# Bus Stop Optimization Based on AFCS (Automatic Fare Collection System) and Demographic Data with GIS

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**I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.**

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# ABSTRACT

## BUS STOP OPTIMIZATION BASED ON AFCS (AUTOMATIC FARE COLLECTION SYSTEM) AND DEMOGRAPHIC DATA WITH GIS



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In recent years, with the increase in the urban population, a significant increase has been observed in the studies on transportation demands in cities. Especially in metropolitan cities, studies on public transportation are of great importance in order to minimize the negative factors such as traffic density, traffic accidents, air pollution, noise pollution and psychological trauma caused by the use of private vehicles.

The use of public transportation can help reduce traffic in cities and saves time and cost and is very effective in reducing environmental pollution. Consequently, there is a need to encourage people to use public transport as opposed to private cars. To be able to do that, the public transport service quality must be high, and the system should be accessible.

This study focuses on this issue of access to public transport. Stops and stations are the access points of public transport systems, and their location is extremely important to ensure that the system penetrates the city and the population. Location of stops and stations can be important factors in a public transport system's ability to become a preferred alternative to travel. Therefore, in improving public transport systems with a view to attract more passengers, an assessment of stop locations can be an important task. Locations of stops and stations cannot be changed for urban rail systems due to the fixed and high-cost investment, but such a change is possible for bus systems.

In this study, regular buses used in public transportation are examined. Decisions regarding the location of buses can be supported with a number of methods that can be described as bus stop optimization methods. This study aims at highlighting the strengths of a method that incorporates the use of geographic information systems into this decision making. For this purpose, a bus line in Istanbul metropolitan area has been studied. The preferred locations of the stops in this bus line (from the perspective of the population in the areas served by the bus) have been examined in two different ways according to the access areas within walking distance and by using bus passenger number data. The results reveal the potentials and advantages of this technique in planning bus lines and their bus stops, which can contribute significantly to the improvement of public transport systems and services.

Keywords: GIS, Bus Stop, Public Transport, Optimization, Planning, Data

# ÖZ


**CBS ile Otomatik Ücret Toplama Sistemi ve Demografik Verilere Dayanan Otobüs Durak Optimizasyonu**



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Son yıllarda, kent nüfusunun artması ile birlikte şehirlerdeki ulaşım ihtiyacına yönelik çalışmalarda ciddi bir artış gözlemlenmektedir. Özellikle metropol şehirlerde, özel araç kullanımı sonucunda ortaya çıkan trafik yoğunluğu, trafik kazaları, hava kirliliği, gürültü kirliliği, psikolojik travma gibi kötü etmenlerin en aza indirilmesi için toplu ulaşım konusundaki çalışmalar büyük önem arz etmektedir.

Toplu taşıma kullanımı kentlerdeki trafiği minimize ederek zaman ve maliyet tasarrufu sağladığı gibi, çevre kirliliğinin azalmasında oldukça etkilidir. Sonuç olarak, insanları özel araçların aksine toplu taşıma araçlarını kullanmaya teşvik etme ihtiyacı vardır. Bunu yapabilmek için toplu taşıma hizmet kalitesi yüksek ve sistem erişilebilir olmalıdır.

Bu çalışma, toplu taşıma araçlarına erişim konusuna odaklanmaktadır. Duraklar ve istasyonlar toplu taşıma sistemlerinin erişim noktaları olduğundan sistemin şehre ve şehir halkına nüfuz etmesini sağlamak için konumları çok önemlidir. Durakların ve istasyonların yeri, toplu taşıma sisteminin seyahat etmede tercih edilen bir alternatif olma becerisinde önemli faktörler olabilir. Bu nedenle, daha fazla yolcu çekmek amacıyla toplu taşıma sistemlerinin iyileştirilmesinde, durak yerlerinin değerlendirilmesi önemli bir görev olabilir. Sabit ve yüksek maliyetli yatırım nedeniyle şehir içi raylı sistemlerde durakların ve istasyonların yerleri değiştirilemez, ancak otobüs sistemleri için böyle bir değişiklik mümkündür.

Bu çalışmada, toplu taşıma araçlarında kullanılan şehiriçi otobüsler incelenmiştir. Otobüslerin yeri ile ilgili kararlar, otobüs durağı optimizasyon yöntemleri olarak tanımlanabilecek birkaç yöntemle desteklenebilir. Bu çalışma, coğrafi bilgi sistemlerinin kullanımını bu karar verme sürecine dahil eden bir yöntemin güçlü yönlerini vurgulamayı amaçlamaktadır. Bu amaçla İstanbul Büyükşehir bölgesinde bir otobüs hattı incelenmiştir. Bu otobüs hattında durakların tercih edilen yerleri (otobüsün hizmet verdiği bölgelerdeki nüfus açısından) yürüme mesafesindeki erişim alanlarına göre ve otobüs yolcu sayısı verileri kullanılarak iki farklı şekilde incelenmiştir. Sonuçlar, bu tekniğin, toplu taşıma sistemlerinin ve hizmetlerinin iyileştirilmesine önemli ölçüde katkıda bulunabilecek otobüs hatları ve otobüs duraklarının planlanmasındaki potansiyel ve avantajlarını ortaya koymaktadır.

Anahtar Kelimeler: CBS, Otobüs Durağı, Toplu Ulaşım, Optimizasyon, Planlama, Veri

Dedicated to my dear family..

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# CHAPTER 1

# INTRODUCTION

The population has been increasing in urban areas since people have migrated from rural to urban for many reasons. In metropolitan cities, this brings problems such as rapid construction, inadequate transportation, pollution and so on. Especially in transportation, private car usage has been increasing due to poor public transportation services which cause congestion, air and noise pollution, a high amount of oil costs, accidents and waste of time. Problems such as congestion, air pollution caused by private car usage lead regulations on the public transit system.

The use of public transportation can help reduce traffic in cities and saves time and cost and is very effective in reducing environmental pollution. Consequently, there is a need to encourage people to use public transport as opposed to private cars. To be able to do that, the public transport service quality must be high and the system should be accessible. Bullard (2003) said that people should have easy access to transit stops, hence best serve the population.  There are several factors to improve quality and make public transport more preferable by passengers. These are;

- Accessibility – having bus stops and routes closer to the passengers;
- Capacity – be sure about demand is welcomed;
- Journey time – duration of the passenger between get and get off;
- Economy – meeting financial things;
- Convenience – being friendliness;
- Comprehensibility –Integration with other modes like rail, metro or tram;
- Integration with public regulations – followed easily from public sites;
- Environmental Factors – visuality, less noise, less air pollution etc;
- Safety –in both routing and stop points;

- Sustainability – related with preferred technology (B.R., 2011).

Taking into consideration these steps, there are many studies done so far to make public transport more preferable. In each of these studies, measurements were performed using different methods and parameters and the results were examined. This study focuses on this issue of access to public transport. Stops and stations are the access points of public transport systems, and their location is extremely important to ensure that the system penetrates the city and the population. The location of stops and stations can be important factors in a public transport system's ability to become a preferred alternative to travel. Therefore, in improving public transport systems with a view to make the bus stops more accessible, an assessment of stop locations can be an important task.

In this study, regular buses used in public transportation are examined. Decisions regarding the location of buses can be supported with a number of methods that can be described as bus stop optimization methods. This study aims at highlighting the strengths of a method that incorporates the use of geographic information systems into this decision making. For this purpose, a bus line in the Istanbul metropolitan area has been studied. The preferred locations of the stops in this bus line (from the perspective of the population in the areas served by the bus) have been examined in two different ways according to the access areas within walking distance and by using bus passenger number data. In the first stage, accessibility to stopping points is discussed from two different aspects. Firstly, the service and buffer areas of the bus stops of line 29c for 200, 400 and 600 meters were calculated using Esri's ArcGIS Application and Network Analyst Extension, then the service and buffer areas were compared. When the service areas and buffer areas are compared, it is emphasized that the service area is a more accurate measurement than the buffer area, considering that the service areas use the actual road data, whereas the buffer area is only determined by the bird flight distance. Then the overlapping ratio of these service areas was compared for 200, 400 and 600 meters. In this study, the criteria in section 2.6 were taken into consideration and the walking distance analysis for the stops was combined with the current structure of the study area and the appropriate walking distance was selected as 400 meters. Demographic data is calculated within the 400-meter service area of the existing bus stops. New stops were established at 400 meters intervals and 400 meters of service areas of the bus stops were created. Demographic data within these new service areas were calculated and compared. The results were interpreted accordingly.

In the second analysis, the service areas of 400 meters around the stops were created and the commercial POI (Point of Interest) data within this area were compared with the ridership data using GIS tools. Accordingly, it was interpreted whether the commercial data had a relationship with the ridership data.

The results reveal the potentials and advantages of this technique in planning bus lines and their bus stops, which can contribute significantly to the improvement of public transport systems and services.

In the next chapter the literature, i.e. previous and current studies on public transport systems, types of public transportation, network configuration, network types, transit travel characteristics, bus systems, criteria for bus stop locations, methods and techniques in planning bus stop locations are presented.

In chapter three, the aim of the study, research methods, data, program, and applications used in the analysis are shown.

In chapter four, the application of GIS in the optimization of bus stops in İstanbul is presented with two methods. Firstly, background information on Istanbul and the bus system are defined. Then, the analysis and development of a GIS-based approach in planning bus stops are presented in two methods; Existing Land Use and Population and the ridership data.

In chapter five, a summary of the research, main findings, and future research are mentioned in detail.

## CHAPTER 2

## PUBLIC TRANSPORT SYSTEMS

### 2.1. Evolution of Urban Public Transportation

Before the 19th century, boats and ferries were the first public transport modes used in cities, since the early settlements have been located along rivers or seacoasts to make use of sea transport and trade. With the emergence of the posting system, stagecoach appeared for carrying posts and passengers for the first time. However, the first form of public transport began in London in 1829 with the introduction of omnibuses. The Omnibus was a high-four-wheeled vehicle towed by 3 horses, with an entrance from the rear, with passengers sitting face to face, carrying 18-20 passengers (Vuchic, 2007).


*Figure 2.1.* Omnibus (URL1)

Omnibus emerged as a vehicle to meet the demands of travel in industrially developing cities, where travel distances had started to increase beyond walking distance. As the first form of public transport, omnibus made it easier to move within the city, but also it made it possible for the city to expand further. After the second half of the 19th century, omnibus became a transport vehicle capable of transporting 28 passengers at a speed of 12 km per hour, enabling people in the middle-income group to move to urban areas outside of walking distance and live in better standards of housing (Vuchic, 2007).

Although the omnibus was great progress in urban transport, which can be referred to as the first revolution of public transport, it had its shortcomings. Uncomfortable driving in the existing stone-paved road conditions, low speed, and limited passenger capacity resulted in omnibuses being replaced by horse-drawn trams.


*Figure 2.2.* Horse Drawn Tram (URL2)

When horse-drawn trams emerged as a type of public transport in 1832, the use of steam locomotives was forbidden in the city, and the trains' passenger wagons were towed by horses. In 1873, cable trams were replaced by horse-drawn trams, which had a high operating cost due to the maintenance of animals.

The second revolution in public transport was electric trams that are mentioned above. In the early years of the 20th century, tram cities increased in number, since this mode provided a comfortable and relatively high-speed ride penetrating historical inner cities as well as enabling the growth of new development areas. In cities that were growing with manufacturing industries. Hence, new job opportunities, migrants from rural areas and other countries increased the population, resulting in a need for new development areas, which took place along tram lines.

While the development of vehicle designs and operating methods previously made in the transportation of the 20th century continued, many important inventions began to be used in transportation. Underground and elevated urban rail systems became the basis of metro lines. While both trams and metro systems used electricity for power and hence required fixed infrastructures, the invention of the diesel engine in the early 20th century changed our understanding of transport systems completely. Diesel engine meant that a fixed route was not necessary, creating major flexibility and increased opportunities for accessing land. Mass production and widespread use of the automobile came after the Second World War, but before that bus public transport system emerged as the new versions of the omnibus, horse-drawn trams and even electric trams.

Buses provided flexibility for serving the demand. Bus services did not require major infrastructure investments. Bus lines could be changed in response to changing demands. Similarly, bus stops could be planned with a flexibility that could effectively respond to demand. These characteristics are still present for most of the modern days' bus services.

Meanwhile, the production of the automobile, the other application of the diesel engine, grew in numbers. In 1924, 400,000 different types of motor vehicles were used in the United Kingdom, while in 1963 the total uncle reached 6.6 million (Kılınçarslan, 2012). In Turkey too, after the 1950s, the choice of transportation changed dramatically. The shift from railway development to the construction of highways in the 1950s had its consequences in urban transport too. In Turkey, after the start of private car production in 1966, the number of cars increased rapidly. In 1970 the annual increase was aimed at 57,000 cars. Nevertheless, public transport usage still constitutes the majority of trips made in Turkish cities.

Increasing use of the automobiles resulted in congestion, emissions causing local pollution as well as climate change, and extreme dependence on, and consumption of petrol in all cities of the world. Besides, urban transport systems based on automobile mobility excluded those who did not drive and created issues of unequal accessibility. As a result, from the 1970s onwards, there has been an increased interest in making good quality public transport services, resulting in many investments in new metro and light rail transit systems, street trams, and buses including bus rapid transit systems.

## 2.2. Classification of Public Transportation

Public transportation should be categorized by route, technology, and services (Vuchic 1981, 2007).

The routes of public transportation systems are divided into 3 categories: A, B, and C. Category A indicates that it is a private road reserved for the use of public transport systems and is 100% separated from the surrounding area. It does not intersect with other vehicle traffic and pedestrian roads. This distinction is provided by grade separation. Category B is the category where the system has a special route allocated to it, but it is possible to operate the system with vehicle and pedestrian traffic with level solutions at intersection areas such as intersections. Category C refers to situations in which systems are operated in a mixed manner with other modes of traffic, without designing a dedicated right-of-way or priority lane on roads or pedestrian areas (Vuchic, 2007).

Public transport system technology covers the relationship between vehicles and surfaces (tire or iron wheel or water vehicle), engine characteristics (diesel, electricity), drive or automatic capability, and power supply to the vehicle.

Classification is also possible according to the urban area covered by the public transport service, the stops of the system and the time of day the service is provided. For example, Public transportation service can be called as express service depending on the number of stops and stations. Depending on the coverage area of the system, there may be public transportation systems that serve only the city center, as well as services that operate only in a campus area or in an airport. There are also public transport systems that serve a wider area outside the urban area.

In addition, in order to provide faster service in some hours, the operation is made by making vehicles skip some stops, which are called accelerated service. Some systems can be operated from only one starting point to the last destination, without stopping anywhere in-between. Many public transport systems operate throughout the day (from 5 am or 6 am till 12 pm or 1 am).

While the classification according to service characteristics is a classification that may change according to the decisions made during the operation phase, the classification based on route and technology characteristics depends on the infrastructure and technologies which are the fixed elements of the systems (Vuchic, 2007).

The following table gives the classification of public transport systems and shows how these modes of public transport are classified by considering these elements.

Table 2.1. *Classification of Urban Public Transport Modes (Vuchic, 1981, 2007)*

| Right-of-way Category | *Highway-Driver streered* | *Rubber Tired, Guided* | *Rail* | *Special* |
|---|---|---|---|---|
| C | Paratransit<br>Shuttle bus<br>Regular Bus<br>Express Bus (on street) | Trolleybus | Streetcar<br>Cable car | Ferryboat<br>Hydrofoil<br>Helicopter |
| B | Semirapid bus | Dual mode | Light rail transit | |

| | | | | |
|---|---|---|---|---|
| A | Bus, Bus on busway only | Trolleybus | Schwebebahn<br>Light rail rapid transit<br>Rail rapid transit<br>Regional rail | Funicular<br>Aerial tramway<br>Continuous short-haul systems |

According to the public transport systems classification, different modes of public transport systems are described below.

### 2.2.1. Paratransit Systems

Grosso (2002) defines the paratransit as a medium form of transportation, placed in between the bus and taxi which includes a wide spectrum of transport services from less formal public transport to area-wide service networks. While public transport systems serve by stopping at certain stops in line with predetermined timetables, “paratransit” or “semi-public transport” systems are those that operate on much more flexible and less fixed conditions in terms of stops and timetables. For instance, in places or corridors where travel requests are not high, passengers use dial a ride system and call the service center to indicate where they want to go; the service center plans all appointments to carry the maximum number of passengers at one time and takes the journeys requested by taking more than one passenger. Iles (2005) confirm that paratransit is involved in the operation of the enterprise. The world by local names: “Dala-Dala” in Tanzania; Exit taxi or ET in Zimbabwe; Jeepney in the Philippines; Matatu in Kenya; Public bus or PLB in Hong Kong; Robot in Jamaica; “Silor” in Thailand; Tempo in Bangladesh; “Tro-Tro” in Ghana; In Indonesia, “Angkutan Quota” and so on. The most common type of public transport in the world as a paratransit type is the system which is common in the cities of developing countries and called "Dolmush" in our country. This public transportation service with a capacity of 5-15 people is a service provided by stopping and picking up passengers at various places with an uncertain timeline and in an uncertain location, usually on a predetermined route. Due to its low capacity, the frequency of services is high, which is considered positive for users. On the other hand, providing services with these low capacity systems in corridors where travel demand is high may cause inefficient use of infrastructure and traffic congestion (Babalık, 2012).

*Figure 2.3.* Paratransit- Dolmush (URL3)

### 2.2.2. Rubber Tired

Buses are the most common public transport systems in cities. There are several types of buses depending on their capacity. Bus applications operated on the same roads as other vehicle traffic is the most common form of bus service, known as regular buses. These have a C category right-of-way. A possible arrangement in bus systems is the creation of *Dedicated Bus Lanes or busways* that would operate as Category B right-of-way. These could be planned as fully segregated as in the case of Bus Rapid Transit systems, or as a bus-only lane, as described below.


*Figure 2.4.* Bus Transport (URL4)

Wright (2002) defines the Bus Rapid Transit (BRT) System as a bus-based public transit system that serves fast, comfortable and cheaper urban transportation. It is a system that combines the comfort and regularity of the rail system with the flexibility of the buses and serves a high number of passengers, leaving a positive impression on the users, which does not require high investment and which can be realized in a short time and which is planned as a rail system and brings a new approach to the passenger transportation operated as a rail system. Most of the BRT applications do not have many costs. However, procedures require serious exertion so that is needed some individual and institutional effort to be implemented (Grava, 2002). Bus Rapid Transit system components determine the system performance and the performance characteristics of the system constitute the benefits of the system. The components of BRT are as follows:

- Stations
- Separated Lanes
- Vehicles
- Turnstiles
- Operation Plans
- Command and Control System

- Passenger Information System

In most cases, it gives better service than metro transit with its relatively low infrastructure cost. There are some qualifications which make BRT more effective and preferable such as fully separated lanes, fast get on-get off, free transfers between lines, safe and comfortable trips, high capacity, emission minimization, real-time trip information and GPS technology to follow vehicle trip.

*Figure 2.5.* Bus Rapid Transit (Wright, 2002)


*Figure 2.6.* Busways (URL5)

Bus lanes are road surfaces reserved for public transport, during some hours of the day or at all times. They are not physically separated from other lanes: instead, their lanes have different colors from other lanes; demarcated or marked. At some points, lanes can be used with other vehicles like taxi, dolmush, etc. Sometimes bus lanes are open to private car usage.


*Figure 2.7.* Bus Lane (URL6)

Trolleybuses are the most traditional buses running on electricity (Effects, 2013). They are systems with rubber tires like buses, which follow the fixed routes since they receive their electricity from overhead wires called dirigible systems. Since they are operated on the same roads as other vehicles, such as buses, they have a Category C route.


*Figure 2.8.* First Trolleybus in İstanbul (URL7)

### 2.2.3. Urban Rail Transit

There are many rail transit systems used in cities. One of them is tramway, which is is a rail system and features light rail technology. Since the power supply is electrical energy from the overhead line, the rails do not have a power supply. Therefore, it is possible to design in-vehicle traffic or pedestrian areas in a right-of-way category C. Tramway systems have a low course due to mixed traffic on level roads. The average commercial speeds generally have a traffic regime of 28-30 km / h maximum cruising speed is 50 km / h. Maximum passenger carrying capacity of tram systems per hour 15,000 passengers / direction. Tram systems do not have a population can be considered as the main transportation system in the settlement but the population is more and whose travel demands exceed the capacity of tram systems centers, which mainly feed the main transportation systems and passenger transfers providing secondary transportation systems (Arlı, 2010, pg.6). Since trams are designed in the city center and pedestrian areas, on narrow streets, in urban textures which require them to take sharp bends, they are planned not to exceed 3 cars per transit unit for the ease of maneuver and safety. In practice, it is generally seen as a maximum of 2 cars.


*Figure 2.9.* Streetcar of Tramway Systems (URL8)

Light Rail systems are flexible and developable. It is not essential to have a separate way over the whole route. But it should be separate from private traffic. Light rail systems could be emerged from traditional tramway systems or occurred and planned as totally new systems (*Light Rail and Metro Systems in Europe*, 2004).

Since the power source is the electrical energy it provides from the overhead line, it is a system that does not have a power supply on its rails, and therefore does not have any technological obstacles in its operation with vehicle and pedestrian areas. For this reason, a light rail system can be designed entirely as right-of-way Category C. Although there is no technological requirement for separation, to increase the commercial speed and service quality of the system, light rail systems are generally planned as systems that use dedicated routes. On the other hand, since the technology of the system does not require a completely separated route, it is possible to make level crossings at the intersection points of the system with vehicle or pedestrian traffic. Light Rail Systems are therefore partially or completely separated systems with category B or Category C right-of-way depending on the design. The word light is since the vehicles of the system are relatively small and light, and the capacity is lower compared to rail systems such as the subway, and the cost is less than the subway systems. They are operated with up to 4 vehicles in a transit unit.

*Figure 2.10.* Light Rail Transit Systems (URL9)

Light Metro Systems use third-rail technology, which uses relatively smaller vehicles specific to light rail systems as a vehicle, which is low in capacity compared to subway systems but technology specific to subway systems. This technology is based on the method of supplying energy from the third rail installed next to the rails, and therefore the whole line should be designed in category A right-of-way as a separated route. It is foreseen that these systems will be converted to the subway when the demand for travel increases due to the fact that both the routes are reserved 100% and the third rail infrastructure exists.

*Figure 2.11.* Light Metro Systems (URL10)

They are high capacity urban rail systems that serve in right-of-way category A designed on underground, level or elevated structures. They are defined as “Heavy Rail Transit”, “Rail Rapid Transit”, “Metro”, “Underground” or “Subway” in terminology. Energy is provided by the third rail technology installed next to the rails. Hence, the entire line must be designed as a separated route in the right-of-way category A.

Metro is the System with high travel capacity. Passengers per hour capacity is 100,000 passengers / direction. The highest travel demands in major cities, metro systems are preferred in the lines where it is detected (Evren, 1996).

*Figure 2.12.* Metro Systems (URL11)

Regional Rail is a rail system that connects not only the residential areas on the periphery of a city but also the different cities, settlements and industrial zones that usually have daily interactions. The difference between long-distance trains is that, rather than connecting the two cities, it connects many settlements and centers within one region and therefore stops at more stations. The difference between Metro and Suburban systems is that it has a service area that goes beyond the urban area, has fewer stations and is faster. These systems, which also use high-speed train technologies, are planned with Category A right-of-way.


*Figure 2.13.* Regional Rail (URL12)

Funicular systems are high transportation systems especially used in city centers. It usually works between two zones with a large height difference between them. Funicular systems consist of both elevator and railway technologies. In high-slope lines, they are wired systems used to connect two points with significant height differences between them. The funicular, which utilizes both elevator and railway technology, is considered to be rail systems in some sources, but actually moves on a cable in which the descending and exiting vehicles balance each other. Passenger transport capacity is low and is planned according to the Category A right-of-way where rail or rubber tire vehicles cannot serve on slopes effectively. The system known as "Tünel" in Istanbul is one of the first funicular samples in the world.

*Figure 2.14.* Funicular Systems (URL13)

### 2.2.4. Sea Transport

Passenger transport capacity is low in the sea transport. The various terms such as passenger ferry and sea bus are used in maritime public transportation provided by sea, river, lake and similar waterways. While the sea bus refers only to urban public transport services, passenger ferry and car ferry are the terms used for both intercity and urban public transport. Sea transport are classified into two forms. The first is based on the type of vehicle used. Monohull systems, relatively faster catamarans, hydrophilic systems, and rarely used hovercraft vehicles are the most commonly used passenger ferries (Vuchic 2007). The second classification relates to the fact that vehicles are either passenger-only vehicles or vehicles carrying both passenger and motor vehicles. It is seen that there are two basic approaches in terms of the type and route of the services provided by all these different vehicles. The first approach is public transport in the form of frequent shuttle services between the two sides of the sea, river or lake. The most common use of maritime transportation in public transportation in the world is such services. In the first type of system, vehicles that are not very fast can be used because they are served at a relatively short distance; however, it is important to design the vehicle in such a way that it saves time for the boarding of passengers.

In the second type of service, it is necessary to use fast vehicles such as catamaran or hydrophilic type, since longer distances are covered by stopping at more piers.

Istanbul is one of the cities that make the most daily journeys compared to cities with public transportation. Sydney and Lisbon are examples of cities that may have similarities to Istanbul where maritime public transport is available (Çancı, 2015).

*Figure 2.15.* Sea Transport (URL14)

## 2.3. Transit Travel Characteristics

*Transit Demand* could be defined as the number of passengers who pay money and use the provided function to arrive somewhere. According to migration and city growth or redevelopment in the regions, *Potential Transit Demand* is important. It is greater than the demand of the passengers on the existing transit system. *Transit travel* might change according to the form and growth of the city. *Level of Service* (LOS) is affected by many reasons like speed, comfort, reliability, and some others stated above. *Improving the Level of Services* can increase transit travel and passenger volume. (Vuchic, 2008, pg. 30)

The volume of transit passengers on a line depends on the price of the alternative modes, taxi, private cars as well as time-consuming choices. This varies from city to city. In dispersed and low dense cities, passengers can prefer private cars although there are alternative public transit systems. On the contrary, in compact and overpopulated cities, even though passengers may have their own cars, they may prefer to use public transport systems which decrease travel time and travel costs. In dense cities, especially in Central Business Districts and other major facility areas, public transportation can become more preferable.

Distribution of the trip purpose of the passengers in the cities with good transit services such as Munich, Paris and San Francisco are stated below.

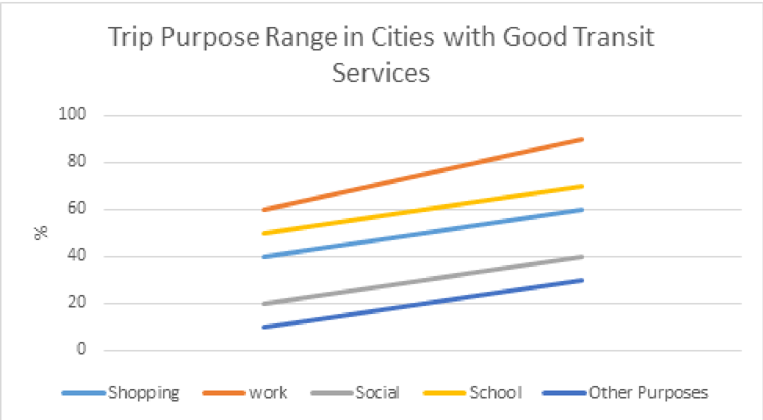


*Figure 2.16.* Trip Purpose Range in Cities

Figure 2.16 shows that for work and school trips, in other words, for commuter trips, public transport can become the leading mode of travel provided that the transit (public transport) service is of good quality. Since it is commuter trips that make up the majority of urban trips, causing congestion, energy consumption and emissions, having commuters choose public transport can be a major advantage in cities.

While public transport is important for commuter trips, bus services are also important in public transport trips. An analysis of trip lengths can support this argument. Trip length distribution changes in cities according to population, form, highway connections and other factors. Trip lengths are shorter than 4 km (between 1 and 4 km) in most US and West European cities. Every transit mode has specific length distributions. In street transit systems, such as buses or trams, average lengths are 4-8 km. (Vuchic, 2008) It may get longer in suburban areas, and rapid transit systems have longer lengths, corresponding to 6 to 12 km. This information shows that bus systems can easily meet the demand for the majority of trips in urban areas since they can effectively provide service for trips of 4 km.

This study also focuses on bus systems as the backbone of public transport systems and as the most common mode of public transport, which clearly can be effective in meeting the majority of transit demand. The following section provides more detailed information on bus systems.

## 2.4. Information Technology in Public Transport Systems

Information technologies also had an impact on transport. After the widespread use of the Internet in the 1980s and finally its full release in 1995, the post-industrial idiom was replaced by the "Information Age". As steam engines are in the industrial society, the important power of the information society based on the new information technology has been the computer. Information technologies that can store, process, transmit and produce new information from this technology have been presented to the service of humanity (Ozturk, 2009). With the urban administrations implementing urban information systems, urban services have been transferred to the digital environment, while the quality and speed of these services increase, their costs decrease and their productivity increases. In the information society, the characteristics of the city are expressed by high population density, qualified employment, the use of advanced technology, and cultural production. (Kılınçarslan, 2012).

With the development of technology, important studies are carried out for obtaining, organizing, processing, analyzing these data, and producing value-added information. The use of maps that enable visualization of the data has also been improved in this process, and maps have been produced and shared in a digital environment. The spread of Geographical Information Systems using spatial and non-spatial data has increased the awareness of data analysis and brought different perspectives to many sectors. Especially in the transportation sector, Intelligent Transportation Systems and Navigation Systems are examples of these applications (Doğru, 2011). Today, Intelligent Transportation Systems use real-time and up-to-date databases built on advanced technologies such as computers, communications, and electronics, and provide solutions for business, control, and management problems in order to improve transportation efficiency, security and service quality. Traffic cameras, road sensors, traffic density maps, variable message systems, mobile information systems, the use of intelligent transport systems in hosting many different applications, such as traffic analysis systems, are also seen as widespread in Turkey (Doğru, 2011). Navigation systems are an indispensable part of our lives today and are widely used in land, air and sea transportation. With the help of intelligent transportation systems and navigation systems in the world, driverless car applications started.

## 2.5. Bus Systems

### 2.5.1. Basic Elements

Bus systems can be analyzed under seven subtitles. These are the route (line, network, stop and stations); the vehicles; usage and users (passengers); operation; capacity and utilization; travel time; and speed. These are described below.

*A Transit Line* is the combination of infrastructure and service provided by public transit (Vuchic, 2002). *A Transit Route* operates overlapped lines on street transit. *A transit network* is a range of transit lines that intersect with each other to decrease operational costs. *A Transit Stop* is where passengers get on or get off transit vehicles. *A Transfer Station* is a location where passengers can transfer between lines. These elements are shown below:

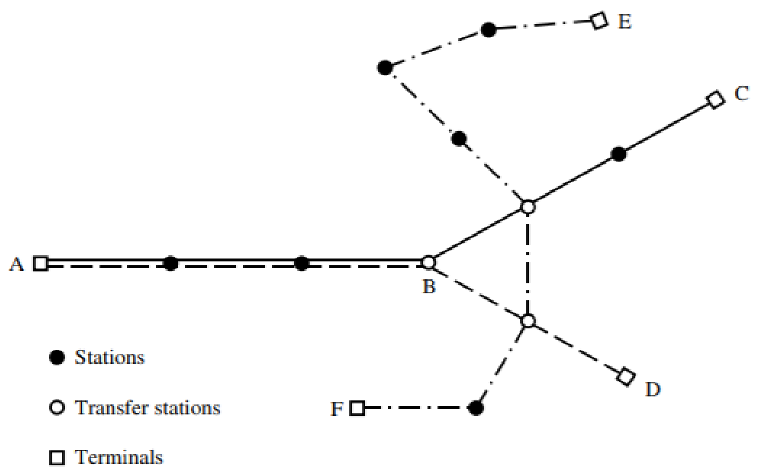


*Figure 2.17.* Line, Network and Station Concepts, (Vuchic, 2001)

*Vehicles* used in bus public transport systems consist of buses, midi-buses, and minibusses. The *Transit Unit* is the concept that corresponds to the range of a number of vehicles traveling physically coupled together. In bus systems, there are usually single buses or articulated buses serving the bus line. *Fleet Size* is the sum of a number of vehicles included in an operation of a linear whole network (Vuchic, 2001).

The demand for travel by transit along the line is defined as passenger flow (prs/time) or passenger volume (prs/h). Passenger demand could be calculated using existing or planned station data because passengers could only use transit stops and stations to get on or get off along the transit line.

*Headway* is the average time interval between two buses on a regular service, mostly expressed in minutes in scheduling. Short headways are preferred by passengers to minimize waiting time. *Frequency* is the number of buses passing the same point in the same direction on the transit line per hour.

*Capacity* is the maximum performance of the system. For public transport systems, vehicle capacity and transit line capacity play an important role in providing a high capacity service. However, it is also important that the capacity is utilized. Utilization is the ratio of passenger flow or volume to capacity.

Travel times can be defined as a specified period of time spent by passengers in making their trips. This can be related to the speed of vehicular traffic flow (i.e. the speed of buses, congestion, etc.) but it can also be related to the time it takes for passengers to board the buses and to get off. Additionally, travel time may also be defined to include the time it takes for users to access the bus stop from their home or work locations.

Vehicle speeds, alignment speeds, vehicle on-line speeds, and passenger speeds are used in transit operations and calculations. *Vehicle Speed* is defined as kilometers per hour. *Alignment Speeds* are composed of three alternatives: line design speed, legal speed, and programmed speed. *Vehicle on-line Speeds* are composed of five different speeds: running speed, station to station speed, operating or travel speed, cycle speed, and platform speed. *Passenger Speeds* are composed of various speeds such as access speed, travel speed on line and origin-destination speed. This last aspect also includes the time that it takes for users to access the bus stop from their home or work locations. Since this access time plays an important role in travel time and total speed, it has an effect on the overall public transport experience of the users. Consequently, this study focuses on bus stop locations, the planning of which is described in further detail below.

### 2.5.2. Network Types

Bus lines can be designed in several different ways depending on the context of the city and such factors as the city form and demand for travel. The most common bus services and network types are as follows (Grava, 2002):

- Shuttle Service is demand-based single route between two locations (Fig.2.18a).
- Radial pattern (through running) is a kind of pattern in which all lines are passing through the center (Fig.2.18b).
- Radial pattern (return running) is also serving the center but the line does not go through the center. Bus routes end at the city center and vehicles return to start point along the same line (Fig.2.18c).
- Gridiron Network operates on grid-iron street patterns (Fig.2.18d).
- Feeder Services are bus lines that feed the heavy transit modes like the metro. They originate and end in a metro station that is generally at the outskirts of the city (Fig.2.18e).
- Trunk Line and line haul service are those in which stops of the long routes are minimized to make the service faster, like expressways (Fig.2.18f).
- Loops and circulators are one-way bus routes generally planned in low-demand areas (Fig.2.18g).

