans regarding service impact areas and walking distances for urban uses. In addition, accessibility in the "Sustainable Urban Transport Plans", which have recently come to the fore in Türkiye, is the subject of detailed analysis. Expressing accessibility with numerical data has made the concept usable in transportation planning (Özuysal et al. 2003).

2.3.1 Accessibility to Public Transportation Systems

A public transport system is a network of transport services, usually run by a government or private companies, that provides transport services to the public and allows access to be offered fairly to all segments of society (Banister, 1995). These systems include modes of transport designed to carry large numbers of passengers. The main objective of this system is to offer an efficient, affordable, safe, and reliable transportation infrastructure in a sustainable and eco-friendly manner (Rodriguez, 2006; Mavoa et al. 2012; Bok and Kwon, 2016; Blackwell, 2017). Encouraging the use of public transport is crucial in promoting mobility while curbing traffic congestion, reducing environmental impact, and minimizing energy consumption.

Transportation policies have historically focused on automobile-based solutions for highways, bridges, and intersections. However, today's transportation plans place public transportation systems at the forefront. To encourage public transportation, transportation planners aim to offer advantages such as comfort, security and door-to-door service, which is why automobile-oriented transportation systems are preferred. Integrating different types of public transportation is crucial for sustainable transportation planning and increasing accessibility. If this integration is not provided, accessibility decreases, demand for public transit reduces, urban traffic increases, and more resources are expended. A systematic operation of all public transport types increases accessibility (Gülhan, 2014).

Decision-makers can give people a say in the city's social, physical and environmental development by including users in the planning process in their work on public transportation to create a sustainable urban system (Curtis, 2007; Salicru et al. 2010). In addition, observing and modelling transportation behavior increases the success of the policies produced in the plans for the accessibility of the public transportation system. Criteria such as time, cost, number of transfers, comfort and safety determine the transportation behavior of the passenger. Another critical factor affecting transportation behavior is public transportation stops that include the city's most important nodes (Ünver, 2013). Stops have more meaning than the definition of "where public transport systems stop and where passengers get on and off" because the locations of the public transport stop in the urban space shape the social life and land use structure around the stops. A short and comfortable walk from the starting point or the destination to a stop is one of the basic rules of multimodal transport planning. At the same time, this approach is an important element in design and planning studies at the neighborhood scale (Hess, 2012). Stops increase accessibility to public transport systems. Therefore, the station perimeter's scope and the road network's design affect accessibility. Many researchers have used station access or the geographical proximity of the passenger to the stops as a fundamental criterion in their studies on accessibility (Hsiao et al. 1997; Lovett et al. 2002; Mavoa et al. 2012; Zhao et al. 2003). Analyzing the accessibility of the public transportation system helps to identify and enhance areas with inadequate accessibility in urban transportation planning and forms the foundation for policy decisions.

To increase public transport usage, it is crucial that travel time is minimized and passengers can easily access the transport systems within a short walking distance (Uludağ, 2010). According to research, the standard distance for a public transport user to walk to a stop is 400 meters, taking roughly five minutes. However, the ideal access distance varies based on different factors. Stops that fall within the 0-400 meters range are considered high-access, 400-800 meters are moderate-access, and 800-1200 meters are poor-access stops (Tablo 2) (Hsiao et al. 1997; Kaszczyszyn and Sypion-Dutkowska, 2019; Kimpel et al. 2007; Murray and Wu, 2003; Neilson and Fowler, 1972; Southworth and Joseph, 203; TCRP, 1996; TOD, 2023; Untermann, 1984; Yiğitcanlar et al. 2010; Zhao et al. 2003). These criteria were used in the accessibility analysis for public transport stops in this study.

Table 2. Accessibility classification of public transport stop

Distance to Public Transport Stop [meters]	Time [minute]	Accessibility Level
0–400	0–5	**High**
400–800	5–10	**Moderate**
800–1200	10–15	**Poor**

2.3.2 Service Area Analysis

Geographic Information Systems (GIS) have an important place in practice and the literature due to their ability to link spatial data with information. However, due to its multidimensional nature and diverse applications, it is challenging to arrive at a universally accepted definition. In certain domains, GIS refers to converting geographical data into an information system that can be effectively utilized. In other fields, it involves transforming the information generated by the system into a spatial product (Aydın, 2021). GIS is a computer-based system that enables the production, storage, correlation, management, updating, querying, analysis, and visualization of spatial data for specific purposes (Kapluhan, 2014; Parker, 1988; Tecim, 2008; Yomralıoğlu, 2009; İncekara et al. 2009; Töreyen et al. 2010; Uluğtekin and Dogru, 2005; ESRI, 2022). It finds application and assists informed decision-making in several areas, including city planning, natural resource management, transportation planning, and disaster management. In the planning process, transportation planners use GIS-based network analysis to evaluate the accessibility of the existing public transportation infrastructure. Network analysis models and scrutinizes networks like power grids, water distribution systems, communication networks, and roads to enhance efficiency. Graph theory, a mathematical branch of study investigating the relationships and properties of objects represented by nodes and edges and their connections, is used in network analysis. This theory is applied to model nodes and links in a network system and to evaluate the connections between nodes or vertices (George, 2008). By doing this, a city's superstructure and infrastructure elements (such as water, energy, and road network) can be reduced to network structures consisting of nodes and edges (Lloyd, 2010). Network analysis is conducted based on accessibility factors such as location identification, closest distance, best distribution, and service areas. This approach involves identifying and measuring optimal routes that help to achieve specific goals, such as finding the shortest route, calculating travel time, determining service areas, and organizing vehicles efficiently (Büke and Ertugaç, 2016; Erkal and Değerliyurt, 2013; Tecim, 2008; Yomralıoğlu, 2009). Network analysis also encompasses assessing network properties such as connectivity, accessibility, and vulnerability. Thus, network analysis contributes to solving complex problems related to planning, making better decisions and increasing productivity.

