EVALUATION OF THE PUBLIC BUS TRANSIT PERFORMANCE BASED ON SMART CARD DATA

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ABSTRACT

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Modern cities require reliable public bus transit (PBT) systems to enhance travel convenience, job growth, and living standards. The Transit Capacity and Quality of Service Manual (TCQSM) Report 100, a reference document for evaluation of PBT, includes network and route characteristics analyzed under two major dimensions of i) availability and ii) comfort and convenience, which have further metrics proposed based on the planning or operational characteristics. For the evaluation of comfort and convenience aspects, new technologies, such as smart card data (SCD), offer new opportunities to draw insights regarding passenger usage patterns and efficiency, which is also the main objective of this study. In this regard, SCD mainly supports estimating the metrics transit auto travel time (TAT), passenger per capacity (PPC), and on-time departures (OTD), which are challenging if estimated by manual data collection. Preparation of SCD also requires data preprocessing in of i) evaluation of data quality and availability, ii) detection of boarding stop locations, iii) matching of PBT route and SCD layers via linear referencing techniques in the GIS environment. For the city of Konya, planning data revealed high Hour-of-Services (HS) levels while low service frequency (SF) values in general. The SCD of the first week of October 2018 is later used to evaluate the quality of service (QOS) for a total of 9 PBT lines with different ridership levels (high, moderate, and low): Regardless of the ridership level, the PBT lines mostly had delays on departures leading to an acceptable OTD (levels of C and D); a similar quality was observed for TAT levels. PPC, however, showed different behavior, which showed low levels of quality on high ridership lines, while it was acceptable for moderate ridership levels. The high PPC levels in the low ridership lines were due to the underutilized PBT capacity of these lines, which are mainly designed to create accessibişity to remote neighborhoods. The evaluation of the selected PBT lines showed the applicability of the SCD for QOS evaluations, which should be performed for each PBT line for metropolitan regions.

Keywords: Public Bus Transit, Smart Card Data, Quality of Service, TCQSM

ÖZ

AKILLI KART VERİLERİNE DAYALI TOPLU OTOBÜS TAŞIMACILIĞI PERFORMANSININ DEĞERLENDİRİLMESİ

Kazemi Afshar, Ali Asghar
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Şubat 2024,144 sayfa

Modern şehirler, seyahat kolaylığını, iş büyümesini ve yaşam standartlarını artırmak için güvenilir toplu otobüs taşıma (TOT) sistemlerine ihtiyaç duyar. Toplu Taşıma Kapasitesi ve Kalite Hizmet Kılavuzu (TTKHK) Rapor 100, TOT değerlendirmesi için bir referans dokümanı olup, ağ ve güzergah özelliklerini i) erişilebilirlik ve ii) konfor ve kolaylık olmak üzere iki ana boyutta analiz eder, bu boyutlar için planlama veya operasyonel özelliklere dayalı olarak önerilen daha fazla metrik içerir. Konfor ve kolaylık yönlerinin değerlendirilmesi için, akıllı kart verileri (AKV) gibi yeni teknolojiler, yolcu kullanım modelleri ve verimlilik hakkında yeni fırsatlar sunar, bu da bu çalışmanın ana amacıdır. Bu bağlamda, AKV özellikle, manuel veri toplama ile tahmin edilmesi zor olan transit otomatik seyahat süresi (TOS), kapasite başına yolcu (KBY) ve zamanında kalkışlar (ZK) metriklerinin tahmin edilmesini destekler. AKV'nin hazırlanması ayrıca, i) veri kalitesi ve erişilebilirliğinin değerlendirilmesi, ii) biniş durak yerlerinin tespiti, iii) TOT güzergahı ve AKV katmanlarının Coğrafi Bilgi Sistemleri (CBS) ortamında lineer referanslama teknikleri ile eşleştirilmesi dahil olmak üzere veri ön işleme gerektirir. Konya şehri için, planlama verileri genel olarak düşük hizmet frekansı (HF) değerlerine karşın yüksek Hizmet Saatleri (HS) seviyelerini ortaya koydu. Ekim 2018'in ilk haftasına ait AKV, farklı yolcu sayısı seviyelerine (yüksek, orta ve düşük) sahip toplam 9 TOT hattının hizmet kalitesini değerlendirmek için daha sonra kullanıldı: Yolcu sayısı seviyesinden bağımsız olarak, TOT hatları genellikle zamanında kalkışlarda gecikmeler yaşayarak kabul edilebilir bir ZK seviyesine (C ve D seviyeleri) ulaştı; TOS seviyeleri için benzer bir kalite gözlendi. Ancak, KBY farklı bir davranış gösterdi, yüksek yolcu sayısına sahip hatlarda kalite düşük seviyelerdeyken, orta yolcu sayısına sahip seviyelerde kabul edilebilirdi. Düşük yolcu sayısına sahip hatlardaki yüksek KBY seviyeleri, bu hatların çoğunlukla uzak mahallelere erişilebilirlik sağlamak üzere tasarlanmış olmasından dolayı bu hatların TOT kapasitesinin yetersiz kullanılmasından kaynaklanmaktadır. Seçilen TOT hatlarının değerlendirilmesi, AKV'nin hizmet kalitesi değerlendirmeleri için uygulanabilirliğini göstermiştir, bu değerlendirmeler metropol bölgeleri için her TOT hattı için yapılmalıdır.

Anahtar Kelimeler: Toplu Otobüs Taşıma, Akıllı Kart Verileri, TTKHK

Dedication

To

- My dearest wife: *Roshanak Khalili,*

  Thank you so much for your patience, help, and endless support throughout this thesis journey. Without you, it would have been so much harder to finish. Your unwavering belief in me gave me the strength to see this through. Thank you also for your endless love. You always inspire me to continue. I love you always.

  I promise to make up for all the missed date nights and weekends spent in the library. I can't wait to embark on our next great adventure together, thesis-free!

My parents: *Ali Akbar & Sholeh*

> This thesis is dedicated to my parents, Ali Akbar and Sholeh. Thank you, Dad, for teaching me the value of knowledge pursued for its own sake and encouraging me to excel in my field. Mom, thank you for showing me that perseverance can accomplish any task.
>
> I am deeply grateful for your unconditional support throughout my studies. I am honored to have you as my parents. Thank you for allowing me to prove and improve myself. I love you.

- My sister: *Hanieh*

  You're more than just my sister; you are my guiding light, protector, and support system. Thank you for always being there for me when I need you most. I love you.

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LIST OF ABBREVIATIONS

ATE	Arrival Time Estimations
ATUS	Intelligent PBT System
DynSeg	Dynamic Segmentation
GIS	Geographical Information System
HS	Hours of Service
LOS	Level of Service
LR	Linear Referencing
OTD	On-time Departure
PBT	Public Bus Transit
PPC	Passenger Per Capacity
QOS	Quality of Service
SC	Smart Card
SCD	Smart Card Data
SF	Service Frequency
ST	Station Kilometer
TAT	Transit-Auto Travel Time
TCQSM	Transit Capacity and Quality of Service Manual
TCRP	Transit Cooperative Research Program
TSA	Transit-Supportive Areas
ULID	Unique Line ID

CHAPTER 1

INTRODUCTION

An effective public bus transit (PBT) system in modern cities is crucial for easy travel, job creation, and a better quality of life. Due to their affordability and extensive reach, buses are a key component of PT systems. Therefore, assessing and improving bus service performance is essential to meet the dynamic demands of urban living. Collecting real-time data is important for managing traffic and optimizing transportation routes. Smart Card Data (SCD), an Intelligent Transportation Systems application, is becoming an increasingly common and cost-effective tool. When passengers use Smart Cards (SCs) for fare collection, SCD provides valuable insights into travel patterns, boarding times, and service usage, which can help improve transit performance.