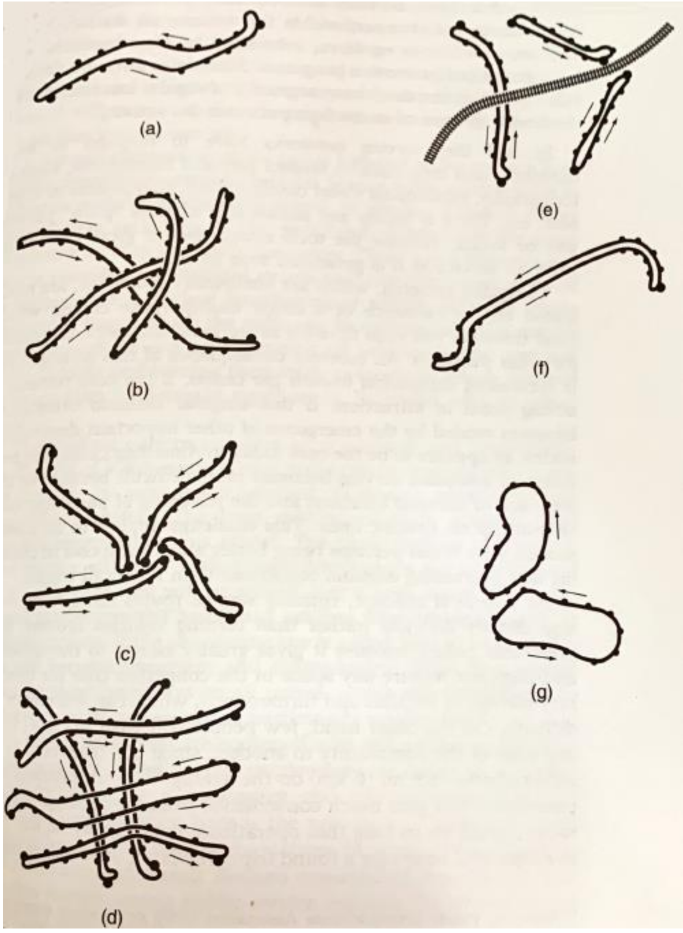


*Figure 2.18.* Network Types (Grava, 2002)

## 2.6. Criteria for Bus Stop Locations

### 2.6.1. Walking Distance

Gonzales and Valverde (2017) claim that walking distance studies have been carried out since the late 1960s. Such studies have focused generally on cities in developed countries, such as Washington DC in the USA, Queensland in Australia, Montreal in Canada, and Madrid in Spain. Different data collection methods -survey, smart card transaction data, others- were applied in different cases.

The first study was made by Peterson in 1966. The scope of this study was to measure the walking distance from the household (origin) to the bus stop (destination). The mean of the distance was calculated as 150.5 meters (Peterson, 1966, cited in Gonzales and Valverde, 2017).

In 1979s, Lam and Morrall added the comparison of winter and summer distances to Peterson's study for the city of Calgary, Canada. After data collection using 1:400 maps for winter, the walking distance was calculated as 373 meters and for summer it was 348 meters (Lam and Morrall, 1979, cited in Gonzales and Valverde, 2017).

Morency studied in Montreal, Canada, he used a regional travel survey in 2003. In his study, he estimated steps rather than distances and 550 steps, equivalent to 440m was estimated from the origin to the destination point (Morency, 2003, cited in Gonzales and Valverde, 2017).

In 2003, Burke and Brown studied both origin-to-destination and destination-to-origin distance, and they claimed that passengers walked about 0.67 km from and to transit stop (Burke and Brown, 2003, cited in Gonzales and Valverde, 2017). The exact route was not known and walk distance was calculated using the shortest path algorithm in Geographical Information Systems.

Hess states that, the assumption of a five-minute walk (which is equal to 400 meters distance) to access public transit (Ammons 2001; Demetsky and Lin 1982; U.S. Federal Transit Administration 1996, Levinson 1992, cited by Hess, 2012) seems to be preferable distance rather than meters, because people prefer measuring their walking with time to distance.

Recently, Viggiano used Access card data to measure the access distance in London. The mean distance to bus stops was calculated as 370 m.

Hernandez and Witter worked on Latin American Cities using the 2009 mobility survey. Distance differs from 56 meters in the central business district to 629 meters in suburbs. The outcome of their research was approximately 400 meters (Hernandez and Witter, 2009, cited in Gonzales and Valverde, 2017).

These studies have been completed by a statistical distribution method using collected data and surveys from the field. By doing this research, three data collection methodologies were applied: 1- household travel or mobility surveys, 2- Bus Stop Surveys using GIS, 3- Fare cards or other data.

For transport planning, travel surveys are costly and require serious processing time in order to use for enacting. On the other hand, technological methods such as farecards and cellphones are effective. However, they require data mining studies and they do not manage to separate the travel mode yet. Final studies were done with the help of Geographical Information Systems, using maps for land use and distance calculation. This method is more accurate and cheaper than other methods. For instance, in research done by Gonzales and Valverde (2017) in San Jose, Costa Rica, distance from households to transit stations were collected via tablet using Google Maps Application. One bus stop was chosen from ten main corridors. In each stop, approximately 30 people out of 305 were surveyed in the early time of the day before real and estimated results were compared. The outcome of this study showed that the real path of the distance can easily be analyzed using map applications.

| **Reference** | **Study Year** | **City** | **Mean (m)** | **Std. Dev. (m)** | **85th Percentile (m)** |
|---|---|---|---|---|---|
| Petersen (1968) [16] | 1966 | Washington D.C. EUA. | 150.5 | 156.1 | 394* |
| Lam and Morral (1982) [12] | 1979-1980 | Calgary, Canada | 373-348 | | 550** |
| Morency et al. (2011) [14] | 2003 | Montreal, Canada | 440 | | |
| Burke and Brown (2007) [2] | 2003 | Queensland, Australia | 670 | 580.0 | 1300 |
| Viggiano et al (2016) [21] | | London, UK. | 370 | | |

*Figure 2.19.* Walking Distance Studies (*Gonzales and Valverde, 2017)*

Mulley (2013) studied about walking distance by using Sydney public transportation data. In this study, it is stated that as shown in Figure 2.20, the mean distance to the stops is 573 meters. 25 percent of trips are less than 235 meters and 75% of walks are less than 824 meters.

| Variable | Category[2] | N | Mean[3] | p-value[4] | SD[5] | LQ[5] | Median | UQ[5] |
|---|---|---|---|---|---|---|---|---|
| **Total** | - | 1906 | 573 | – | 417 | 235 | 518 | 824 |
| **Trip characteristics** | | | | | | | | |
| **Transport mode** | Train | 667 | 805 | **0.000 | 375 | 539 | 749 | 1018 |
| | Bus | 1084 | 461 | Base | 382 | 162 | 364 | 655 |
| | School bus | 155 | 360 | **0.002 | 386 | 50 | 185 | 600 |
| **Region** | Inner Sydney | 968 | 570 | Base | 385 | 273 | 520 | 785 |
| | Outer Sydney | 638 | 636 | **0.003 | 452 | 261 | 572 | 922 |
| | Sydney fringe | 46 | 446 | *0.034 | 429 | 50 | 342 | 781 |
| | Central Coast | 69 | 327 | **0.000 | 338 | 50 | 185 | 611 |
| | Newcastle | 85 | 435 | **0.002 | 435 | 52 | 285 | 676 |
| | Illawarra | 56 | 518 | 0.322 | 421 | 144 | 421 | 805 |
| **Trip purpose** | Work | 695 | 646 | Base | 418 | 316 | 582 | 900 |
| | Education | 471 | 483 | **0.000 | 412 | 97 | 400 | 778 |
| | Shopping/pers business | 394 | 501 | **0.000 | 383 | 179 | 429 | 738 |
| | Social/recreation | 295 | 639 | 0.817 | 429 | 304 | 582 | 878 |
| **Fare type** | Full fare | 952 | 636 | Base | 419 | 312 | 580 | 889 |
| | Free: school pass | 333 | 425 | **0.000 | 393 | 50 | 320 | 679 |
| | Concession: pensioner | 251 | 485 | **0.000 | 372 | 202 | 403 | 685 |
| | Concession: student | 189 | 643 | 0.832 | 411 | 318 | 582 | 921 |
| **Ticket type** | Single or return | 636 | 632 | Base | 425 | 287 | 582 | 906 |
| | Periodical pass | 569 | 645 | 0.599 | 425 | 313 | 581 | 886 |
| | Multi-trip ticket | 257 | 454 | **0.000 | 322 | 206 | 394 | 654 |
| **Day of week** | Weekday | 1638 | 569 | Base | 417 | 227 | 513 | 824 |
| | Weekend day[6] | 268 | 601 | 0.251 | 416 | 285 | 555 | 826 |
| **Time of day** | Am peak | 1164 | 554 | Base | 410 | 208 | 508 | 812 |
| | Inter-peak | 532 | 587 | 0.135 | 420 | 263 | 511 | 814 |
| | Pm peak | 83 | 593 | 0.404 | 392 | 256 | 570 | 825 |
| | Evening | 127 | 682 | **0.003 | 461 | 330 | 633 | 1008 |
| **Public transport trip duration** | Up to 15 minutes | 782 | 545 | Base | 384 | 234 | 501 | 775 |
| | 15 – 29 minutes | 689 | 567 | 0.300 | 419 | 235 | 518 | 790 |
| | 30 – 44 minutes | 267 | 604 | 0.057 | 451 | 229 | 520 | 922 |
| | 45 minutes and longer | 168 | 680 | **0.001 | 480 | 292 | 644 | 1012 |
| **Demographic characteristics** | | | | | | | | |
| **Sex** | Female | 977 | 563 | Base | 421 | 223 | 505 | 813 |
| | Male | 929 | 584 | 0.270 | 411 | 250 | 531 | 844 |
| **Age** | Younger than 19 years | 498 | 505 | **0.000 | 423 | 117 | 425 | 779 |
| | 19 – 29 years | 445 | 634 | 0.587 | 416 | 303 | 570 | 889 |
| | 30 – 49 years | 528 | 619 | Base | 400 | 305 | 583 | 870 |
| | 50 – 64 years | 241 | 600 | 0.547 | 448 | 265 | 511 | 836 |
| | 65 years and older | 194 | 452 | **0.000 | 352 | 181 | 383 | 664 |
| **Labor force status** | Full-time work | 685 | 644 | Base | 422 | 313 | 586 | 889 |
| | Part-time work | 194 | 627 | 0.632 | 404 | 316 | 548 | 903 |
| | Economically inactive | 385 | 488 | **0.000 | 378 | 208 | 397 | 693 |
| | Post-school education | 194 | 621 | 0.512 | 408 | 290 | 570 | 902 |
| | School | 429 | 484 | **0.000 | 417 | 78 | 398 | 775 |
| **Personal income pa** | Less than $13,000 | 545 | 579 | *0.023 | 432 | 208 | 531 | 848 |
| | $13,000 – 41,599 | 522 | 574 | *0.012 | 410 | 256 | 502 | 812 |
| | $41,600 – 83,199 | 367 | 644 | Base | 410 | 319 | 597 | 901 |
| | $83,200 and over | 187 | 619 | 0.479 | 398 | 313 | 581 | 850 |
| **Vehicles in household** | 0 | 521 | 573 | 0.569 | 405 | 256 | 512 | 795 |
| | 1 | 750 | 587 | Base | 421 | 255 | 528 | 839 |
| | 2 or more | 632 | 559 | 0.226 | 421 | 196 | 507 | 839 |
| **Driving license** | Yes | 1007 | 611 | Base | 414 | 287 | 568 | 864 |
| | No | 614 | 573 | 0.077 | 420 | 233 | 515 | 818 |

1. Total is all HTS walk trips from home to public transport of less than 2 kilometers in 2006, 2007, and 2008.
2. Categories with fewer than 40 respondents or undefined ("other") are excluded from this table.
3. Mean walking distance is compared to a chosen base for each variable using a standard two-tailed t-test.
4. *Significant with $p<0.05$, **significant with $p<0.01$ (all tests are two-tailed tests).
5. SD=Standard deviation; LQ=Lower quartile threshold (25%); UQ=Upper quartile threshold (75%).
6. Weekends include public holidays.

*Figure 2.20.* Walking Distance from home to public transport (Mulley, 2013)

#### 2.6.1.1. Statistical Analysis: Methods of Walking Distance

The statistical analysis of the sample and empirical distributions of walking to bus stops will be explained with formulas below.

As using a variable of walking distance, there are three different continuous positive distributions; exponential, gamma and log normal.

Gonzales and Valverde (2017) state that the exponential distribution has been proposed to model walking distance since it can approximately model the decay of several users with an increase in distance. The probability density function of a random variable d is:

$$f(d) = \begin{cases} \lambda e^{-\lambda d} & d \geq 0 \\ 0, & d < 0 \end{cases}$$

Where $\lambda > 0$ and known as rate. The cumulative distribution function is:

$$f(d) = \begin{cases} 1 - e^{-\lambda d} & d \geq 0 \\ 0, & d < 0 \end{cases}$$

1–Cumulative Distribution function is the decay function:

$$D(d) = \begin{cases} 1 - \left(1 - e^{-\lambda d}\right) = e^{-\lambda d} & d \geq 0 \\ 0, & d < 0 \end{cases}$$

The exponential distribution function mode is close to zero and the highest probability is located at zero distance that shows that another probability distribution function with a better model could be considered.

There are three Goodness of fit statistics that are used to select appropriate statistical distribution model walking distances. These are the log likelihood (loglik), the Acaice Information Criteria (AIC), and the Bayesian Information Criteria (BIC). For these models, the lowest outcome is accepted.

The second important point is that the socio-economic status of the people used in the analysis is vital. People with very low or very high incomes are not to be included in the study.

Table 2.2. Measured Walking Distance (Gonzales and Valverde, 2017)

| Statistical Parameters | *Real Distance(m)* | *Perceived Distance(m)* | *Stated-Preference Distance(m)* |
|---|---|---|---|
| Mean | 310.0 | 361.2 | 427.6 |
| Standard Deviation | 227.3 | 305.9 | 323.0 |
| Minimum | 25 | 10 | 40 |
| 25th Percentile | 150 | 150 | 220 |
| 50th percentile | 250 | 300 | 375 |
| 75th Percentile | 400 | 500 | 525 |
| 85th Percentile | 500 | 700 | 656 |
| Maximum | 1400 | 2000 | 2500 |

In Daniel and Mulley's study (2013), the distance estimation method in a household travel survey was used. By using this method, the origin and destination of every trip were geocoded as coordinate x and y and calculated using Esri's ArcGIS application. By doing this, both shorter and longer distances are calculated. Citizens might prefer walking through the park, or short cut instead of a road network, or, for safety reasons, for example, they might prefer a long way to walk. Datasets of 1906 trips in Sydney were used for the analysis. Figure 2.21 shows the distribution of walking trips to public transport.

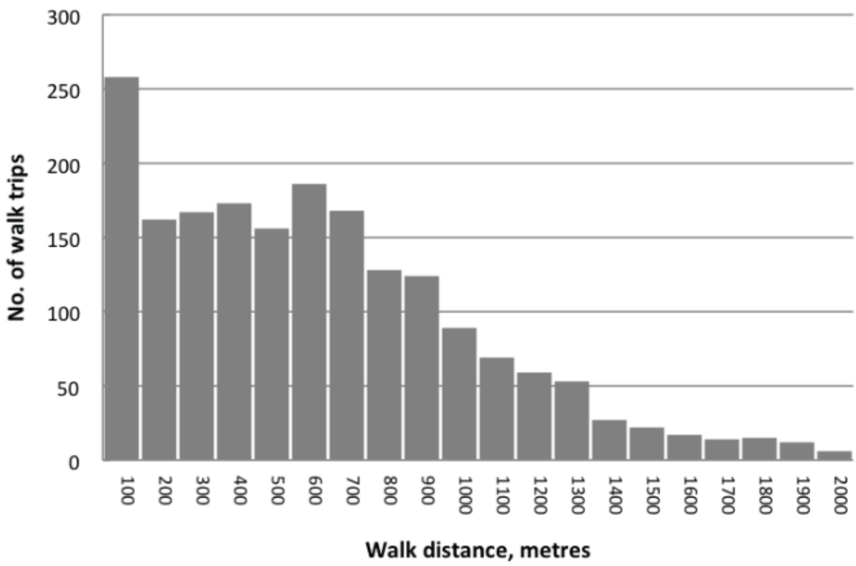


*Figure 2.21.* Frequency of walking distance from home to public transport (Daniel and Mulley, 2013)

Here are the variables, measurements and analysis shown in Figure 2.22:

| Variable | Category[2] | N | Mean[3] | p-value[4] | SD[5] | LQ[5] | Median | UQ[5] |
|---|---|---|---|---|---|---|---|---|
| Total | - | 1906 | 573 | – | 417 | 235 | 518 | 824 |
| **Trip characteristics** | | | | | | | | |
| **Transport mode** | Train | 667 | 805 | ****0.000** | 375 | 539 | 749 | 1018 |
| | Bus | 1084 | 461 | Base | 382 | 162 | 364 | 655 |
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| **Region** | Inner Sydney | 968 | 570 | Base | 385 | 273 | 520 | 785 |
| | Outer Sydney | 638 | 636 | ****0.003** | 452 | 261 | 572 | 922 |
| | Sydney fringe | 46 | 446 | ***0.034** | 429 | 50 | 342 | 781 |
| | Central Coast | 69 | 327 | ****0.000** | 338 | 50 | 185 | 611 |
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| **Fare type** | Full fare | 952 | 636 | Base | 419 | 312 | 580 | 889 |
| | Free: school pass | 333 | 425 | ****0.000** | 393 | 50 | 320 | 679 |
| | Concession: pensioner | 251 | 485 | ****0.000** | 372 | 202 | 403 | 685 |
| | Concession: student | 189 | 643 | 0.832 | 411 | 318 | 582 | 921 |
| **Ticket type** | Single or return | 636 | 632 | Base | 425 | 287 | 582 | 906 |
| | Periodical pass | 569 | 645 | 0.599 | 425 | 313 | 581 | 886 |
| | Multi-trip ticket | 257 | 454 | ****0.000** | 322 | 206 | 394 | 654 |
| **Day of week** | Weekday | 1638 | 569 | Base | 417 | 227 | 513 | 824 |
| | Weekend day[6] | 268 | 601 | 0.251 | 416 | 285 | 555 | 826 |
| **Time of day** | Am peak | 1164 | 554 | Base | 410 | 208 | 508 | 812 |
| | Inter-peak | 532 | 587 | 0.135 | 420 | 263 | 511 | 814 |
| | Pm peak | 83 | 593 | 0.404 | 392 | 256 | 570 | 825 |
| | Evening | 127 | 682 | ****0.003** | 461 | 330 | 633 | 1008 |
| **Public transport trip duration** | Up to 15 minutes | 782 | 545 | Base | 384 | 234 | 501 | 775 |
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| | 30 – 44 minutes | 267 | 604 | 0.057 | 451 | 229 | 520 | 922 |
| | 45 minutes and longer | 168 | 680 | ****0.001** | 480 | 292 | 644 | 1012 |
| **Demographic characteristics** | | | | | | | | |
| **Sex** | Female | 977 | 563 | Base | 421 | 223 | 505 | 813 |
| | Male | 929 | 584 | 0.270 | 411 | 250 | 531 | 844 |
| **Age** | Younger than 19 years | 498 | 505 | ****0.000** | 423 | 117 | 425 | 779 |
| | 19 – 29 years | 445 | 634 | 0.587 | 416 | 303 | 570 | 889 |
| | 30 – 49 years | 528 | 619 | Base | 400 | 305 | 583 | 870 |
| | 50 – 64 years | 241 | 600 | 0.547 | 448 | 265 | 511 | 836 |
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| **Labor force status** | Full-time work | 685 | 644 | Base | 422 | 313 | 586 | 889 |
| | Part-time work | 194 | 627 | 0.632 | 404 | 316 | 548 | 903 |
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| **Personal income pa** | Less than $13,000 | 545 | 579 | ***0.023** | 432 | 208 | 531 | 848 |
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| **Vehicles in household** | 0 | 521 | 573 | 0.569 | 405 | 256 | 512 | 795 |
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2. Categories with fewer than 40 respondents or undefined ("other") are excluded from this table.
3. Mean walking distance is compared to a chosen base for each variable using a standard two-tailed t-test.
4. *Significant with $p<0.05$, **significant with $p<0.01$ (all tests are two-tailed tests).
5. SD=Standard deviation; LQ=Lower quartile threshold (25%); UQ=Upper quartile threshold (75%).
6. Weekends include public holidays.

*Figure 2.22.* Calculation of walking distance from home to stops (Daniel and Mulley, 2013)

In another method, (Durand., Tang, Gabriel, Sener, Oluyomi, Knell, Kohl, 2016) cross-sectional analysis is used. 2573 people of 6949 transit trip that define California household travel survey data was measured. In Figure 2.23, sample characteristics; in Figure 2.24, the initial model is presented.

| **Characteristic** | **Median (interquartile range) or percentage** |
|---|---|
| *Individual and household characteristics* | |
| Age (years) | 49 (35–58) |
| Household vehicles | 1 (0–2) |
| Household size | 3 (2–4) |
| Household income (categorical) | $35,000–49,999 ($10,000–24,999 to $100,000–149,999) |
| Renter | 53% |
| Female | 53% |
| Hispanic or Latino | 35% |
| Employed | 62% |
| Disabled | 12% |
| *Trip characteristics* | |
| Local or rapid bus | 64% |
| Heavy rail | 18% |
| Light rail | 10% |
| Express or commuter bus | 4% |
| Transit access trip distance (miles) | 0.32 (0.13–1.35) |
| Active access (i.e., walking) | 72% |
| Trip originated at home | 31% |

*Figure 2.23.* Sample characteristics

Regression model coefficients and average marginal effects.

| Variables | Probit coefficient | 95% Confidence interval | Average marginal effect |
|---|---|---|---|
| Access trip distance (miles) | **−0.80** | −1.02, −0.58 | −0.12 |
| Trip origin (1 = home; 0=non-home) | **0.55** | 0.41, 0.68 | 0.08 |
| *Month (ref = January)* | | | |
| February | 0.10 | −0.13, 0.32 | 0.01 |
| March | 0.13 | −0.07, .033 | 0.02 |
| April | 0.21 | −0.19, 0.62 | 0.03 |
| May | −0.10 | −0.33, 0.13 | −0.02 |
| June | −0.10 | −0.35, 0.14 | −0.02 |
| July | 0.10 | −0.15, 0.35 | 0.01 |
| August | −0.04 | −0.25, 0.17 | −0.01 |
| September | −0.05 | −0.28, 0.18 | −0.01 |
| October | −0.12 | −0.32, 0.07 | −0.02 |
| November | 0.05 | −0.19, 0.29 | 0.01 |
| December | −0.08 | −0.31, 0.15 | −0.01 |
| Income | 0.02 | −0.02, 0.05 | 0.002 |
| Household size | 0.03 | −0.01, 0.07 | 0.004 |
| Homeowner (1=yes; 0=no) | 0.09 | −0.04, 0.23 | 0.01 |
| Sex (1 = male; 0 = female) | 0.05 | −0.04, 0.15 | 0.01 |
| Hispanic (1 =yes; 0 =no) | 0.06 | −0.07, 0.20 | 0.01 |
| Born in USA (1 = yes; 0 = no) | 0.06 | −0.06, 0.17 | 0.01 |
| Possess driver's license (1 =yes; 0=no) | −0.01 | −0.14, 0.13 | −0.001 |
| Currently employed (1 =yes; 0 =no) | −0.05 | −0.16, 0.06 | −0.01 |
| Disability (1=yes; 0=no) | **−0.20** | −0.35, −0.04 | −0.03 |
| *Education (ref = not high school grad)* | | | |
| High school graduate | −0.08 | −0.24, 0.08 | −0.01 |
| Some college credit | −0.06 | −0.27, 0.14 | −0.01 |
| Associate or technical school degree | 0.06 | −0.20, 0.33 | 0.01 |
| Undergraduate degree | −0.07 | −0.28, 0.13 | −0.01 |
| Graduate/professional degree | −0.11 | −0.32, 0.10 | −0.02 |
| Age (years) | **−0.004** | −0.01, −0.001 | −0.001 |
| *Residence type (ref. = Single family detached)* | | | |
| Single family attached | 0.01 | −0.16, 0.17 | 0.001 |
| Mobile home | 0.04 | −0.42, 0.51 | 0.01 |
| Building with 2–4 units | 0.03 | −0.13, 0.20 | 0.01 |
| Building with 5–19 units | 0.16 | −0.04, 0.36 | 0.02 |
| Building with ≥ 20 units | 0.17 | −0.004, 0.35 | 0.03 |
| *Day of week (ref. = Sunday)* | | | |
| Monday | −0.04 | −0.21, 0.12 | −0.01 |
| Tuesday | −0.10 | −0.27, 0.07 | −0.02 |
| Wednesday | -0.12 | −0.29, 0.05 | −0.02 |
| Thursday | −0.05 | −0.23, 0.14 | −0.01 |
| Friday | 0.10 | −0.12, 0.33 | 0.01 |
| Saturday | 0.04 | −0.21, 0.28 | 0.01 |
| Number of vehicles at household | −0.05 | −0.12, 0.01 | −0.01 |
| *Destination mode (ref. = local bus)* | | | |
| Express bus | −0.13 | −0.34, 0.08 | −0.02 |
| Premium bus | 10.20 | −0.87, 0.47 | −0.03 |
| Public transit shuttle | 0.66 | −0.035, 1.36 | 0.07 |
| Heavy rail | **−0.24** | −0.38, −0.10 | −0.04 |
| Light rail | −0.08 | −0.25, 0.08 | 10.01 |
| Street car | −0.25 | −0.59, 0.09 | −0.04 |
| Trip number | **0.03** | 0.01, 0.05 | 0.004 |
| Intercept | **1.51** | 1.11, 1.90 | |

Boldface text indicates significant parameter estimates ($p \leq 0.05$).

*Figure 2.24.* Regression Model Coefficients and results (*(Durand., Tang, Gabriel, Sener, Oluyomi, Knell, Kohl, 2016)*

## 2.6.2. Catchment Area

In public transport planning, the catchment areas of stops are measured to analyze the potential passengers in a Euclidian distance from the stop (Andersan, Landex, 2008). There are different studies of GIS-based catchment area analyses according to the aim.

The Circular Buffer Area is the easiest approach. The Service Area analysis is based on road networks which are in more detail. Both are described below.

#### 2.6.2.1. Circular Buffer

Although Circular Buffer Approach is used to determine the access areas around the stops, geographical criteria are not taken into account because Euclidian distance is used (Andersen, Landex, 2008). Because in many cases, these distances can be longer or shorter than actual walking distances due to natural or man-made boundaries such as rivers, buildings, railways. This disadvantage is often handled by applying a detour factor that minimizes the buffer distance to retrieve the longer walking distance. However, in some instances where the length of the detours changes seriously around the stops, this solution is not very accurate. In addition, some areas that are separated from the stop such as rivers could be taken as part of the stop's catchment area. To avoid this problem, some GIS applications are used.

#### 2.6.2.2. Service Area

Service area could be calculated based on real networks, making interpolation of a buffer based on existing distances. There is an example of a catchment area of Christianshavn Metro Station in Copenhagen. This is shown in Figure 2.25 and described in further detail below.

#### 2.6.2.3. Comparison of Buffer Area and Service Area

The Circular Buffer Area shows catchment area size and the number of passengers bigger than the actual situation. This can partly overcome by applying a detour factor which is calculated by real road networks on the buffer distance of the circular buffers. But the detour factor is related to the layout of the street and road network bundle with the natural edges in the stop's surroundings. There is an example of the Christianshavn Metro Station in Copenhagen described in the work by Andersen and Landex (2008) below. The difference between buffer and service area is shown in Figure 2.25.

The variation of the buffer and service area methods and the proportion is presented in Table 2.3:

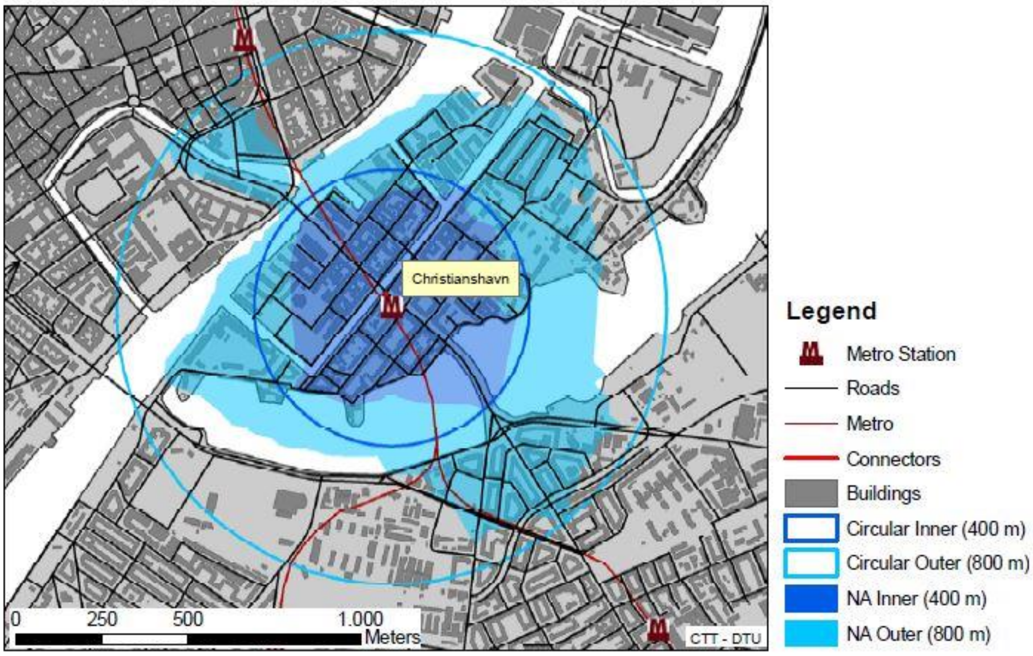


*Figure 2.25.* Comparison of Buffer and Service Area *(Andersen, Landex, 2008)*

Table 2.3. *Proportions between Buffer and Service Area (Andersen, Landex, 2008)*

| Station | *Area (600m Circular Buffer)* | *Area (600m Service Area Buffer* | *Proportion* |
|---|---|---|---|
| Bispebjerg | 1,130,970 m² | 419,879 m² | 0.37 |
| Charlottenlund | 1,130,970 m² | 728,505 m² | 0.64 |
| Christianshavn | 1,130,970 m² | 663,117 m² | 0.59 |
| Dybboelsbro | 1,130,970 m² | 596,301 m² | 0.53 |
| Hellerup | 1,130,970 m² | 855,473 m² | 0.76 |
| Jaegersborg | 1,130,970 m² | 652,961 m² | 0.58 |
| Noerrebro | 1,130,970 m² | 842,050 m² | 0.74 |
| Sjaeloer | 1,130,970 m² | 715,351 m² | 0.63 |
| Svanemoellen | 1,130,970 m² | 703,817 m² | 0.62 |
| Sydhavn | 1,130,970 m² | 654,828 m² | 0.58 |

Table 2.3 demonstrate that proportion between Circular buffer and Service area varies from 0.37 to 0.76 which means Service area approach is more precise.

### 2.6.3. Effect on Speed

Low speed resulting in longer travel times is one of the important issues that can make people not to use public transport. Most problems related to speed are formed not by technical factors, but by the increasing number of private cars. More vehicles on the streets decrease travel speed, with vehicles sometimes having to shut off the engine due to occurring traffic jams.

Many sources focus on bus stop spacing standards. When bus stops are frequent and hence closer to each other, they penetrate more areas and walking distance decreases which reduces arrival time to the bus stops. However, when the distance between bus stops decreases, the speed of buses decrease, operational cost increases and service will be slower. In North America, the distance between stops is 100m. In Europe and Australia, it is 400 m or more (White, 2009).

Assuming that walking speed is equal to 4.5 km/h, the guidance is stated in Table 2.4:

Table 2.4. *Guidance on Bus Stop Spacing (White, 2009)*

| Utilisation | *Stop Spacing* | *Average Walking Time (at 75 m/min)* |
|---|---|---|
| City area, central commercial, service, administration, conventional service | 300 m | 4 min |
| Urban areas with high density, dense residential areas, commercial activities, educational sites | 400 m | 6 min |
| Urban areas with low density, residential area | 600 m | 8 min |

In city centers, bus stops are closer to each other whereas they are far away from each other in low-density residential areas. In short-distance stops, operational cost increases and the speed of buses decreases as mentioned above. This problem could be minimized by skipping some stops and applied as a part of the service hierarchy approach.

## 2.7. Methods and Techniques in Planning Bus Stop Locations

Murray (2012) states that in public transport planning, two major system needs are the reachability and efficiency of the system.

In public transport, different parameters express desirabilities, such as the number of transit lines and their frequencies, the number of express stops and also the quality of the bus stop accessibility by pedestrians.

As mentioned in section 2.6, the location of the bus stops can be used to attract more passengers. Therefore, where and how the bus stops are located is very important. There are many different methods studied. Some of them are described below.

### 2.7.1. Coverage Modelling Approach

The access coverage distance is influenced by various factors, such as the walking conditions to the transit stops (Agrawal, Schlossberg, & Irvin, 2008), the age groups distribution in the target areas (Neilson & Fowler, 1972).

In a coverage modeling approach, the aim is to maximize the number of pedestrians that can easily access public transportation, while decreasing the number of stops to decrease time and oil cost for reliability. Coverage is processed as a binary variable, doing non-linear decline in demand with distance difficult to account for (Farhan & Murray, 2006). A distance-based approach, such as the p-median, minimizes the weighted average travel time for individuals to the closest access point and saving the number of stops (Hakimi, 1964).

While existing facility location models typically do not pay regard to accessibility of stops and significance of stops in terms of destinations reached, the ability of the spatial interaction coverage to include these attributes and better model distance decay makes it an attractive option (Alam, Thompson, & Brown, 2010).

The formulization of Spatial Interaction Coverage Model (Murray, 2012) is stated below:

Table 2.5. *Spatial interaction Coverage Model Parameters (Murray, 2012)*

| Variables | *Definition* |
|---|---|
| i | index for demand nodes |
| j | index for candidate facility locations |
| I | set of demand nodes |
| J | set of all candidate facility locations |
| $d_{ij}$ | shortest distance or travel time between demand node I and candidate location j |
| R | service access distance standard |
| $W_j$ | attraction weight for candidate facility location j |
| $a_i$ | demand at location I |
| α | exponent controlling attraction weight |
| β | exponent controlling distance $d_{ij}$ |
| $N_i$ | $\{j \vert d_{ij} < R\}$; set of candidate facility locations within a threshold distance R of demand node i |
| $X_j \begin{cases} 1 \\ 0 \end{cases}$ | 0 if existing candidate facility location j is included in the system, 0 is otherwise |
| $S_{ij}$ | Interaction between demand node i and candidate facility location j |

Then the spatial interaction coverage model is:

Maximize Z= $\sum_{i \in l} \quad \sum_{j \in \mathbb{N}_i} S_{ij}$

Subject to $S_{ij} = \left[ \frac{a_i w_j^{\alpha} \, d_{ij}^{-\beta}}{\sum_{k \in N_i} w_k^{\alpha} d_{ik}^{-B} x_k} \right] x_j \forall i \in l, \forall i \in J$

Then; $\sum_{j \in J} S_{ij} \leq a_i \ \forall i \in l$ and $\sum_{j \in J} X_j = p$

$S_{ij} \geq 0 \ \ \forall i \in l, \forall j \in J \ and \ \ X_j \ \in 0{,}1 \ \forall j \in J$

### 2.7.2. Total Bus Stop Time Optimization

Total bus stop time is the other approach that is the summation of dwell time which is the duration between bus parking at a bus stop and set back to the traffic. Total bus stop time minimization enhances the sustainability of the bus transit routes and bus transit planning in dense urban areas.

Bus stops close to intersection points and mid blocks are analyzed by multivariate regression analysis with the help of the ordinary least squares method.

Ten variables are used in this analysis:

Table 2.6. *Ten variables used in regression analysis (Arhin, S. 2016)*

| Variables |
|---|
| Bus Route Number |
| S1 Number of passengers boarding |
| X Number of passengers boarding |
| Y Number of passengers alighting |
| D1 Time door opens |
| D2 Time door closes |
| S2 Time bus pulls away from the bus pad after the doors closed |
| Presence of street parking adjacent to the bus stop |
| Number of lanes at the approach where bus stop is |
| Length of bus pad |

The regression model of this analysis is stated below:

TBST= $D_1 k_1 + P_b k_2 + P_k k_3 + L_n k_4 + B_p k_5 + P_a k_6 + \varepsilon$

Table 2.7. *Model Variables and Definitions, Arhin 2016*

| Variables | *Definition* |
|---|---|
| $D_t$ | dwell time |
| $P_b$ | number of passengers boarding |
| $P_k$ | street parking |
| $L_n$ | Number of approach lanes |
| $B_p$ | Bus path length (inch) |
| $P_a$ | Alighting passengers |

In a study by Arhin (2016) the standard multivariate regression modal was applied to calculate the TBST regression models during peak periods of bus stops. In fact, the overall statistical significance of each regression model was tested using the F-test (ANOVA) at a 5% level of significance for each bus stop type (Arhin, 2016). Kolmogorove Smirnov (KS) test, R2, and adjusted R2, F-test, normal probability plots and residual plot were applied to check the model.