There are six tools available in ArcGIS software for network analysis, each with a specific purpose. These tools are a new route, new closest facility, new location allocation, new vehicle routing problem, new O.D. cost matrix, and new service area. Figure 4 displays the Network Analyst extension and the corresponding network analysis tools provided by ArcGIS software. These tools are designed for various contexts, problems or objectives. For instance, the new route tool is utilized to identify the shortest path between two points on a network. In contrast, the new location-allocation tool helps determine the most suitable locations for facilities such as hospitals or fire stations. The most suitable tool to analyze the accessibility of public transport stops is the network service area tool.

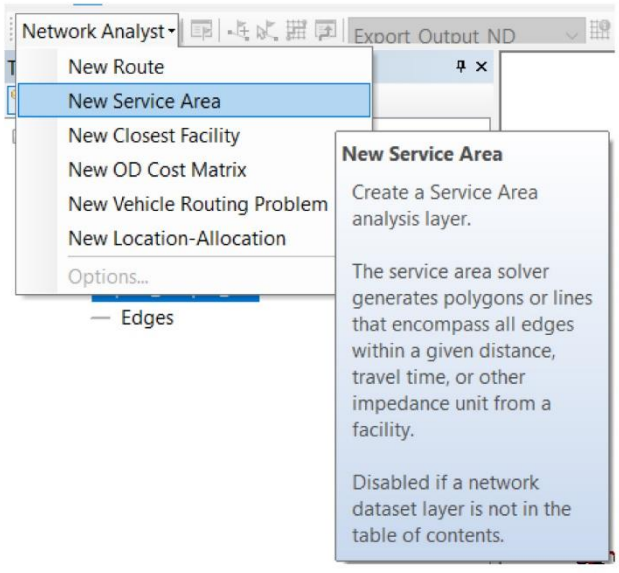

Figure 4. Network analyst extension and network analysis tools in ArcGIS software

The service area tool analyses the accessibility of public transportation stops by creating service areas around each one based on time or distance (ESRI, 2023). This analysis shows how far people can travel from each stop within a given period and highlights areas lacking public transportation.

For example, the tool can determine service areas that can be accessed on foot within a specific time frame (e.g. 5, 10, or 15 minutes) or distance (e.g. 400, 800, or 1200 meters) from a particular starting point such as a stop, station, or hospital. Moreover, network analysis can evaluate the accessibility of service areas. For example, identifying the service areas related to a specific service, such as a hospital, training area, or fire department, can determine how many people, employees, or students that service area can serve (ArcGIS Desktop, 2022).

New service area and buffer analysis tools are used to create accessibility analysis. In both of these analyses, determining the distance is essential. It is seen that the buffer analysis is generally used while performing the accessibility analysis regarding the service areas of the services in Türkiye (Ersoy, 2015). Buffer analysis measures accessibility as bird flight from the vector geographic objects such as a point, line, or polygon to a certain distance. However, since the buffer analysis does not consider the geographical structure or existing transportation infrastructure, the accessibility maps it produces are simple and intuitive but far from reality (ArcGIS Desktop, 2022). Ignoring topography and transportation infrastructure data when determining accessible areas is a significant disadvantage of buffer analysis.

On the other hand, using the new service area tool to create an accessibility analysis makes the result more realistic and objective by considering the existing topographical structure and transportation network as parameters (Yılmaz and Kamacı Karahan, 2020). For example, Balasubramani et al. (2016) used both methods to analyze the accessibility of fire stations in the city to other areas of use and compared the results (Figure 5). They clearly show the difference that arises when neglecting the topography and transportation infrastructure in determining accessible areas. This example highlights that when measuring the accessibility of people living in a specific area and examining the impact area of a particular service, the results obtained from the buffer analysis are less accurate than those obtained from the service area analysis (Kun et al. 2012; Balasubramani et al. 2016; Bari, 2013). Hence, it is evident that using service area analysis for accessibility analysis yields more precise results.

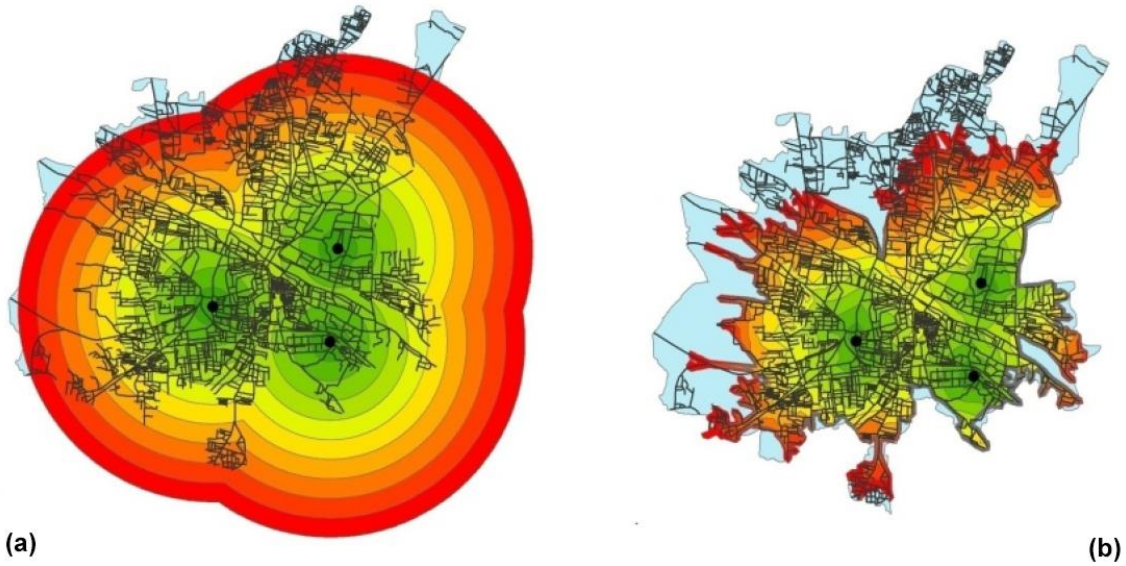

Figure 5. a) Buffer analysis, b) New service area (Balasubramani et al. 2016)

This study analyses the accessibility of public transportation stops in Istanbul using the service area tool. It determined accessible roads based on road network data and then determined the areas covering these roads, revealing the service areas of the stops. The study used walking distances of 5, 10, and 15 minutes (equivalent to 400 m, 800 m, and 1200 m) as parameters to assess accessibility. In the accessibility analysis, other factors such as pedestrian walking speed, walking distance, and the road network were also considered. In addition, since the population that can access the stops was determined within the scope of the study, the number of people living in each building in Istanbul is a parameter used within the scope of the study. Therefore, the buildings located in the accessible area to public transportation stops and the population living in these buildings were determined. Thus, the study indicated the population within 0-5, 5-10, and 10-15 minutes walking distance of the public transportation stops.