SCs are primarily used for tasks like access control to bus services. They offer a unique opportunity to track how a transit network is used in real-time, which can help increase customer satisfaction and generate more revenue for public authorities. Analyzing SCD can reveal daily, weekly, and seasonal patterns in usage across different types of transit cards, such as those for adults, students, and seniors. Planning and managing PBT can be challenging, especially in countries like Türkiye, where cities are rapidly growing. Based on experience or feedback, traditional methods are often less effective in larger cities. SCD offers a solution by enabling detailed data collection and providing valuable insights into the performance of PBT services. However, efficient analysis and visualization tools are needed to make the most of this data.

1.1 Aim of the Study

This thesis utilizes SCD to assess the performance of PBT systems. It employs guidelines from the Transit Capacity and Quality of Service Manual (TCQSM) to explore different aspects of the bus system mainly grouped in two dimensions: i) availability and b) comfort and convenience, which have further metrics proposed based on the planning or operational characteristics of the PBT network and lines. It also identifies and solves issues related to data quality, route mapping, and timing. The main goal is to use this information to evaluate and suggest improvements and create a PBT system that effectively meets the community's needs. Additionally, this thesis examines how SCD can be used to assess and enhance PBT performance. By combining data from various sources and employing multiple methods, the study focuses on developing recommendations to improve PBT services.

1.2 Scope of the Study

The questions addressed in this study can be listed as follows:

- How can SCD be used to evaluate PBT performance?
- What are the main challenges associated with using SCD for PBT performance evaluation, and what potential solutions can be implemented to address these challenges?
- What is the limitation of SCD in PBT performance evaluation? And how to overcome these limitations

Various tools and techniques are used in this study to address the research questions. The performance evaluation of PBT is guided by the standards set in the TCQSM. Transforming SCD into helpful information for performance assessment presents several challenges. These include ensuring data quality, addressing missing data, incorporating unavailable bus route data through GIS procedures, and determining bus speed and travel times. The numerical results are obtained for 9 selected PBT lines in Konya, Türkiye.

1.3 Layout of the Thesis

The layout of this thesis is as follows: In Chapter 2, the literature on SCD use in PBT, data pre-processing, linear referencing (LR), and evaluation of transit performance are summarized. Chapter 3 provides an overview of calculating PBT service quality. The methodology for this study is presented in Chapter 4. Konya's PBT quality of service (QOS) and performance evaluation are discussed in Chapter 5, followed by the conclusion and further recommendations in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature on SCD in PBT

SCs in PBT are becoming more popular, but this technology has existed since 1968. The concept was developed by two German inventors, Dethloff and Grotrupp, who patented a plastic card with a microchip (Shelfer & Procaccino, 2002). The Japanese also registered a patent for their version in 1970. Also in 1970, Motorola developed the first secure single-chip microcontroller, which the French banking system used to improve transaction security. While SCs have been around for decades, their use has significantly increased since 1990 due to technological advancements such as the internet and mobile communication (Attoh-Okine & Shen, 1995). SC technology, which allows contactless transactions, is becoming increasingly popular in various industries. Germany has implemented SCs in healthcare since 1992, and France has used them for postal, telephone, and telegraph services since 1982. SCs have multiple uses, such as access control, medical information, DNA results, fingerprints, affiliation, storing biometric data, and banking data. (Attoh-Okine & Shen, 1995)

Many transit agencies have adopted SC technology as a payment option. It is a secure method of validating user identity and paying fares (Barry, et al., 2002). This technology has also made the drivers' job easier since they no longer have to collect fares (Trépanier & Chapleau, 2006). In addition to improving data quality, SCs give transit a more modern appearance and offer new opportunities for innovative fare structuring (Dempsey, 2015).

2.1.1 SC Technologies

SCs are small, durable devices that store and process data. They can be used for various applications such as identification, authorization, and payment (Lu, 2007). Initially invented in the 1970s, the technology has since evolved, and many new features have been added to the original concept (Shelfer & Procaccino, 2002).

A card can come equipped with either memory or a microprocessor for preprogrammed tasks. Contact cards are placed directly on the reader, while contactless cards use high-frequency waves like RFID technology. The reader's electromagnetic field provides the energy for contactless cards. The data on the card can be encrypted using the triple data encryption standard. The card's memory depends on the application, with 2-4kb suggested for financial and personal data storage. Nowadays, up to 64kb is available. PBT cards typically require less memory since most information is not stored on the card. (Shelfer & Procaccino, 2002; Barry, et al., 2002)

Table 2.1 Characteristics of SC standards (McDonald, 2003)

Technology	**Frequency (MHz)**	**Data speed (kbps)**	**Activation distance**	**System**	**Applications**
ISO/IEC14443 (Type A or B)	13.56	106	10 cm	Open or closed	Transport, offline purchasing, vending, and physical access control.
ISO/IEC15693 Vicinity card	13.56	26	Upto 1 m	Closed	Physical access control, ticketing, parking, and drive-thrust.
Felica ISO / IEC15408 EAL4	13.56	212	n/a	n/a	Transport, identification, and others
NFC, ISO / IEC18092	13.56	212	Upto 20 cm	Open	Payment.
EZ-PASS PUHF	5900	n/a	3 to 10 m	Closed	Highway toll booths and fast-food drive-thru

A chip is embedded in the SC within layers of plastic. However, it must remain uncovered to connect with the reader’s PINs. The contactless SC can fully embed the chip in plastic but is typically visible. Additionally, a small antenna is installed in the contactless card. (Shelfer & Procaccino, 2002). SCs that require physical contact follow the ISO/IEC7816 standard. This standard governs the layout and usage of the contact plate (parts 1 and 2 of ISO7816), the electrical interfaces (part 3), and the selection of applications (part 4). For contactless cards, other standards regulate the lower interface levels between the cards and terminals. (McDonald, 2003). **Table 2.1** shows the characteristics of SC standards.

2.1.2 SCD Use in PBT

The SCD uses in PBT are categorized into strategic, tactical, and operational levels, as van de Velde (1999) outlined. Strategic studies use SCD for long-term insights into network planning and user behavior, influencing decisions that shape future transit system enhancements. Tactical studies utilize SCD, providing a medium-term approach to refining schedules and service routes based on usage patterns. Operational studies employ SCD, providing a short-term strategy, focusing on performance metrics and the smooth functioning of fare collection systems, ensuring immediate and efficient transit operations. (Van de Velde, 1999)

The strategic level is pivotal in understanding long-term planning. Agard et al. (2006) utilized boarding data to classify user types and interpret travel habits across different times. Bagchi and White (2005) leveraged time-space and personal travel data to evaluate users' travel behavior consistency, aiming to optimize marketing campaigns. Blythe (2004) managed demand through route load profiles, enhancing public transit's appeal by adapting to user needs. Trépanier et al. (2004) and Park and Kim (2008) focused on planning PBT networks and forecasting future trends, respectively. Trépanier and Morency (2010) use SCD to understand better transit patterns, which is essential for service adjustment and network extension.