There might be three solutions for nonlinear optimization. These are infeasible, unbounded and feasible. Hence, the model is:

TBST= $f\,(D_{t,}P_{b,}P_{k,}L_{n,}B_{p,}P_a\ )$

| Time period | Model equation | $R^2$ | ANOVA | |
|---|---|---|---|---|
| | | | F-value | *p*-value |
| a.m. | $TBST_{AM} = 1.40D_t - 1.90P_b - 1.19P_k + 2.45L_n - 0.001B_p - 0.02P_a + 14.6$ | 0.67 | 7.81 | 0.00 |
| Mid-day | $TBST_{MID} = 1.12D_t + 0.26P_b - 1.87P_k + 0.52L_n - 0.002B_p - 0.15P_a + 17.23$ | 0.96 | 96.89 | 0.00 |
| p.m. | $TBST_{PM} = 1.17D_t - 0.02P_b - 1.55P_k - 2.07L_n + 0.0002B_p - 0.42P_a + 21.72$ | 0.95 | 70.51 | 0.00 |

*Figure 2.26.* Regression Model by time of the day at intersections

| Time period | Model equation | $R^2$ | ANOVA | |
|---|---|---|---|---|
| | | | F-value | *p*-value |
| a.m. | $TBST_{AM} = 1.73D_t - 2.19P_b + 3.91P_k - 0.15L_n + 0.002B_p - 1.21\ P_a - 0.0009$ | 0.73 | 10.17 | 0.00 |
| Mid-day | $TBST_{MID} = 1.12D_t + 0.04P_b - 0.86P_k + 0.50L_n + 0.005B_p - 0.27P_a + 8.71$ | 0.98 | 164.16 | 0.00 |
| p.m. | $TBST_{PM} = 1.12D_t + 0.19P_b - 0.50P_k - 0.19L_n + 0.004B_p - 0.07P_a + 7.94$ | 0.99 | 360.27 | 0.00 |

*Figure 2.27.* Regression Model by time of the day at midnight blocks

Summaries of total bus stop time analysis were computed by time period and type of bus stop. The major statistics were the means, standard deviations, and 95% confidence intervals.

Table 2.8. Summary results of the total bus stop time

| Bus Stop Type | *Time Period* | *Dwell Time (s)* | *Max. TBST (s)* |
|---|---|---|---|
| Intersections | a.m | 20.4 | 42.5 |
| | Mid-day | 28.9 | 47.1 |
| | p.m. | 27.8 | 66.8 |
| Mid-blocks | a.m. | 18.5 | 36.0 |
| | Mid-day | 19.6 | 33.2 |
| | p.m | 17.7 | 31.2 |

This model shows that total bus stop times change according to the time period and the bus stop location. The concept of total bus stop time measurement will be effective for transit planning to improve reliability.

### 2.7.3. Cost and Trip Calculation Methods

Another method used in planning bus stop locations is cost and trip calculation methods. In this method, origin-destination matrix is analyzed to predict optimum bus stop locations and spacing. Operator cost of the two roads are calculated and compared with each other.

Sonmez (2015) states that land use, population density, socio economic conditions affect the trip ambition that changes the rate of trips. Trip distribution is determined by using origin-destination matrix given in Table 2.9.

Table 2.9. Origin-Destination Matrix (Üçer, 2009))

| Origin/ Destination | 1 | 2 | 3 | Z |
|---|---|---|---|---|
| 1 | $T_{11}$ | $T_{12}$ | $T_{13}$ | $T_{14}$ |
| 2 | $T_{21}$ | | | |
| 3 | $T_{31}$ | | | |
| Z | $T_{Z1}$ | | | $T_{zz}$ |

The cost between routes is to calculate the shortest path shown in Figure 2.28:

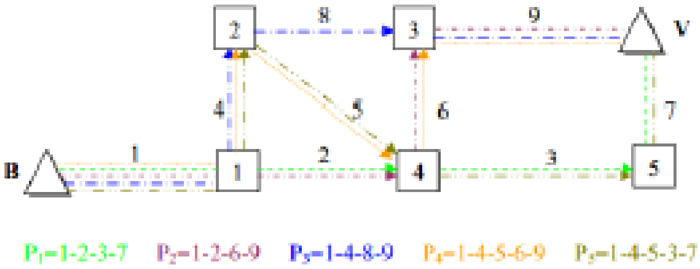


*Figure 2.28.* Network sample (Üçer, 2009)

The calculation of the operator cost (CK) is (Sonmez, 2015, pg 970-971):

CK= $\Sigma_l \Sigma_k L_l f_l Ck_k \delta_{k,l}$ where $L_l$ is the length of route 1 (km per bus) and $f_l$is the frequency of route 1 (bus per hour). $CK_k$ is the unit cost per kilometer covered by bus type k; $\delta_{k,l}$ is the mute variable worth 1 if bus type k is assigned to route 1 and 0 if not. Hence, the calculation of the operation cost is (Sönmez, 2015, pg 970-971):

OC= CK+CR+CF+CP where CK is unit cost per km covered by bus; CR is unit cost per hour standing still with engine running; CF is unit fixed cost per hour; CP is the unit cost per hour of the staff.

### 2.7.4. Customized Buses Timetables Model

In this model, the aim is to plan the stops and timetables of the buses. The passenger's perspective and related model is defined below. According to this approach, vehicle, waiting and arrival time costs define the passenger time cost. The vehicle is denoted with h, and the travel demand of the passenger is i:

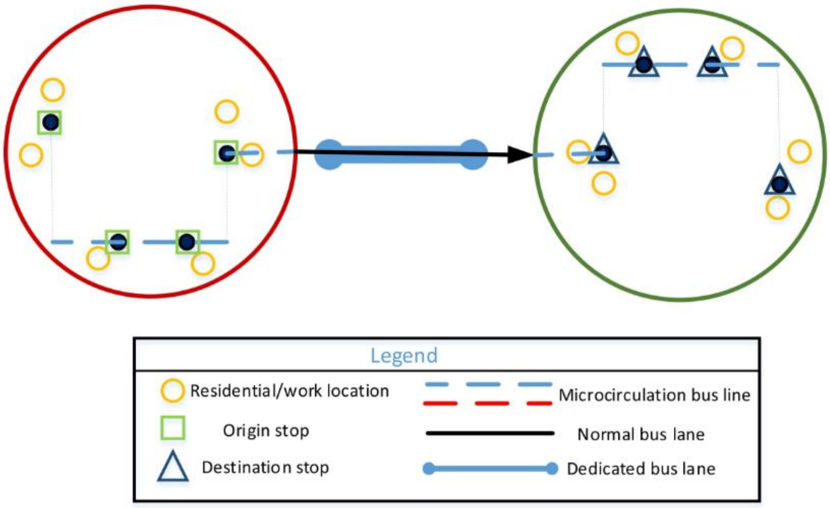


*Figure 2.29.* One customized bus on one line (Zhoa, 2017)

Whether vehicle h meets the travel demand of passenger i;

YN (i,h)=$\delta(i,h)\beta(i,h)\tau(i,h)\theta(i,h)$

Where $\delta(i,h)$ indicates whether passenger i boards at the boarding stop of vehicle h; $\beta(i,h)$ indicates whether passenger I alights at alighting stop j of vehicle h; $\tau(i,h)$ indicates whether the actual arrival time vehicle h is earlier than the expected time of passenger i, $\theta(i,h)$ indicates whether starting time of vehicle h is the latest time at which passenger i can take the vehicle.

According to passenger travel value, the calculation is *(Zhoa, 2017)*:

$R_x = \sum_{i=1}^{n} R_x(i)$

## 2.8. Summary

The review of the literature shows that bus systems as the most common mode of public transport have an important role to play in providing accessibility and mobility in urban areas, and their usage can be highly affected by the location of their bus stops. A fewer number of stops through the transit line will decrease travel time and will help the system cover more travel distance over the fixed period of time (FTA, 1996; Furth & Rah-bee, 2000; Saka, 2001; Wirasinghe & Ghoneim, 1981). However, to operate with fewer bus stops means that a certain number of bus stops should be eliminated and this will increase the travel time for passengers to reach transit facilities (Foda & Osman, 2010; Murray, 2003). Nevertheless, this can negatively affect the accessibility of the bus systems and hence the number of its users.

As stated in the example studies above, in some analysis, demographic parameters were used; and in some both demographic and ridership data were taken into consideration. The parameters used influenced the analysis. There is no study on how the service areas change when the distance between the existing stops is optimized, or, how the number of commercial activities in the existing settlements affects the number of boarding passes. The aim of this study is to optimize the stop points and to measure the relationship between the commercial and residential areas in the service areas and the number of passengers. The next chapter presents the methodology of the research carried out in this study.

# CHAPTER 3

# METHODOLOGY

## 3.1. Aim of the Study

As shown in the literature review presented in the previous chapter~~,~~ fewer stops through the transit line will decrease travel time and cover more travel distance over the fixed period (FTA, 1996; Furth & Rah-bee, 2000; Saka, 2001; Wirasinghe & Ghoneim, 1981). However, the elimination of bus stops will also increase the travel time for passengers to reach transit facilities (Foda & Osman, 2010; Murray, 2003), negatively affecting the accessibility of the bus systems and hence the number of users. As mentioned above, there are several stop optimization managements in different ways around the world.

The aim of this study is to optimize stops and design according to stop demands by using GIS tools, and after understanding the relationship between population density and ridership, measure the relationship between the commercial in the service areas and the ridership and to change the locations of the stops in the current situation or to create express lanes for some hours at some stop points.

The research of the study consists of two stages. In the first stage, Esri's ArcGIS Desktop platform, which is a Geographical Information Systems Application used for managing data, creating map, performing spatial analysis, is used to determine the 400-meter buffer and service areas by both separately and the grouping of the 38 departures and 33 arrivals on a line and the population, age groups (15-29, 30-44, 45-60, 60+), Socio-economic Status Groups (A, B, C, D) measurement of demographics; measurement of current stop intervals. In addition, both the surface difference between the buffer and the service areas as well as the difference of the above-mentioned population parameters are revealed. After these measurements are made, by using

Network Analyst extension of ArcGIS Desktop platform, the study will determine new stop points at 400 meters standard distances, making comparisons between the existing stops and the resulting optimization stops within the service areas of demographic data. The reason of using this software extension is that Network Analyst Extension could determine the real road network data and calculate analysis such as route directions, service area, shortest path, route directions and origin-destination analysis.

In the second stage, one-day boarding data belonging to the stops are used. By using the boarding data of the stops, the boarding data of the stops are first grouped as 2 hours, then the boarding data and stop passenger density are examined by detailing them as half an hour between 5am-11am and 5pm-9pm hours. Demographics of Population, Age Groups (15-29, 30-44, 45-60, 60+) and Socio-Economic Status Groups (A, B, C, D) in the service areas of the stops have been measured by using ArcGIS Business Analyst Web Application. In this application, demographic data is attributed to polygon area of borders such as provinces, counties, neighborhood or postal code. This demographic data is calculated by using this method. Thus, the stop points where the population is small and the number of boarding passes is determined again with the help of this application. The density of the attraction points; ATMs, Business Facilities, Grocery Stores, Restaurants, Nightlife, Banks, Shopping, Hotels, Cinemas, Performing Arts, Bowling Centre, Sports Complex, Convention/ Exhibition Centre, Hospitals, Higher Education, Schools, Libraries, Museums, Police Stations, Post Offices, Clothing Store, Pharmacy and Consumer Electronics Stores in the determined stop points have been calculated and compared. Accordingly, the study examined whether the number of boarding passes, which are high in places where the population is low, has a relationship with the attraction points.

### 3.1.1. Method of Research

#### 3.1.1.1. Data

For this study, the city of Istanbul-was defined as the study area since public transport accessibility is an extremely important issue in this city due to its size, problems of congestion, and citizens dependent on public transport. For this purpose, IETT was visited and data was requested for stop optimization. As a result, 29C route data was obtained from IETT. This line is parallel to metro lines, intersecting with the stops of Fındıklı M.S.U., Kabataş, Levent, 4 Levent, Sanayi Mahallesi, ITU Ayazağa, Atatürk Oto Sanayi, Darüşşafaka and Hacıosman. Also, 29C line intersects with the Metrobus in one point that is Zincirlikuyu Stop. In order to evaluate the current situation regarding this line on the European side of Istanbul, demographic data of the neighborhoods where the line passes were required. Moreover, POI is needed to understand the relationship between bus stops and commercial density. Therefore, these data were obtained from private companies.

The data which are used in this research are stated in detail below:

- Bus Stop Data
- Total Population (Demography)
- Residential Units Density
- Age Groups (15-29, 30-44, 45-59, 60 and 60 Plus)
- Socio-Economic Status of A Plus, A, B, C, D (Demography)
- Province, District and Neighborhood Borders
- Road Network
- Point of Interest (POI)

Bus Stop data is obtained from the Department of Information Technologies, IETT (Istanbul Electricity Tram and Tunnel Establishment) in .csv format. The date of the data is Tuesday, 17$^{th}$ March, 2015. The data includes one whole day round trip for bus line 29C with the length of 37 kilometers. It has 38 stops of South bound and 33 stops of North Bound. It starts from Tarabyaüstü(Bus Stop 1), stops are Spor Tesisleri (Bus Stop 2), Tarabyaüstü Park (Bus Stop 3), Seyh Edebali Parkı (Bus Stop 4), Meydan (Bus Stop 5), Ömürtepe (Bus Stop 6), Köşkevler (Bus Stop 7), Cumhuriyet Mahallesi (Bus Stop 8), Merkez Camii (Bus Stop 9), Mekkenur Camii (Bus Stop 10), Hacı Osman Mahallesi (Bus Stop 11), Tarabya Yolu (Bus Stop 12), Hacıosman (Bus Stop 13), Hacı Osman (Bus Stop 14), Fatih Ormanı (Bus Stop 15), Derbent (Bus Stop 16), Fatih Park Orman (Bus Stop 17), Ataturk Sanayi Kavşak (Bus Stop 18), Atatürk Oto Sanayi (Bus Stop 19), Fakülte (Bus Stop 20), Fevziye Mektepleri (Bus Stop 21), Maslak (Bus Stop 22), Maslak Kavsağı (Bus Stop 23), Seyrantepe Yolu (Bus Stop 24), Sanayi Mahallesi (Bus Stop 25), 4. Levend (Bus Stop 26), Fabrikalar (Bus Stop 27), Levent (Bus Stop 28), Zincirlikuyu (Bus Stop 29), Zincirlikuyu Metrobüs 1 (Bus Stop 30), Balmumcu (Bus Stop 31), Darphane (Bus Stop 32), Ertuğrul Sitesi (Bus Stop 33), Yildiz Teknik Üniversitesi (Bus Stop 34), Barbaros Bulvarı (Bus Stop 35), Beşiktas Meydan (Bus Stop 36), Akaretler (Bus Stop 37), ends in Kabataş (Bus Stop 38). One-way Journey time takes at least 42 minutes (IETT, 2019). By taking into account the historical data of the Google Maps Application (2019) journey time is seen like 60 minutes depending on traffic between 7 am-9 am in the morning and between 5 pm-7 pm in the afternoon. The attributes of the data are Door Code, Route Code, Line Code, Point Code, Order Number, Number of Passengers getting on the bus, Pass Time, Bus Stop Names, Bu Stop Order, X Coordinates and Y Coordinates.

Route 29C pass on Kireçburnu, Cumhuriyet, Ptt Evleri, Maslak, Huzur, Tarabya, Çamlıtepe, Darüşşafaka, Pınar, Reşitpaşa neighborhoods of **Sarıyer District;** Konaklar, Levent, Nisbetiye, Levazım, Balmumcu, Mecidiye, Yıldız, Cihannuma, Sinanpaşa, Vişnezade of **Beşiktaş District;** Yeşilce, Sultan Selim, Emniyet Evleri neighborhoods of **Kağıthane District** and Esentepe neighborhood of **Şişli District**

**Total population** and **Age Groups 15-29, 30-44, 45-59, 60 and 60 Plus** data are provided by Michael Bauer Research Company that is a bundle with Esri's Business Analyst Platform. The data are compiled on Administrative, postcode and microscale levels compatible with existing available boundaries.

**Socio-Economic Status of A Plus, A, B, C, D; Residential Unit Density, Province, District, and Neighborhood Boundaries data** are obtained by Address Map Company. These data are matched with Neighborhood borders in Geodatabase (.gdb) format.

**Socio-Economic Status** (SES) is the measure level in inequality within and between the people living in an area (Smith, 2011). Socio-economic status data is measured by taking into account specific parameters. There are parameters of Groups Stated below:

- **Group A**
    - Almost all have University Degree, 30% of them have master degree
    - Nearly half of them are paid employees as a qualified specialist (lawyer, Doctor, Engineer, etc.)
    - With more than 20 Employees close to 10% White collar
    - 25% Large and Small Business Owner (Almost half of them have no employees)
    - 40% have a spouse who is also working
    - 20% of households have money savings
    - 30% of them prefer holiday village or resort for their holidays
    - Half of them have their own library or bookshelf
- **Group B**
    - 60% of them have University Degree, 35% of them graduated from High School or 2 years University
    - 60% of them are Civil Servant, Technical Personnel, Experts (Non-administrator)
    - 15% of them Large and Small Business Owner (Most of them have 1-5 employees)
    - 30% have a spouse who is also working
    - 13% of households have money savings
    - 20% of them prefer holiday village or resort for their holidays
    - 30% of them have their own library or bookshelf

- **Group C1:**
    - 60 % of them have High School Degree, (20% of 60% are graduated from Vocational High School) and 10% of them have upper degree
    - 40% of them are traders, shopkeepers, 30% of them are skilled workers having high school degrees
    - 15% of them are Civil Servant, Technical Personnel
    - Near 15% of them are retired
    - 13% have a spouse who is also working
    - 5% of households have money savings
    - 20% of them prefer holiday village or resort; 40% of them visit their relatives on their holidays
    - 20% of them have their own library or bookshelf
- **Group C2**
    - 20% of them are graduated from high school. 80% are graduated from high school or they are less educated
    - Most of them have primary school degree, regular employees (60%)
    - 10% of them work as individual-mobile
    - 20% of them are retired
    - Less than 10% have a spouse who is also working
    - 70% of them do not go to holiday. 25% of them go to visit their relatives on their holidays
    - 10% of them have their own library or bookshelf

- **Group D**
    - Over 70% primary school graduates or have not completed primary school, the rest is middle school
    - 30% of them are retired
    - More than 20% are workers (piece of work) (TUAD, 2012)
    - 30% of them are small farmers

- %10 of them are housewife
- 80% of them do not go to holiday. Rest of them go to their hometowns on their holidays

- **Group E**
  - Over 95% primary school graduates or have not completed primary school
  - 30% of them are unemployed
  - 40% of them are retired and they do not work, 30% of them are retired and they work as an employee
  - 20% of left are house wife and they take help (TUAD, 2012)

With these factors, Weighted Score Calculations is used to measure the Socio-Economic Groups of B, C, D, and E in this walking time area. TUIK (Turkish National Research Institution) data was used. Socio-economic data is generated from Turkey Social Demographic Status Index with the calculation of education, income, occupation parameters defined above. These data are analyzed with STATA 12, which is a statistical software program for data science. The construct validity of the index is analyzed by factor analysis and the single-factor variance is calculated for each neighborhood. The single-factor variance is 53%. The Cronbach-Alfa internal consistency coefficient of the attitude scale is found as 0.66.

Province, District, and Neighborhood are vector data that show borders. This data is compatible with the National Address Database. To analyze population and Socio-Economic Status A, B, C, D, E of neighborhoods, these borders are geographically needed.

**Road Network and POI** data are obtained by Esri's Streetmap Premium data. Road Network data includes Point and line layers. The Point layers are City Center POIs (names of cities located in a midpoint of administrative zones or neighborhoods), Distance Markers (placed along roads at regular intervals), Network System Junctions (Connect edges of network), Override Points (Connections of edge network dataset) and Override Points (connection points of merged line features of dissolved dataset). Line Layers are Map Admin Line (Administrative Boundary Lines), Map Highways (Highway lines), Map Major Roads (Major Roads), Map Motorways (Motorways), Map Railroad Link (Railroad features), Map Water Link (Water Features), One Way Arrows (Direction of travel on one-way streets), The Turn Restrictions (Restrictions to the road network), Streets for Network (Streets for network routing), Sign Posts (Sign Text Information), Streets (Streets, highways, roads, ramps and ferries with their attribution relevant for route calculation and route guidance) Point of Interest data include ATM, Business Facility, Grocery Store, Restaurant, Nightlife, Bank, Shopping, Hotel, Cinema, Performing Arts, Bowling Centre, Sports Complex, Convention/ Exhibition Centre, Hospital, Higher Education, School, Library, Museum, Police Station, Post Office, Clothing Store, Pharmacy, Consumer Electronics Store.

#### 3.1.1.2. Program and Applications

Firstly, obtained data has been prepared by Microsoft's Excel application. ArcGIS Platform which is a Geographic Information Systems Application and its extensions were used in the analyses. ArcGIS Pro is used to create and edit datasets and make buffer areas. By selecting the Buffer button in the application, Buffer areas could be created around selected points, lines or area features. The buffer distance is shown in map units by default.

ArcGIS Pro Extension, Network Analyst, was used to create and edit network datasets, calculate service areas. ArcGIS Network Analyst extension helps to create service areas around any location and a network. A Network service area is a region where all accessible streets are included. Both distance and time parameters could be used to calculate a service area. For example, 7 minutes service area of a point covers all the streets that can be reached within 7 minutes from point to all directions. Also, land metrics, demographics values or other values could be measured after the service area is created.

The optimized stop points were determined with the help of Network Analyst over ArcGIS Online. The platform calculates the nearest network location with the help of pre-defined rules and symbolizes the stop with the Located symbol. In this analysis, the distance of optimized stop points is defined as 400 meters.

After creating the service and the buffer areas, demographic values in these areas are needed to be measured. At this point, ArcGIS Business Analyst Application is used. In Business Analyst Application, the Geo-Enrichment service is used to apply a specific geographic retrieval methodology to aggregate data for rings and other polygons. A geographic retrieval methodology in Business Analyst Application determines how data is collected and encapsulated or clustered for input features. As it is mentioned in 3.1., demographic data is attributed to the polygon area of borders such as provinces, counties, neighborhood or postal code and calculated by using the Data Allocation method. This method apportions block group data to defined areas by examining where the population is located within the block group and specifies how much of the population of a block group overlaps a defined area. The Business Analyst application was also used to compare and score boarding data with the population.

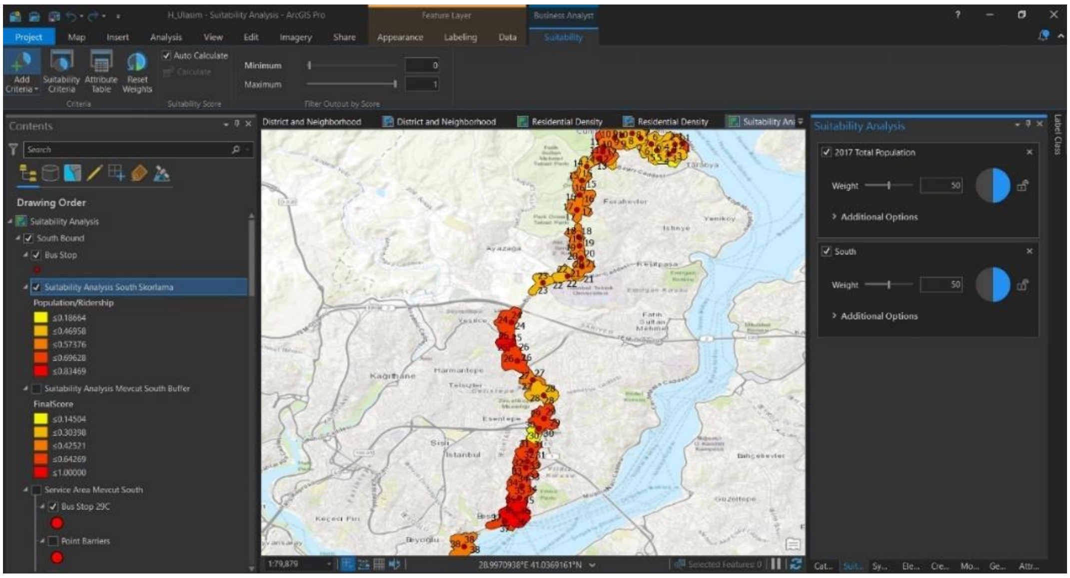


*Figure 3.1.* ArcGIS Pro Application

### 3.1.1.3. Analysis

In the analysis stage, data are prepared in excel format for the analysis first. The obtained IETT data was edited and uploaded to the ArcGIS platform. Other demographic data, province district neighborhood border data, and POI data were uploaded in .mxd format to the ArcGIS Application.

The available stop points were examined as North and South Bound. The distance of these stops was calculated by Network Analyst extension and grouped by round-trip matching. Both Sound Bound, North Bound, and Round-Trip analysis were performed separately.

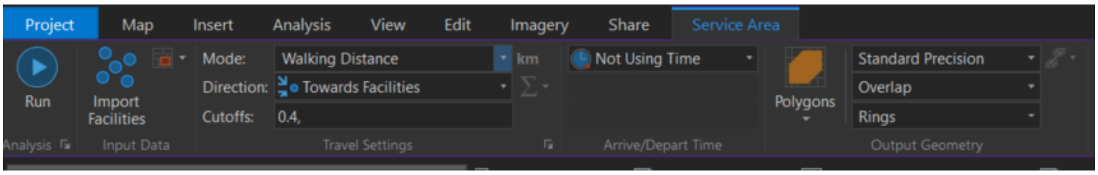


*Figure 3.2.* Creating the Service Area in ArcGIS Pro

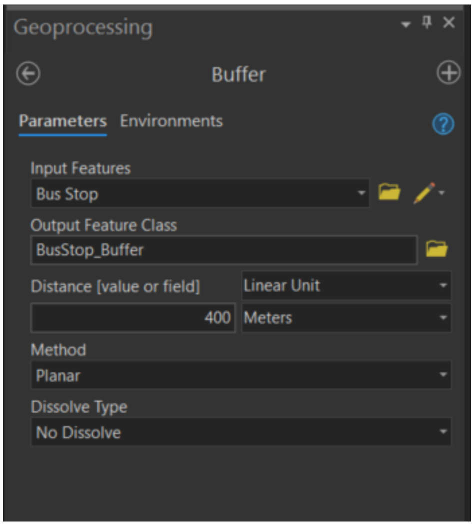


*Figure 3.3.* Creating the Buffer Area in ArcGIS Pro

Firstly, the stop points were geocoded according to WGS 84 System with the ArcGIS Pro application. The distances between departure (South Bound) and arrival (North Bound) stops were measured separately with the Network Analyst extension. The South and North Bound stops were grouped according to the distance between them.

The 400-meter walking distance service and buffer areas in the above-mentioned literature survey were calculated. The studied line was applied as 400 meters walking distance area since it is not considered as CBD region and it is demographically dense.

Separate service areas and buffer areas of South Bound, North Bound, and Round Trip (South and North Bound) stops were determined. Demographic data mentioned above in 400 meters Buffer and Service areas were calculated by using the Business Analyst application. Afterward, these data were exported to the excel and the results were compared. The aim was to show the difference between the service and the buffer areas. The service area is calculated according to the existing road network data and the buffer area is calculated according to the Euclidean distance. Therefore, the data between the two fields are very different from each other. In some optimizations, especially when planning a new line, service areas might be used instead of buffer areas. Ignoring the existing stop points and considering them as a new line, the network analyst application with equal intervals of 400 meters was placed on the line. Service areas around the new stop points were calculated and demographic data within these service areas were calculated. Then, existing stop points data were compared with the optimized stops data.

In the second stage, boarding data were also taken into consideration. Boarding data were proportional to the current population. The service areas where the population was low, the number of boarding passes were scored with the Business Analyst method. To compare this score with land use and attraction points (POIs), a set of attraction points (mentioned in Chapter 3.1.1.1.) in the analyzed stop service areas was also calculated, and density analysis was performed. Then, these two analyses were compared and their relationship with each other was examined.

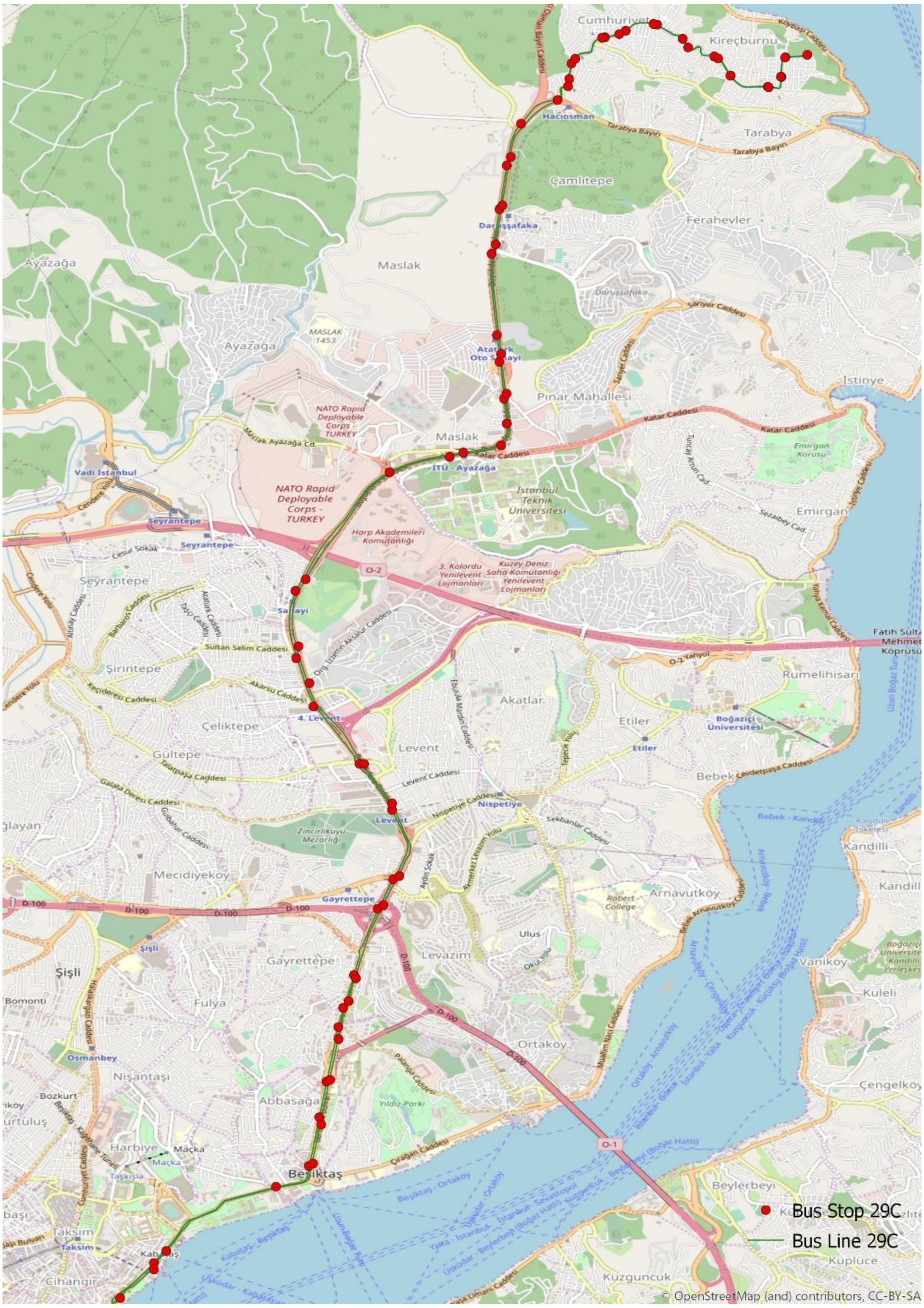


*Figure 3.4.* 29C Bus Route

#### 3.1.1.4. Weighted Score Calculations

Weighted score calculations are included in the Suitability Analysis of Business Analyst Application. For suitability analysis, related sites are selected on the map. By using weighted score calculations, parameters can be defined whether they have a positive or negative impact on suitability analysis. For example, less of the SES of Group A and more of Group B might be preferred for suitability analysis. In that case, Group A is chosen as a reverse impact and Group B is chosen as a positive impact in the application. To explain the weighted score calculation, an example is stated below.

First, it is examined how the number of Group_B, Group_C, and Group_D contributed to this score.

Bus Stop 1 has 80 people in Group B.

The maximum value for Group B across all the Bus Stops is 227 people of Group_B for the Bus Stop 26.

Similarly, the smallest value for Group B across all the Bus Stops is 10 people of Group_B for the Bus Stop 15.

In this analysis, the greater number of people with Goup_B is desired. This is a positive relationship, so these values are plugged into this formula to calculate the score for GP for Bus Stop 1

$$\left(\frac{Bus\ Stop\ 1 - Min\ Value}{Max\ Value - Min\ Value}\right)$$

It is calculated as belows:

$$\left(\frac{59 - 10}{227 - 10}\right) = \quad 0{,}225$$

Bus Stop 1 has a score of 0,225 (Fig.7). Once the score is calculated, the weight is then applied to the value to determine how much Group B will contribute to the total suitability score for the site. In this analysis, a weight of 33% was applied to Group B. Hence, the weighted score for Group B is calculated as 0,075.

0.225 X 0.33= 0.075

The whole weighted score calculation for Group_B can be expressed as:

$$\text{Weighted Score of Group B (Bus Stop 1)} = 0{,}33X\ abs\left(\frac{Bus\ Stop\ 1 - Min\ Value}{Max\ Value - Min\ Value}\right)$$

Abs: absolute value function

### 3.2. Expected Results

Two things were targeted in this analysis. The first one is the rapid and visualized calculation of the analysis using GIS to examine how the parameters used in creating new bus stops on the same line cover the areas served, and how they appeal to the target population.

The second is the use of boarding data for the analysis of existing stopping points. By comparing the boarding data with the population data in the service areas, an analysis of the points where the boarding is too low and the population is too high, or, where the boarding is too high and the population is too low is carried out. Accordingly, it was investigated whether this was related to the POI density in the existing service areas. At this point, although there was no population, it was investigated whether boarding data were dense due to the concentration of attraction centers such as schools, hospitals, cafes, and restaurants in that service area.

Accordingly, it is envisaged which data will be used and at what stage with the help of GIS and how this analysis will affect decision making.

# CHAPTER 4

# APPLICATION OF GIS IN OPTIMIZATION OF BUS STOPS IN ISTANBUL

## 4.1. Background Information on Istanbul

Istanbul has been growing spatially, featuring a certain level of sprawl and higher spatial distribution of facility areas. In Istanbul, the number of vehicles has also been increasing as shown in Table 4.1.