3. Results

The study revealed service areas where pedestrians could access the stops in Istanbul's rubber-tyred, rail and maritime public transportation systems. Afterwards, the population accessing all public transportation systems was calculated. In Istanbul, the rubber-tyred transportation system operates with four modes: IETT, Metrobus, taxi-dolmus and minibus. Approximately 15000 stop data from Istanbul Metropolitan Municipality regarding the rubber-tyred public transportation system are defined as point data in the GIS database. Using this data, service area analysis was made for each stop according to 5, 10 and 15-minute walking distances, thereby revealing the accessible areas of the rubber-tyred public transportation stops. Then, the population living in the buildings remaining in the accessible service area of the stops was collected, and the population that could access rubber-tyred public transportation stops in the city was calculated. Finally, the population that can access the stops of the rubber-tyred public transportation system is calculated as a proportion of the population of Istanbul in 2020. The percentage of the population that can access the stops in question is then presented.

When the accessible areas in Istanbul, which can be reached by walking in 5, 10 and 15 minutes to the stops of the rubber-tyred public transportation system, are examined, it can be seen that accessibility is exceptionally high in the city centre (Figure 6). However, the findings illustrate that the availability of rubber-tyred public transportation stops reduces somewhat as one moves towards the city's outskirts. As a result of this analysis, it is clear that the areas within 10-15 minutes walking distance to the stops, expressed in red, either have insufficient stops and road connections or remain in natural threshold areas such as forests, pastures, or agricultural areas. In addition, the findings show that the size of the areas that can be reached by walking distance of 0-5 minutes to the rubber-tyred public transport stops is more than the sum of the areas accessible by walking distance of 5-10 and 10-15 minutes (Figure 6).

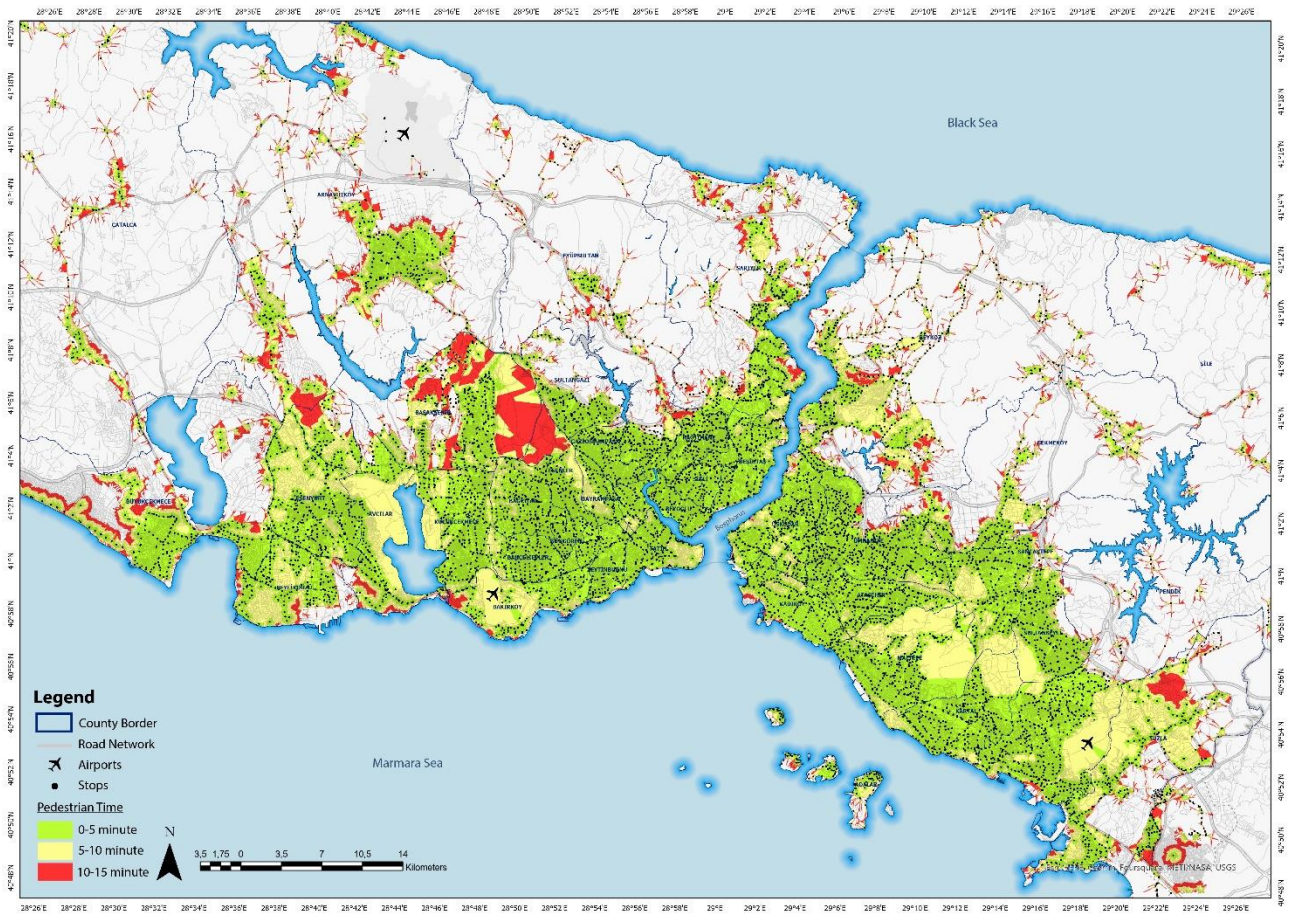

Figure 6. Accessibility analysis of rubber-tyred public transport stops

In Istanbul, 89.87% of the population can reach the rubber-tyred public transportation system stops within a 0-5 minute walking distance. A further 7.91% of the population can reach it within 5-10 minutes, and 1.40% can reach it within 10-15 minutes (Figure 7). In total, a remarkable 99.18% of Istanbul's population can access a rubber-tyred public transport stop within 0-15 minutes of walking.