Table 2.2 Summary of studies on SCD use in PBT

No	Reference	Data	Outcome
Strategic level			
1	Agard et al. (2006)	Boarding	Defined user types, understood user behavior
2	Bagchi and White (2005)	Trip	Analyzed travel behavior consistency
3	Blythe (2004)	Route load	Managed demand, adapted to user needs
4	Chu et al. (2009)	Boarding	Improved route planning, schedules
5	Utsunomiya et al. (2006)	Boarding,User	Create marketing strategies, forecast demand
6	Park and Kim (2008)	Historical	Estimated trends and improved network
7	Trépanier et al. (2004)	Boarding	Planned public transit network
8	Trépanier et al. (2009)	Boarding	Improved stop estimation accuracy
9	Trépanier and Morency(2010)	SCD	Modeled user loyalty and retention
Tactical level			
10	Bagchi and White (2004)	Trip,User	Reconstructed trips, improved schedule
11	Blythe (1998)	User Behavior	Created loyalty scheme
12	Bagchi and White (2005)	Trip	Assisted in service adjustment
13	Chapleau and Chu (2007)	Boarding	Analyzed passenger habits, improved transfers
14	Hoffman et al. (2009)	SCD	Evaluated transfer journeys
15	Munizaga et al. (2010)	Boarding	Estimated destinations, created matrices
16	Utsunomiya et al. (2006)	Historical	Aided in service adjustment
17	Morency et al. (2006)	Boarding, Trip	Classified cards, analyzed user behavior
18	Seaborn et al. (2009)	SCD	Identified complete journeys
19	Trépanier et al. (2007)	Boarding, Trip	Developed algorithm for alighting estimation
Operational level			
20	Attoh-Okine and Shen (1995)	SCD, Payment	Managed payments, reduced costs
21	Chu and Chapleau (2008)	Boarding	Detected and corrected transaction errors
22	Deakin and Kim (2001)	Historical,User	Implemented flexible pricing
23	Morency et al. (2007)	Boarding	Analyzed user behavior, assessed performance
24	Park and Kim (2008)	SCD, Trip	Understood user characteristics
25	Reddy et al. (2009)	SCD	Provided operational statistics, reduced costs
26	Trépanier&Vassivière (2008)	Boarding	Aided in service adjustment, equipment checks

Tactical level is essential in understanding mid-term planning. Bagchi and White (2004) reconstructed user trips to improve scheduling. Munizaga et al. (2010) developed algorithms for estimating potential destinations, contributing to creating a detailed origin-destination matrix for subway stations. Hoffman et al. (2009) evaluated transfer journeys to enhance passenger convenience, and Seaborn et al. (2009) identified complete journeys to minimize transfers.

The operational level is pivotal in understanding short-term planning. Attoh-Okine and Shen (1995) discussed the efficiency of payment management. Chapleau and Chu (2008) improved system reliability by detecting and correcting transaction data errors. Deakin and Kim (2001) implemented time-of-day pricing for flexible fare structures. Morency et al. (2007) utilized boarding data to assess schedule adherence. Park and Kim (2008) and Reddy et al. (2009) provided operational statistics to understand user characteristics and reduce costs. Trépanier and Vassivière (2008) used SCD to adjust service and detect defective equipment. A detailed list of SCD uses in PBT studies is presented in **Table 2.2**.

2.1.3 SCD Clean up

Data cleaning and refining are crucial steps in data processing. Any issue in a transaction can lead to errors in constructing the passenger’s trip chain. Data usually contains errors caused by system failure or faulty human operation. The errors can arise from GPS, failure in matching a transaction and service, and driver faults. Generated datasets from fair collection systems often have errors caused by software, hardware, and users. Software issues include system bugs, missing requirements, and time synchronization problems. Hardware issues may include false GPS location information, broken readers, or SCs. Users’ problems include shared cards, failed tap-on/off, and lost cards. (Kusakabe & Asakura, 2014; FDOT, 2014; Robinson & Manela, 2012)

SCD can have various problems that can be categorized into four groups. The first group is software-related issues caused by incorrect software, including business rules and logic. The second group is data-related issues, which are caused by inaccurate data. The third group is hardware-related issues, which are caused by faulty hardware. Lastly, the fourth group is user-related issues, which can result from accidental and deliberate actions. (Robinson, et al., 2014)

There are three main categories for existing methods of detecting and processing data. These categories address three types of data problems: insufficient data (missing entries, alighting data, whole transactions, following boarding information, or direction of travel), illogical values, and duplicate transactions (Li, et al., 2018). Initially, incomplete data was removed, but Alsger et al. recommend completing missing data by matching it with historical data rather than deleting it (Alsger, et al., 2015). A summary of such problems related to SCD is provided in **Table.2.3**

There may be situations where some trips cannot be matched successfully. One reason for this could be the inappropriate maximum walking distance. If the walking distance is too long, two separate trips may be mistaken for one. Conversely, many transfer trips might be missed if they are too short. To address this, a distance sensitivity analysis could be conducted. Alternatively, if a passenger begins their journey one day and completes it the next, adjustments can be made to the time of day based on their travel habits. (Alsger, et al., 2015)

Sometimes, tracking each trip with a SC may not be possible when using different modes of transportation like cars, taxis, or bicycles. In such cases, historical transaction data can be used. Furthermore, the next boarding station may not always be the closest to the previous alighting stop, especially in areas with many shops. The rule “Travel will not walk a long distance when transferring” needs to be improved considering the land use (Alsger, 2017). Additionally, passengers may not always return to their starting station after their last trip of the day, so the rule “Travelers will end their last trip of the day at the station where they began their first trip of the day" needs to be refined (Nassir, et al., 2011). **Table 2.4** shows the main transaction problems and processing methods with SCD.

Table 2.3 Summary of problems with SCD

Problem Type	Cases
Hardware	GPS unit and aerial malfunctions; Odometer and gyrocompass failures; Faulty AVL system locations; Broken SC readers and cards; Communication disruptions
Operational	GPS multi-pathing; Buses on diversion; Trip curtailments; Driver behavior issues; Malicious damage to equipment
Data	Incorrect bus stop locations and headings; Missing Road centerline data; Wrong schedule data; Outdated data uploads; Erroneous input data
Software	Erroneous trip definitions; System bugs; Vulnerability to hacking; Lack of destination data; Missing system requirements; Issues with time synchronization
User	Failure to tap in/out; Premature tap outs; Stolen or lost cards; Use of invalid cards; Multiple cards causing errors; Card sharing

Table 2.4 Processing method with SCD problem (Li, et al., 2018)

Main Transaction Problems	Processing Method
Missing entries/exit	Eliminated
Missing one whole transaction in the set of a person's travel data	Eliminated
No next boarding information	Eliminated
Illogical values across two attributes	Thorough analysis and subsequent pre-processing of data
Missing the direction of the travel attribute value	Checking travel direction of other transaction records with the same trip, then mitigating it
Duplicate transactions	Eliminated