Table 4.1. Number of Vehicles by Years, Istanbul City (TUIK)

| **Year** | *Automobile* | *Minibus* | *Bus* | *Van* | *Truck* | *Motorcycle* |
|---|---|---|---|---|---|---|
| 2014 | 2274368 | 73482 | 46203 | 593533 | 127395 | 240297 |
| 2015 | 2463995 | 83017 | 46413 | 612444 | 131746 | 258773 |
| 2016 | 2644411 | 85979 | 45208 | 632869 | 133654 | 274059 |
| 2017 | 2813027 | 90121 | 44351 | 657572 | 134318 | 291791 |
| 2018 | 2887581 | 94873 | 42614 | 669994 | 136083 | 309991 |

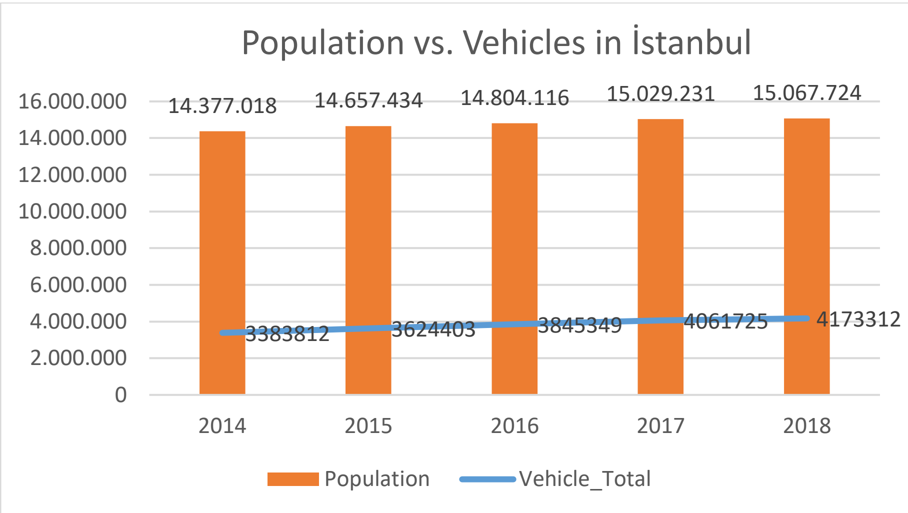


*Figure 4.1.* Population and Number of Vehicles Change in Last 5 Years (TUIK, 2018)

As seen in Figure 4.1, the number of vehicles increases with the increment of population. IETT 2019 data shows that highway transportation is 77,1% of total public transportation. IETT Bus/Metrobus, Bus AC. and Private Public Bus compose 29,7% that is a significant ratio for public transportation in Istanbul. The table below shows the number of passengers using public transportation per day and transportation mode.

Table 4.2. Transportation Mode and Trip Generation, Istanbul City (TUIK)

| Transport Mode | *Passengers per Day* | *Rate (%)* |
|---|---|---|
| **Rail System** | **2.822.291** | **18,6** |
| Metro/Light Rail | 1.654.777 | 10,9 |
| Tram | 677.222 | 4,5 |
| Telfer / Nostalgic Tram / Tunnel / Funicular | 59.674 | 0,4 |
| TCDD/Marmaray | 430.618 | 2,8 |
| **Highway** | **11.682.191** | **77,1** |
| IETT Bus/Metrobus | 2.059.151 | 13,4 |
| Private-Public Bus | 1.607.036 | 10,6 |
| Bus AC | 860.801 | 5,7 |
| Minibus | 2.911.163 | 19,2 |
| Taxi/Taxi Dolmush | 1.403.949 | 9,3 |
| Service | 2.867.502 | 18,9 |
| **Seaway** | **644.851** | **4,3** |
| IDO | 163.434 | 1,1 |
| City Lines | 231.444 | 1,5 |
| Private Vessel | 249.973 | 1,7 |
| **Total** | **15.149.333** | **100** |

In order to support the Tramway Company, which has been operating since .1871, Dersaadet Tramway Company was granted permission to operate 4 buses. In 1928, Bağlarbaşı Deposu, which was used as a tram car, was turned into a garage. In 1930, 4 Renault Scemia buses started to operate between Beyazıt and Karaköy.

During the transfer of the company to IETT, the company had 3 buses. In 1942, 23 White buses were ordered but 9 of them were delivered and 3 Scania buses were scrapped. At the end of the same year, 25 Scania-Vabis gasoline trucks were imported from Sweden and allocated to IETT by the Trade Office. On April 3, 1943, a fleet of 29 was formed with the purchase of 15 buses from the truck and 5 Scania-Vabis buses in 1944. This fleet was sent to Ankara on October 17, 1946, to replace the buses that were burned in the Ankara Municipality bus depot. Shortly thereafter, with the initiative of the Municipality, a fleet of 16 buses, including 12 Tvvin Couch, 2 Chevrolet, and 1 Fargo brand, served until 1955. Until 1960, Skoda, Bussing, and Magirus continued to buy buses in various brands and the number of buses in the fleet was 525. In 1968 and 1969, a total of 300 Leyland buses were purchased, and in 1979-1980 Mercedes-Benz, Magirus and Icarus buses were purchased and 495 buses were purchased. In 1983-1984 MAN branded buses were commissioned. In 1997, with the purchase of MERCEDES buses with Euro 2 standards, a fleet of 2580 buses was reached by the end of 2001. In the following years, the first double-decker buses joined the fleet, and with the introduction of the Metrobus line, long double-bellows buses were purchased. Finally, in 2013, 1705 new buses were purchased and launched to reduce fleet age to less than 5 years.

### 4.2. Bus System

There are 3039 buses, 13 garages and 11.751 bus stops in Istanbul (IETT, 2019). According to an analysis by IETT, daily bus trips in Istanbul are significant in comparison to some of the metropolitan cities in the world. This analysis by IETT is seen in Figure 4.2.

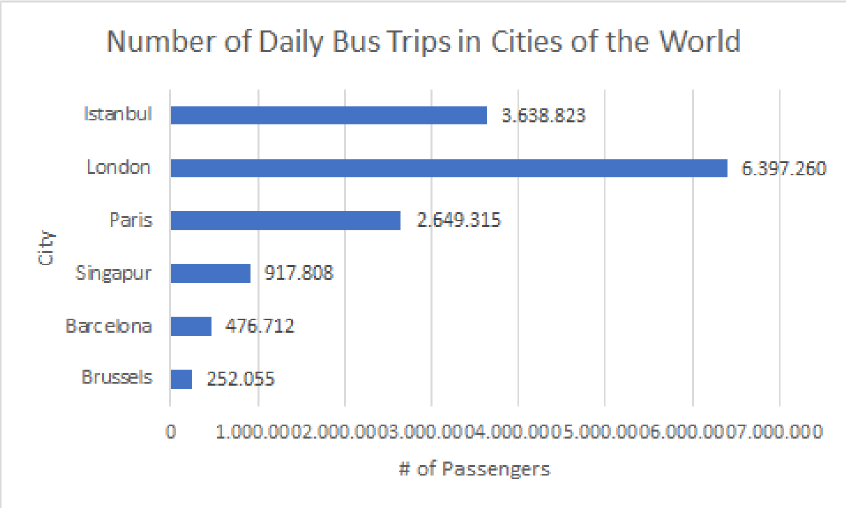


*Figure 4.2.* Bus Trips per Day in Cities of the World

## 4.3. The Analysis and Development of a GIS-Based Approach in Planning Bus Stops

### 4.3.1. Analysis Based on Existing Land Use and Population

Firstly, initially from IETT, belonging to line 29C with x and y coordinates 38 departures (South Bound) and 33 arrival stops (North Bound) were mapped with ArcGIS Pro application. As it is seen in Figure 4.3., the 29C line starts from Tarabyaüstü on the European side and ends at Kabataş. Provincial and district boundaries where the line passes are visualized on the map. The name of the districts and quarters where the line and stops pass are shown in Table 4.3.

This line is visualized on the map with neighborhood-based residential units data (Figure 4.4.). Neighborhood-based residential unit data were grouped with natural breaks method. The purpose of this method is to group the data in such a way that they can best group similar values and divide the data into classes so that the difference is the most.

The stops in the south and north bound were visualized on the map and grouped as south-and-north bound according to the distance to each other. In this analysis, it was seen that some stops in the south bound were skipped. Accordingly, the stops numbered 13,14, 18, 23 and 37 in the direction of departure do not have equivalence in the north bound.

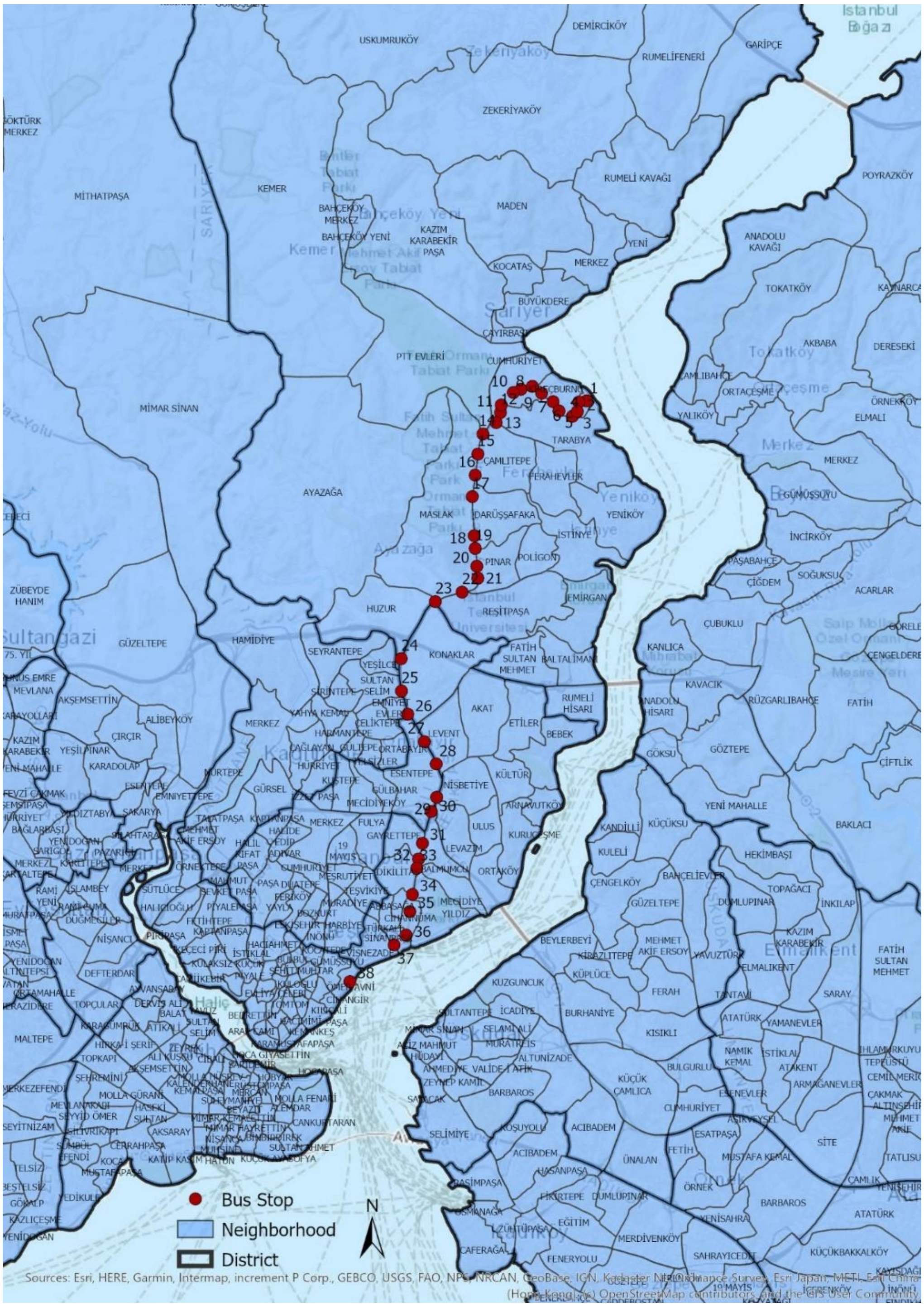


*Figure 4.3.* Study Area, Bus Stop 29C

Table 4.3. *Residential Units of Districts (Adres Harita, 2017)*

| District | *Neighborhood* | *Residential Units* | *Residential Units (%)* |
|---|---|---|---|
| Beşiktaş | Sinanpaşa | 1.313 | 1,16 |
| Beşiktaş | Cihannuma | 2.226 | 1,97 |
| Beşiktaş | Balmumcu | 1.617 | 1,43 |
| Beşiktaş | Levazım | 3.516 | 3,12 |
| Beşiktaş | Vişnezade | 3.860 | 3,42 |
| Beşiktaş | Yıldız | 3.128 | 2,77 |
| Beşiktaş | Mecidiye | 5.152 | 4,57 |
| Beşiktaş | Nisbetiye | 6.778 | 6,01 |
| Beşiktaş | Levent | 1.346 | 1,19 |
| Beşiktaş | Konaklar | 6.079 | 5,39 |
| Sarıyer | Tarabya | 8.784 | 7,79 |
| Kağıthane | EmniyetEvleri | 3.967 | 3,52 |
| Kağıthane | Sultan Selim | 13.497 | 11,97 |
| Kağıthane | Yeşilce | 4.524 | 4,01 |
| Sarıyer | Huzur | 4.328 | 3,84 |
| Sarıyer | Maslak | 8.715 | 7,73 |
| Sarıyer | Pınar | 4.277 | 3,79 |
| Sarıyer | Darüşşafaka | 5.104 | 4,53 |
| Sarıyer | Çamlıtepe | 4.345 | 3,85 |
| Sarıyer | Reşitpaşa | 6.079 | 5,39 |
| Sarıyer | Kireçburnu | 3.210 | 2,85 |
| Sarıyer | Cumhuriyet | 4.289 | 3,80 |
| Sarıyer | PTT Evleri | 1.633 | 1,45 |
| Şişli | Esentepe | 5.022 | 4,45 |

As can be seen in Table 4.3., Sultan Selim in Kağıthane district includes the highest number of residential units with 11,97% of the study area whereas Sinanpaşa with 1,16% in Beşiktaş district has the least. The average number of residential units included in these neighborhoods is 4700. According to natural breaks in Figure 4.4., the average results of the residential units are placed in the second break, which is $\leq$7783.

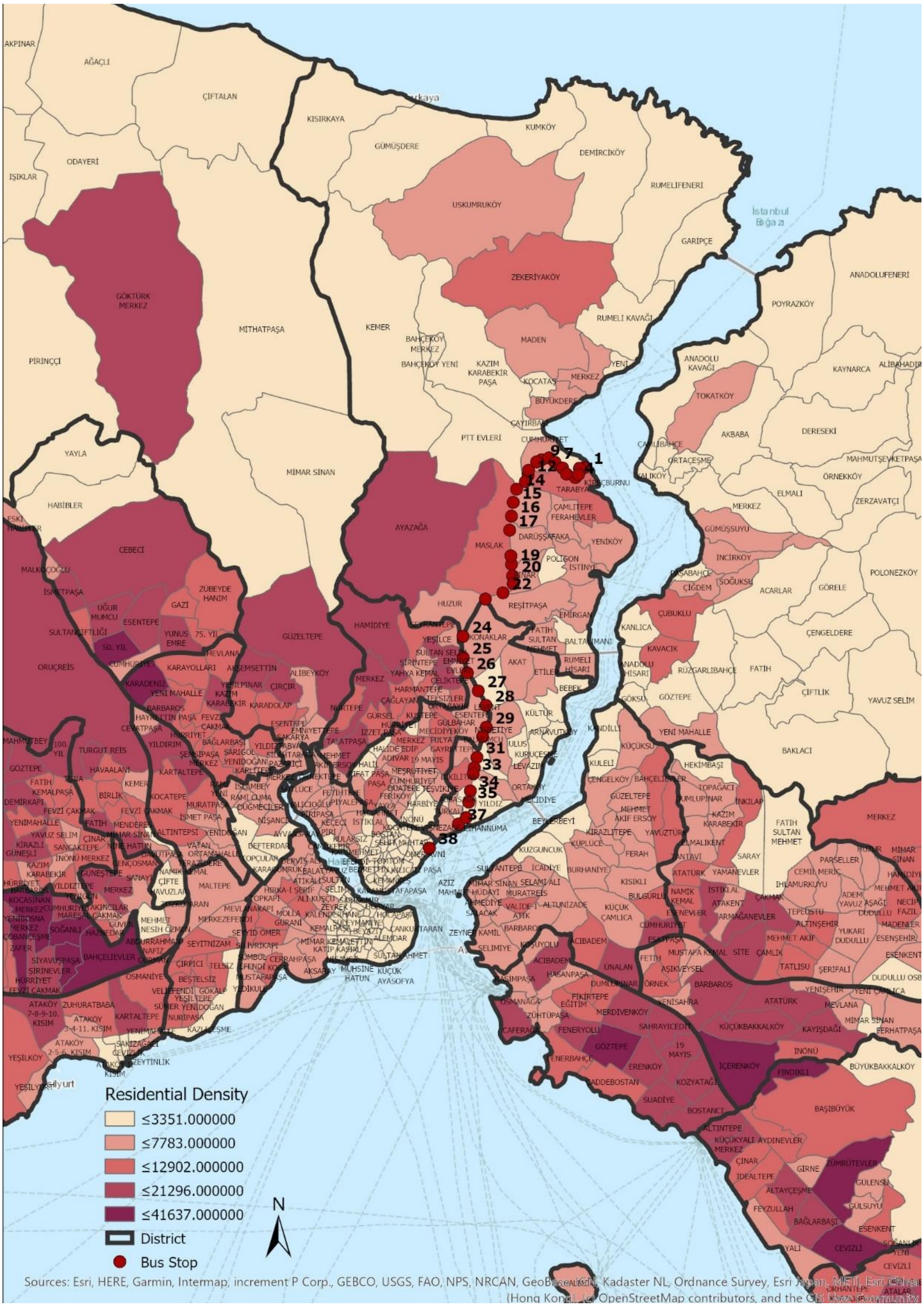


*Figure 4.4.* Residential Units in Neighborhoods

The stops were handled in 3 different ways as south bound, north bound, and north-and-south bound. The distance between the ordered stop points for these 3 separate cases was measured with the ArcGIS Network Analyst tool. As it is seen in Table 4.4., the closest distance between the 2 currently available stops is approximately 144 meters in the south bound and approximately 136 meters in the north bound. The farthest distance between the 2 ordered stops is approximately 1399 meters in the south bound and approximately 1655 meters in the north bound. When all the stops are examined, the average distance between stops is 439 meters in the south bound and approximately 488 meters in the north bound.

Table 4.4. *Distance between stops*

| ***Stops (South Bound)*** | ***Distance from Stop1*** | ***Distance (m)*** | ***Stops (North Bound)*** | ***Distance from Stop1*** | ***Distance (m)*** |
|---|---|---|---|---|---|
| 1 | 0+000.00 | 0 | 1 | 0+000.00 | 0 |
| 2 | 0+169.00 | 169,00 | 2 | 0+171.01 | 171,01 |
| 3 | 0+297.91 | 199,98 | 3 | 0+299.88 | 197,09 |
| 4 | 0+441.33 | 143,71 | 4 | 0+441.47 | 141,60 |
| 5 | 0+622.03 | 305,91 | 5 | 0+624.40 | 315,76 |
| 6 | 0+710.42 | 231,13 | 6 | 0+681.83 | 197,70 |
| 7 | 0+1011.13 | 300,71 | 7 | 0+937.26 | 255,43 |
| 8 | 0+1252.25 | 241,12 | 8 | 0+1292.80 | 355,54 |
| 9 | 0+1499.99 | 247,74 | 9 | 0+1574.35 | 281,55 |
| 10 | 0+1672.85 | 172,86 | 10 | 0+1710.34 | 135,99 |
| 11 | 0+2040.85 | 368,00 | 11 | 0+2005.22 | 294,88 |
| 12 | 0+2198.34 | 157,49 | 12 | 0+2289.43 | 284,21 |
| 13 | 0+2428,69 | 230,36 | 13 | 0+3126.41 | 836,98 |
| 14 | 0+2796.63 | 367,94 | 14 | 0+3619.31 | 492,91 |
| 15 | 0+3232.47 | 435,84 | 15 | 0+4017.98 | 398,67 |
| 16 | 0+3678.04 | 445,57 | 16 | 0+5124.86 | 1106,88 |
| 17 | 0+4132.97 | 454,92 | 17 | 0+5529.09 | 404,23 |
| 18 | 0+4955.81 | 822,85 | 18 | 0+6052.74 | 523,65 |

| | | | | | |
|---|---|---|---|---|---|
| 19 | 0+5225.26 | 269,45 | 19 | 0+6463.89 | 411,16 |
| 20 | 0+5600.07 | 374,81 | 20 | 0+8119.35 | 1655,45 |
| 21 | 0+5853.04 | 252,97 | 21 | 0+8799.46 | 680,11 |
| 22 | 0+6295.87 | 442,83 | 22 | 0+9180.87 | 381,41 |
| 23 | 0+6894.41 | 598,54 | 23 | 0+10099.13 | 918.26 |
| 24 | 0+8293.08 | 1398,67 | 24 | 0+10550.78 | 451,65 |
| 25 | 0+8972.76 | 679,69 | 25 | 0+11286.95 | 736,17 |
| 26 | 0+9478.90 | 506,14 | 26 | 0+11605.50 | 318,55 |
| 27 | 0+10156.64 | 677,74 | 27 | 0+12374.45 | 768,95 |
| 28 | 0+10684.81 | 528,17 | 28 | 0+12612.21 | 237,76 |
| 29 | 0+11385.07 | 700,26 | 29 | 0+13002.91 | 390,70 |
| 30 | 0+1170.49 | 322,42 | 30 | 0+13420.11 | 417,20 |
| 31 | 0+12400.25 | 692,77 | 31 | 0+13878.18 | 458,07 |
| 32 | 0+12742.78 | 342,53 | 32 | 0+14276.34 | 398,16 |
| 33 | 0+12940.46 | 197,68 | 33 | 0+15706.48 | 1430,14 |
| 34 | 0+13498.87 | 558,40 | | | |
| 35 | 0+13862.68 | 363,81 | | | |
| 36 | 0+14362.33 | 499,64 | | | |
| 37 | 0+14689.12 | 326,79 | | | |
| 38 | 0+15900.92 | 1211,79 | | | |

As seen in Table 4.5., the stops in the south bound at distances of 200-400 meters and those in the north bound are usually at distances of 200-400 m and 600+ meters.

Table 4.5. *Number of stops at walking distance*

| Direction | *0-200m* | *201-400m* | *401-600m* | *601m+* |
|---|---|---|---|---|
| South Bound | 6 | 15 | 9 | 7 |
| North Bound | 5 | 8 | 7 | 8 |

The Network analyst tool, the ArcGIS Pro extension, was used to calculate both buffer and the service areas in existing stops. Accordingly, the buffer and service areas around the stops of south bound and north bound were created separately. Since the service area is calculated according to the actual road network and the buffer area is calculated according to the bird flight distance, the spatial difference between these two areas is different. Buffer areas may be preferred from time to time in planning, in small scale decisions, if there is not a line passing through that region or in small scale urban planning studies such as Environmental Plan. In this study, since a larger-scale analysis was performed, service areas were calculated and an optimization study was performed accordingly. The difference between service and the buffer areas of bus stop 22 is shown in Figure 4.5.

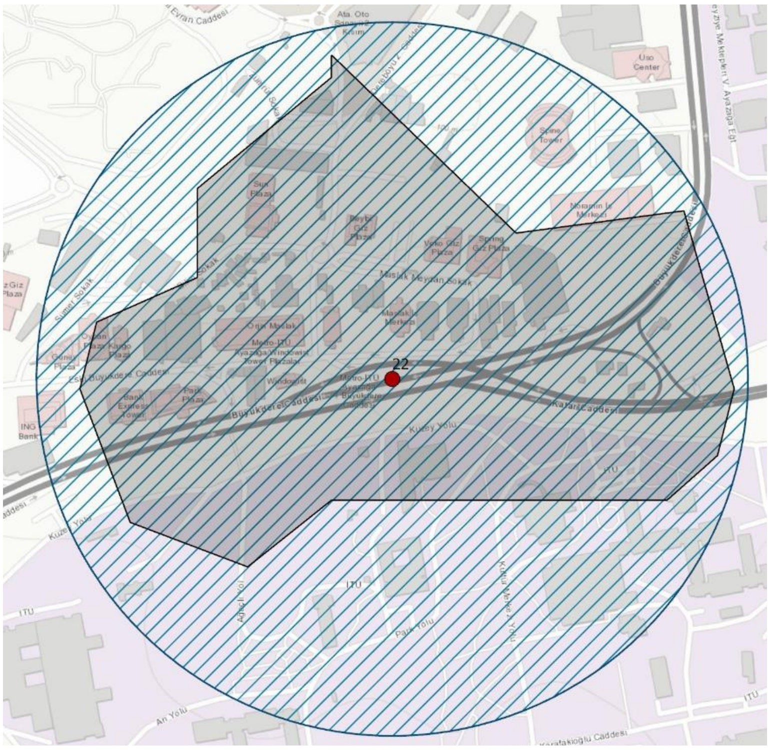


*Figure 4.5.* Difference Between Buffer and The Service Area

In this analysis, 200, 400, and 600 meters of walking distance was used for creating the service areas as the basis for the population density of the study area. Moreover, 200, 400 and 600 meters of bird flight distance was used for creating the buffer area around the stops and to compare with the service areas of the stops. As it is seen in Figure 4.6, 200, 400, and 600 meters walking distance service areas are created for bus stop 22. The shape and coverage of these three areas are different from each other.

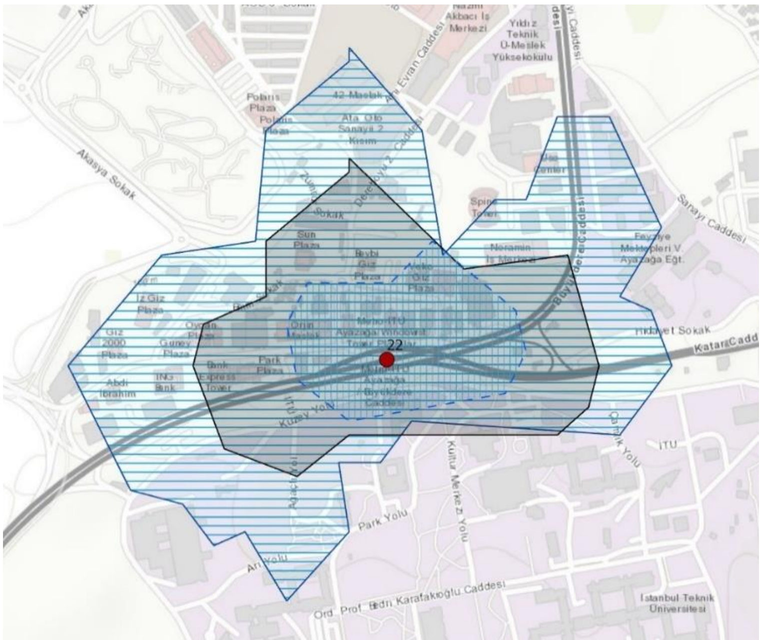

*Figure 4.6.* Service Areas of 200m, 400m and 600m

In addition, buffer areas of 200, 400, and 600 meters is shown in Figure 4.7. below.

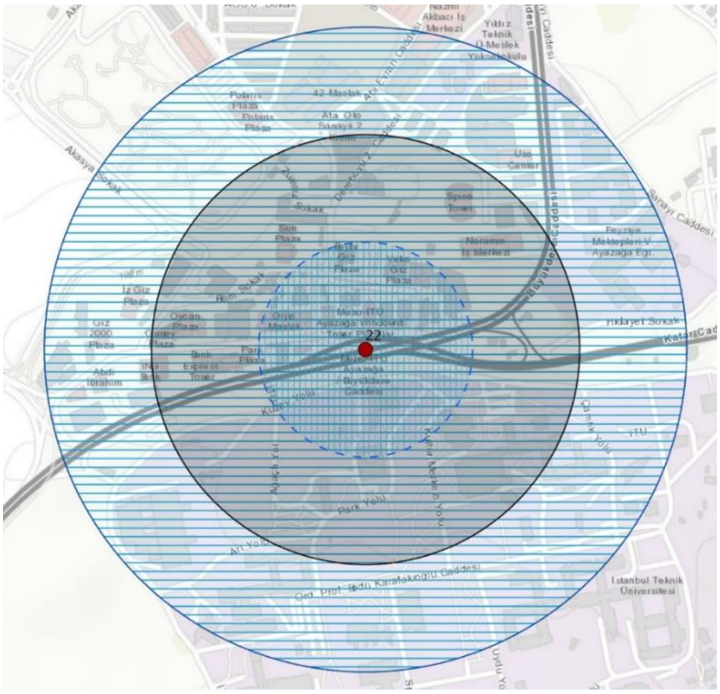

*Figure 4.7.* Buffer Areas of 200, 400 and 600 meters

In this study, 200, 400, and 600 meters service and the buffer areas are calculated separately around the bus stops by using ArcGIS Network Analyst tool. In Figures 4.8, 4.9 and 4.10, the difference between buffer areas is shown.

Both service and the buffer areas and the population included in these areas are calculated and compared. Table 4.6. shows the difference between the buffer and the service areas and the ratio between them.

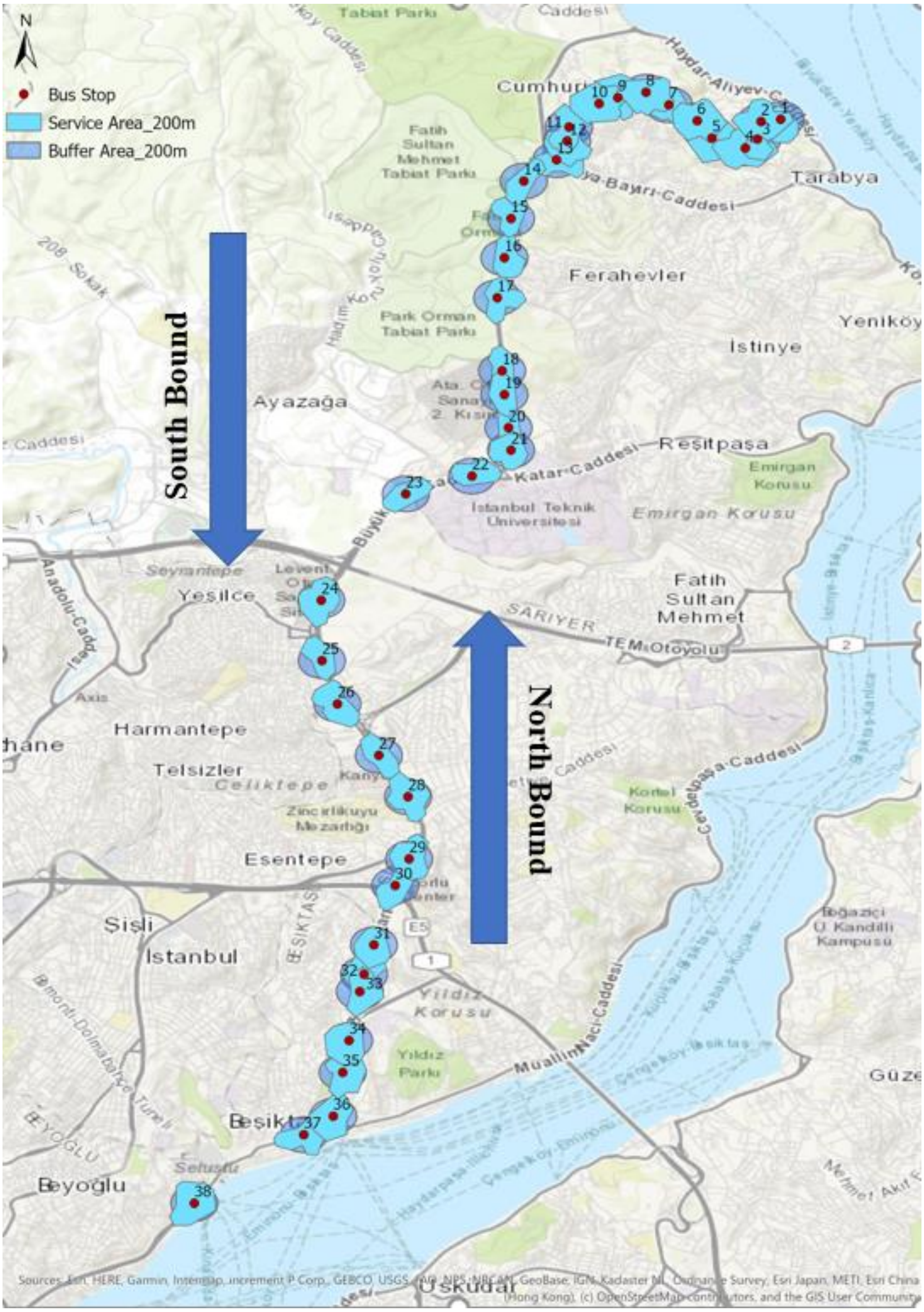


*Figure 4.8.* 200 m Service and Buffer Area, North and South Bound

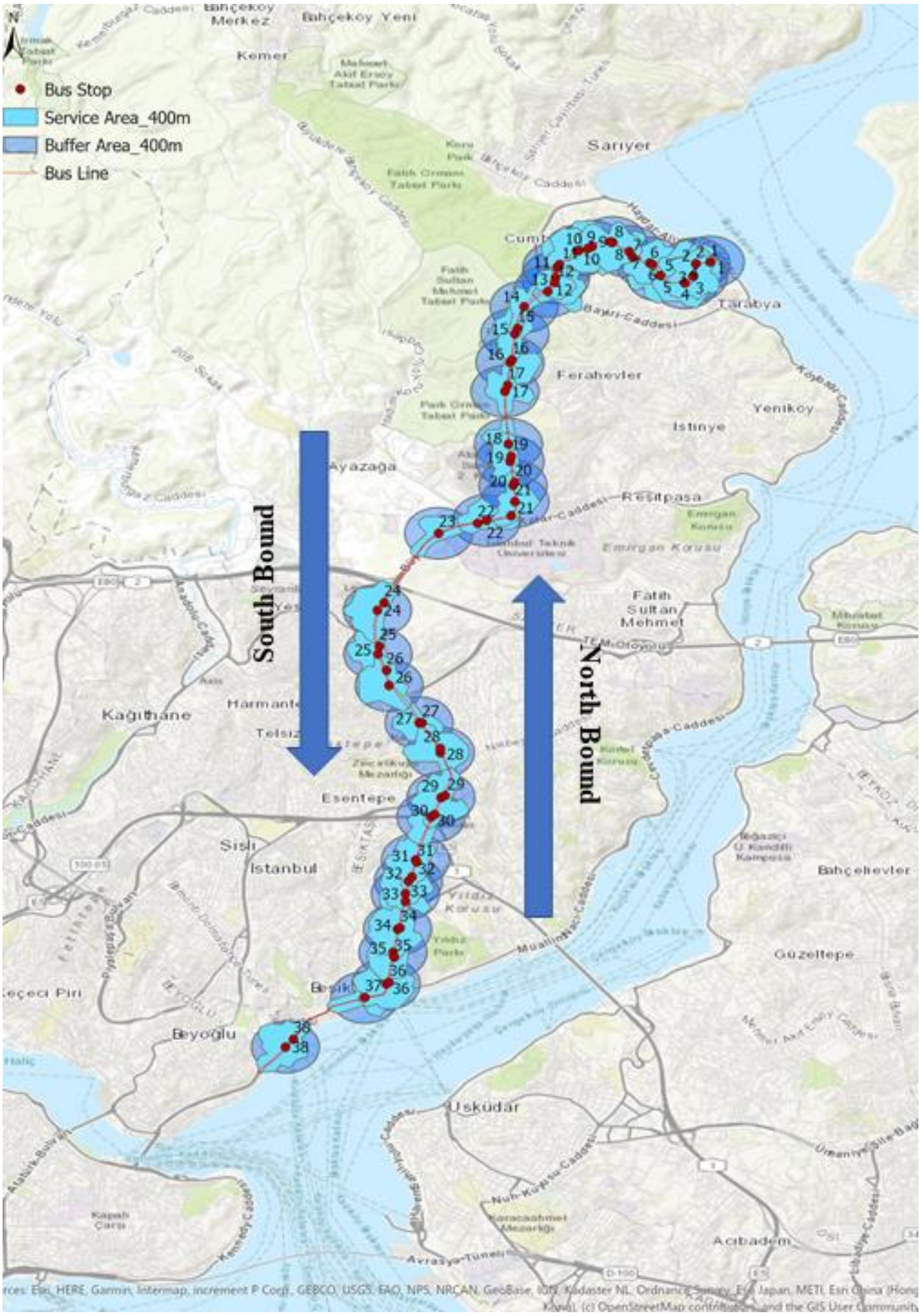


*Figure 4.9.* 400m Service and Buffer Area, South and North Bound

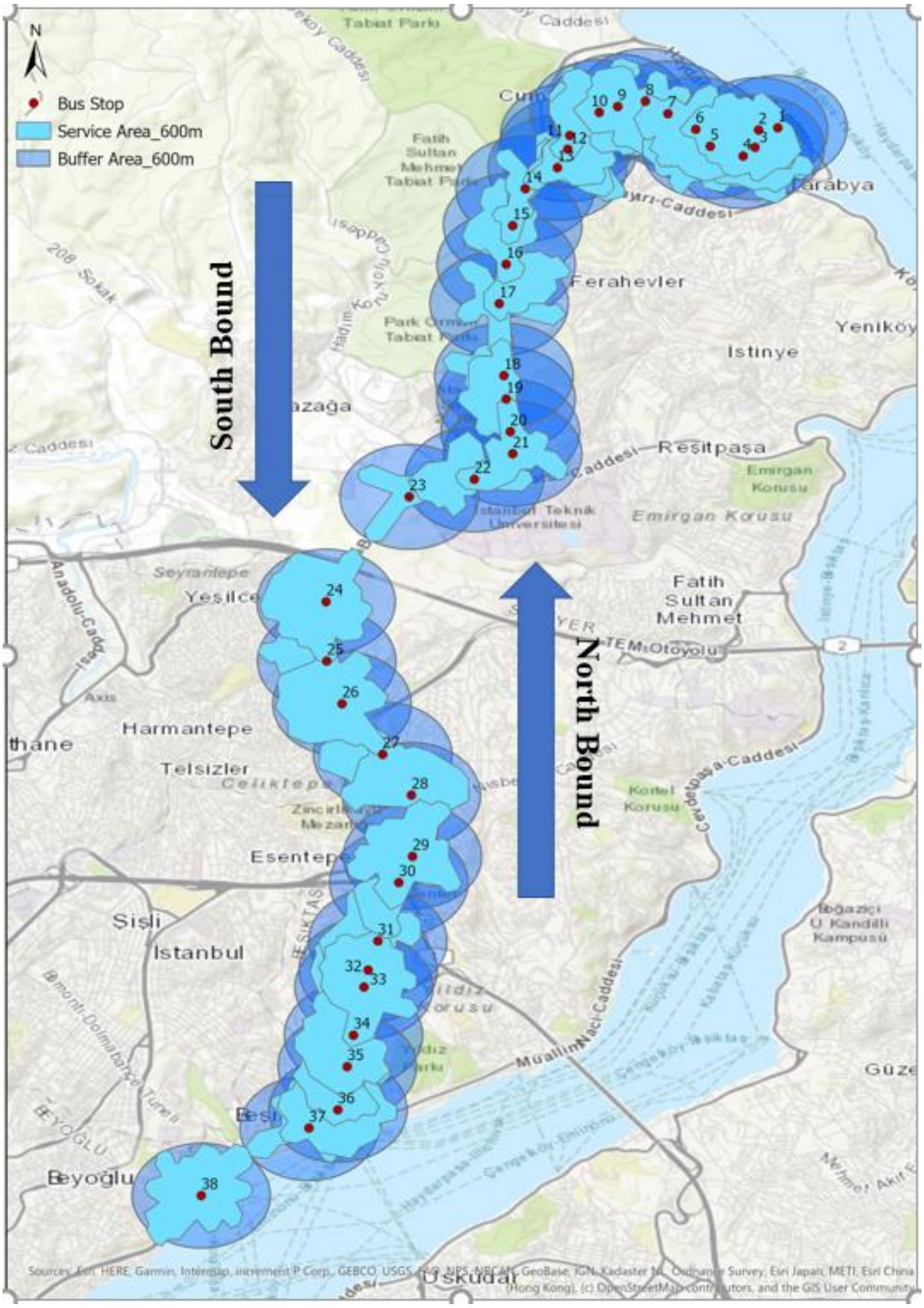


*Figure 4.10.* 600m Service and Buffer Area, North and South Bound

Table 4.6. *Difference Between Service and Buffer Area for 200,400 and 600 meters*