Almost everyone in Istanbul can easily reach a public transport stop within 15 minutes by walking. Furthermore, it is worth noting that only 10.13% of the population cannot reach a rubber-tyred public transport stop within the ideal 5-minute walking time.

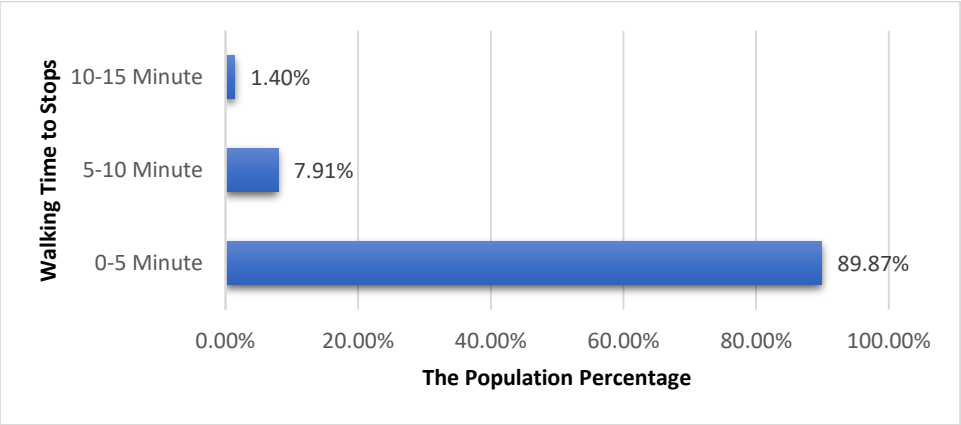

Figure 7. The population percentage accessing the rubber-tyred public transportation system stops

Rail network analysis in Istanbul determined the service areas within 0-5, 5-10, and 10-15 minutes walking distance from rail system stations (Figure 8). The findings show that residents on the European Side of Istanbul possess superior accessibility to rail systems compared to those on the Anatolian Side. Individuals benefit from direct or indirect access to multiple rail system options on the European side. Conversely, on the Anatolian side, only those living within a 15-minute walking distance from rail system stations can access the rail system within an acceptable time due to limited rail system lines. In addition, even densely populated areas on the Anatolian side encounter poor accessibility to rail systems primarily due to a lack of investment. Upon examining Figure 8, it becomes apparent that the accessibility to stations on the M4 Kadıköy-Tavşantepe Metro Line, which runs parallel to the E-5 highway, is poor. The primary contributing factors to this are the stations being situated on a multi-lane road, short walkways leading directly to the stations, and dangerous, uncomfortable, and unhealthy pedestrian intersections. Therefore, utilizing the stations on this line without transfer is a challenge.

Figure 9 shows the population ratios that can reach Istanbul's existing rail system stations by walking for 5, 10, and 15 minutes. The proportion that can reach the stations in 0-5 minutes is 2.88%, while 11.65% can reach it within 5-10 minutes and 18.05% in 10-15 minutes. The rail system offers numerous advantages, such as alleviating traffic, shorter journeys, and being more sustainable than other transportation systems. Therefore, more stations that are accessible within a 0-15 minute walking range in the urban area can increase the use of the rail system and reduce the burden on other types of transportation. Currently, the proportion of the population that can access stations within the 0-15 minutes range is only 32.58%, so approximately 67% of Istanbul's population cannot reach a rail system stop within the ideal accessibility period or must walk for more than 15 minutes. These findings highlight the importance of the integrated operation of different transportation modes, greater transfer opportunities between types, and investments made in terms of accessibility.