2.1.4 Significance of SCD

In recent years, SCD has become a valuable resource for transit agencies and PBT authorities to enhance their services and infrastructure. SCs are a convenient payment option and offer a rich information source for transit agencies and researchers. As a result, more transit agencies are adopting SC systems to reduce costs, quality, quantity of data, frequent updates, and passenger convenience. (McDonald, 2003; Pelletier, et al., 2010)

Transit authorities spend around 5-15% of their revenue on collecting and processing fares through traditional methods like cash payments, collection boxes, and equipment maintenance and staff. However, implementing SC systems may require a higher initial investment in in-vehicle equipment or at stations. However, it can significantly reduce the cost and time spent collecting and processing fares compared to traditional methods. (Alsger, 2017)

Transit authorities can benefit from SCD since they are much easier to track and generate more accurate financial reports. SC systems are much more efficient than traditional ticket and cash payments and require far fewer staff. In addition, SCs can support multiple fare types and be adjusted by reprogramming the reading devices, making them incredibly versatile and adaptable to changing circumstances. (Blythe, 2004; Pelletier, et al., 2010)

Traditional data collection methods are limited due to their high cost and time requirements. However, using SCD as a new source of information can provide a large and continuous dataset. This approach reduces the user's involvement in the survey process, improving data quality. (Bagchi & White, 2005; Alsger, 2017)

Many PBT systems rely on infrequent passenger onboard bus surveys to analyze travel behavior and demand. However, significant changes in the transit system during this time can lead to errors in analysis and planning, requiring additional surveys and costs. Alternatively, SCD collection is continuous, automated, and available year-round. This allows for a better understanding of travel behavior and demand and allows for analysis of seasonal changes, different times of day, and transit system updates. (Bagchi & White, 2005; Deschaintres, et al., 2019)

Using SCs for fare payment offers numerous benefits, including improved passenger convenience and reduced vehicle delays. SCs interact quickly with vehicle readers, making boarding faster and easier for passengers. This also reduces the workload on vehicle drivers. Additionally, SCs can be used for several years, are easy to recharge, and do not require users to insert the card into a reader like magnetic cards. SCs are a reliable and efficient option for fare payment. (Blythe, 2004; Chu, 2015)

While using SCs for PBT offers numerous advantages, it also has limitations. Implementing SC systems requires a considerable investment in equipment on vehicles or at stations, information systems infrastructure, and dedicated staff (Deakin & Kim, 2001). Additionally, it is common for the passenger's final destination not to be disclosed, and there may be a lack of information regarding the purpose of the trip or the user's evaluation of the service. Therefore, service providers should conduct surveys to validate their assumptions and usage analysis (Bagchi & White, 2005). It is important to ensure that market penetration is adequate to obtain a representative sample of the entire population. However, the reliability of SCD may be less specific when dealing with more complex cards. Additionally, the lack of personal attributes, such as gender, age, and income, is the most significant drawback of this type of data. (Blythe, 2004). **Table 2.5** shows the Summary of studies on the significance of SCD.

Table 2.5 Summary of studies on the significance of SCD

Reference	Key Findings
McDonald (2003); Pelletier, et al. (2010)	SCs enhance PBT services, reduce costs, and improve passenger convenience.
Alsger (2017)	SC systems reduce fare collection costs and time but require high initial investment.
Blythe (2004); Pelletier, et al. (2010)	SC systems are more efficient than traditional methods, supporting multiple fare types with fewer staff.
Bagchi & White (2005); Alsger (2017); Deschaintres, et al. (2019)	SCD offers continuous data, improving travel behavior analysis and reducing manual survey needs.
Blythe (2004); Chu (2015)	SCs quicken boarding, reduce vehicle delays, and lighten driver workload, enhancing the passenger experience.
Deakin & Kim (2001); Bagchi & White (2005); Blythe(2004)	Implementing SCs involves significant investment and faces data limitations, necessitating supplementary surveys.

2.2 GIS Processes for SCD

2.2.1 Boarding Stop Estimation from SCD

Several studies have utilized electronic ticketing and GPS data to estimate the boarding stops of bus trips in different cities. For instance, Zhao et al. (2007) used this method in Chicago, USA. Yin et al. (2010) combined bus information with SCD to determine each passenger's bus route and direction. Nassir et al. (2011) used electronic ticket information and automatic passenger counters to estimate the origin and destination of bus trips. Yang et al. (2013) developed a model that predicts PBT trip chains using Oyster and iBus data to record passenger information and analyzed the travel characteristics of bus passengers using a specific methodology. (Zhao, et al., 2007; Yang & Chen, 2013; Yin, et al., 2010; Alsger, 2017; Nassir, et al., 2011)

2.2.2 Linear Referencing

LR is a technique used in engineering to locate objects along linear features such as roads. This involves referencing the object's location to a fixed point (Curtin, et al., 2007). For example, mile markers are commonly used on kilometer markers and freeways. LR is a methodology for locating object data (such as points, lines, or polygons) according to their position at a specific path instead of their coordinates. (Esri, 2019)

Instead of traditional coordinate systems, LR utilizes concepts and methods that aid in correlating features to their exact locations on a network. This method proves helpful when the positioning of items on a network holds more importance than their location in a two-dimensional or three-dimensional space. (Curtin & Turner, 2019). In various industries, LR is a helpful tool that can be employed for the management, monitoring, and analysis of infrastructures and roads. It plays a crucial role in transit applications, enabling several activities like route planning and analysis, automatism car location, and inventory management of bus stops and facilities. (Esri, 2019)

Recording additional attributes about roads can be challenging without LR. This method allows attribute value changes to be handled as events along the roads, eliminating the need to split the road into smaller segments. Implementing LR can be done using (Geographical Information System) GIS software packages. However, their documentation often focuses on creating and locating events without mentioning data preparation or capture phases. A pre-defined model or framework is necessary for successful implementation. (Alsger, 2017)

2.2.3 Model Builder

LR tools are available on ArcGIS Desktop. This software offers many tools, including spatial analysis, data management, and map creation. It supports multiple data formats and allows the identification of spatial patterns and trends using powerful analytical tools and workflows (Esri, 2019). ArcGIS is commonly used in studies related to PBT. For example, Curries and Mesbah (2011) utilized an ArcGIS platform to analyze transit performance in Melbourne, Australia, by visualizing spatial and temporal patterns of changes. Similarly, Zhang et al. (2018) utilized ArcGIS to analyze ridership demand data during specific periods (Saryuz, 2020). Model Builder in ArcGIS simplifies GIS workflows by efficiently transferring tool outputs to another tool without extensive coding. It also lets users convert tools into Python scripts for different models.