| 200m | | | 400m | | | 600m | | |
|---|---|---|---|---|---|---|---|---|
| Service Area (m²) | Buffer Area (m²) | Service / Buffer Area (m²) | Service Area (m²) | Buffer Area (m²) | Service / Buffer Area (m²) | Service Area (m²) | Buffer Area (m²) | Service / Buffer Area (m²) |
| 120.143 | 125.581 | 95,67% | 342.851 | 502.488 | 68,23% | 486.218 | 1.130.725 | 43,00% |
| 120.112 | 125.581 | 95,65% | 360.674 | 502.488 | 71,78% | 691.942 | 1.130.725 | 61,19% |
| 90.756 | 125.581 | 72,27% | 351.732 | 502.488 | 70,00% | 715.468 | 1.130.725 | 63,28% |
| 112.815 | 125.581 | 89,83% | 460.335 | 502.488 | 91,61% | 864.304 | 1.130.725 | 76,44% |
| 123.421 | 125.581 | 98,28% | 378.047 | 502.488 | 75,24% | 854.419 | 1.130.725 | 75,56% |
| 121.038 | 125.581 | 96,38% | 318.098 | 502.488 | 63,30% | 803.148 | 1.130.725 | 71,03% |
| 121.550 | 125.581 | 96,79% | 414.738 | 502.488 | 82,54% | 608.692 | 1.130.725 | 53,83% |
| 119.065 | 125.581 | 94,81% | 428.391 | 502.488 | 85,25% | 699.438 | 1.130.725 | 61,86% |
| 124.019 | 125.581 | 98,76% | 423.372 | 502.488 | 84,26% | 825.922 | 1.130.725 | 73,04% |
| 118.965 | 125.581 | 94,73% | 223.611 | 502.488 | 44,50% | 740.115 | 1.130.725 | 65,45% |
| 122.730 | 125.581 | 97,73% | 298.375 | 502.488 | 59,38% | 672.192 | 1.130.725 | 59,45% |
| 120.895 | 125.581 | 96,27% | 265.950 | 502.488 | 52,93% | 634.820 | 1.130.725 | 56,14% |
| 124.617 | 125.581 | 99,23% | 297.010 | 502.488 | 59,11% | 550.193 | 1.130.725 | 48,66% |
| 92.878 | 125.581 | 73,96% | 255.400 | 502.488 | 50,83% | 401.370 | 1.130.725 | 35,50% |
| 99.231 | 125.581 | 79,02% | 241.796 | 502.488 | 48,12% | 523.670 | 1.130.725 | 46,31% |
| 97.357 | 125.581 | 77,53% | 172.889 | 502.488 | 34,41% | 588.139 | 1.130.725 | 52,01% |
| 106.770 | 125.581 | 85,02% | 255.695 | 502.488 | 50,89% | 497.393 | 1.130.725 | 43,99% |
| 94.081 | 125.581 | 74,92% | 249.117 | 502.488 | 49,58% | 460.058 | 1.130.725 | 40,69% |
| 88.439 | 125.581 | 70,42% | 220.660 | 502.488 | 43,91% | 443.605 | 1.130.725 | 39,23% |
| 94.089 | 125.581 | 74,92% | 349.631 | 502.488 | 69,58% | 345.308 | 1.130.725 | 30,54% |
| 98.797 | 125.581 | 78,67% | 311.309 | 502.488 | 61,95% | 441.527 | 1.130.725 | 39,05% |
| 93.625 | 125.581 | 74,55% | 352.275 | 502.488 | 70,11% | 542.928 | 1.130.725 | 48,02% |
| 94.334 | 125.581 | 75,12% | 268.524 | 502.488 | 53,44% | 406.031 | 1.130.725 | 35,91% |
| 120.098 | 125.581 | 95,63% | 368.092 | 502.488 | 73,25% | 811.730 | 1.130.725 | 71,79% |
| 89.180 | 125.581 | 71,01% | 363.186 | 502.488 | 72,28% | 662.151 | 1.130.725 | 58,56% |
| 122.838 | 125.581 | 97,82% | 252.805 | 502.488 | 50,31% | 800.088 | 1.130.725 | 70,76% |
| 95.313 | 125.581 | 75,90% | 331.218 | 502.488 | 65,92% | 620.358 | 1.130.725 | 54,86% |
| 124.986 | 125.581 | 99,53% | 388.203 | 502.488 | 77,26% | 741.827 | 1.130.725 | 65,61% |
| 121.454 | 125.581 | 96,71% | 393.158 | 502.488 | 78,24% | 709.422 | 1.130.725 | 62,74% |
| 95.332 | 125.581 | 75,91% | 381.181 | 502.488 | 75,86% | 520.908 | 1.130.725 | 46,07% |
| 103.580 | 125.581 | 82,48% | 367.305 | 502.488 | 73,10% | 736.353 | 1.130.725 | 65,12% |
| 121.240 | 125.581 | 96,54% | 421.780 | 502.488 | 83,94% | 798.536 | 1.130.725 | 70,62% |
| 110.885 | 125.581 | 88,30% | 251.337 | 502.488 | 50,02% | 722.511 | 1.130.725 | 63,90% |
| 125.021 | 125.581 | 99,55% | 399.458 | 502.488 | 79,50% | 748.707 | 1.130.725 | 66,21% |
| 124.852 | 125.581 | 99,42% | 343.273 | 502.488 | 68,31% | 749.917 | 1.130.725 | 66,32% |
| 120.189 | 125.581 | 95,71% | 229.088 | 502.488 | 45,59% | 811.185 | 1.130.725 | 71,74% |
| 124.210 | 125.581 | 98,91% | 459.185 | 502.488 | 91,38% | 688.756 | 1.130.725 | 60,91% |
| 125.087 | 125.581 | 99,61% | 372.087 | 502.488 | 74,05% | 751.003 | 1.130.725 | 66,42% |

As it is seen in Table 4.6., the size of the buffer and the service areas are close to each other in 200 meters. This area size difference increases at 400 and 600 meters. The average of service and buffer areas for 200, 400 and 600 meters are shown in Table 4.7.

Here are the reasons why the service size does not approach the buffer size:

- **Land use:** As it can be seen from the map, Fatih Sultan Mehmet Natural Park, Park Forest Natural Park, Atatürk Auto Industry Zone 2nd Part, Istanbul Technical University, Levent Auto Industry Zone, Military Region, Zincirlikuyu Cemetery, affect the size of the service area.
- **Natural Boundaries:** Areas such as ring road and sea pier affect the size of the service area.
- **Accessibility of pedestrian and vehicle road network:** It is important that the pedestrian roads are used for the specified walking distance of 400 meters are accessible.

Table 4.7. *Average Service and the Buffer Areas Around the Bus Stops*

| 200m | | | 400m | | | 600m | | |
|---|---|---|---|---|---|---|---|---|
| Service Area ($m^2$) | Buffer Area ($m^2$) | Service / Buffer Area (%) | Service Area ($m^2$) | Buffer Area ($m^2$) | Service / Buffer Area (%) | Service Area ($m^2$) | Buffer Area ($m^2$) | Service / Buffer Area (%) |
| 111.158 | 125581 | 88,51% | 330574,6 | 502.488 | 65,79% | 649.220 | 1.130.725 | 57,42% |

As it is seen Table 4.7., the service area is 88,51% of the buffer area in 200; 65,79% in 400 and 57,42% in 600 meters. The reason that the difference between service and buffer space is growing in 600 meters might be due to land use. There are university campuses, parks, military areas and sea around the bus stops.

The actual road network data is used when calculating the service area. Thus, these areas measured according to the driving or walking distances of pedestrians or vehicles give a more accurate result than buffer areas. Therefore, in this analysis, the use of a service area was preferred to measure stop attraction criteria. The following route has been followed as to which service areas of 200, 400 and 600 meters will be preferred in the analysis.

In Figures 4.8., 4.9 and 4.10., overlapping increments are observed from 200 meters to 400 and 600 meters. In order to avoid the recalculation of the population in the intersecting areas, the service areas were merged in itself using the ArcGIS Pro platform and population density in these areas was measured. The merged service areas are seen in Figures 4.11., 4.12. and 4.13.

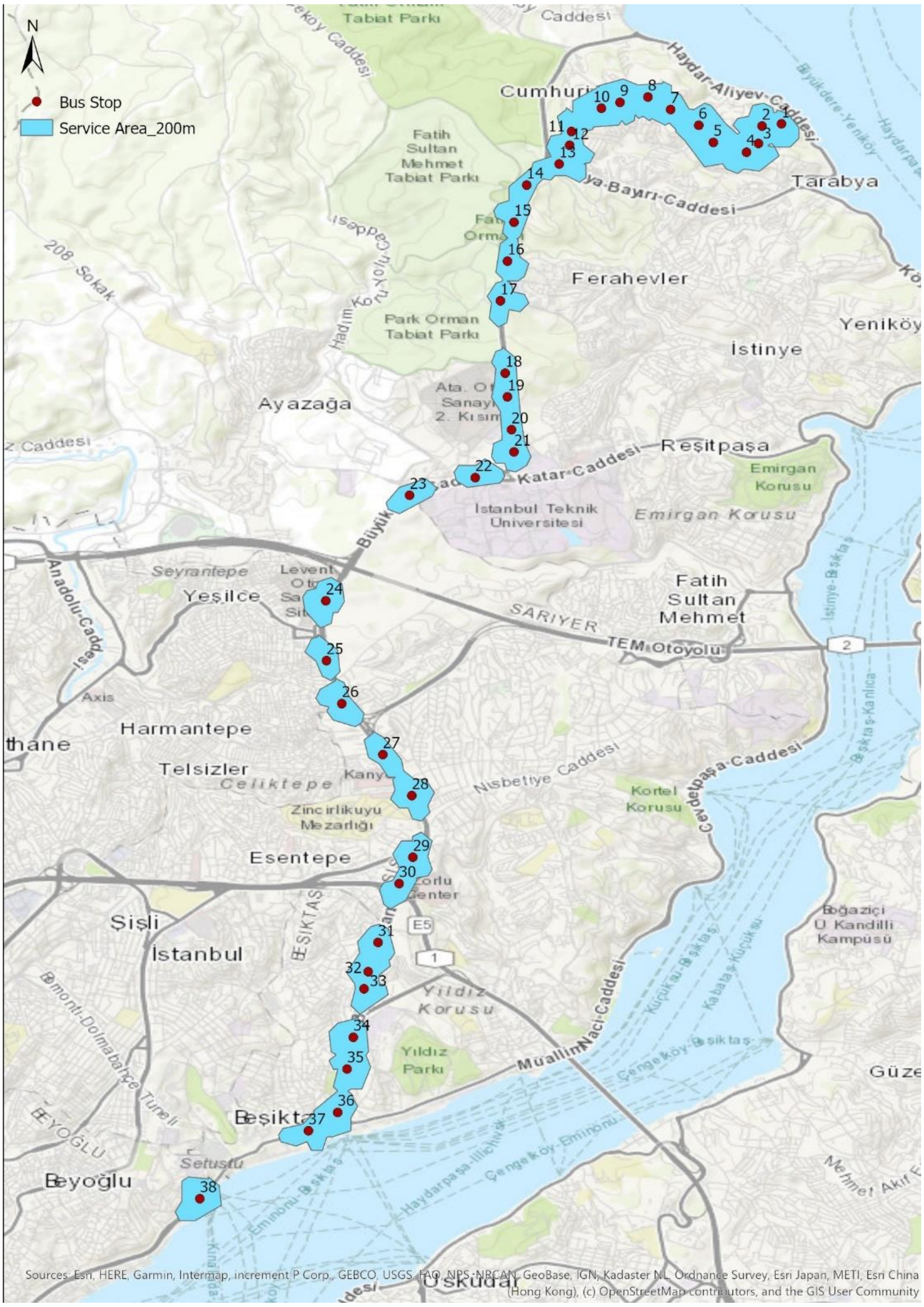


*Figure 4.11.* Merged Service Areas, 200m

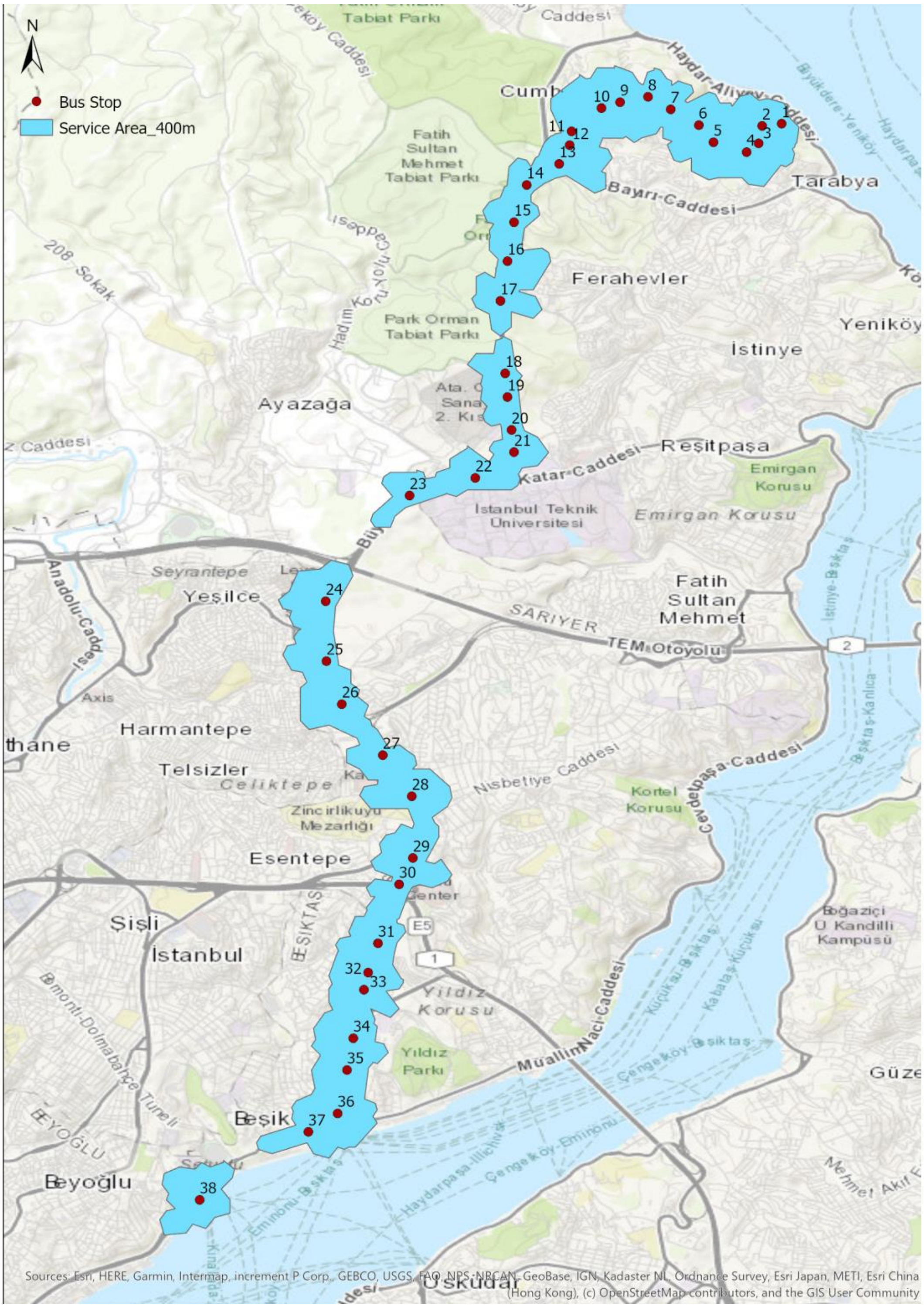


*Figure 4.12.* Merged Service Areas, 400m

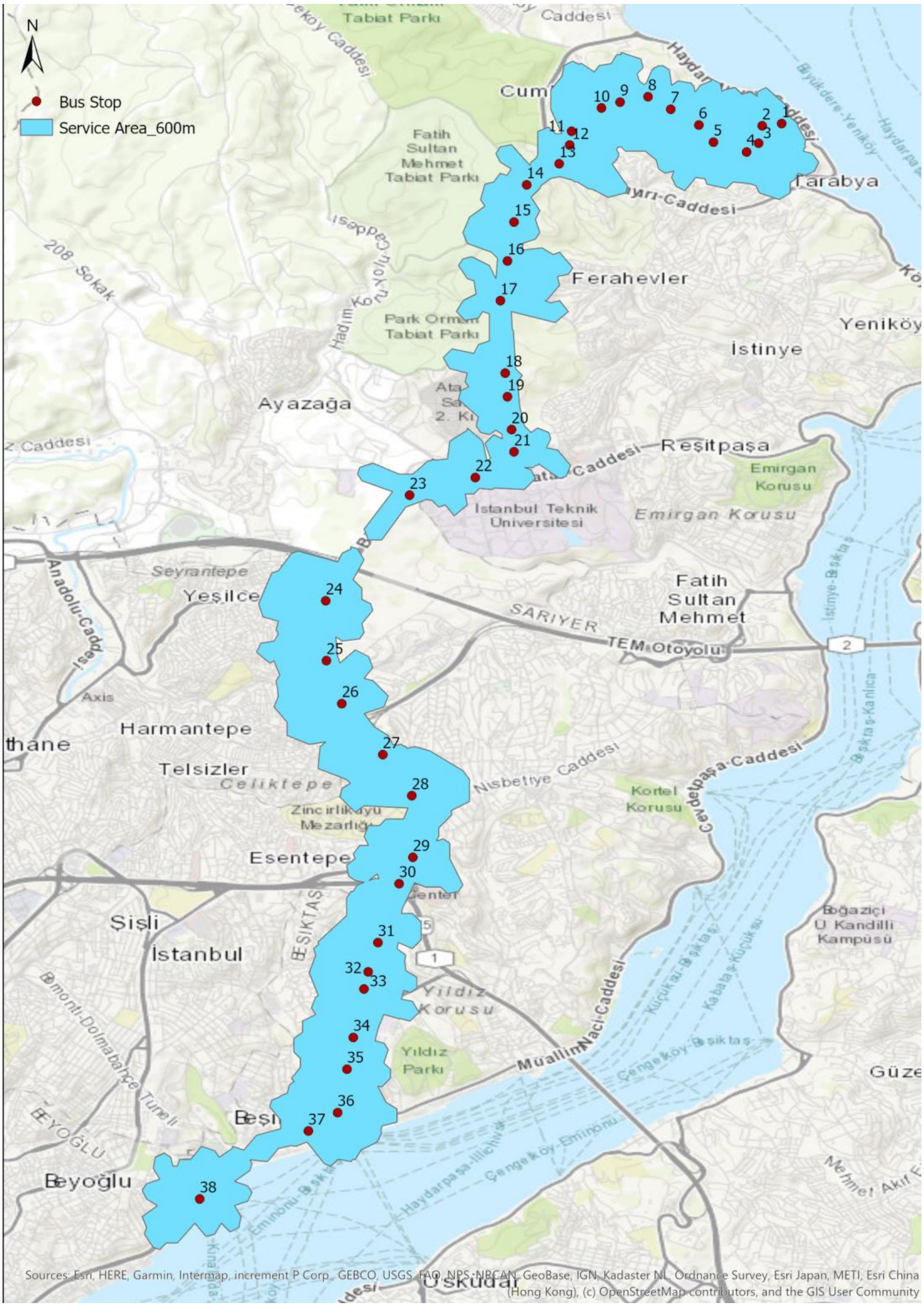


*Figure 4.13.* Merged Service Areas, 600m

Table 4.8. *Overlap in Service Areas*

| Service Area | Merged Area ($m^2$) | Total Area ($m^2$) | Population in the Merged Area | Population in the Total Area | Area Overlap (%) | Population Difference (%) |
|---|---|---|---|---|---|---|
| 200m | 3.642.611 | 4.592.413 | 45.528 | 56.814 | 20,68% | 19,86% |
| 400m | 7.264.710 | 12.561.836 | 95.484 | 160.473 | 42,17% | 40,50% |
| 600m | 11.422.188 | 24.670.350 | 156.526 | 464.518 | 53,70% | 66,30% |

In Table 4.8., the area overlap ratio is 20,68% in 200 meters, 42,17% in 400 meters and 53,70% in 600 meters. When the merged and the total area are compared, it is seen that the total population differs by 19,86% in 200 meters, 40,50% in 400 meters and 66,30% in 600 meters. It means that some of the bus stops serve the same population in some service areas which intersect with each other.

It is claimed in Section 2.6.3 that especially in city centers where the Central Business District(CBD) is placed, less distance between 2 stops is important for decrease the density and improve accessibility. As seen in Table 2.4., when the average walking time is defined as 75meters/minute, 200 meters take 2.6 minutes walking time which is mostly used in CBD. It is seen in Figure 4.11. that 200 meters of service areas do not cover the line well. There are many gaps on the line and the number of served population in these service areas are few in comparison with 400 and 600 meters. For 400 meters service area, it takes 6 minutes to reach the bus stop. This metric is mostly used in urban areas with high density. The coverage on the route is quite well compared to 200 and 600 meters. 600 meters takes 8 minutes of walking time that is used for urban areas with low density. In this line, coverage of 600 meters is well and nearly no gaps on the line. However, the 29C route passes dense residential areas and 8 minutes of walking time might cause passengers to decrease the attraction to this route. For these reasons, 400 meters of service area criteria is decided to be used in the next analysis.

For South Bound, North Bound and North and South Bound, 400 meters service and the buffer areas are calculated and the demographic parameters of the total population, Group A, Group B, Group C, Group D; Age Group 15-29, 30-44, 45-59, 60+ in these areas are measured. These areas are shown in Figures 4.9, 4.14 and 4.15.

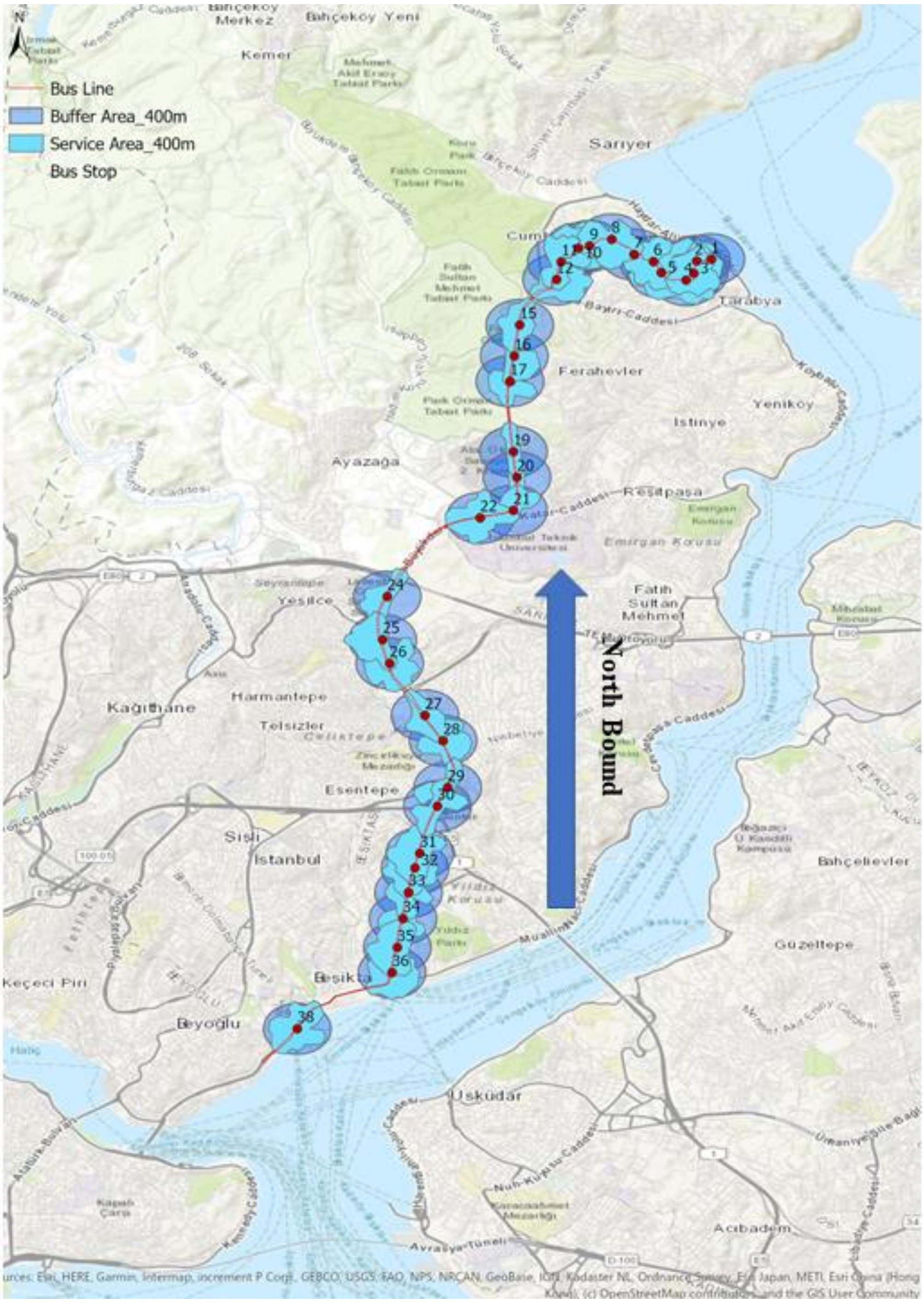


*Figure 4.14.* 400m Service and Buffer Area, North Bound

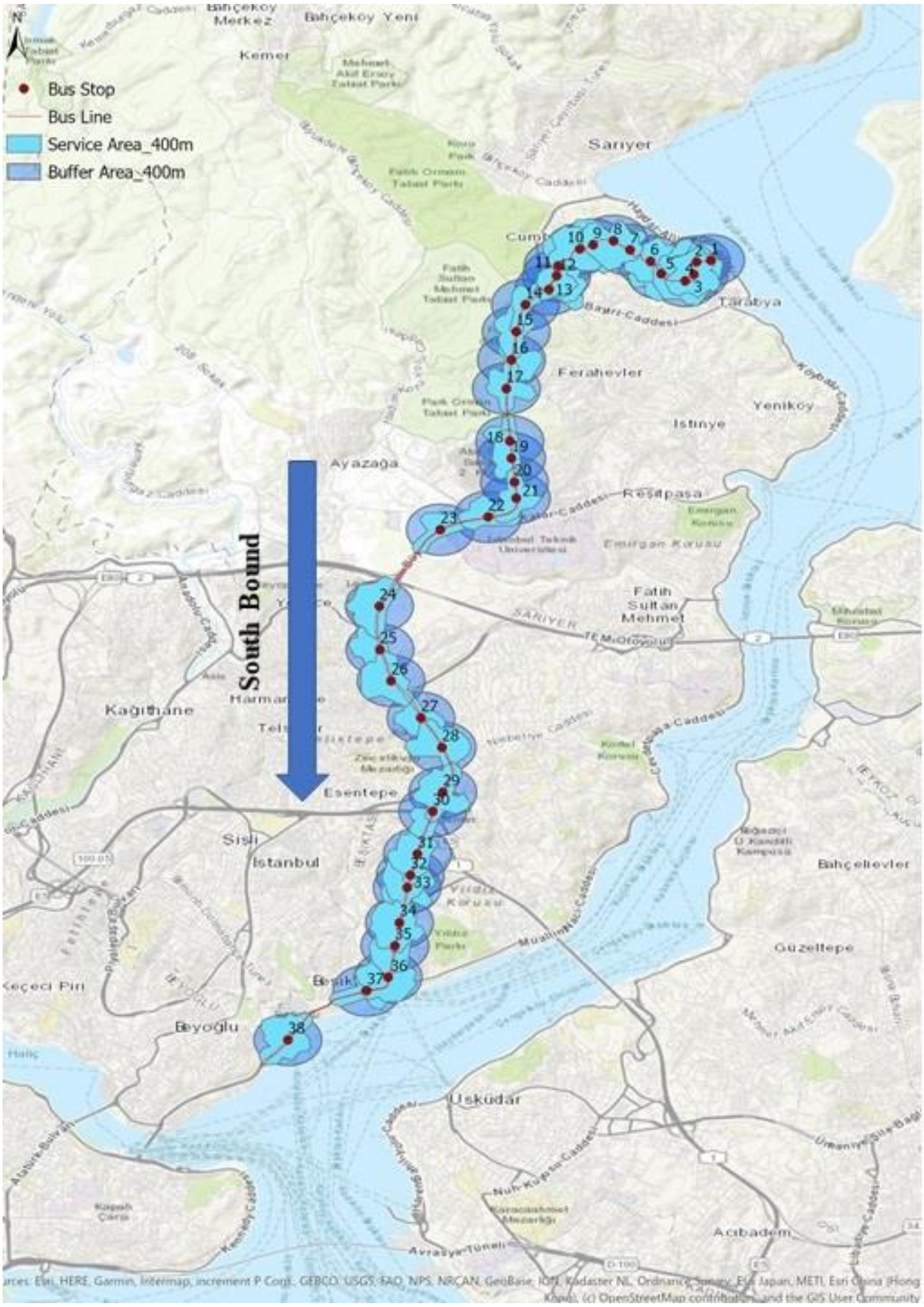


*Figure 4.15.* 400 m Service and Buffer Area, South Bound

After creating buffer areas south-and-north bound, arrival and departure stops, demographic data within these areas were examined. These data consist of population, socio-economic status (Groups A, B, C, and D), age breakdowns (15-29, 30-44, 45-49 and 60+). The total of the buffer areas is 19,02 kilometers square. The total number of populations of 38 stops in 400-meter buffer areas is 212.017. The total number of people in Group A is 48.458, Group B is 48.706, Group C is 40.640 and Group D is 28.015. Sum of age between 15-29 is 48.591, age 30-44 is 57.720, age 45-60 is 36306, age 60+ is 32.349.

The buffer area with the lowest population is the 15th stop and the highest is the 26th stop. Group A is the busiest area at the 26th stop and B, C and D groups at the 25th stop. The minimum population of Group A, B, C, and D is in the buffer area around the 15th stop. 15-29 and 30-44 age group is the most intense stop 21, 45-59 age group 22, 60+ 37 is located in the buffer area. The 15-29 and 30-44 age group is at the 12th stop, the 45-59 age group is 36, the 60 and over age group is located in the buffer area around the 12th stop. The average socio-economic population in the Buffer area is 1275, B 1281, C 1050 and D 743. The average number of persons aged 15-29 in the Buffer area is 1281, persons aged 30-44 are 1518, people aged 45-59 are 955 and people aged 60 and over are 851. The buffer areas of the stops mainly cover the population in the A and B groups. It densely includes the population between the ages of 30-44.

The whole results are included in Table 4.9.