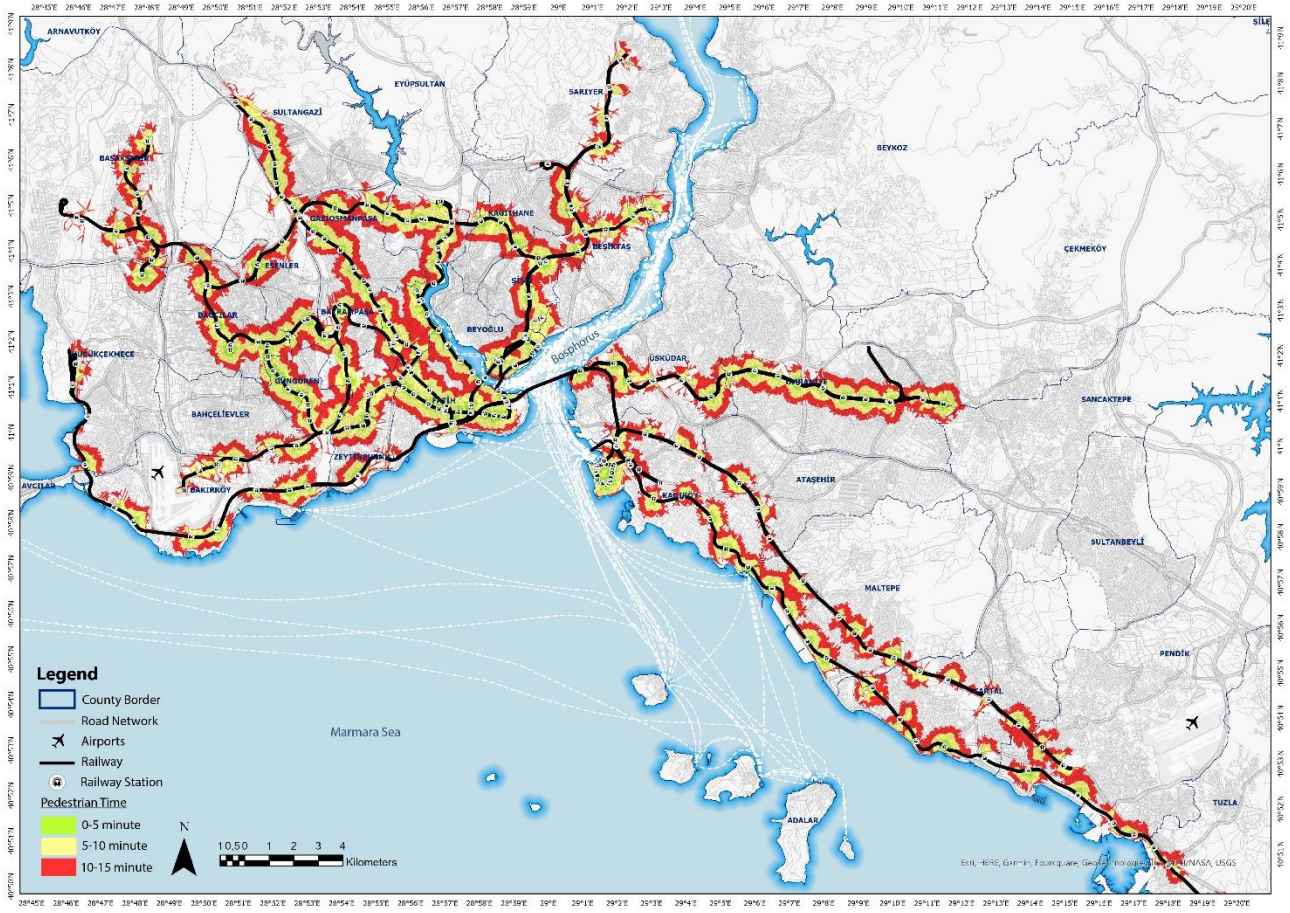

Figure 8. Accessibility analysis of rail system stations

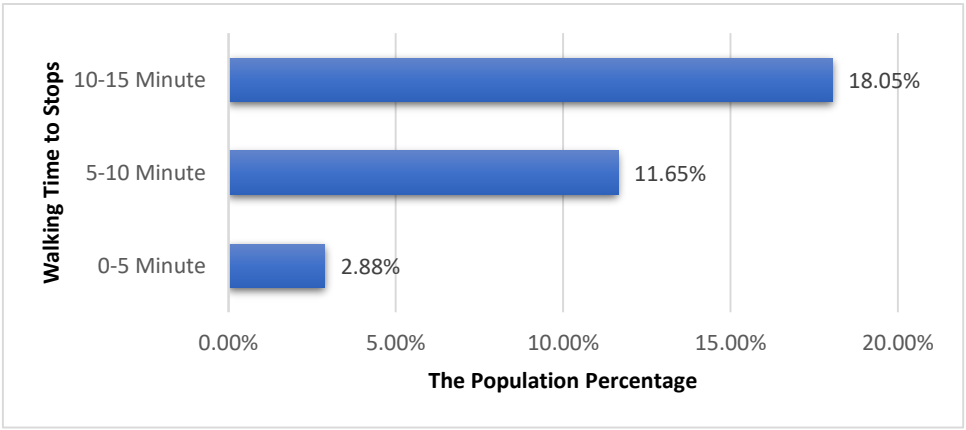

Figure 9. The population percentage accessing the rail transportation system stations

Maritime transportation is an exceptional mode of transportation in Istanbul. Figure 10 displays the accessible areas within a 5, 10, and 15-minute walking distance from Istanbul's maritime transportation system piers. When the figure is examined, it is apparent that the accessible areas of the ports are limited, especially within the Istanbul Bosphorus Conservation Area, due to the sloping topography. Additionally, poor pedestrian access connections to the Yenikapı and Harem Ferry Piers and restrictive vehicle roads between the pier and residential areas contribute to limited access. To improve the potential of Istanbul's maritime transportation system, further investment is required to ensure accessibility to ports is increased, transfer points are elevated, and newly planned piers are located in areas with high accessibility.

In Istanbul, the maritime public transportation system has the lowest number of daily passengers compared to other forms of public transportation (IBB, 2020). The maritime transportation system comprises around 115 piers, defined as point data in the ArcGIS environment for accessibility analysis. Figure 11 illustrates the proportion of the population that can reach these piers by walking within intervals of 0-5, 5-10, and 10-15 minutes. The data shows that only 0.17% of the population can reach piers within a 0-5 minute walking distance, 1.00% within a 5-10 minute walking distance, and 2.02% within a 10-15 minute walking distance. This indicates that the number of people who can reach the piers within a reasonable walking distance is relatively low in Istanbul. This can be attributed to some piers being situated in areas with low population density and commercial activities. Additionally, some piers fall within the Istanbul Bosporus Conservation Area, where the population density is relatively low, and there are some topographical challenges.