CHAPTER 3

EVALUATION OF PUBLIC BUS TRANSIT (PBT) QUALITY OF SERVICE AND PERFORMANCE

3.1 Devoloping an Approach for Evaluating PBT Performance

Performance measurement evaluates the productivity of a system using resources. This is essential for assessing the system's efficiency, identifying areas that need improvement, and monitoring transit services. Performance indicators evaluate the system's inputs and outputs, and regular measurements show progress toward goals. Researchers propose many different performance indicators, but there is much diversity in how they are calculated. Performance measurement helps identify imbalances in supply and demand. (TRB, 2004b; Eboli & Mazzulla, 2011)

In the realm of transportation planning and management, it is essential to have a comprehensive understanding of performance indicators. One of the most notable reports on the topic is Transit Cooperative Research Program (TCRP) Report 88, which presents three key performance indicators: cost-efficiency, cost-effectiveness, and service effectiveness (TCRP88, 2002). Some studies suggested various indicators in different groupings. These include Cost Efficiency, which considers metrics such as cost per kilometer or cost per hour; Cost-Effectiveness, examining factors like cost per passenger trip or ridership relative to expenditure; Service Utilization or Effectiveness, measured by passenger trips per kilometer or hour; Vehicle Utilization or Efficiency, taking into account kilometers driven per vehicle; Service Quality, evaluated through metrics like average speed or distance between vehicles' accidents; and Labor Productivity, looking at aspects such as passenger trips per employee or vehicle kilometers per staff member. (Carter & Lomax, 1992; Bruno, et al., 2002; Trompet & Liu, 2011; WB, 2011; Zhang, et al., 2016)

It is important to note that many performance indicators for transit systems are based on the operator's point of view and are represented as whole numbers. This can make it difficult to understand how well the transit system performs. The passenger's perception is crucial when evaluating the transit system's performance. Transit agencies can ensure that their services meet customer expectations by focusing on service quality indicators from the passenger's perspective. (TRB, 1999b; Fielding, 1992; Zhang & Wu, 2023)

Meyer suggested a structured three-tier approach for evaluating performance indicators. The first category considers factors such as the population within the service area, passenger trips, distance traveled by vehicles, and vehicle operating hours. The second category focuses on effectiveness indicators, encompassing service provision, the quality maintained, and availability. Finally, the third tier emphasizes efficiency metrics, including elements such as the cost-effectiveness of operations, the utilization of vehicles, employee productivity, energy usage, and fare structures. (Meyer, 2000)

The European Commission has defined eight quality standards for PBT, encompassing various facets of service. These include Availability, referring to the readiness and presence of transportation services; Accessibility, which considers how easily services can be reached; Information, focused on the clarity and availability of details about services; Time, related to punctuality and scheduling; Customer Care, dealing with the attention and service provided to passengers; Comfort, looking at the ease and pleasure of the ride; Security, regarding the safety and protection of passengers; and Environmental Impacts, assessing the ecological footprint and sustainability of the transportation system (EN13816, 2002).

Vuchic laid out a framework consisting of five distinct classifications for evaluating performance indicators in transportation. The first category focuses on transportation quantity or volume, looking at elements such as the number of vehicles, the size and capacity of the fleet, the number of routes, network length, and annual passenger numbers. The second division assesses system and network performance through metrics like service intensity within the network and the average speed of the transit system. The third group deals with transportation work and productivity, examining factors like annual vehicle, space, and passenger kilometers. The fourth classification zeroes in on indicators of transit system efficiency, such as kilometers traveled per vehicle per year, passengers per kilometer per vehicle, daily passengers per employee, and kilometers traveled per kilowatt-hour. Lastly, the fifth category emphasizes consumption rates and utilization metrics, considering operating costs per passenger, per vehicle-kilometer, and the number of scheduled vehicles relative to fleet size. (Vuchic, 2007; Vuchic, 2005)

Vuchic identified several factors that impact passenger satisfaction with PBT, including reliability, convenience, safety, security, availability, accessibility, travel time, comfort, and environmental impact (Vuchic, 2005). Eboli and Mazzulla identified the primary quality attributes of city bus transportation as information, customer care, availability, environmental impact, reliability, cleanliness, safety and security, and comfort. (Eboli & Mazzulla, 2011; Eboli & Mazzulla, 2016). In line with these factors, TRB developed a comprehensive evaluation method for PBT performance, which includes 31 criteria and 400 indicators. (TRB, 2003a)

It is important to establish performance standards and Level of Service (LOS) metrics for providers and users to improve the quality of PBT. The TRB's second edition of the Highway Capacity Manual (HCM) introduced the methodology in 1965. It is typically used to evaluate highways by classifying traffic patterns and giving quality grades based on performance evaluations. Performance measures are divided into six categories, labeled with notes from F (representing the lowest level) to A (representing the highest level). (Alsger, 2017; TCRP88, 2002)

The LOS concept evaluates how well highways and freeway's function. Over time, it was also applied to PBT services, intersections, sidewalks, and road sections (Roess, et al., 2010). The TCQSM provided the first official definition of 'LOS' for PBT in 1999 (TCRP88, 2002). Many researchers have worked on developing LOS standards and thresholds. Botzow (1974), Eboli & Mazzulla (2007, 2011) looked at various performance indicators, including factors such as the distance between vehicles, the coverage of the service area, the spacing of bus routes, and the spacing of bus stops (Eboli & Mazzulla, 2011; Alsger, 2017; Li, et al., 2018). Golob et al. (1972) suggested factors such as travel time, waiting periods, vehicle design, human interaction and environment within the transport, and the overall convenience of the service determine a LOS. (Barry, et al., 2002).

In 1974, Botzow proposed that various factors, including travel time, headway, number of transfers, temperature, ventilation, noise, acceleration, and vibration, could determine the quality of a PBT system. Eventually, a group of experts established a standard for PBT known as the LOS or QOS standard, which has six grades ranging from A to F. This standard is outlined in the TCQSM, as featured in the TCRP Report 100, which presents a detailed framework for evaluating PBT systems, focusing on two key aspects: availability and comfort/convenience. This comprehensive approach aids transit planners and authorities in assessing and improve the QOS provided to passengers. (Dalton, et al., 2000; TCRP88, 2002; TCRP100, 2003)

The availability refers to how readily and frequently the transit services are accessible to the public. This aspect primarily orbits around the frequency of the service - how often buses or trains run - and the operating hours, which determine the transit system’s accessibility during different times of the day or night. The availability metrics are crucial as they directly affect a commuter’s ability to utilize PBT for daily needs. Frequent and well-scheduled services are critical to a highly functional transit system that efficiently serves many users. Moreover, the category of comfort/convenience includes evaluating the number of passengers and the crowd levels in the transit vehicles, which can significantly impact a passenger’s comfort. Standing areas, their adequacy during peak hours, and the presence and quality of amenities such as seating, air conditioning, and cleanliness all fall under this category. Additionally, the overall reliability of the service - encompassing aspects such as punctuality and consistency - is a vital component of comfort/convenience.

This dimension of the transit service is essential for ensuring passenger satisfaction and developing a positive perception of the PBT system. Utilizing this framework has benefited transportation planners in enhancing PBT systems' efficiency and user experience. (TCRP100, 2003; Hassan, et al., 2013; ITSO, 2021)

3.2 Performance Measures in the TCQSM

The terms LOS and QOS are frequently used in the literature concerning the evaluation of PBT performance. These concepts, while closely related, often appear interchangeably across various studies. They serve as indicators of how well a transit service is performing from the perspectives of both the service provider and the user. The term 'QOS' will be used exclusively throughout this thesis to maintain consistency and clarity. The TCQSM provides an authoritative framework for evaluating PBT services, encompassing a range of performance metrics that help to define the QOS. For PBT systems, TCQSM outlines two critical areas of service evaluation: Availability and Comfort/Convenience. Three key indicators characterize availability. The 'Hours of Service'(HS) metric indicates the total operational duration of transit services within a day, providing insights into the transit system's responsiveness to the community's needs. 'Service Frequency'(SF) reflects how regularly transit vehicles are scheduled, which is crucial for passengers relying on PBT for their daily commutes. The 'Transit-Supportive Areas'(TSA) indicator denotes the regions with the necessary infrastructure to support an effective transit network, thus facilitating greater user accessibility.