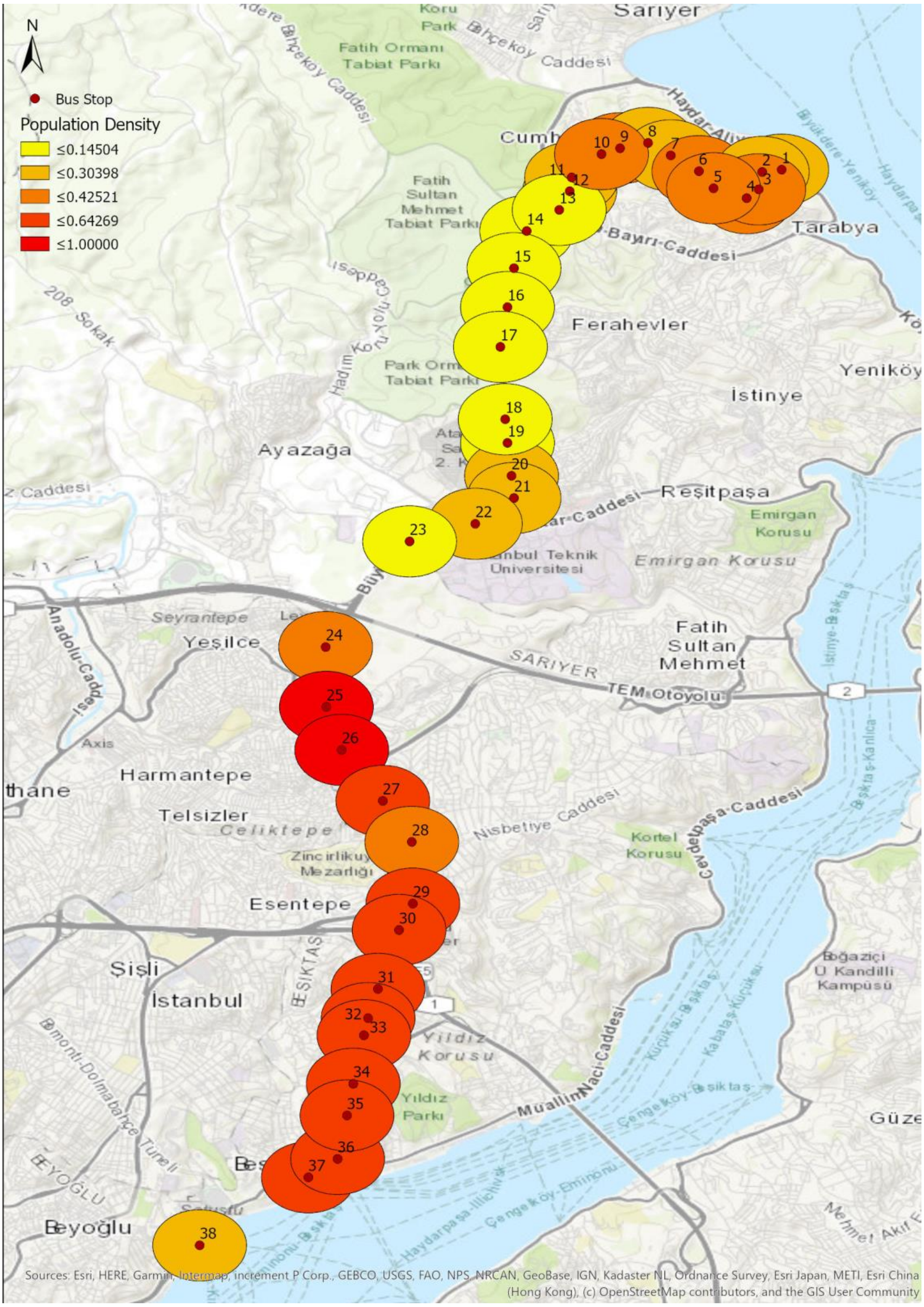


*Figure 4.16.* Buffer Area Analysis (400m)

Table 4.9. *Demographics in the Buffer Area*

| Stops | *Population.* | *GroupA* | *GroupB* | *GroupC* | *GroupD* | *Age 15-29* | *Age 30-44* | *Age 45-59* | *Age 60+* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3660 | 1174 | 875 | 702 | 357 | 789 | 500 | 601 | 564 |
| 2 | 4860 | 1679 | 1251 | 1005 | 512 | 812 | 1060 | 774 | 489 |
| 3 | 5682 | 1762 | 1311 | 1051 | 534 | 897 | 1172 | 855 | 540 |
| 4 | 5681 | 1699 | 1264 | 1013 | 513 | 1240 | 1623 | 1183 | 745 |
| 5 | 5715 | 1739 | 1294 | 1037 | 526 | 958 | 1254 | 913 | 575 |
| 6 | 5337 | 1701 | 1340 | 1081 | 596 | 1020 | 1336 | 973 | 613 |
| 7 | 4814 | 1215 | 1440 | 1197 | 944 | 1131 | 1481 | 1079 | 679 |
| 8 | 4518 | 642 | 1421 | 1178 | 1324 | 1204 | 1576 | 1149 | 723 |
| 9 | 5849 | 581 | 1920 | 1603 | 1648 | 2770 | 2611 | 1665 | 1550 |
| 10 | 6031 | 603 | 1945 | 1624 | 1665 | 239 | 304 | 208 | 126 |
| 11 | 4289 | 723 | 1333 | 1131 | 1071 | 579 | 753 | 551 | 350 |
| 12 | 3825 | 710 | 1047 | 881 | 761 | 174 | 223 | 144 | 82 |
| 13 | 2723 | 526 | 679 | 569 | 448 | 335 | 433 | 297 | 178 |
| 14 | 1077 | 173 | 312 | 238 | 182 | 341 | 443 | 310 | 189 |
| 15 | 773 | 113 | 229 | 165 | 124 | 610 | 774 | 456 | 233 |
| 16 | 1531 | 291 | 443 | 353 | 263 | 941 | 1211 | 748 | 401 |
| 17 | 1576 | 507 | 424 | 367 | 223 | 1124 | 1360 | 863 | 480 |
| 18 | 1621 | 294 | 480 | 298 | 194 | 970 | 917 | 582 | 341 |
| 19 | 2609 | 385 | 806 | 522 | 405 | 528 | 604 | 346 | 195 |
| 20 | 4141 | 501 | 1355 | 994 | 931 | 1410 | 1680 | 980 | 464 |
| 21 | 4763 | 580 | 1568 | 1195 | 1151 | 3640 | 3967 | 2338 | 1225 |
| 22 | 3417 | 414 | 1080 | 766 | 696 | 3566 | 3937 | 2435 | 1377 |
| 23 | 2081 | 403 | 558 | 396 | 266 | 1749 | 2237 | 1368 | 1024 |
| 24 | 5781 | 858 | 1728 | 1569 | 1366 | 1468 | 1943 | 1204 | 948 |
| 25 | 14218 | 2969 | 4006 | 3394 | 2944 | 1667 | 2170 | 1447 | 1194 |
| 26 | 14023 | 3525 | 2847 | 2351 | 1502 | 1843 | 2309 | 1505 | 1224 |
| 27 | 7471 | 782 | 599 | 490 | 307 | 1683 | 2016 | 1353 | 1260 |
| 28 | 6490 | 756 | 463 | 409 | 194 | 1789 | 2126 | 1476 | 1359 |
| 29 | 7447 | 1151 | 721 | 752 | 372 | 1712 | 2030 | 1422 | 1304 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 30 | 7905 | 1018 | 650 | 629 | 319 | 2162 | 2262 | 1473 | 1359 |
| 31 | 7262 | 2350 | 1445 | 1557 | 810 | 2727 | 2591 | 1518 | 1260 |
| 32 | 7745 | 2817 | 1846 | 1811 | 957 | 1278 | 1674 | 768 | 1359 |
| 33 | 7416 | 2701 | 1764 | 957 | 940 | 776 | 1016 | 466 | 1304 |
| 34 | 8125 | 2958 | 1824 | 1740 | 854 | 1030 | 1349 | 619 | 1359 |
| 35 | 9305 | 3309 | 2158 | 1856 | 899 | 1204 | 1577 | 723 | 1518 |
| 36 | 9414 | 2410 | 1785 | 1423 | 701 | 382 | 482 | 143 | 1550 |
| 37 | 9166 | 1958 | 1430 | 1123 | 512 | 1211 | 1586 | 727 | 1564 |
| 38 | 3676 | 481 | 1065 | 483 | 224 | 752 | 1133 | 644 | 644 |

After buffer areas, service areas of bus stops are created and south-and-north bound, arrival and departure stop, demographic data within these areas were examined. These data consist of population, socio-economic status (Groups A, B, C, and D), age breakdowns (15-29, 30-44, 45-49 and 60+) as of buffer areas. The total of the service areas is 12,15 kilometers square. The total number of populations of 38 stops in 400-meter service areas is 160.473. The total number of people Group A is 42.577, Group B is 39.039, Group C is 32.298 and Group D is 22.063. Sum of age between 15-29 is 35.163, Age 30-44 is 41.037, age 45-60 is 28.018, age 60+ is 19.978.

The service area with the lowest population is the 15th stop and the highest is the 25th stop. The maximum population of Group A is at the 34$^{th}$ stop, Group B, C, and D is at the 25th stop. The minimum population of Group A, B, C, and D is in the service area around the 15th stop.

The maximum number of Age Group 15-29, 30-44 and 45- 60 are included in the service area of stop 25, whereas the 60+ Age group is in Stop 35. The minimum population of 15-29, 30-44, 45-60 and 60+ plus are included in the service area of the 15$^{th}$ stop.

The average population in service areas is 4223. The average socio-economic population in the service area is 1120 of SES A, 1027 of SES B, 850 of SES C, and 580 of SES D. The average number of persons aged 15-29 in the service area is 925, persons aged 30-44 are 1079, persons aged 45-59 are 737 and people aged 60 and over are 525. The service areas of the stops mainly cover the population in the A and B groups. It densely includes the population between the ages of 30-44.

In Figure 4.10, service analysis of the bus stops is shown. Service areas of the bus stops are created and mapped according to total population density. As it is seen, stops 25 and 26 are densest service areas. Table 4.10 shows the demographic results of the service areas.

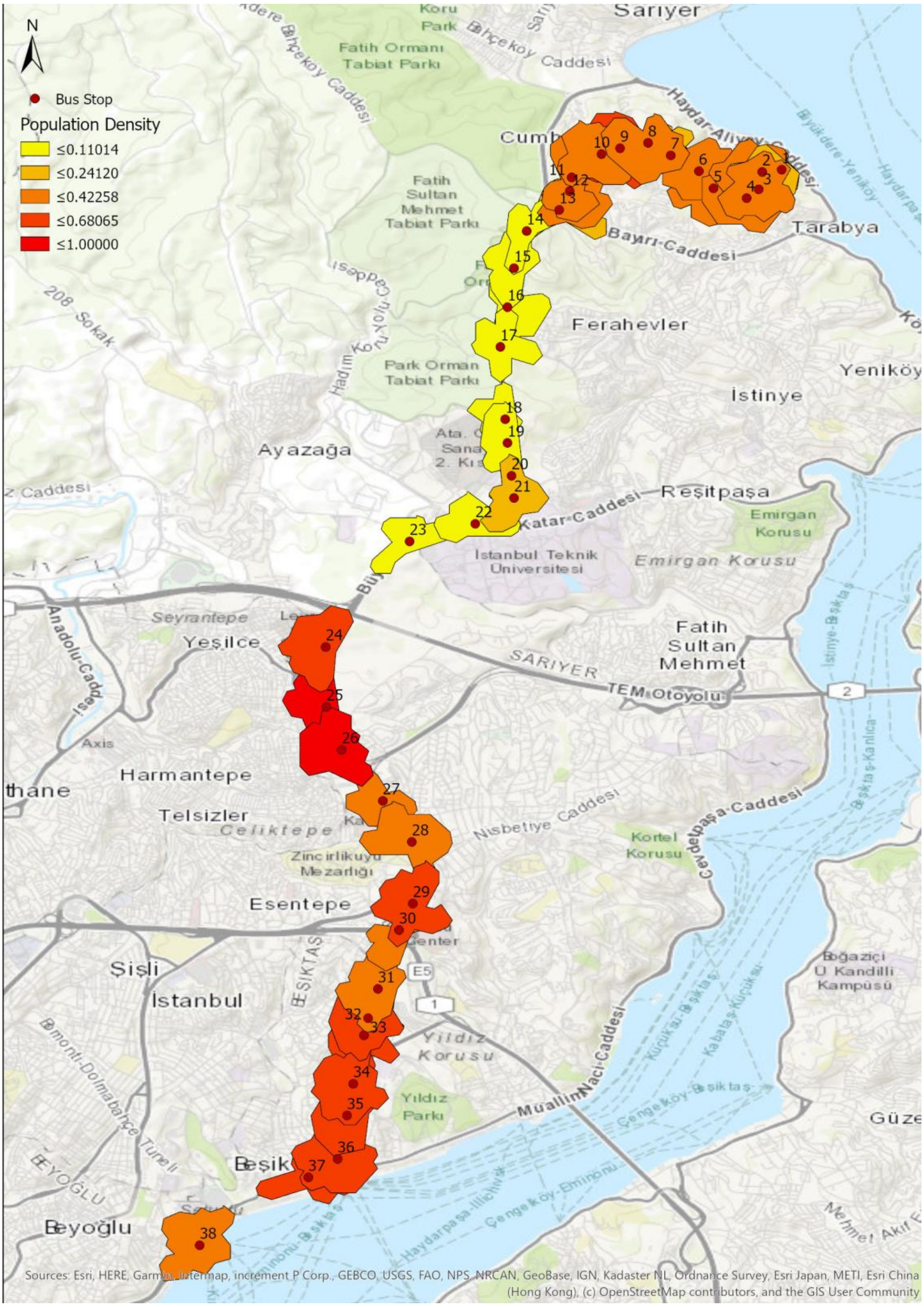


*Figure 4.17.* Service Area Analysis (400m)

Table 4.10. *Demographics in the Service Area, 400m*

| Stops | *Population* | *GroupA* | *GroupB* | *GroupC* | *GroupD* | *Age 15-29* | *Age30-44* | *Age 45-60* | *Age 60+* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2672 | 915 | 682 | 548 | 279 | 566 | 741 | 540 | 340 |
| 2 | 4412 | 1557 | 1161 | 932 | 476 | 935 | 1224 | 892 | 562 |
| 3 | 3994 | 1479 | 952 | 764 | 388 | 847 | 1108 | 808 | 508 |
| 4 | 4639 | 1407 | 1047 | 839 | 425 | 983 | 1287 | 938 | 590 |
| 5 | 5078 | 1871 | 1269 | 937 | 476 | 288 | 364 | 217 | 646 |
| 6 | 4518 | 1485 | 1164 | 939 | 514 | 958 | 1254 | 914 | 575 |
| 7 | 3206 | 670 | 916 | 750 | 610 | 679 | 890 | 648 | 408 |
| 8 | 4067 | 639 | 1209 | 1050 | 982 | 862 | 1129 | 822 | 518 |
| 9 | 5433 | 706 | 1742 | 1457 | 1506 | 1152 | 1508 | 1099 | 692 |
| 10 | 5064 | 337 | 1643 | 1368 | 1422 | 1073 | 1205 | 1024 | 645 |
| 11 | 3560 | 592 | 1064 | 891 | 954 | 754 | 989 | 700 | 476 |
| 12 | 3560 | 653 | 992 | 835 | 733 | 755 | 987 | 720 | 452 |
| 13 | 2218 | 426 | 560 | 470 | 373 | 471 | 614 | 449 | 285 |
| 14 | 749 | 129 | 206 | 162 | 122 | 164 | 209 | 147 | 92 |
| 15 | 589 | 94 | 186 | 131 | 89 | 134 | 171 | 109 | 61 |
| 16 | 1103 | 228 | 316 | 260 | 192 | 239 | 311 | 217 | 132 |
| 17 | 845 | 310 | 221 | 190 | 101 | 185 | 239 | 164 | 99 |
| 18 | 1232 | 289 | 360 | 232 | 147 | 288 | 364 | 217 | 113 |
| 19 | 1784 | 287 | 544 | 352 | 262 | 415 | 528 | 314 | 163 |
| 20 | 1557 | 206 | 504 | 370 | 339 | 352 | 454 | 283 | 153 |
| 21 | 2528 | 306 | 828 | 636 | 616 | 592 | 714 | 456 | 256 |
| 22 | 1612 | 193 | 509 | 344 | 301 | 444 | 443 | 274 | 154 |
| 23 | 1071 | 218 | 285 | 198 | 123 | 261 | 315 | 179 | 104 |
| 24 | 5487 | 899 | 1694 | 1457 | 1357 | 1352 | 1590 | 925 | 435 |
| 25 | 11439 | 2263 | 3272 | 2774 | 2484 | 2985 | 3177 | 1871 | 938 |
| 26 | 10582 | 2699 | 2107 | 1732 | 1083 | 2736 | 2966 | 1816 | 1003 |
| 27 | 4105 | 666 | 253 | 205 | 196 | 385 | 437 | 250 | 166 |
| 28 | 4957 | 1299 | 732 | 483 | 334 | 736 | 948 | 715 | 513 |
| 29 | 5687 | 1219 | 716 | 725 | 461 | 891 | 1360 | 796 | 600 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 30 | 4146 | 1963 | 891 | 973 | 303 | 1006 | 1242 | 765 | 686 |
| 31 | 5174 | 2563 | 1191 | 973 | 403 | 1206 | 1442 | 965 | 886 |
| 32 | 6077 | 2209 | 1365 | 1386 | 592 | 1304 | 1571 | 1053 | 965 |
| 33 | 5672 | 2350 | 1350 | 1306 | 598 | 1310 | 1556 | 1083 | 996 |
| 34 | 6773 | 2755 | 1579 | 1504 | 732 | 1857 | 1887 | 1220 | 1122 |
| 35 | 7118 | 2580 | 1856 | 1530 | 841 | 2123 | 1986 | 1256 | 1148 |
| 36 | 7974 | 1998 | 1494 | 1191 | 588 | 1373 | 1218 | 1407 | 899 |
| 37 | 6210 | 1252 | 918 | 725 | 342 | 1888 | 1708 | 1087 | 1038 |
| 38 | 3601 | 865 | 1261 | 679 | 319 | 614 | 901 | 678 | 559 |

Difference between service areas and the buffer areas play an important role in this analysis. As it is seen in Figure 4.9., there is a difference between the service area and the buffer area. The buffer area is calculated according to the bird flight distance and the service area is calculated according to the road network data, sometimes taking into account the time parameter.

In this analysis, the ratio of the service area to the buffer area varies between 34% and 92% according to the service and buffer areas created by the ArcGIS Network Analyst extension. The ratio of the total service area size to the total size of the buffer area is approximately 65,79%. The area where the service area is least is 172.889 m2 with 15th stop circumference and the biggest place is 460.335 m2 with 4th stop circumference. The buffer area is 502.488m2 and is the same size for all stops. As seen in Figure 4.10; The buffer areas at stops 1, 36, 37 and 38 cover the sea, although there are no pedestrian or motorways to reach there.

This is proof that the buffer areas are not a precise measurement of bus stop optimization. In Table 4.11., the demographic difference between service and the buffer areas are shown.

Table 4.11.*Demographic difference between Service and Buffer Areas*

| | *Population* | *Group A* | *Group B* | *Group C* | *Group D* | *Age 15-29* | *Age 30-44* | *Age 45-60* | *Age 60+* |
|---|---|---|---|---|---|---|---|---|---|
| Service to Buffer Area (%) | 75% | 87% | 80% | 80% | 78% | 72% | 71% | 77% | 61% |

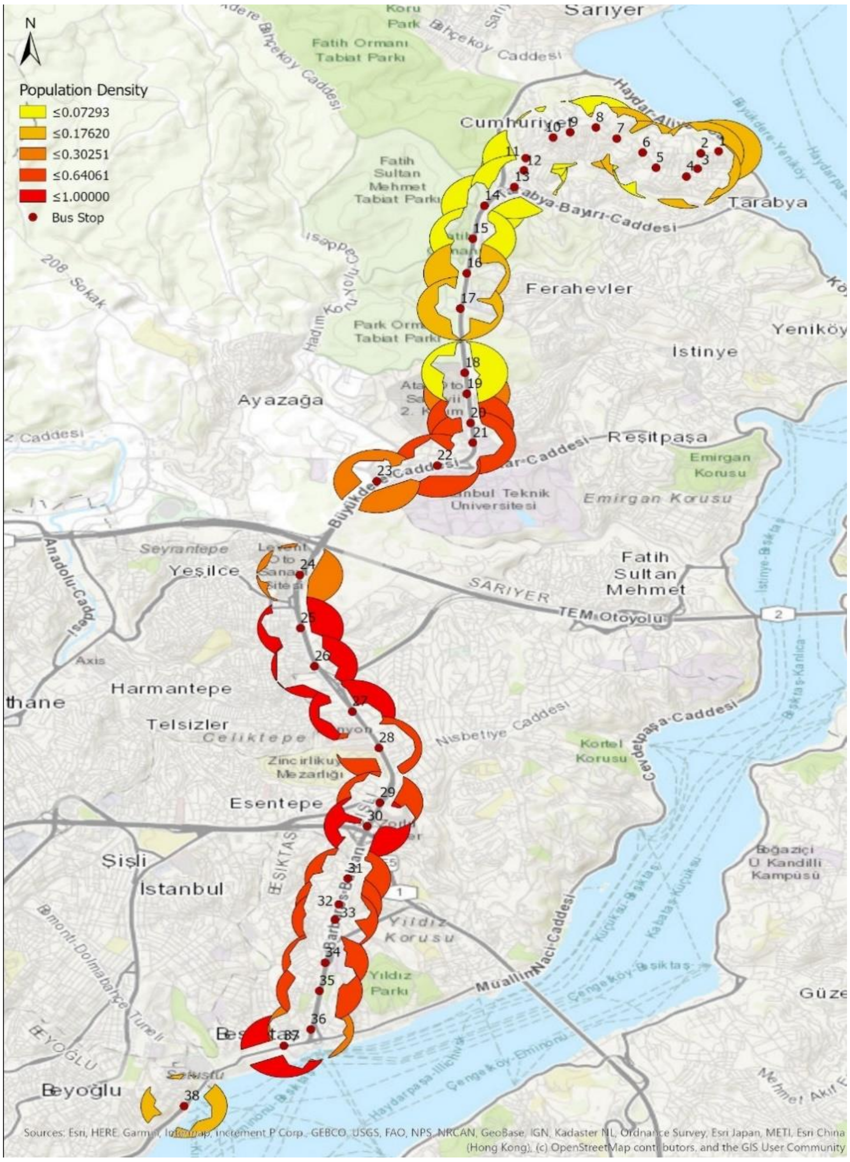


*Figure 4.18.* Difference Between Service and Buffer Area

The reason that the service area at the 16th stop is very small compared to the buffer area is that there is a natural park there as seen from the base map.

After examining the locations of the stops, neighborhoods, and districts, distances between stops, service area, buffer area and demographic differences between them, stop points were optimized with ArcGIS Network Analyst based on 400 meters walking distance. Accordingly, Figure 4.19. shows the available and optimized stopping points.

As a result of the optimization, 5 new stops were created. As can be seen in Figure 4.19; Stops 37 and 38 include N42 and N41; N35 is between stops 30 and 31; N31 is between stops 28 and 29, and N23 stops added between stops 23 and 24 are new stops added to the line. The locations of stops 6,7, 18-21 and 32-34 have not changed much.

As shown in Figure 4.20, the service areas of 400 meters walking distance around the optimized stops serve without any gaps on the line.

Accordingly, the population in these new service areas, SES (A, B, C, D), Age Groups (15-29, 30-44, 45-60 and 60+) were calculated and examined. The total of the service areas is 13,09 kilometers square. The total number of population of 38 stops in 400-meter service areas is 179.375. The total number of people Group A is 46.819, Group B is 46.398, Group C is 39.536 and Group D is 28.910. Sum of age between 15-29 is 42.434, Age 30-44 is 48.897, age 45-60 is 31.742, age 60+ is 23.235.

The service area with the lowest population is the 14th stop and the highest is the 26th stop. The maximum population of Group A is at the 26th stop, Group B, C, and D are at 15th stop. The minimum population of Group A is at 11th stop, Group B is at 22th, Group C and D are at 14th stop. The maximum population of the Age Groups 15-29, 30-44 and 45- 60 are age group are included in the service are of stop 26 whereas 60+ is in stop 39. The minimum population of 15-29, 30-44, 45-60 and 60+ plus are included in the service area of 14th stop. The average socio-economic population in the service area is 1088 of SES A, 1079 of SES B, 919 of SES C and 672 of SES D. The average number of persons aged 15-29 in the service area is 986, persons aged

30-44 are 1137, persons aged 45-59 are 738 and people aged 60 and over are 540. The service areas of the stops mainly cover the population in the A, B and C groups. It densely includes the population between the ages of 15-29 and 30-44.

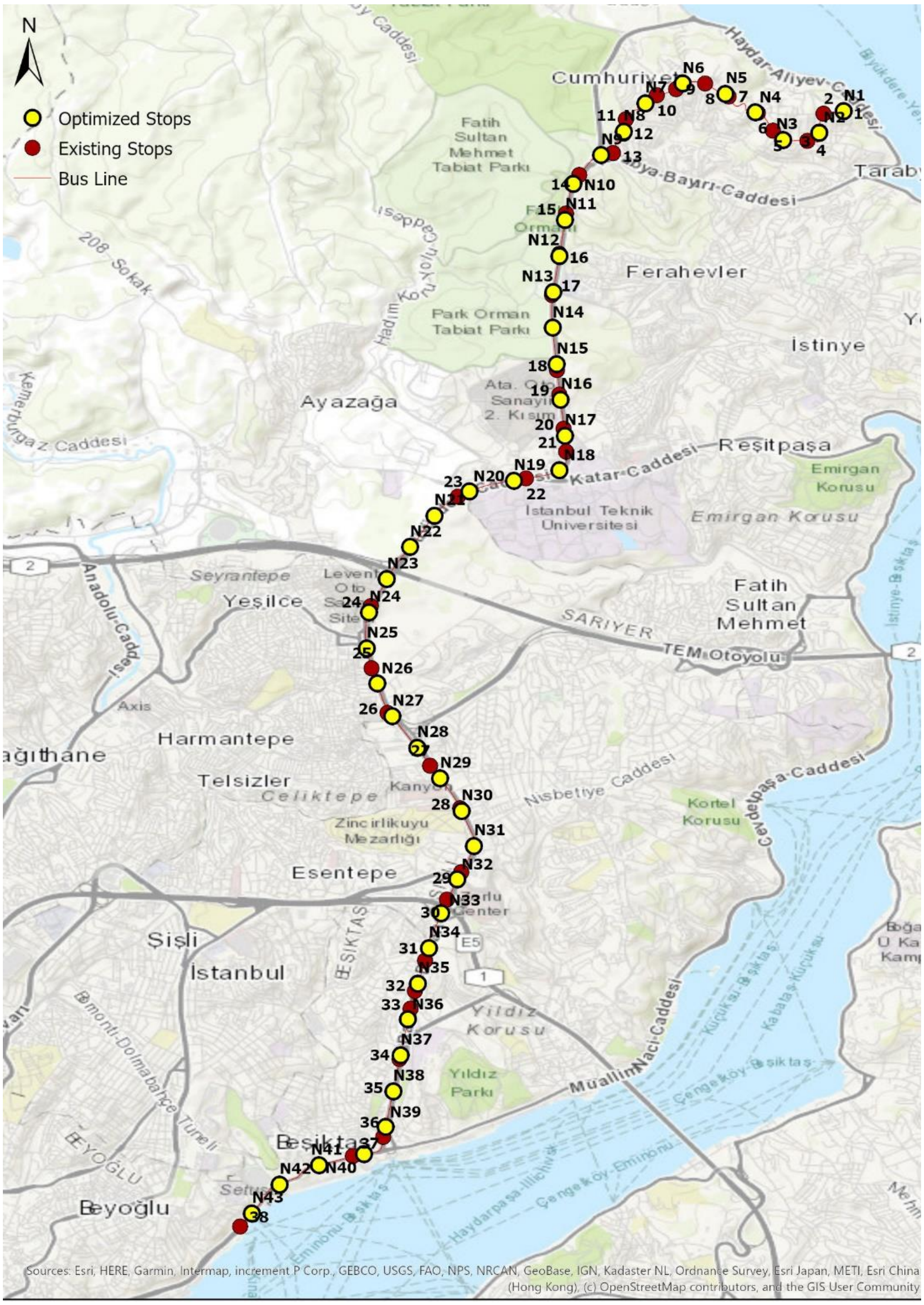


*Figure 4.19.* Optimized Stops

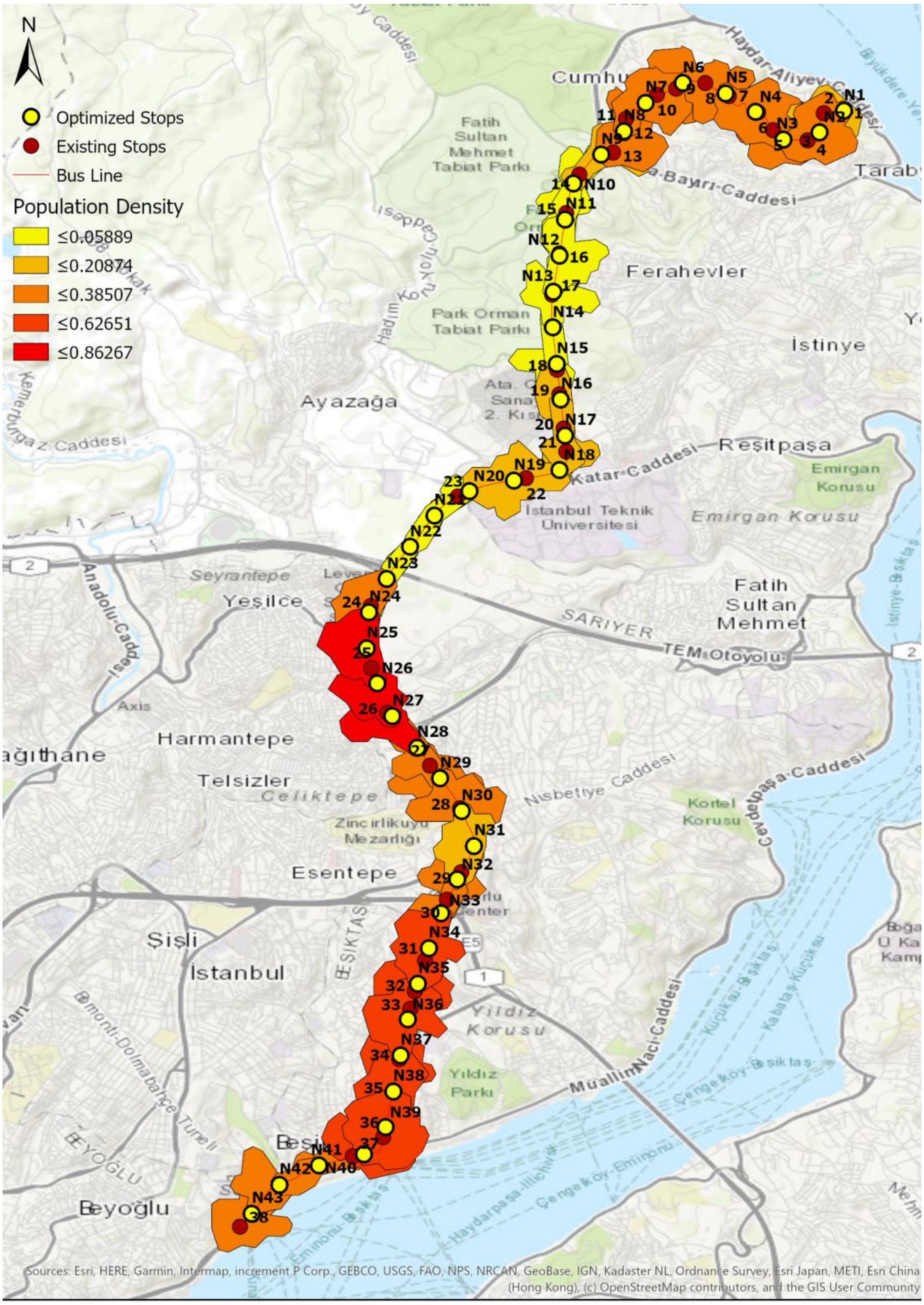


*Figure 4.20.* Population Density of Optimized Stops Service Area (400m)

Table 4.12. *Demographics of Optimized Stops*

| Stops | *Population* | *Group A* | *Group B* | *Group C* | *GroupD* | *Age 15-29* | *Age 30-44* | *Age 45-60* | *Age 60+* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2672 | 915 | 682 | 548 | 279 | 566 | 741 | 540 | 340 |
| 2 | 3853 | 1214 | 904 | 725 | 368 | 817 | 1069 | 779 | 490 |
| 3 | 5103 | 1553 | 1156 | 907 | 498 | 934 | 1223 | 891 | 561 |
| 4 | 4406 | 1432 | 1125 | 907 | 498 | 934 | 1223 | 891 | 561 |
| 5 | 3293 | 723 | 990 | 818 | 696 | 698 | 914 | 666 | 419 |
| 6 | 4939 | 508 | 1626 | 1366 | 1386 | 1047 | 1371 | 999 | 629 |
| 7 | 4346 | 449 | 1423 | 1191 | 1222 | 921 | 1206 | 879 | 553 |
| 8 | 3596 | 651 | 1027 | 866 | 771 | 763 | 997 | 727 | 458 |
| 9 | 1740 | 322 | 465 | 388 | 316 | 371 | 481 | 351 | 223 |
| 10 | 653 | 104 | 194 | 150 | 116 | 145 | 183 | 126 | 78 |
| 11 | 523 | 74 | 155 | 107 | 79 | 119 | 152 | 96 | 53 |
| 12 | 1105 | 229 | 317 | 262 | 194 | 239 | 310 | 218 | 133 |
| 13 | 928 | 338 | 244 | 210 | 113 | 203 | 262 | 181 | 109 |
| 14 | 368 | 100 | 102 | 71 | 38 | 84 | 107 | 67 | 37 |
| 15 | 1174 | 242 | 342 | 221 | 138 | 274 | 347 | 207 | 108 |
| 16 | 1623 | 263 | 499 | 335 | 260 | 375 | 478 | 288 | 151 |
| 17 | 1684 | 203 | 551 | 403 | 378 | 382 | 491 | 305 | 165 |
| 18 | 2226 | 271 | 728 | 547 | 521 | 552 | 626 | 398 | 225 |
| 19 | 2442 | 294 | 769 | 532 | 474 | 697 | 656 | 414 | 241 |
| 20 | 923 | 177 | 254 | 176 | 117 | 230 | 268 | 155 | 92 |
| 21 | 744 | 195 | 182 | 139 | 72 | 163 | 224 | 126 | 81 |
| 22 | 449 | 149 | 98 | 89 | 39 | 97 | 138 | 76 | 47 |
| 23 | 820 | 273 | 180 | 163 | 72 | 173 | 251 | 139 | 89 |
| 24 | 5128 | 808 | 1559 | 1339 | 1255 | 1272 | 1477 | 860 | 412 |
| 25 | 10473 | 1509 | 3285 | 2812 | 2786 | 2714 | 2924 | 1721 | 852 |
| 26 | 12713 | 3250 | 3160 | 2628 | 1962 | 3315 | 3531 | 2081 | 1063 |
| 27 | 11833 | 2796 | 2485 | 2056 | 1444 | 2094 | 3295 | 2058 | 1111 |
| 28 | 4866 | 699 | 445 | 364 | 175 | 607 | 644 | 173 | 217 |
| 29 | 5414 | 1540 | 1333 | 1270 | 927 | 1284 | 1632 | 989 | 751 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 30 | 4798 | 1351 | 1135 | 988 | 836 | 1072 | 1439 | 887 | 701 |
| 31 | 3758 | 1185 | 985 | 892 | 731 | 855 | 1108 | 717 | 576 |
| 32 | 5031 | 1460 | 1220 | 1212 | 1007 | 1182 | 1474 | 955 | 770 |
| 33 | 3890 | 1082 | 871 | 859 | 686 | 929 | 1113 | 720 | 566 |
| 34 | 5628 | 1815 | 1242 | 1296 | 820 | 1230 | 1487 | 1045 | 934 |
| 35 | 6202 | 2339 | 1502 | 1528 | 749 | 1233 | 1507 | 974 | 887 |
| 36 | 5602 | 2157 | 1374 | 1377 | 626 | 1294 | 1539 | 1065 | 983 |
| 37 | 5833 | 2083 | 1306 | 1242 | 607 | 1577 | 1624 | 1054 | 970 |
| 38 | 7118 | 2522 | 1772 | 1547 | 849 | 2123 | 1886 | 1256 | 1148 |
| 39 | 8557 | 2923 | 2309 | 1965 | 1256 | 2536 | 2378 | 1511 | 1399 |
| 40 | 7259 | 2374 | 1818 | 1526 | 945 | 2180 | 2003 | 1276 | 1206 |
| 41 | 4809 | 1360 | 1176 | 1042 | 775 | 1259 | 1089 | 837 | 857 |
| 42 | 6307 | 1789 | 1712 | 1454 | 1108 | 1828 | 1708 | 1129 | 1148 |
| 43 | 4546 | 1098 | 1526 | 1018 | 721 | 1066 | 1321 | 915 | 841 |

Differences between existing and optimized stops are measured and compared. Accordingly, a 4.6% growth was observed in the area served by the optimization of stops. An increase of 10.54% in the population, 9.06% in Group A, 15.86% in Group B, 18.31% in Group C, and 23.68% in Group C were measured in these areas. An increase of 17.13% in the 15-29 age group, 16% in the 30-44 age group, 11.73% in the 07, 45-60 age group and 14% in the 60+ age group is observed.