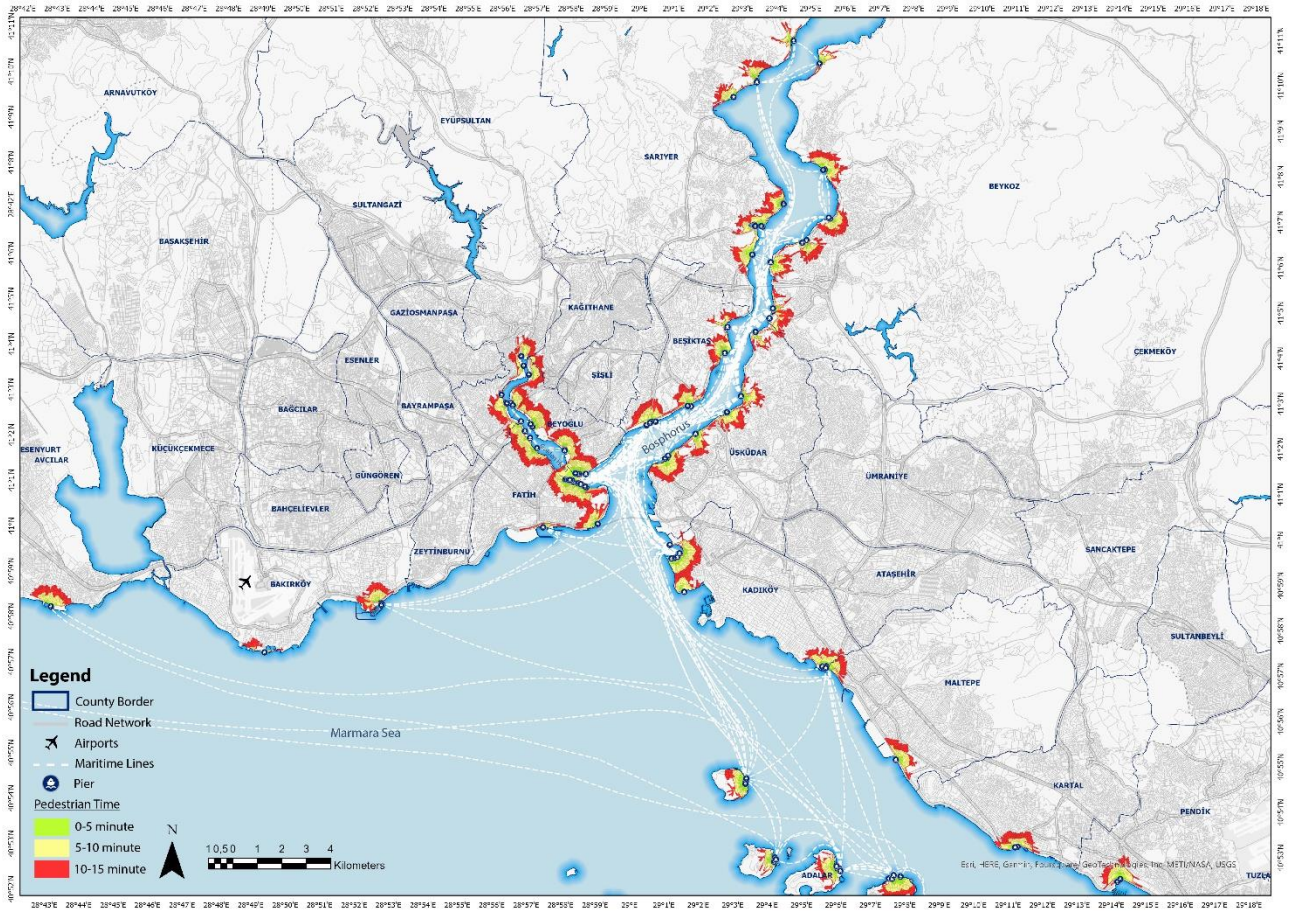

Figure 10. Accessibility analysis of maritime public transportation system piers

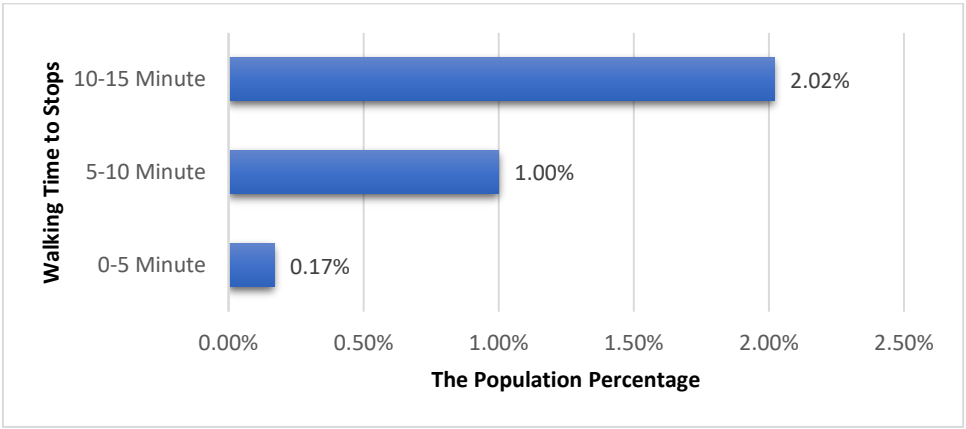

Figure 11. The population percentage accessing the maritime public transportation system piers

As part of the study, service area analysis for all public transportation stops in Istanbul was made (Figure 12), and some inferences can be made. In this respect, the main reason for restricting accessibility at stops with poor accessibility is that natural thresholds, such as forests and pastures or artificial thresholds, such as vehicle roads, generally limit access to the areas. Another reason is that some areas have insufficient transportation infrastructure due to low population density.