In parallel, the dimension of Comfort and Convenience is evaluated through its own set of indicators. 'On-time Departure'(OTD) is a critical measure of service reliability, indicating how punctual the transit services are concerning their schedules. The 'Transit-Auto Travel Time' (TAT) compares PBT's journey times with those of private automobiles, highlighting its efficiency. Lastly, 'Passenger Per Capacity'(PPC) assesses the balance between the transit system's capacity and the number of passengers, an essential factor in preventing overcrowding and ensuring a comfortable travel experience. Two datasets were analyzed to evaluate the QOS. The first dataset examined SCD to evaluate comfort and convenience factors such as PPC, TAT, and OTD. The second dataset examined the bus schedule data provided by the municipality to evaluate availability factors such as HS and SF. The results for each attribute were classified based on the QOS grades outlined in the guidelines. Together, these indicators from the TCQSM guide the assessment of PBT systems, identifying strengths and areas for improvement and ensuring that services are available and meet the high standards of comfort and convenience users expect. **Table 3.1** shows the PBT Performance criteria based on TCQSM. **Figure 3.1** shows the framework of PBT performance measures by TCQSM.

Table 3.1 PBT Performance criteria based on TCQSM

Quality of Service (QOS)						
	A	**B**	**C**	**D**	**E**	**F**
Availability (with Planning Data)						
HS	19-24	17-18	14-16	12-13	4-11	0-3
SF	<10	10-14.	15-20	21-30	31-60	>60
TSA	90-100%	80-90%	70-80%	60-70%	50-60%	<50%
Comfort and Convenience (with SCD)						
PPC	0.00-0.50	0.51-0.75	0.76-1.00	1.01-1.25	1.26-1.50	>1.50
TAT	≤0	1-15	16-30	31-45	46-60	>60
OTD	95-100%	90-95%	85-90%	80-85%	75-80%	<75%

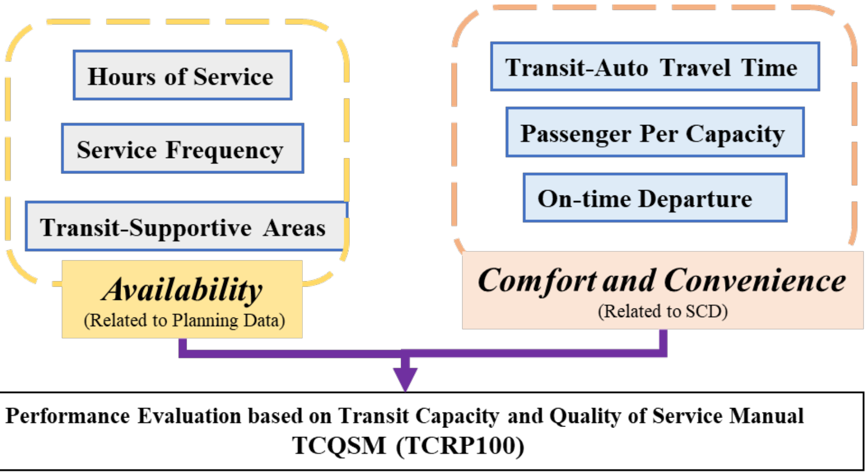


Figure 3.1 Framework of PBT performance measures by TCQSM

3.2.1 Transit Supportive Areas (TSA)

Service coverage measures the area accessible on foot from transit services. Although it does not provide a complete assessment of transit accessibility, it is crucial for identifying the range of options individuals have to access PBT from various locations, considering factors like SF and operational hours. Service coverage is specific to the entire transit system, meaning that coverage exists in a particular area if a specific route segment or transit stop offers the service. However, as service coverage spans a large area, assessing its QOS is a more time-intensive process, requiring more information than other methods of evaluating transit availability. A geographic information system can simplify this task. In this study, the ArcGIS software's buffering feature is used to draw circles of appropriate sizes around transit stops, thus calculating the transit service coverage area. The QOS for service coverage is determined based on the air distance within 400 meters (0.25 miles) of a bus stop or 800 meters (0.5 miles) of a busway or rail station. The QOS, in relation to TSA, is displayed in **Table 3.2.** The TSA can be calculated using **Equation 3.1.**

$$\boldsymbol{TSA} = \left(\boldsymbol{A_C} \middle/ \boldsymbol{\sum_1^n A_S} \right) \times \mathbf{100} \qquad \mathbf{3.1}$$

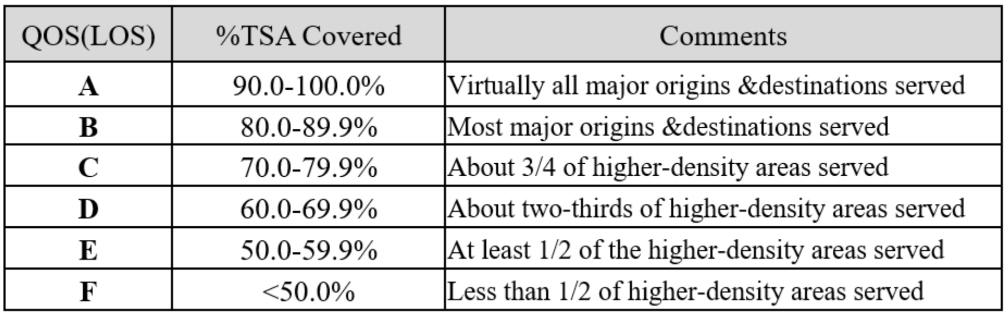
Where *TSA : Transit-Supportive Area*

A_C : *Total area of the city*

A_S : *Area of the bus stop with 400-meter buffer*

n : number of last stops

Table 3.2 Quality of Services for Transit-Supportive Areas (TCRP100, 2003)



QOS(LOS)	%TSA Covered	Comments
A	90.0-100.0%	Virtually all major origins &destinations served
B	80.0-89.9%	Most major origins &destinations served
C	70.0-79.9%	About 3/4 of higher-density areas served
D	60.0-69.9%	About two-thirds of higher-density areas served
E	50.0-59.9%	At least 1/2 of the higher-density areas served
F	<50.0%	Less than 1/2 of higher-density areas served

3.2.2 Hours of Service (HS)

This attribute involved measuring the operating hours of each service, commonly referred to as the hour of service. The schedule for each service was obtained from the Konya municipality website “Intelligent PBT System” (ATUS), and the first and last trips of bus services were recorded to collect the hour of service data. The hour of service for each route was then calculated by subtracting the last trip from the first trip of services. Each route’s QOS could be evaluated based on the service hours, as shown in **Table 3.3.** The HS can be calculated by using **Equation 3.2.**