According to percentage increment, most common changes are seen in Group C and Age Group 15-29 whereas it is numerically seen in Group B and Age Group 30-44 (Table 4.13.)

Table 4.13. *Difference between Existing and Optimized Stops*

| Factors | *Existing* | *Optimized* | *Increment (%)* |
|---|---|---|---|
| Population | 160.473 | 179.375 | 10,54 |
| Group A | 42.577 | 46.819 | 9,06 |
| Group B | 39.039 | 46.398 | 15,86 |
| Group C | 32.298 | 39.536 | 18,31 |

| | | | |
|---|---|---|---|
| Group D | 22.063 | 28.910 | 23,68 |
| Age 15-29 | 35.163 | 42.434 | 17,13 |
| Age 30-44 | 41.037 | 48.897 | 16,07 |
| Age 45-60 | 28.018 | 31.742 | 11,73 |
| Age 60+ | 19.978 | 23.235 | 14,02 |
| Service Area | 12.561.836 | 13.094.876 | 4,60 |

Accordingly, when an investigation is made according to population and land use, it has been observed in the study carried out considering the walking distance of 400 meters that 5 additional stops should be added to 38 stops on the existing 29C line. Thus, a significant change is observed in the number of populations served by the line.

**4.3.2. Analysis Based on Ridership**

As mentioned in the literature review, boarding data is one of the important that data used in some studies in terms of stop optimization. In this analysis, passengers boarding data was used to analyze the demands of passengers using these bus stops.

Data, obtained from IETT, have daily ridership start from 5 am to 9 pm. Data is determined by two classifications. Firstly, data is classified by two-hour intervals: 5-7 am, 7-9 am, 9-11 am, 11 am-1 pm, 1-3 pm, 3-5 pm, 5-7 pm and 7-9 pm for south bound and north bound. Passengers of bus stops are calculated by this interval. Figure 4.21 shows the peak hours of the bus stops of south bound.

As shown in Figure 4.21, for south bound, the maximum number of ridership is between 7 am-9 am and 9 am-11 am, respectively. The minimum number of ridership is between 5 pm-7 pm. Bus stop 11 has the lowest number of ridership, stop 19 and 15 follow it. Bus Stop 4 has the highest number of ridership, stop 30 and 9 follow it.

In Figure 4.22, for north bound, it is seen that the maximum number of ridership is between 1 pm-3 pm and 3 pm-5 pm. The minimum number of ridership is between 5 am-7 am. Bus stop 36 has the highest number of ridership whereas stop 8 has the lowest in north bound.

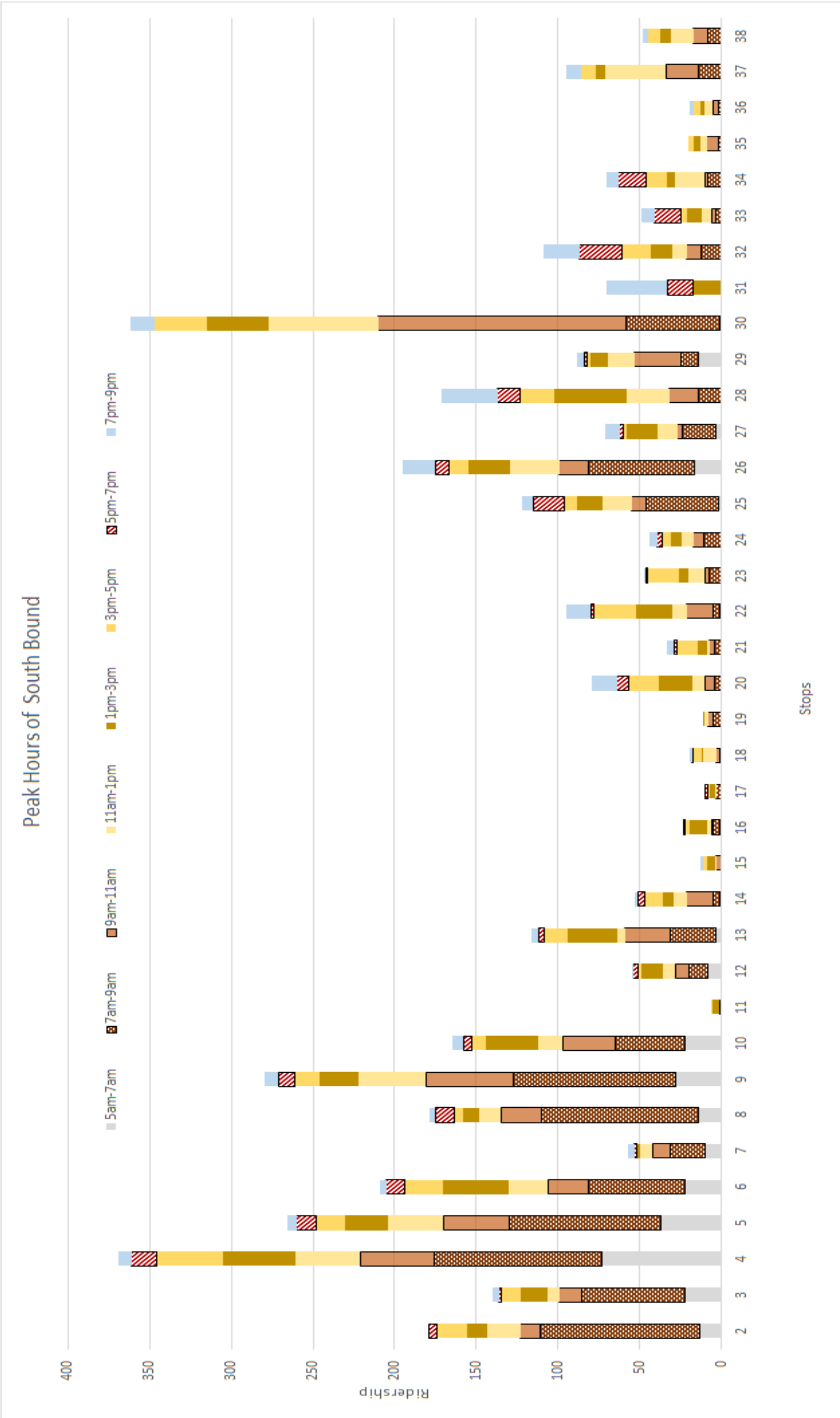


*Figure 4.21.* Ridership of two hours interval-South Bound

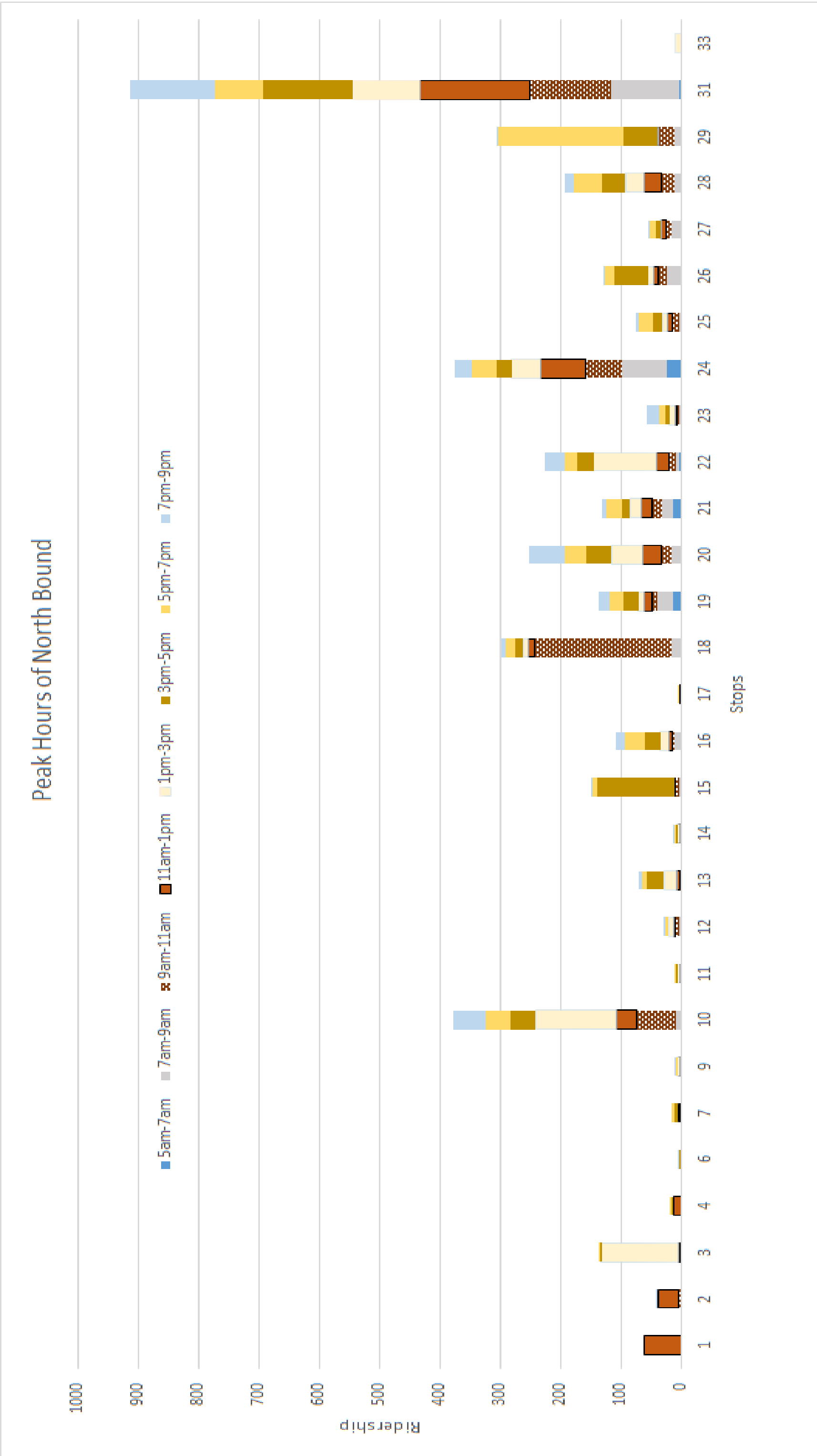


*Figure 4.22.* Ridership of two hours interval-North Bound

For north and south bound, seen in Figure 4.23, the sum of north bound and south bound data is similar to each other. For instance, bus stop 5, 26, 27, 28, 29, 30, 31, 32, 33 and 34 have close ridership for north bound and south bound. In some stops, south bound ridership is bigger than the north bound. It is easily seen that in Stop 2, for example, although south bound ridership is 179, north bound ridership is zero. This situation is same for bus stops between 3- 10, 13, 14, 15, 18, 22, 25, 29, 37 and 38. In some stops, however, north bound ridership is bigger than the south bound. For instance, in stop 12, North bound ridership is 379 whereas south bound is 55. It is same for bus stop 16, 17, 19, 20, 21, 23,24, 26,27, 28, 30, 31, 32, 33, 34, 35, and 36.

According to sum of ridership for north and-south bound, bus stop 36 has the highest value of 933, on the contrary, bus stop 7 has the lowest value of 18.

The maximum difference between north bound and south bound ridership is at the bus stop 36, which has 19 of south bound and 914 of north bound. On the contrary, the minimum difference between north and south bound is at the bus stop 19, which has 11 of south, 12 of north bound.

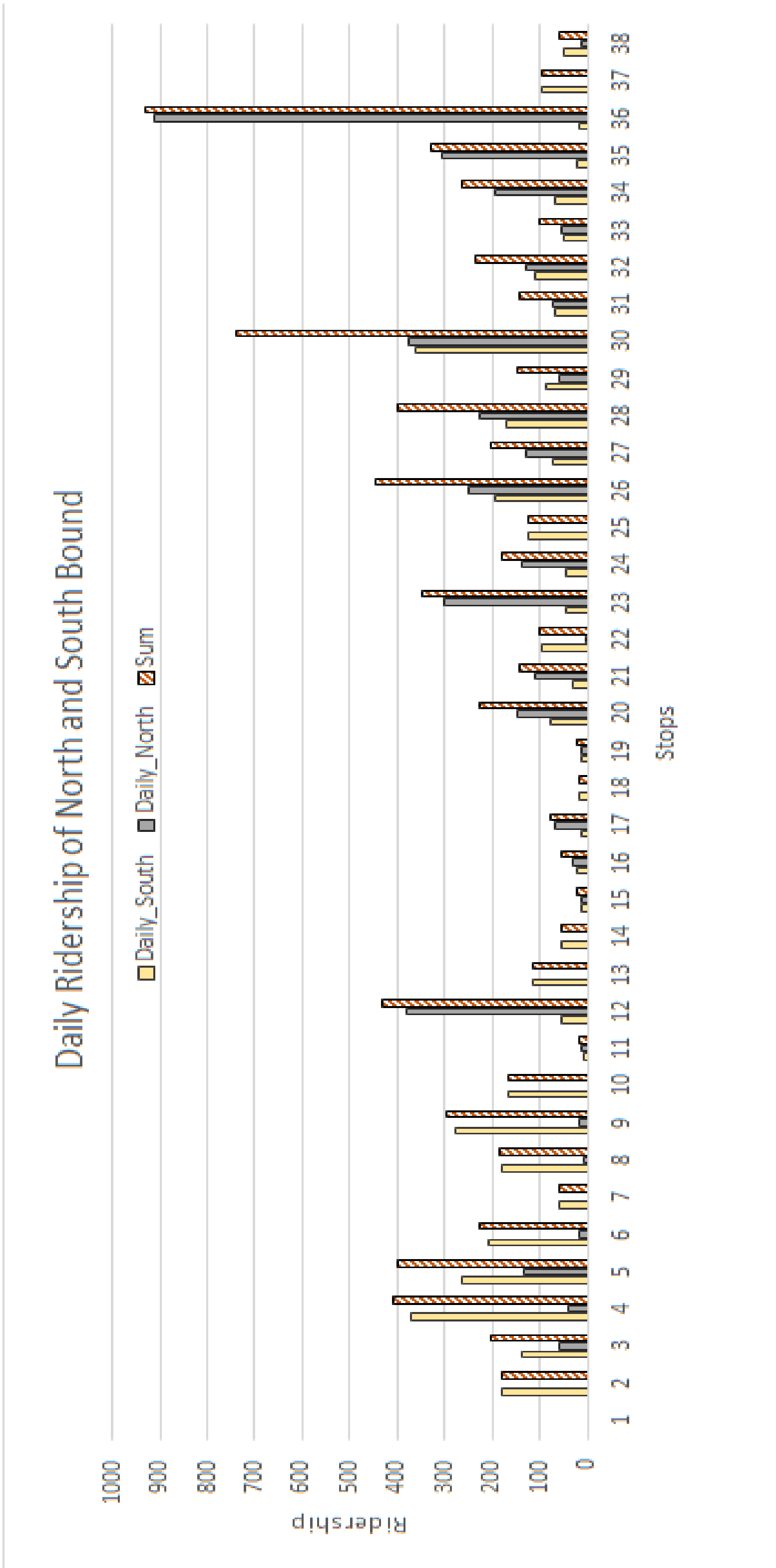


*Figure 4.23.* Daily Ridership of South and North Bound

The data was re-examined by dividing it into half-hour intervals for 5 am-11 am and 5 pm-9 pm for both south and north bound. At half-hour intervals, the intervals at which the number of ridership were concentrated were examined in detail for south bound and north bound.

As seen in Figure 4.24, for south bound, the highest ridership is between 8 am-8.30 am with the number of 292 and lowest ridership is between 5 am-5.30 am with the number of 24.

In Figure 4.25, for north bound, the highest ridership is between 9.30 am-10 am with number of 199 whereas the lowest ridership is between 7 am-7.30 am with the number of 21.

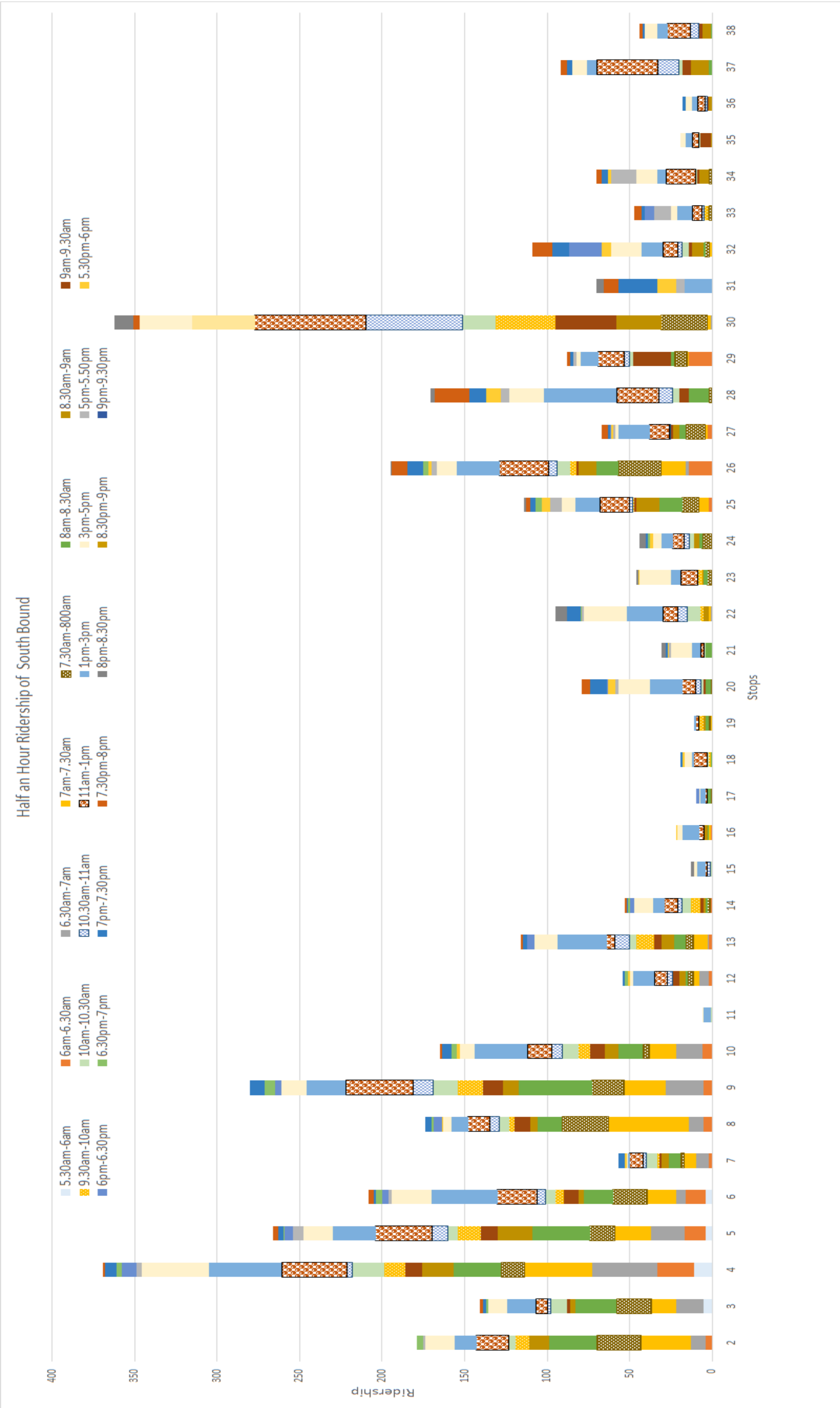


*Figure 4.24.* Half an hour Ridership, South Bound


*Figure 4.25.* Half an Hour Ridership, North Bound

After the peak hour analysis, the relationship between population and ridership is examined. ArcGIS Network Analyst extension was used to create 400 meters walking distance service areas. After that, ArcGIS Business analyst application- suitability analysis tool was used to define the areas where the population is high and ridership was low. Population and south bound ridership are weighted as %50 and %50 in this analysis. To measure the lowest ridership in high dense population area, ridership was chosen as an inverse impact as it is seen in Figure 4.26.

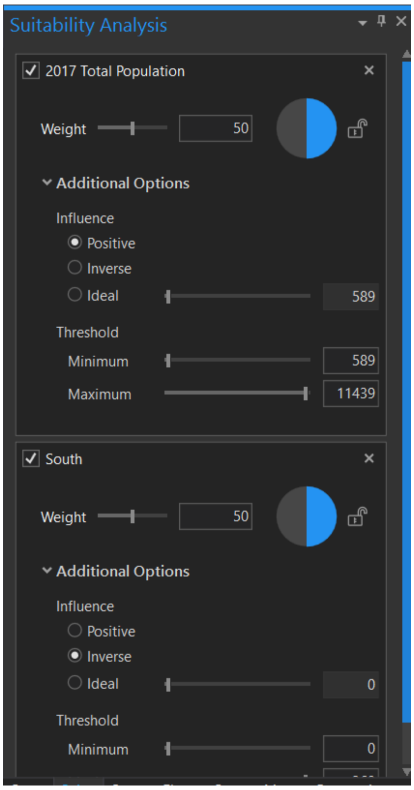


*Figure 4.26.* Business Analyst Suitability Analysis Box

The demographic results are seen in Figure 4.27. Weighted score calculations mentioned in section 3.1.1.4. is used to identify the maximum population to minimum ridership for both north bound, south bound and north and south bound of each bus stop. According to south bound results, final score changes from 0,17 to 0,83. Bus Stop 30 has the final score of 0, 17 where the amount of ridership is quite balanced with the amount of the population living in that service area. On the other hand, Bus

Stop 25 has the final score of 0,83 where the amount of ridership is very low compared to the population living in the service area. In Figure 4.28., the south bound density map generated according to the final score is shown.

| Bus Stop | South Bound Ridership | Total Population | Score of Total Population | Weighted Score of Total Population | Score of South Ridership | Weighted Score of South Ridership | Final Score |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 2672 | 0,19 | 0,10 | 1,00 | 0,50 | 0,60 |
| 2 | 179 | 4412 | 0,35 | 0,18 | 0,51 | 0,26 | 0,43 |
| 3 | 140 | 3994 | 0,31 | 0,16 | 0,62 | 0,31 | 0,47 |
| 4 | 369 | 4639 | 0,37 | 0,19 | 0,00 | 0,00 | 0,19 |
| 5 | 266 | 5078 | 0,41 | 0,21 | 0,28 | 0,14 | 0,35 |
| 6 | 209 | 4518 | 0,36 | 0,18 | 0,43 | 0,22 | 0,40 |
| 7 | 57 | 3206 | 0,24 | 0,12 | 0,85 | 0,42 | 0,54 |
| 8 | 179 | 4067 | 0,32 | 0,16 | 0,51 | 0,26 | 0,42 |
| 9 | 280 | 5433 | 0,45 | 0,22 | 0,24 | 0,12 | 0,34 |
| 10 | 165 | 5064 | 0,41 | 0,21 | 0,55 | 0,28 | 0,48 |
| 11 | 6 | 3560 | 0,27 | 0,14 | 0,98 | 0,49 | 0,63 |
| 12 | 55 | 3560 | 0,27 | 0,14 | 0,85 | 0,43 | 0,56 |
| 13 | 116 | 2218 | 0,15 | 0,08 | 0,69 | 0,34 | 0,42 |
| 14 | 53 | 749 | 0,01 | 0,01 | 0,86 | 0,43 | 0,44 |
| 15 | 13 | 589 | 0,00 | 0,00 | 0,96 | 0,48 | 0,48 |
| 16 | 23 | 1103 | 0,05 | 0,02 | 0,94 | 0,47 | 0,49 |
| 17 | 10 | 845 | 0,02 | 0,01 | 0,97 | 0,49 | 0,50 |
| 18 | 19 | 1232 | 0,06 | 0,03 | 0,95 | 0,47 | 0,50 |
| 19 | 11 | 1784 | 0,11 | 0,06 | 0,97 | 0,49 | 0,54 |
| 20 | 79 | 1557 | 0,09 | 0,04 | 0,79 | 0,39 | 0,44 |
| 21 | 33 | 2508 | 0,18 | 0,09 | 0,91 | 0,46 | 0,54 |
| 22 | 95 | 1612 | 0,09 | 0,05 | 0,74 | 0,37 | 0,42 |
| 23 | 47 | 1071 | 0,04 | 0,02 | 0,87 | 0,44 | 0,46 |
| 24 | 44 | 5487 | 0,45 | 0,23 | 0,88 | 0,44 | 0,67 |
| 25 | 122 | 11439 | 1,00 | 0,50 | 0,67 | 0,33 | 0,83 |
| 26 | 195 | 10582 | 0,92 | 0,46 | 0,47 | 0,24 | 0,70 |
| 27 | 71 | 4105 | 0,32 | 0,16 | 0,81 | 0,40 | 0,57 |
| 28 | 171 | 4957 | 0,40 | 0,20 | 0,54 | 0,27 | 0,47 |
| 29 | 88 | 5687 | 0,47 | 0,23 | 0,76 | 0,38 | 0,62 |
| 30 | 362 | 4146 | 0,33 | 0,16 | 0,02 | 0,01 | 0,17 |
| 31 | 70 | 5174 | 0,42 | 0,21 | 0,81 | 0,41 | 0,62 |
| 32 | 109 | 6077 | 0,51 | 0,25 | 0,70 | 0,35 | 0,61 |
| 33 | 49 | 5672 | 0,47 | 0,23 | 0,87 | 0,43 | 0,67 |
| 34 | 70 | 6773 | 0,57 | 0,28 | 0,81 | 0,41 | 0,69 |
| 35 | 20 | 7118 | 0,60 | 0,30 | 0,95 | 0,47 | 0,77 |
| 36 | 19 | 7974 | 0,68 | 0,34 | 0,95 | 0,47 | 0,81 |
| 37 | 95 | 6210 | 0,52 | 0,26 | 0,74 | 0,37 | 0,63 |
| 38 | 48 | 3601 | 0,28 | 0,14 | 0,87 | 0,43 | 0,57 |

*Figure 4.27.* Population vs. Ridership Scores at Bus Stops of South Bound

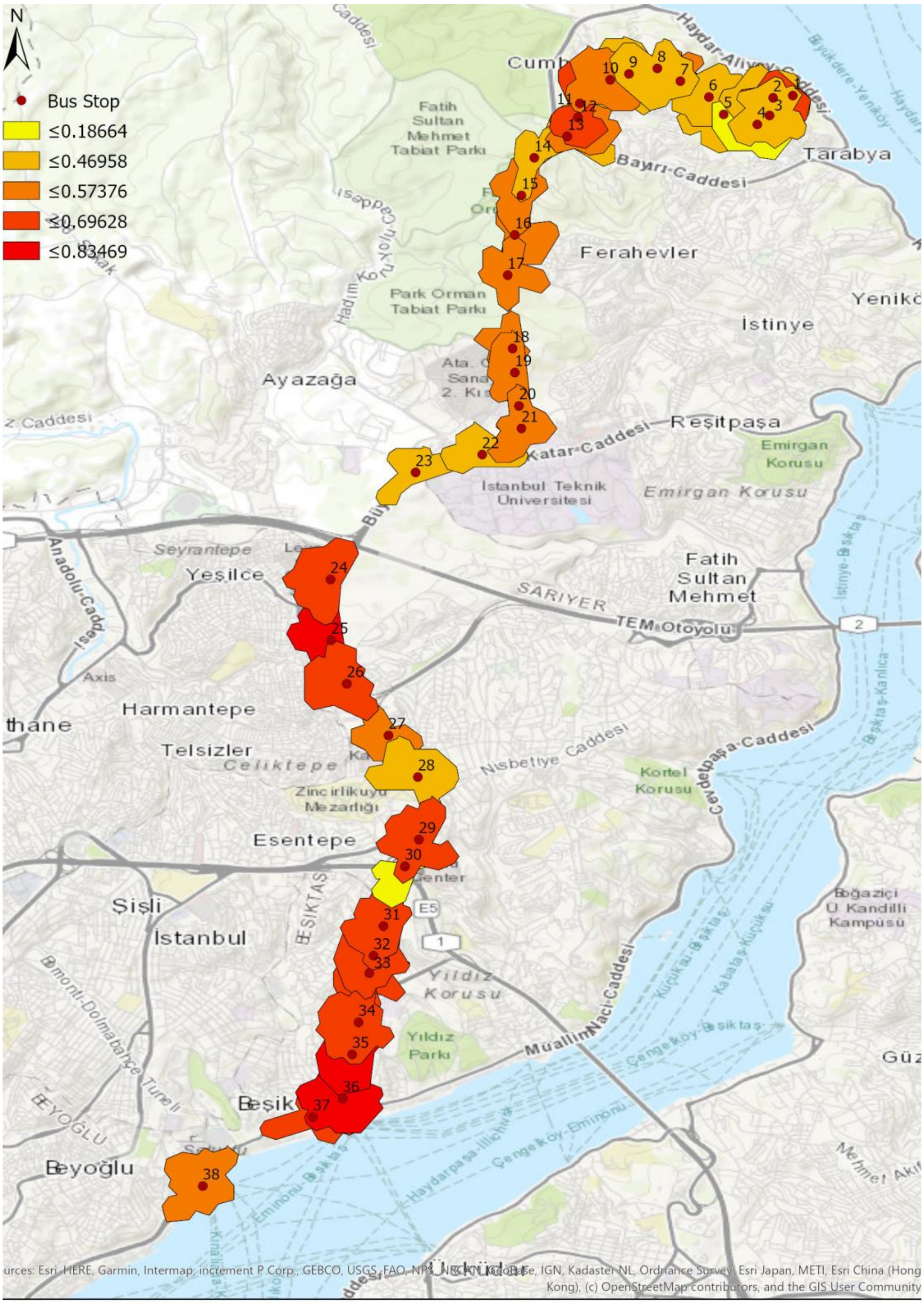


*Figure 4.28.* Maximum Population, Minimum Ridership Density Maps, South Bound

According to north bound results, seen in Figure 4.29., the final score changes from 0,30 to 1,00. Bus Stop 32 has the final score of 0,30 where the amount of ridership is quite balanced with the amount of the population living in that service area. On the other hand, Bus Stop 21 has the final score of 1,00 where the amount of ridership is zero although there is a population living in the service area. In Figure 4.30., north bound density map generated according to the final score is shown.

| Bus Stop | North Bound Ridership | Total Population | Score of Total Population | Weighted Score of Total Populatio | Score of South Ridership | Weighted Score of South Ridershir | Final Score |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 2.672 | 0,19 | 0,10 | 1,00 | 0,50 | 0,60 |
| 2 | 0 | 4.412 | 0,35 | 0,17 | 1,00 | 0,50 | 0,67 |
| 3 | 61 | 3.994 | 0,31 | 0,16 | 0,93 | 0,47 | 0,62 |
| 4 | 39 | 4.723 | 0,38 | 0,19 | 0,96 | 0,48 | 0,67 |
| 5 | 135 | 5.078 | 0,41 | 0,20 | 0,85 | 0,43 | 0,63 |
| 6 | 18 | 5.036 | 0,41 | 0,20 | 0,98 | 0,49 | 0,69 |
| 7 | 0 | 3.525 | 0,27 | 0,14 | 1,00 | 0,50 | 0,64 |
| 8 | 6 | 4.342 | 0,34 | 0,17 | 0,99 | 0,50 | 0,67 |
| 9 | 16 | 5.246 | 0,42 | 0,21 | 0,98 | 0,49 | 0,70 |
| 10 | 0 | 5.121 | 0,41 | 0,21 | 1,00 | 0,50 | 0,71 |
| 11 | 12 | 3.588 | 0,28 | 0,14 | 0,99 | 0,49 | 0,63 |
| 12 | 379 | 3.505 | 0,27 | 0,13 | 0,59 | 0,29 | 0,43 |
| 13 | 10 | 489 | 0,00 | 0,00 | 0,99 | 0,49 | 0,49 |
| 14 | 29 | 1.035 | 0,05 | 0,02 | 0,97 | 0,48 | 0,51 |
| 15 | 69 | 896 | 0,04 | 0,02 | 0,92 | 0,46 | 0,48 |
| 16 | 12 | 992 | 0,04 | 0,02 | 0,99 | 0,49 | 0,52 |
| 17 | 149 | 1.850 | 0,12 | 0,06 | 0,84 | 0,42 | 0,48 |
| 18 | 109 | 2.021 | 0,14 | 0,07 | 0,88 | 0,44 | 0,51 |
| 19 | 5 | 2.378 | 0,17 | 0,08 | 0,99 | 0,50 | 0,58 |
| 20 | 136 | 2.163 | 0,15 | 0,07 | 0,85 | 0,43 | 0,50 |
| 21 | 0 | 11.715 | 1,00 | 0,50 | 1,00 | 0,50 | 1,00 |
| 22 | 251 | 9.920 | 0,84 | 0,42 | 0,73 | 0,36 | 0,78 |
| 23 | 131 | 3.357 | 0,26 | 0,13 | 0,86 | 0,43 | 0,56 |
| 24 | 227 | 4.374 | 0,35 | 0,17 | 0,75 | 0,38 | 0,55 |
| 25 | 58 | 3.021 | 0,23 | 0,11 | 0,94 | 0,47 | 0,58 |
| 26 | 376 | 4.317 | 0,34 | 0,17 | 0,59 | 0,29 | 0,46 |
| 27 | 74 | 5.844 | 0,48 | 0,24 | 0,92 | 0,46 | 0,70 |
| 28 | 129 | 6.132 | 0,50 | 0,25 | 0,86 | 0,43 | 0,68 |
| 29 | 54 | 4.534 | 0,36 | 0,18 | 0,94 | 0,47 | 0,65 |
| 30 | 194 | 5.124 | 0,41 | 0,21 | 0,79 | 0,39 | 0,60 |
| 31 | 307 | 7.190 | 0,60 | 0,30 | 0,66 | 0,33 | 0,63 |
| 32 | 914 | 7.291 | 0,61 | 0,30 | 0,00 | 0,00 | 0,30 |
| 33 | 10 | 3.860 | 0,30 | 0,15 | 0,99 | 0,49 | 0,64 |

*Figure 4.29.* Population vs. Ridership Scores at Bus Stops of North Bound

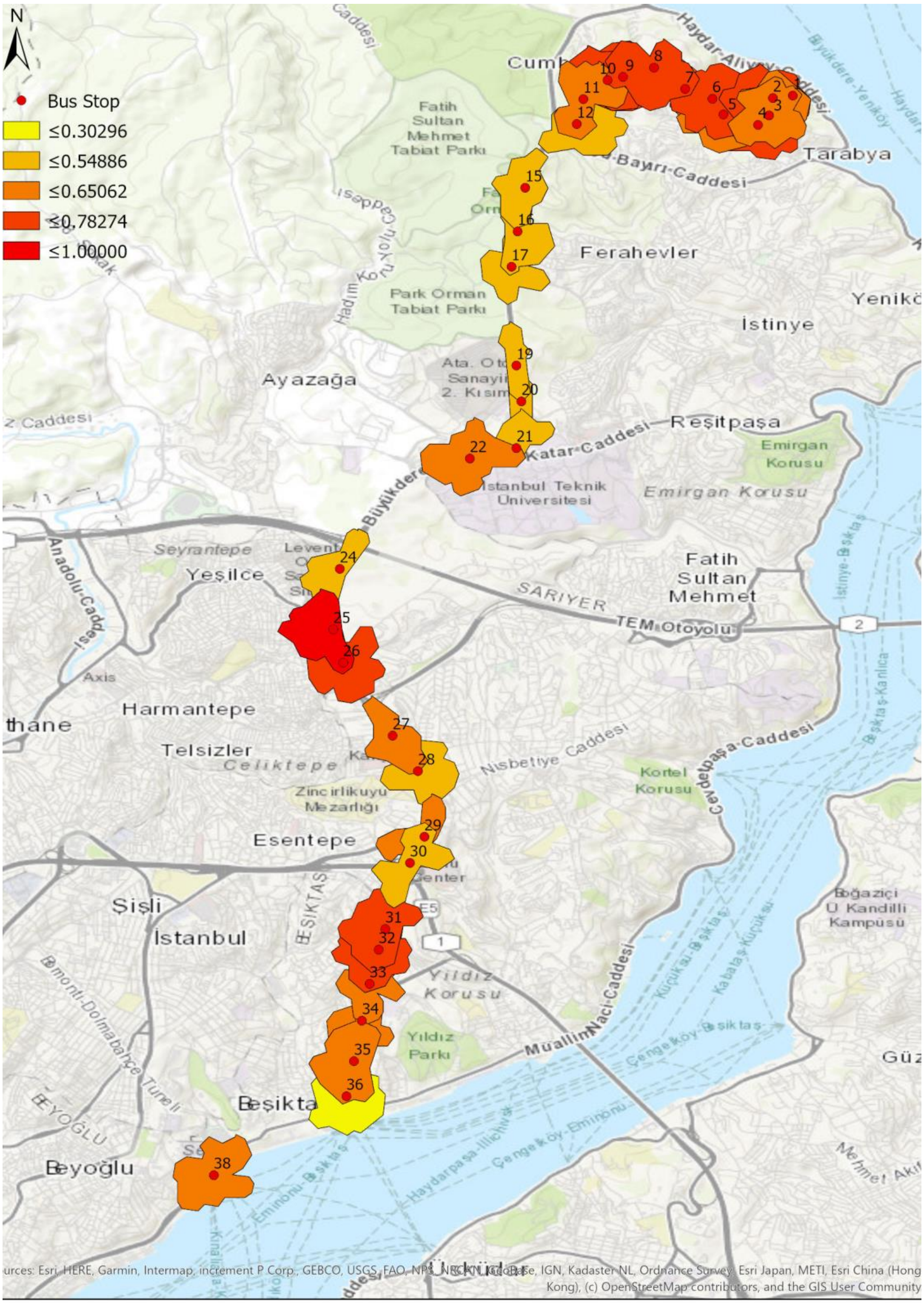


*Figure 4.30.* Maximum Population, Minimum Ridership Score- Density Maps, North Bound