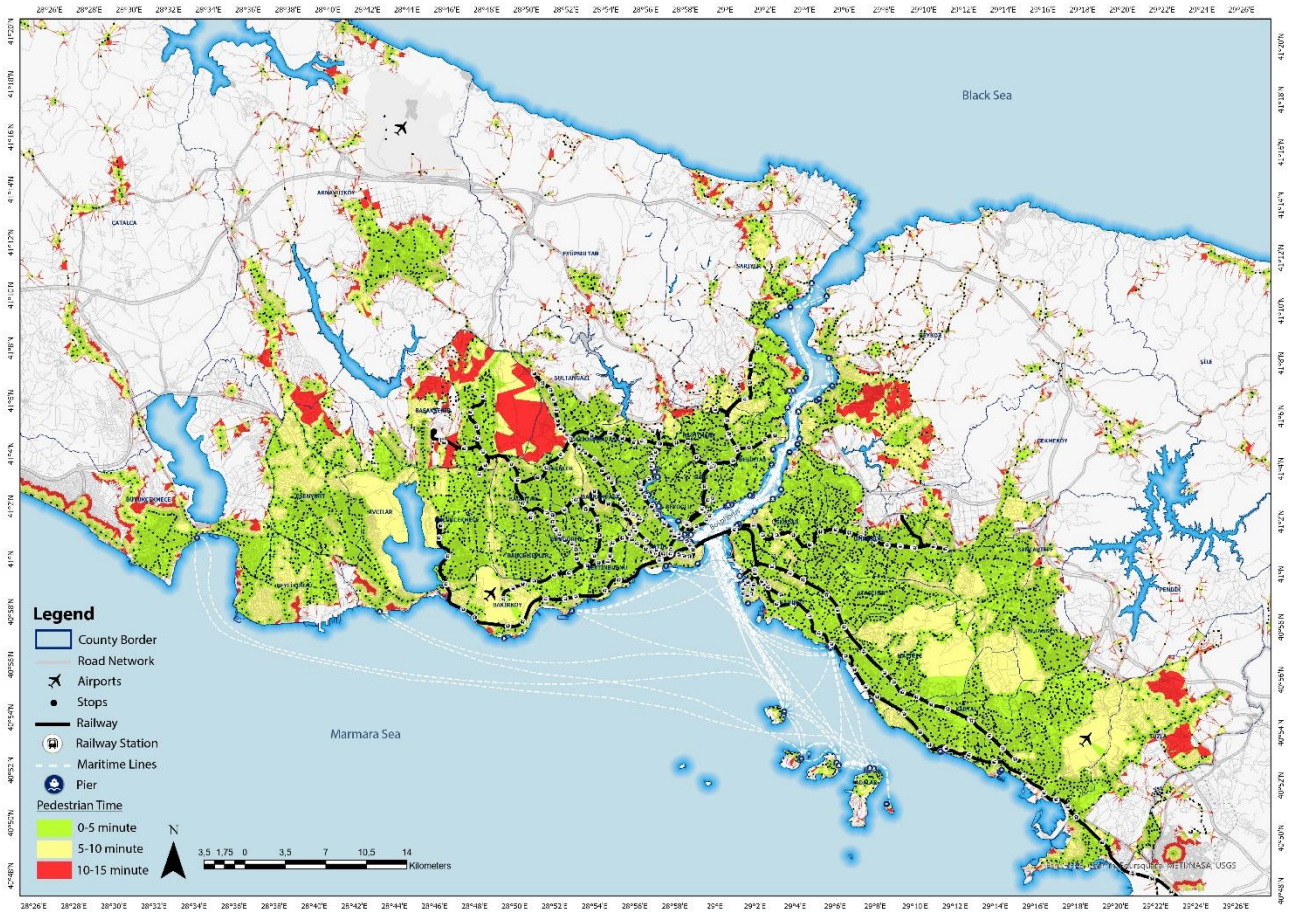

Figure 12. Accessibility analysis of all public transportation system stops/stations/piers in Istanbul

Figure 13 shows that 89.92% of Istanbul's population can reach all public transportation stops within a 0-5 minute walking distance. Additionally, 99.37% of the population can access public transportation within 15 minutes of walking. These rates show that most of the population of Istanbul can easily access public transportation systems in as little as 5 minutes, while almost all of them can access the public transportation systems within an acceptable walking time of 15 minutes. However, the rubber-tyred public transportation system accounts for most of this, with 89.87% of the population reaching a public transportation stop by walking for 0-5 minutes. In contrast, only a mere 3.05% of the population can access rail and maritime transportation stops within a 0-5 minute walking distance. This situation shows that a tiny proportion of Istanbul's population can benefit from the fast, safe, clean, environmentally friendly rail and maritime transportation systems.

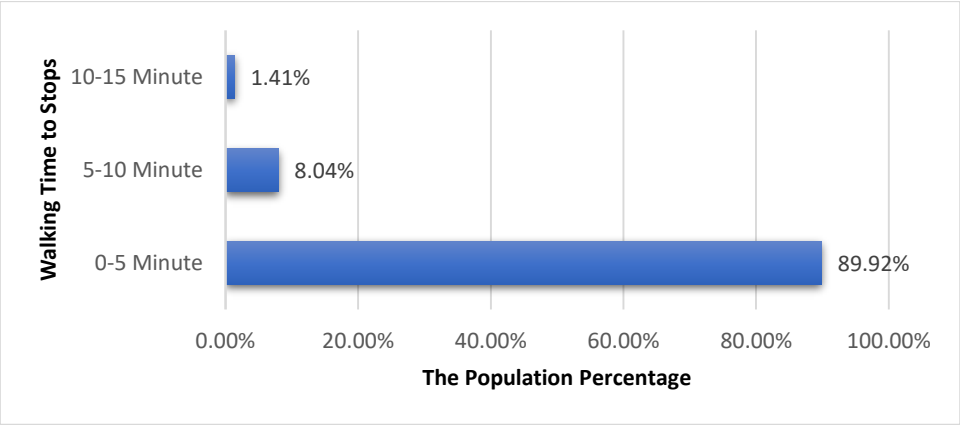

Figure 13. The population percentage accessing the public transport system stations in Istanbul

5. Discussion

The accessibility of public transportation plays a vital role in people's transport preferences. Upon examining the accessibility of Istanbul's public transportation system stops, the most crucial aspect to highlight is the dominance of the rubber-tyred public transportation system stops (Table 3). The rubber-tyred public transport system meets 89.87% of the 89.92% population, which can reach all public transport stops in 0-5 minutes. However, the rail and maritime public transportation system stops are only accessible to 3.05% of the population within 0-5 minutes and 12.65% within 5-10 minutes. These figures suggest that Istanbul's people have inadequate access to a sustainable and eco-friendly public transportation system.