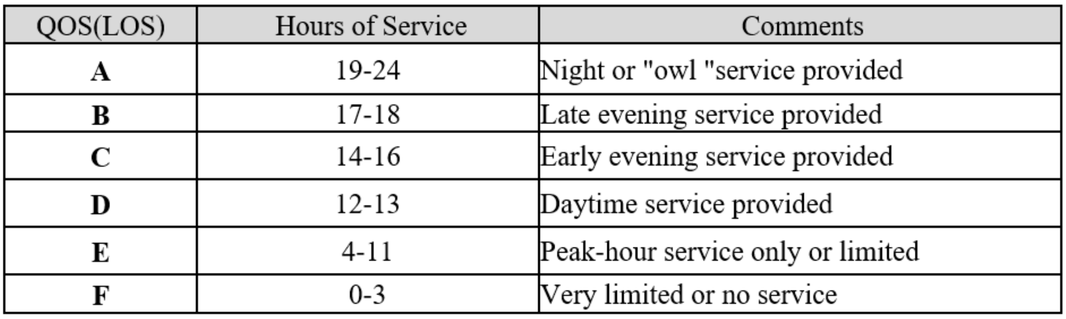
$$\boldsymbol{HS = (H_{LT} - H_{FT}) + 1} \qquad \textbf{3.2}$$

Where *HS : Hours of services*

H_{LT} : *Hour of the last trip*

H_{FT} : *Hour of the first trip*

Table 3.3 Quality of services for hours of services (TCRP100, 2003)



QOS(LOS)	Hours of Service	Comments
A	19-24	Night or "owl "service provided
B	17-18	Late evening service provided
C	14-16	Early evening service provided
D	12-13	Daytime service provided
E	4-11	Peak-hour service only or limited
F	0-3	Very limited or no service

3.2.3 Service Frequency (SF)

Each route’s service frequency was determined by its daily SF attributes. Bus schedule data was obtained from the ATUS website. The process involved gaining the schedule for each route for a whole day, measuring the departure interval for each route, and determining the average departure time interval for each route. The QOS was classified according to **Table 3.4** based on the average departure intervals. The SF can be calculated by using **Equation 3.3.**

$$\mathbf{SF} = \sum(\boldsymbol{H_n} - \boldsymbol{H_{n+1}}) / \boldsymbol{N} \tag{3.3}$$

Where *SF : Average headway for service frequency*

H : Headway

n : Trip number

N : Total trip number

Table 3.4 Quality of services for service frequency (TCRP100, 2003)

QOS(LOS)	Avg . Headway (min)	veh /h	Comments
A	<10	>6	Passengers do not need schedules
B	10-14	5-6	Frequent service, passengers consult schedules
C	15-20	3-4	Maximum desirable time to wait if bus /train missed
D	21-30	2	Service unattractive to choice riders
E	31-60	1	Service is available during the hour
F	>60	<1	Service unattractive to all riders

3.2.4 Passenger Per Capacity (PPC)

This study analyzed the hourly passenger count for each ULID against the available hourly seating capacity of the buses to evaluate the PPC factor in Konya's bus system. Passenger numbers were determined using SCD, reflecting the number of passengers boarding the ULIDs hourly. The bus's seating capacity was calculated by multiplying the number of buses (obtained from bus schedule data) on each route by their seating capacities, with data from ATUS indicating each bus has a capacity for up to 100 passengers, including 27 seats and 73 standing spaces. The PPC ratio was then calculated by dividing the hourly passenger by bus capacity, and these ratios were averaged to determine the daily mean PPC value for each ULID. The study addressed the variations in bus route characteristics and passenger behaviors between weekdays and weekends by conducting separate evaluations for these timeframes. The passenger demand data for each line was obtained from the "Boarding stop assignment" section and was used to calculate the passenger load factor. **Table 3.5** shows the QOS based on the PPC. The PPC can be calculated by **Equation 3.4.**

$$\boldsymbol{PPC} = {\sum \boldsymbol{N_P^i}}\Big/{\sum \boldsymbol{N_{BS}^i}} \qquad \textbf{3.4}$$

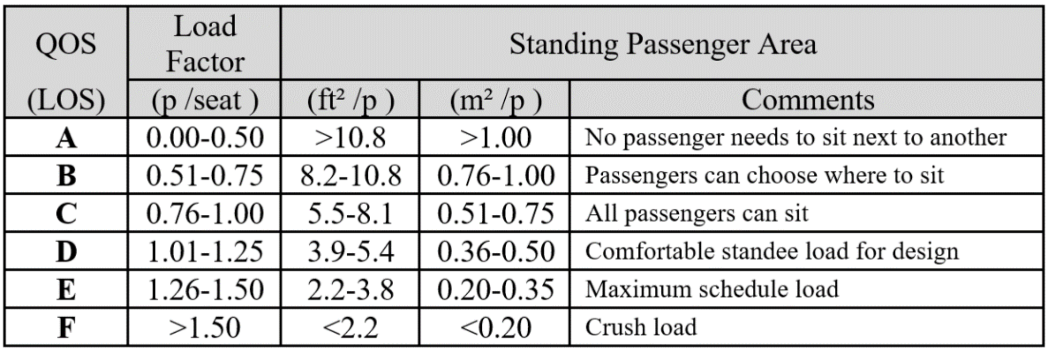
Where PPC: Passenger per Capacity

N_P: Number of boarded passengers

N_{BS}: Number of bus passenger capacity

i : Hour of day

Table 3.5 Quality of Services for Passenger Load Factor (TCRP100, 2003)



QOS	Load Factor	Standing Passenger Area		
(LOS)	(p /seat)	(ft² /p)	(m² /p)	Comments
A	0.00-0.50	>10.8	>1.00	No passenger needs to sit next to another
B	0.51-0.75	8.2-10.8	0.76-1.00	Passengers can choose where to sit
C	0.76-1.00	5.5-8.1	0.51-0.75	All passengers can sit
D	1.01-1.25	3.9-5.4	0.36-0.50	Comfortable standee load for design
E	1.26-1.50	2.2-3.8	0.20-0.35	Maximum schedule load
F	>1.50	<2.2	<0.20	Crush load

3.2.5 On-Time Departure (OTD)

The OTD ratio determined the bus departure punctuality based on the municipality's existing schedule (*D_A)*. The actual departure time for each lane was obtained from the LR section. The method to collect the following is the schedule for each line collected from the municipality. Secondly, the actual departure for the entire day was calculated from LR steps (*D_S)*. Thirdly, the time difference between actual and scheduled departures for each route was determined. According to transit systems, a vehicle is considered “late” if it falls behind schedule by more than 5 minutes. Then, the percentage of on-time departures for each route’s overall departure was calculated. Each route’s QOS for OTD was classified based on the calculated percentage of on-time departures. **Table 3.6** shows the QOS category for OTD percentage. The OTD percentage can be calculated by **Equation 3.5.**

$$\boldsymbol{D_D = D_A^i - D_S^i}$$

$$\boldsymbol{OTD = \left({N_{OT}}/{N_T} \right) \times 100} \qquad \textbf{3.5}$$

Where D_D : Time difference between actual and scheduled departure

D_A : Actual departure time

D_S : Scheduled departure time

i : Trip number

OTD : on-time percentage

N_{OT} : Number of on-time departures (less than 5 min delay)