According to the south and north bound results, it is observed in Figure 4.31 that the final score changes from 0,00 to 0,50. Bus Stop 36 has the final score of 0,00 where the amount of ridership is well balanced with the amount of the population living in that service area. On the other hand, Bus Stop 1 has the final score of 1,00 where the amount of the south and north ridership is zero although there is a population living in the service area. In Figure 4.32., south and north bound density map generated according to the final score is shown.

| Bus Stop | North and South Bound Ridership | Total Population | Score of Total Population | Weighted Score of Total Population | Score of North and South Ridership | Weighted Score of North and South Ridership | Final Score |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 2.672 | 0,19 | 0,10 | 0,60 | 1,00 | 0,50 |
| 2 | 179 | 4.412 | 0,35 | 0,18 | 0,58 | 0,81 | 0,40 |
| 3 | 201 | 3.994 | 0,31 | 0,16 | 0,55 | 0,78 | 0,39 |
| 4 | 408 | 4.639 | 0,37 | 0,19 | 0,47 | 0,56 | 0,28 |
| 5 | 401 | 5.078 | 0,41 | 0,21 | 0,49 | 0,57 | 0,29 |
| 6 | 227 | 4.518 | 0,36 | 0,18 | 0,56 | 0,76 | 0,38 |
| 7 | 57 | 3.206 | 0,24 | 0,12 | 0,59 | 0,94 | 0,47 |
| 8 | 185 | 4.067 | 0,32 | 0,16 | 0,56 | 0,80 | 0,40 |
| 9 | 296 | 5.433 | 0,45 | 0,22 | 0,56 | 0,68 | 0,34 |
| 10 | 165 | 5.064 | 0,41 | 0,21 | 0,62 | 0,82 | 0,41 |
| 11 | 18 | 3.560 | 0,27 | 0,14 | 0,63 | 0,98 | 0,49 |
| 12 | 434 | 3.560 | 0,27 | 0,14 | 0,40 | 0,53 | 0,27 |
| 13 | 116 | 2.218 | 0,15 | 0,08 | 0,51 | 0,88 | 0,44 |
| 14 | 53 | 749 | 0,01 | 0,01 | 0,48 | 0,94 | 0,47 |
| 15 | 23 | 589 | 0,00 | 0,00 | 0,49 | 0,98 | 0,49 |
| 16 | 52 | 1.103 | 0,05 | 0,02 | 0,50 | 0,94 | 0,47 |
| 17 | 79 | 845 | 0,02 | 0,01 | 0,47 | 0,92 | 0,46 |
| 18 | 19 | 1.232 | 0,06 | 0,03 | 0,52 | 0,98 | 0,49 |
| 19 | 23 | 1.784 | 0,11 | 0,06 | 0,54 | 0,98 | 0,49 |
| 20 | 228 | 1.557 | 0,09 | 0,04 | 0,42 | 0,76 | 0,38 |
| 21 | 142 | 2.508 | 0,18 | 0,09 | 0,51 | 0,85 | 0,42 |
| 22 | 100 | 1.612 | 0,09 | 0,05 | 0,49 | 0,89 | 0,45 |
| 23 | 346 | 1.071 | 0,04 | 0,02 | 0,34 | 0,63 | 0,31 |
| 24 | 180 | 5.487 | 0,45 | 0,23 | 0,63 | 0,81 | 0,40 |
| 25 | 122 | 11.439 | 1,00 | 0,50 | 0,93 | 0,87 | 0,43 |
| 26 | 446 | 10.582 | 0,92 | 0,46 | 0,72 | 0,52 | 0,26 |
| 27 | 202 | 4.105 | 0,32 | 0,16 | 0,55 | 0,78 | 0,39 |
| 28 | 398 | 4.957 | 0,40 | 0,20 | 0,49 | 0,57 | 0,29 |
| 29 | 146 | 5.687 | 0,47 | 0,23 | 0,66 | 0,84 | 0,42 |
| 30 | 738 | 4.146 | 0,33 | 0,16 | 0,27 | 0,21 | 0,10 |
| 31 | 144 | 5.174 | 0,42 | 0,21 | 0,63 | 0,85 | 0,42 |
| 32 | 238 | 6.077 | 0,51 | 0,25 | 0,63 | 0,74 | 0,37 |
| 33 | 103 | 5.672 | 0,47 | 0,23 | 0,68 | 0,89 | 0,44 |
| 34 | 264 | 6.773 | 0,57 | 0,28 | 0,64 | 0,72 | 0,36 |
| 35 | 327 | 7.118 | 0,60 | 0,30 | 0,63 | 0,65 | 0,32 |
| 36 | 933 | 7.974 | 0,68 | 0,34 | 0,34 | 0,00 | 0,00 |
| 37 | 95 | 6.210 | 0,52 | 0,26 | 0,71 | 0,90 | 0,45 |
| 38 | 58 | 3.601 | 0,28 | 0,14 | 0,61 | 0,94 | 0,47 |

*Figure 4.31.* Population vs. Ridership Scores at Bus Stops of South and North Bound

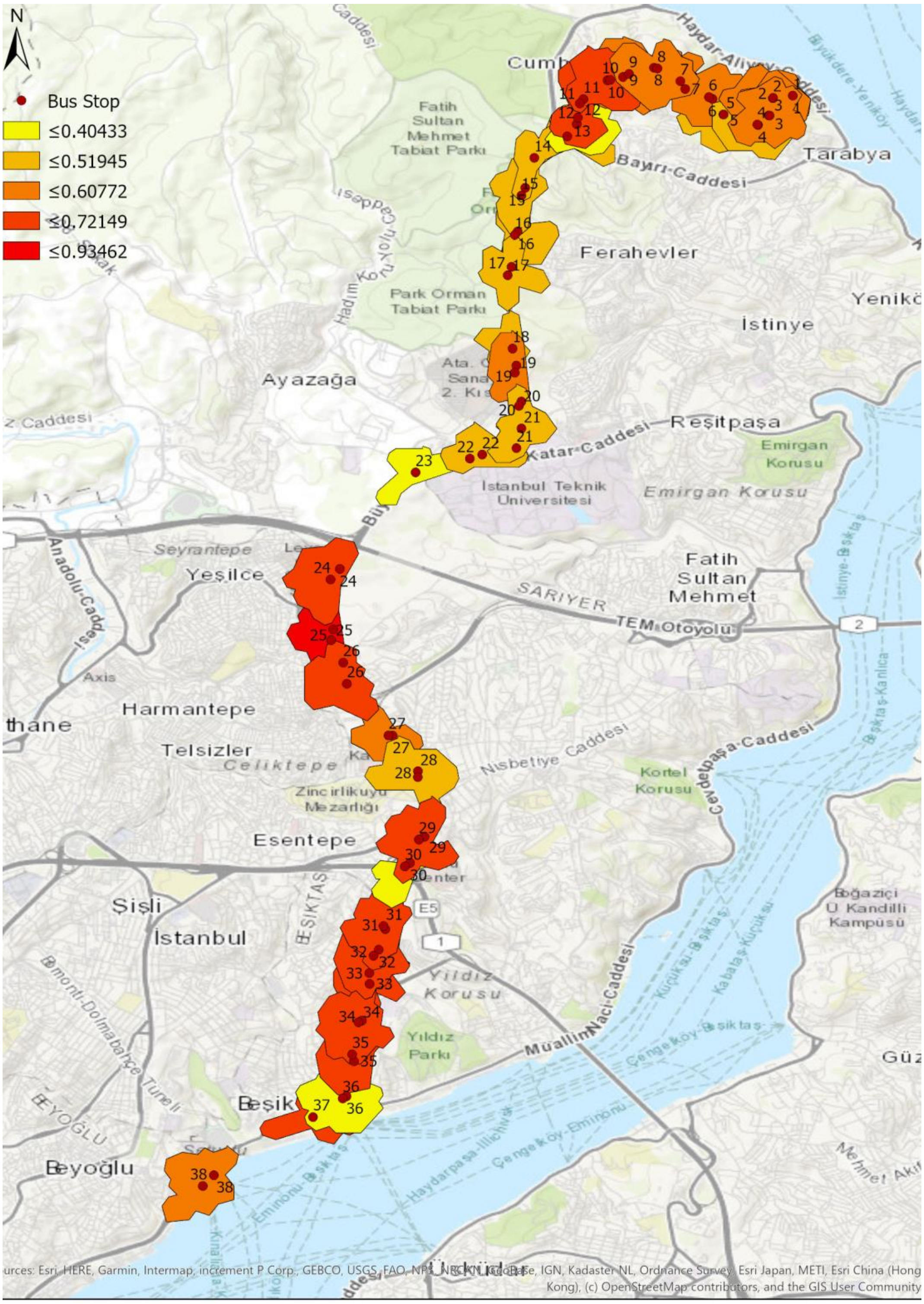


*Figure 4.32.* Maximum Population, Minimum Ridership Score- Density Maps, South and North Bound

After examining the relationship between the ridership and population, to better understand this relationship, Point of Interest within the service areas of the stops were examined. ATM, Business Facility, Grocery Store, Restaurant, Nightlife, Bank, Shopping, Hotel, Cinema, Performing Arts, Bowling Centre, Sports Complex, Convention/ Exhibition Centre, Hospital, Higher Education, School, Library, Museum, Police Station, Post Office, Clothing Store, Pharmacy, Consumer Electronics Store locations placed in the service areas are measured. The highest score is seen in stop 36 which has 615 POIs in its service area. Also, Bus stop 36 has the highest ridership which is 933 south and north bound. Lowest score is seen in stop 1 that has 3 POIs in its service area. The score of the POI in the service areas are seen in Figure 4.33.

In Figure 4.34., score of POIs in the service areas are taken into account and the density maps was created. It can be easily seen on the map that the number of POIs increases through the south. The reason of this is the neighborhoods of Levent, Şişli, Sinanpaşa, Vişnezade, Levazım, Emniyet Evleri have dense business facilities that workplaces are included in. On the other hand, the neighborhoods of Cumhuriyet, PTT Evleri, Kireçburnu are more residential areas than other neighborhoods.

| Bus Stop | POI | Score of POI | Weighted score of P( | Final Score |
|---|---|---|---|---|
| 1 | 3 | 0,00 | 0,00 | 0,00 |
| 2 | 16 | 0,02 | 0,02 | 0,02 |
| 3 | 21 | 0,03 | 0,03 | 0,03 |
| 4 | 33 | 0,05 | 0,05 | 0,05 |
| 5 | 35 | 0,05 | 0,05 | 0,05 |
| 6 | 19 | 0,03 | 0,03 | 0,03 |
| 7 | 14 | 0,02 | 0,02 | 0,02 |
| 8 | 24 | 0,03 | 0,03 | 0,03 |
| 9 | 53 | 0,08 | 0,08 | 0,08 |
| 10 | 58 | 0,09 | 0,09 | 0,09 |
| 11 | 52 | 0,08 | 0,08 | 0,08 |
| 12 | 37 | 0,06 | 0,06 | 0,06 |
| 13 | 20 | 0,03 | 0,03 | 0,03 |
| 14 | 7 | 0,01 | 0,01 | 0,01 |
| 15 | 8 | 0,01 | 0,01 | 0,01 |
| 16 | 8 | 0,01 | 0,01 | 0,01 |
| 17 | 6 | 0,00 | 0,00 | 0,00 |
| 18 | 37 | 0,06 | 0,06 | 0,06 |
| 19 | 93 | 0,15 | 0,15 | 0,15 |
| 20 | 58 | 0,09 | 0,09 | 0,09 |
| 21 | 64 | 0,10 | 0,10 | 0,10 |
| 22 | 121 | 0,19 | 0,19 | 0,19 |
| 23 | 38 | 0,06 | 0,06 | 0,06 |
| 24 | 101 | 0,16 | 0,16 | 0,16 |
| 25 | 208 | 0,33 | 0,33 | 0,33 |
| 26 | 240 | 0,39 | 0,39 | 0,39 |
| 27 | 270 | 0,44 | 0,44 | 0,44 |
| 28 | 472 | 0,77 | 0,77 | 0,77 |
| 29 | 222 | 0,36 | 0,36 | 0,36 |
| 30 | 186 | 0,30 | 0,30 | 0,30 |
| 31 | 117 | 0,19 | 0,19 | 0,19 |
| 32 | 95 | 0,15 | 0,15 | 0,15 |
| 33 | 70 | 0,11 | 0,11 | 0,11 |
| 34 | 118 | 0,19 | 0,19 | 0,19 |
| 35 | 151 | 0,24 | 0,24 | 0,24 |
| 36 | 615 | 1,00 | 1,00 | 1,00 |
| 37 | 552 | 0,90 | 0,90 | 0,90 |
| 38 | 101 | 0,16 | 0,16 | 0,16 |

*Figure 4.33.* Score of POIs in South and North Bound

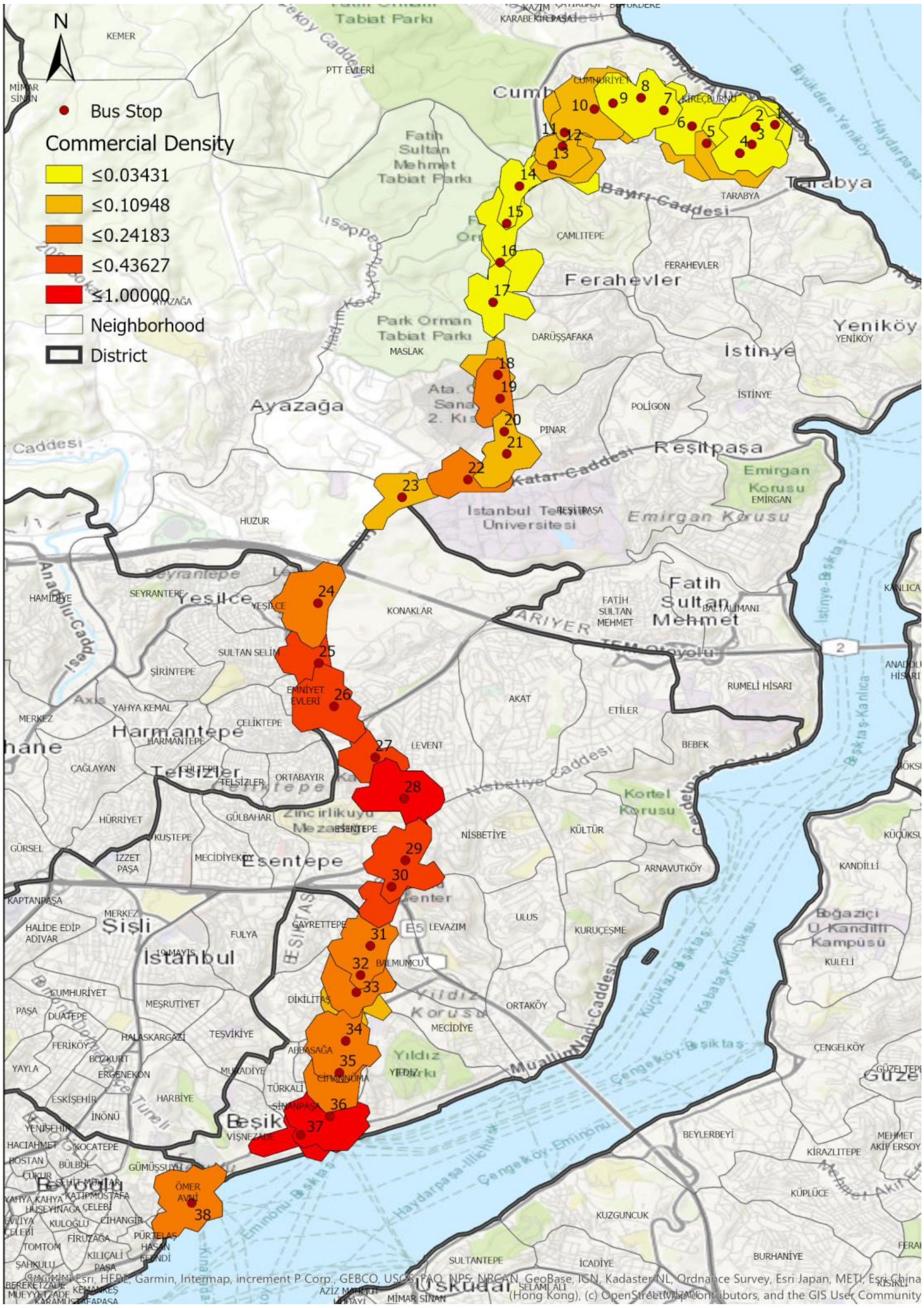


*Figure 4.34.* Commercial Density in Service Areas(400m)

## 4.4. Findings

The analysis and development of a GIS based approach in planning bus stop is applied in two ways. First of all, for both of the analysis, bus stops are mapped and they are grouped as north bound, south bound, north-and-south bound. It was observed that bus stop 13, 14, 18, 23 and 37 in south bound have no matches in north bound.

In the first analysis, existing land use and population are taken into account. Different distances of 200, 400 and 600 meters were studied in order to determine the distance that would be preferred for the attraction areas of the bus stops. The differences between the service buffer area of 200, 400 and 600 meters around the stops were remarked. As the walking distance increases, increment of the differences between the buffer and the service area changes. When the study area is examined, it can be said that the reason might be the effect of land use such as university campus, military area and the Marmara Sea which is the natural border. Hence, service area is chosen to measure the population in the attraction area around the bus stops. It was seen that residential area is middle dense, hence, 400 meters walking distance service area of each bus stop was created. According to the results, total size of the buffer areas is 34% bigger than the total size of the service areas. For each bus stop, ratio changes between 34% and 92%.

It is measured that demographic factors included in service areas; demography is 75%, Socio Economic Status of A is 87%, B is 80%, C is 80, D is 78%, Age Groups of 15-29 is 72%, 30-44 is 71%, 45-60 is 77%, 60+ is 61% of the buffer areas. To understand the coverage and potential service capacity, service areas were preferred.

Sequential bus stop distance is calculated to understand its compatibility with the standards. It was seen that the distance between sequential stops is minimum of 144m and maximum of 1399m in south bound; minimum 135m and maximum of 1655m in north bound. There are serious gaps between some stops and on the contrary; some stops are very close to each other. The average distance between stops is 439 meters in the south bound and approximately 488 meters in the north bound.

In order to understand the effects of walking distance between stops, bus stops were optimized as 400 meters of walking distance through the 29C-line by ArcGIS Network Analyst extension. After bus stops are relocated, 400 meters of walking distance service areas were created for the new stops. The same demographic parameters mentioned above were recalculated for the service areas of new bus stops.

The new results were compared to the results of existing bus stops. It is observed that with optimized stops, service area increased as %4,60 so the serviceability was improved. The increment in population is 10,54%, in Group A is 9,06%, in Group B is 15,86%, in Group C is 18,31%, in Group D is 23,68%, in Age 15-29 is 17,13%, in Age 30-44 is 16,07%, in Age 45-60 is 14,02%, in Age 60+ is 14,02%. This means that with the optimization of the bus stop, new service areas covers the area on the line without any gaps and served more people which means stops are more accessible by the people.

In the second analysis, ridership data of the bus stops were taken into account. Ridership data was divided into 2 hours intervals to understand the peak hours of ridership. It was seen that for south bound, the maximum number of ridership is between 7 am-9 am and 9 am-11 am, respectively. The minimum number of ridership is between 5 pm-7 pm. For north bound, it is seen that the maximum number of ridership is between 1 pm-3 pm and 3 pm-5 pm. The minimum number of ridership is between 5 am-7 am.

To analyze the peak hours in detail, 5 am-11 am, 5 pm-9 pm was divided into 30 minutes. It is measured that, for south bound, the highest ridership is between 8am-8.30 am with the number of 292 and lowest ridership is between 5 am-5.30 am with the number of 24. For north bound, the highest ridership is between 9.30 am-10 am with the number of 199 whereas the lowest ridership is between 7 am-7.30 am with the number of 21.4. The reason for the peak hours in the morning in South Bound is that the bus line is dense as a residential area. In order to understand the relationship between ridership and population, the areas where the population is high and ridership is low were calculated for both south and north bound and mapped by Esri's Business Analyst application. It is observed that for south bound results, the final score varies from 0,17 to 0,83. Bus Stop 30 has the final score of 0, 17 is where the amount of ridership is quite balanced with the amount of the population living in that service area. On the other hand, Bus Stop 25 has the final score of 0,83 where the amount of ridership is very low compared to the population living in the service area. According to north bound results, the final score varies from 0,30 to 1,00. Bus Stop 32 has the final score of 0,30 is where the amount of ridership is quite balanced with the amount of the population living in that service area. On the other hand, Bus Stop 21 has the final score of 1,00 where the amount of ridership is zero although there is a population living in the service area. According to the south and north bound results, the final score changes from 0,00 to 0,50. Bus Stop 36 has the final score of 0,00 is where the amount of ridership is well balanced with the amount of the population living in that service area. On the other hand, Bus Stop 1 has the final score of 1,00 where the amount of south and north ridership is zero although there is a population living in the service area. In order to understand where the amount of ridership is very low compared to the population living in the service area for some bus stops, Commercial POI's in the service areas are calculated and mapped.

When compared with point data, the following findings are revealed. When the stops numbered 1, 2, 3, 7, 11, 13, 14, 15, 16, 17, 18, 19,22, 23, 33 are examined, the number of POIs is also low in places where the number of passengers is low relative to the population. The service areas of these stops can be called a more residential area. The population living in the areas served by these stops may prefer the use of private vehicles or alternative modes of transportation. Time intervals and stop distances can be examined and arranged as express for some hours as taking into account peak hours are shown in Figure. 4.17 and 4.18. Also, other lines that intersect with this line has to be taken into account. Because people might prefer to use another line rather than this line according to their trip purpose.

Stops numbered 4, 5, 6, 8, 9, 10, 20, 21, 24, 31, 32, 38 were found to be balanced in terms of the number of passengers according to the population and accordingly the number of POIs there was also balanced. This can be called a semi-commercial semi-residential area. Stops 25, 26, 27, 28, 29, 30, 34, 35, 36, 37 include stops where the number of passengers and POI is above average and the population is slightly above average. We can call this place the Central Business District (CBD). Scheduling can be arranged because there are lots of demand, this region can be supported by other lines.

As a result, it was observed that there is a significant relationship between the number of boarding and POI density in the IETT data used in the second analysis. For bus stop planning in this line, scheduling could be rearranged according to the relationship between the POI density in service areas and the ridership. For instance, some stops like 13 or 14 could be express in some hours between 5 am-7 am to decrease operational cost and time-saving. Or, some stops could be supported with other lines intersecting with them like in the case of 35 or 36 to improve the attractiveness of the stops and serve more people.

# CHAPTER 5

# CONCLUSION

## 5.1. Summary of the Research

This study aimed to optimize the stop parameters on a line to serve more people in the service area of the bus stops. In this study, the 29C line data was obtained from IETT (2015); Address Map of Socio-Economic Status data (2017), housing density data and neighborhood border data from Esri ArcGIS Online, total population and age breakdown data in Esri Business Analyst (15-29, 30-44, 45-59, 60 and 60 Plus (2017)), and POI data (2018) were used.

For this purpose, the research consists of two stages. In the first stage, the measurement of the distance between the existing stops was made with the ArcGIS Network Analyst Extension, the creation of the buffer and service areas of the stops, the measurement of the differences of demographic data within the buffer and service area by using Esri's Business Analyst Application was realized, then re-positioning of the stops on the line was completed by taking the standard distance criterion of 400 meters with ArcGIS Network Analyst Extension. The service areas of the new stops were optimized accordingly, and demographic data and the existing data results were compared.

In the second stage, the ridership data of the bus stops were added to the analysis, and the relationship of the ridership data with the population and commercial POIs in the service areas was observed. First, the ridership data were divided into 2-hour intervals, then 5am-11am, 5pm-9pm hours were divided into half-hour intervals.

By using Esri Business Analyst application, the number of places where population is high and ridership is low were calculated. After this, Commercial POIs including ATM, Business Facility, Grocery Store, Restaurant, Nightlife, Bank, Shopping, Hotel, Cinema, Performing Arts, Bowling Centre, Sports Complex, Convention/ Exhibition Centre, Hospital, Higher Education, School, Library, Museum, Police Station, Post Office, Clothing Store, Pharmacy, Consumer Electronics Store locations within the same service areas were measured and mapped. According to this, where the population is small and the number of boarding passes is high compared with the commercial density data, it is predicted that the size of the boarding numbers may be related to the commercial density. Finally, Peak hours of the bus stops and this data were compared with each other.

### 5.2. Main Findings of the Research

As mentioned above, in the first stage of this study, which consists of two stages, a study was conducted according to the current population density and land use. As a result of this stage, important findings were obtained. First of all, the approaches in the methodology section about how to use the service area distance parameter in the city have been analyzed and it has been decided which parameter to use in the analysis. After the application of three different distance metrics, which are 200, 400 and 600 meters, to the bus stops, it was seen that study area is dense residential area and following the method by White (2009) so that it was decided to use the 400 meters distance in the analysis considering the population density and land-use of the study area. After that, for existing bus stops, 400 meters service and the buffer areas are created and the difference between them has been revealed. This difference between areas ranges from 34% to 93% and greatly influences optimization decisions. Moreover, calculated demographic results show that total population of the service areas is 75%, Group A is %87%, Group B is 80%, Group D is 78%, Age Group 15-29 is 72%, 30-44 is 71%, 45-60 is 77% and 60+ is 61% of the total buffer areas. The results of this analysis support the argument by Andersen and Landex (2008) who stated that the service area approach is more precise than buffer areas in bus stop optimization.

Another point was shown in Figure 4.10 that some areas were not served by the service areas of existing stops. In order to understand the distance between existing bus stops, the distance between sequential stops were calculated. As shown in Table 4.8. distance between most of the stops are less than 400 meters although most of the study area is residential, not the central business district and some of them are more than 600 meters which causes lacking serving to some areas in some points, it might depend on land use such as military area and university.

According to the residential and population density of the study area, following the method stated by White (2009), for urban areas with high density, dense residential areas, commercial activities, and educational sites, 400-meter walking distance which equals 6 minutes walking was used. Taking into account this 400-meter parameter, bus stops on the line were optimized by ArcGIS Network Analyst Extension. As a result, 5 new bus stops were identified. Also, as shown in Figure 4.13, service areas are adjacent to each other on the line, which means there is no gap on the bus line. After demographic parameters are calculated in optimized service areas and compared with existing service areas of the bus stops, it is seen that more people could be served by the new bus stops. Accordingly, potential service capacity could increase by 4.6% growth was observed in the area served by the optimization of stops. An increase of 10.54% in the population, 9.06% in Group A, 15.86% in Group B, 18.31% in Group C, and 23.68% in Group C were measured in these areas. An increase of 17.13% in the 15-29 age group, 16% in the 30-44 age group, 11.73% in the 07, 45-60 age group and 14% in the 60+ age group was observed. According to percentage increment, most common changes were seen in Group C and Age Group 15-29 whereas it is numerically seen in Group B and Age Group 30-44. Especially, increment in Group B and Group C is important because these groups are more likely to use public transport.

In the second stage, the ridership data of the bus stops were added to the analysis, and the relationship of the ridership data with the population and commercial POIs in the service areas was observed. According to two-hour intervals of the data, for south bound, the maximum number of ridership is between 7 am-9 am and 9 am-11 am, respectively. This might be due to the higher population density in the service areas of the bus stops when moved to south. The minimum number of ridership is between 5 pm-7 pm. This might be due to the higher population density in the service areas of the bus stops when moved to the south. Bus stop 11 has the lowest number of ridership, stop 19 and 15 follow it.  Bus Stop 4 has the highest number of ridership, stop 30 and 9 follow it. For north bound, it is seen that the maximum number of ridership is between 1 pm-3 pm and 3 pm-5 pm. The minimum number of ridership is between 5 am-7 am. Bus stop 36 has the highest number of ridership whereas stop 8 has the lowest in north bound. For north and south bound, seen in Figure 4.15, the sum of north bound and south bound data is similar to each other. For instance, bus stop 5, 26, 27, 28, 29, 30, 31, 32, 33 and 34 have close ridership for north bound and south bound. In some stops, south bound ridership is bigger than the north bound. It is easily seen that in Stop 2, for example, although south bound ridership is 179, north bound ridership is zero. This situation is same for bus stops between 3- 10, 13, 14, 15, 18, 22, 25, 29, 37 and 38. In some stops, however, north bound ridership is bigger than the south bound. For instance, in stop 12, North bound ridership is 379 whereas south bound is 55. It is same for bus stop 16, 17, 19, 20, 21, 23,24, 26,27, 28, 30, 31, 32, 33, 34, 35, and 36. According to peak hours of south and north bound, it could be realized that bus stops on the edge of the route have more passenger data; and peak hours appear to be 7-9 am and 9-11 am, which means these areas might be residentially or commercially dense.

These differences might be caused by the attraction points in the service areas like workplaces, shopping centers, banks, etc. In order to understand this difference better, places where the ridership is low and the population is high are measured and visualized on the map. Then, for the same service areas, Commercial POI density is measured. When compared with point data, the following findings are revealed. When the stops numbered 1, 2, 3, 7, 11, 13, 14, 15, 16, 17, 18, 19,22, 23, 33 are examined, the number of POIs is also low in places where the number of passengers is low relative to the population. The service areas of these stops can be called a more residential area. The population living in the areas served by these stops may prefer the use of private vehicles or alternative modes of transportation. Time intervals and stop distances can be examined and arranged as express for some hours as taking into account peak hours as shown in the Figures 4.17 and 4.18. Also, other lines that intersect with this line has to be taken into account. Because people might prefer to use another line rather than this line according to their trip purpose.

Stops numbered 4, 5, 6, 8, 9, 10, 20, 21, 24, 31, 32, 38 were found to be balanced in terms of the number of passengers according to the population and accordingly the number of POIs there was also balanced. This can be called a semi-commercial semi-residential area. Stops 25, 26, 27, 28, 29, 30, 34, 35, 36, 37 include stops where the number of passengers and POI is above the average and the population is slightly above average. We can call this place the Central Business District (CBD). Scheduling can be arranged because there are lots of demand, this region can be supported by other lines.

As a result, it was observed that there is a significant relationship between the number of boarding and POI density in the IETT data used in the second analysis. For bus stop planning in this line, scheduling could be rearranged according to the relationship between the POI density in service areas and the ridership. For instance, some stops like 13 or 14 could be express in some hours between 5 am-7 am to decrease operational cost and time-saving. Or, some stops could be supported with other lines intersecting with them, like 35 or 36, to improve the attractiveness of the stops and serve more people.

## 5.3. Future Research

As Murray (2012) states in public transport, different parameters express desirabilities, such as the number of transit lines and their frequencies, the number of express stops and also the quality of the bus stop accessibility by pedestrians.

One of the most important elements in the bus transportation system is accessibility. The location of the bus stops is very important to make them accessible to the citizens. To attract more passengers and improve public transport systems, analysis of stop locations is important. In this study, the places where the stops serve are examined in two different ways: the current population and the ridership data of the stops. In this study, if the stops had landing data as well as the boarding data, the number of stops and the travel capacity of the stops could be grouped so that bus times could be arranged more precisely. In addition, if data for different lines intersecting at multiple points in one region instead of one line were obtained, the demands on the stops could be measured more precisely and optimization could be made more precisely.

In carrying out these analyzes the use of GIS tools is important. In particular, the use of GIS tools is essential for geographically measured service and buffer areas, for measuring demographics and point data within them, for examining and mapping their relationships. According to this, it is foreseen that the decisions might be different in the analyzes where different parameters are handled by using GIS tools. For example, the first analysis was based on stop intervals and 5 new stops were added to the existing system. At this point, as well as the increase in the population served and other demographic data, stall penetration and service area have also grown. In the other analysis, the relationship between the number of boarding passes and the population was examined and compared with other data, namely POI data, i.e. points of interest in the stop service areas. When the analysis results obtained from this study were examined, it was predicted that residential areas and commercial areas affected both the number of boarding passes and the choice of boarding hours and an optimization study could be conducted accordingly.

In future studies, such studies can be evaluated by joining multiple bus line data to the analysis. It is possible to reach the results such as ridership data or schedule of the bus line passing through the station by the help of measuring in which areas the intersecting lines serve, which bus line the passengers prefer, where the existing line service area intersects with the other lines of the service area.

In addition, different findings can be obtained from the analysis results by using other demographic data such as unemployment data and household income, etc.

Other parameters of factors such as capacity and journey time could be used in further research to look at other aspects to make public transport more preferable by the passengers.

In future studies, the costs of the optimized stops and the duration time of buses can be analyzed, the cost matrix can be extracted and the results can be compared with the current situation.

By taking into consideration the city plans such as the master plan, implementation plan, urban plans can be made easily, measurable and practical decisions with numerical values in the decision mechanism of these studies. Similar decisions can be made for planning, or forecasting models can be created, especially for regions with similar demographic and commercial structures.

Other public transport modes of lines and their data (stops, boarding data, etc.) can also be included in the analysis to discuss which public transport alternative they have chosen and how this affects the choice of the stop. Thus, more sensitive decisions can be made by considering integrated transportation systems according to the integrity of the city.

Another point is the number of passengers alighting data. Although this data is not kept in our country, the inclusion of the number of landing data may affect the analysis on issues such as which regions are attraction regions like Central Business District. This can influence decisions regarding whether to increase or decrease the number of stops. Also, it might help to add a new route or remove the existing route for some stops to the transportation system.

The importance of GIS methods and analysis of bus stops in public transportation planning is emphasized in this study. In this study, GIS tools were used to determine the current and potential passenger attraction capacity of the stops. At this point, walking distances were calculated from the actual road network data and the socio-economic status of the passengers, age groups, and commercial attraction centers around the station were measured. Accurate measurement of the demands at the stops and determining the travel potential correctly and carrying out studies accordingly might make more accurate decisions in planning studies. According to this, location-based analysis plays an important role in the estimation and decision-making processes in similar studies that may be conducted in the future.

It was emphasized that the studies carried out by using different parameters could be enriched from different perspectives, and it was predicted that there are practical and comprehensive methods that can be used for future city planning decisions. In this way, relevant actions can be taken to encourage passengers to use buses. Hence, negative factors such as traffic accidents, air pollution, noise pollution caused by the use of private vehicles would be minimized and time and cost-saving in transportation would be provided.

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