Table 3. Population-based comparison of accessibility of public transport types

Public Transport Types	Walking Time Range	Population	Population Percentage Rate
Rubber-tyred Public Transport Stops	0-5 Minute	13.895.449	89,87%
	5-10 Minute	1.223.690	7,91%
	10-15 Minute	217.208	1,4%
	0-15 Minute	**15.336.347**	**99,18%**
Rail System Stations	0-5 Minute	445.713	2,88%
	5-10 Minute	1.801.837	11,65%
	10-15 Minute	2.790.486	18,05%
	0-15 Minute	**5.038.036**	**32,58%**
Maritime Public Transportation System Piers	0-5 Minute	26.075	0,17%
	5-10 Minute	154.526	1.00%
	10-15 Minute	311.844	2,02%
	0-15 Minute	**492.445**	**3,18%**
All Public Transportation System Stops/Stations/Piers	0-5 Minute	13.904.430	89,92%
	5-10 Minute	1.242.671	8,04%
	10-15 Minute	217.492	1,41%
	0-15 Minute	**15.364.593**	**99,37%**
Total population (2020)			**15.462.452**

Rubber-tyred public transportation systems offer flexibility, practicality, and low cost. However, rail and maritime transportation systems are more sustainable and eco-friendly because they produce fewer emissions, have shorter travel times, and carry more passengers than rubber-tyred systems (Alessandro et al. 2020). Rail and maritime transportation also provide a faster, safer, more comfortable, and cost-effective way to move around busy cities like Istanbul, where population density and traffic congestion are major issues (Beškovnik and Golnar, 2020; Pietrzak and Pietrzak, 2020; Tardivo et al. 2021). To address these challenges and create a more sustainable public transportation system, it is essential to prioritize the development of policies and investments in rail and maritime transportation systems.

Passengers are influenced by various factors such as time, cost, number of transfers, comfort, and safety when choosing transportation options. This reveals the importance of the integrated operation of different types of transportation and readily available transfer possibilities between the types. When the Istanbul public transportation system is evaluated, it can be seen that it is challenging for people to use rail stations with poor accessibility without a direct link. Furthermore, the limited accessibility of the piers and inadequate means of transferring to them are the main reasons for the inability of the vast majority of people to use maritime transportation. Therefore, to encourage pedestrians to use public transport, it is necessary to increase the number of transfer stops and integrate the various modes of transportation. In addition, promoting bicycle use requires establishing secure and safe bicycle parking facilities at public transport stops.

The study found that only a small percentage (2.88%) of the population can access the fast, comfortable, and reliable rail public transportation system within a 0-5 minute walking distance. This highlights that disadvantaged groups may not be able to benefit from this service. According to the WMO (2023), around 1.3 billion people worldwide, including one out of every 16 people in Türkiye (ASHB, 2023), have at least one disability. This, along with other disadvantaged groups such as low-income individuals and older people, emphasizes the importance of an accessible public transportation system in society. In this context, policies for public transportation systems should not overlook the needs and priorities of these groups. The safe access and use of public transportation systems, especially by disadvantaged groups who do not have the opportunity to travel outside of public transportation, enables them to participate in various activities and lead more active lives. For this reason, disadvantaged groups should have access to public transportation systems within a 5-minute walking distance. It is thus important to spread rail public transportation systems throughout the city and improve integration between different types of public transportation to provide these groups access to basic public services and greater independence. Public transportation systems should also be designed with universal design principles to ensure equal opportunities for disabled and elderly individuals. Providing equal and fair transportation opportunities to all members of society is essential for a sustainable and livable city.

6. Conclusions

Public transportation systems appeal to all segments of society and contribute to social equality. Increasing policies to develop public transportation systems will reduce the use of private cars, thus helping to reduce traffic density and carbon emissions in cities. In this context, public transport stops should be accessible for sustainable and integrated public transport systems. To achieve this, stops must be easily accessible and integrated with other forms of transportation. Accessibility is a crucial factor that affects transportation and land use decisions, and planners must evaluate the transportation network's efficiency and identify improvement areas. Ensuring equal access to transportation services for all members of society is crucial for improving their quality of life and making necessary services more accessible. Therefore, accessibility should be a top priority in urban and transportation planning. However, upon examination of the literature, it becomes evident that there has been insufficient focus on accessibility, particularly in Türkiye. A significant finding from existing studies highlights the crucial role of accessibility in the planning field, and there is a need to further disseminate academic research for its implementation.

As stated in the Method section, utilizing the Service Area Analysis instead of Buffer Analysis for determining accessibility offers a more objective approach. In this framework, accessible areas for each station have been created based on the 0-5, 5-10 and 10-15 minute walking distances to the stops, stations and piers of the rubber-tyred, rail and maritime public transportation systems in Istanbul's public transportation system. The population living in accessible areas was determined using the selection tool of ArcGIS software. Thus, the present structure of Istanbul's public transportation systems was analyzed from an accessibility standpoint, revealing the population capable of utilizing each transportation type.

One of the study's key findings highlights the importance of improving the accessibility of rail and maritime systems in Istanbul's public transportation network. To achieve this, it is essential to develop policies that promote the expansion of these transportation systems and increase investment in them.

By doing so, more individuals can access affordable, safe, and efficient public transportation and reach their desired destinations with greater ease and comfort. The study emphasizes the need for new metro lines in both the north-south and north/east-south/west directions, particularly on the Anatolian Side, as depicted in the visuals presented.

The results indicate that the public transport system in Istanbul relies heavily on rubber-tyred transportation, posing an accessibility challenge. To improve accessibility, enhancing transfer capabilities at all public transport stops is crucial. This can be achieved by facilitating transfers between different modes of transport and increasing the number of transfer points. Additionally, improving accessibility between stops, stations, and piers will encourage greater use of public transport. However, it is essential to avoid recommending transfer points in areas with large surface areas or natural/artificial thresholds, as these can be difficult to access for pedestrians.

The accessibility of the stops, stations and piers in the Istanbul public transportation system was analyzed by associating them with the population data. Nevertheless, different studies reveal that socio-economic criteria such as comfort, cost and public transport frequency should also be considered in the analysis of accessibility (Todd, 2008). Therefore, future studies should be conducted on accessibility analysis, including these criteria. Furthermore, future studies could focus on integrating public transport with other modes of transportation like walking, cycling, micro-mobility vehicles, and automobiles to improve the Istanbul transportation system. Additionally, the affordability of public transport services for low-income groups living on the city's outskirts and enhancing access for elderly and disabled individuals should be addressed. To support such studies, a GIS infrastructure is needed to create and update attribute information for all road networks in Türkiye, including slope, capacity, and number of lanes.

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