N_T : Number of all trips

Table 3.6 Quality of services for on-time departure (TCRP100, 2003)

QOS(LOS)	On-Time Percentage	Comments
A	95.0-100.0%	1 late transit vehicle every 2 weeks (no transfer)
B	90.0-94.9%	1 late transit vehicle every week (no transfer)
C	85.0-89.9%	3 late transit vehicles every 2 weeks (no transfer)
D	80.0-84.9%	2 late transit vehicles every week (no transfer)
E	75.0-79.9%	1 late transit vehicle every day (with a transfer)
F	<75.0%	1 late transit vehiDFRFcle at least daily (with a transfer)

3.2.6 Transit-Auto Travel Time (TAT)

Once individuals consider using PBT regularly, one of the primary factors is how much longer their trip will take in comparison to driving a car. AQOS measurement, known as TAT, is utilized to assess this. This measurement incorporates the time required for walking, waiting, and transferring. It calculates the difference in door-to-door travel time between car and bus. Essentially, it indicates how much longer or shorter a PBT trip will take.

In terms of calculating travel time for PBT, the TCQSM manual takes into account the time it takes to walk from one’s starting point to the transit stop (usually around 3 minutes), the wait time for the transit (about 5 minutes), the time spent on board the transit (which varies), and the time it takes to walk from the transit stop to the final destination (again, usually around 3 minutes). If any transfers are necessary, the time for those is also factored in. For automobile travel, the time spent in the car is considered, as well as the time needed to park the car and walk to the final destination (around 3 minutes on average). The walking distance is calculated based on a maximum of 0.4 km (0.25 mi) at a velocity of 5 km/h (3 mph), which takes approximately 5 min. However, not all PBT users have to walk that far.

For the analysis, a three-step process was implemented. Firstly, the travel times between various transit locations by bus and automobile were calculated. Secondly, the differences in travel time between these locations were computed. Thirdly, the QOS concerning the difference between PBT and automobile travel times was determined.

The first step involved estimating the travel times between various transit locations and automobiles and creating a spreadsheet for subsequent reference. This phase solely considered the travel times between destinations, excluding factors such as the time required to access the transit or any waiting periods. The PBT travel time calculation was sourced from the “Linear Referencing” section. In that section, buses' speeds and expected arrival times are calculated. Then, the travel time between stops and for the whole route is calculated. Besides, automobile travel times in Konya were determined using TomTom Traffic Stats. The dataset consisted of the average speed and travel time for private cars on each segment of the road over 24 hours. The October dataset was selected for further analysis and exported to

ArcGIS. Using the “Network Analysis” feature in ArcGIS, the direct route between two positions was determined by specific situations. Then, the estimated travel time and speed for private cars at the shortest route were calculated.

During Step 2, the analysis calculated the differences in travel time between locations. This involved taking the transit travel time for each location pair and subtracting the auto travel time. It also considered additional factors, such as time for accessing transit and waiting, while excluding the time spent on activities related to auto access, like walking to or from parking facilities. The analysis was based on a set of assumptions. First, it was presumed that passengers would spend an average of 4 minutes walking at the beginning and end of their journey. Second, if the time between transit vehicles (headway) was 10 minutes or less, the waiting time was assumed to be half that headway at the beginning of a trip. If the headway was greater than 10 minutes, the waiting time was a fixed 5 minutes, considering passengers would likely rely on a timetable in such situations. Finally, it was assumed that the process of parking and walking added an average of 2 minutes to each end of an auto trip.

During Step 3, the QOS related to the difference between PBT sit and automobile travel times was determined. This involved calculating the average travel time differences for each pair of locations along each line. The number of stops on each line was divided into four equal segments. Travel times were then computed between the first and last stops in each quarter. For example, in a line with 100 stops, bus travel times were calculated between the 1st and 25th stops, 25th and 50th stops, 50th and 75th stops, and 75th and 100th stops. Subsequently, the travel time for the shortest automobile route between these points was calculated by using TomTom data. **Table 3.7** was used to determine the QOS. The difference in TAT is calculated by **Equation 3.6.**

$$\boldsymbol{TAT = \sum TT_A - \sum TT_B} \tag{3.6}$$

Where *TAT : Transit auto travel time difference*

TT_A : Auto travel time

TT_B : Bus travel time

Table 3.7 Quality of services for Transit-auto travel time (TCRP100, 2003)

QOS(LOS)	Travel Time Difference (min)	Comments
A	≤0	Faster by transit than by automobile
B	1-15	About as fast by transit as by automobile
C	16-30	Tolerable for choice riders
D	31-45	Round -trip at least an hour longer by transit
E	46-60	Tedious for all riders; may be best possible in small cities
F	>60	Unacceptable to most riders

3.3 Potential Use of SCD for TCQSM measures

The potential use of SCD for TCQSM measures highlights the efficiency in evaluating city-wide QOS through planning data such as HS, SF, and TSA. These metrics traditionally rely on planning data to assess the overall accessibility and availability of transit services at a city level. However, when evaluating line-specific metrics of comfort and convenience, the scenario changes significantly. Usually, gathering data on metrics like TAT, which can vary significantly during peak and off-peak hours,PPC, and OTD would require extensive manual data collection efforts. These efforts can be particularly challenging due to the variability within a single day or differences in peak conditions for routes not passing through city centers, necessitating numerous observations. In this context, the utilization of SCD provides substantial ease, enabling a more detailed and dynamic analysis of these line-specific comfort and convenience without labor-intensive manual data collection, thus reflecting the true variability and performance across different times and routes.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Framework

The study began with data pre-processing and cleanup to understand the data structure, detect and remove missing data, and solve errors in the data. Next, the bus route was created by identifying bus stops and correcting errors. This step also involved creating a stop list, segmented route, start and end stops, latitude, longitude, ULID, and distance for each ULID. Step three involved estimating the boarding stops and directions for each trip on the bus lines. Step four estimated the expected arrival time (ATE), travel time, and speed. Step five involved evaluating PBT performance based on TCQSM (see Chapter 3). These steps generated all the necessary data for analyzing PBT performance using TCQSM. **Table 4.1** and **Figure 4.1** represent the framework of the study.

Table 4.1 Framework of the study

Process Step	Activities	Definition
Data Pre-processing and Cleanup	- Understand data structure - Detect and remove missing data - Detect and resolve data errors	Preparing and refining the data for analysis by understanding its structure and correcting any inconsistencies or gaps.
Creation of Bus Routes from Bus Stops	- Create a stop list for each ULID - Create a segmented route for each ULID	Developing a detailed route map by listing and segmenting the stops for each ULID.
Estimation of Boarding Stops and Trip Direction	- Determine boarding stop - Determine the direction of the bus	Identifying the specific stops where passengers board and the direction of the bus for each trip.
ATE and Travel Time	- Calculate the expected arrival time - Calculate travel time - Calculate speed	Calculating the timings of bus arrivals, the duration of travel between stops, and the bus's average speed.
Evaluation of PBT Performance	- Calculate comfort and convenience factors - Calculate availability factors	Evaluating the performance of the public transit system based on factors affecting passenger comfort, convenience, and service availability.

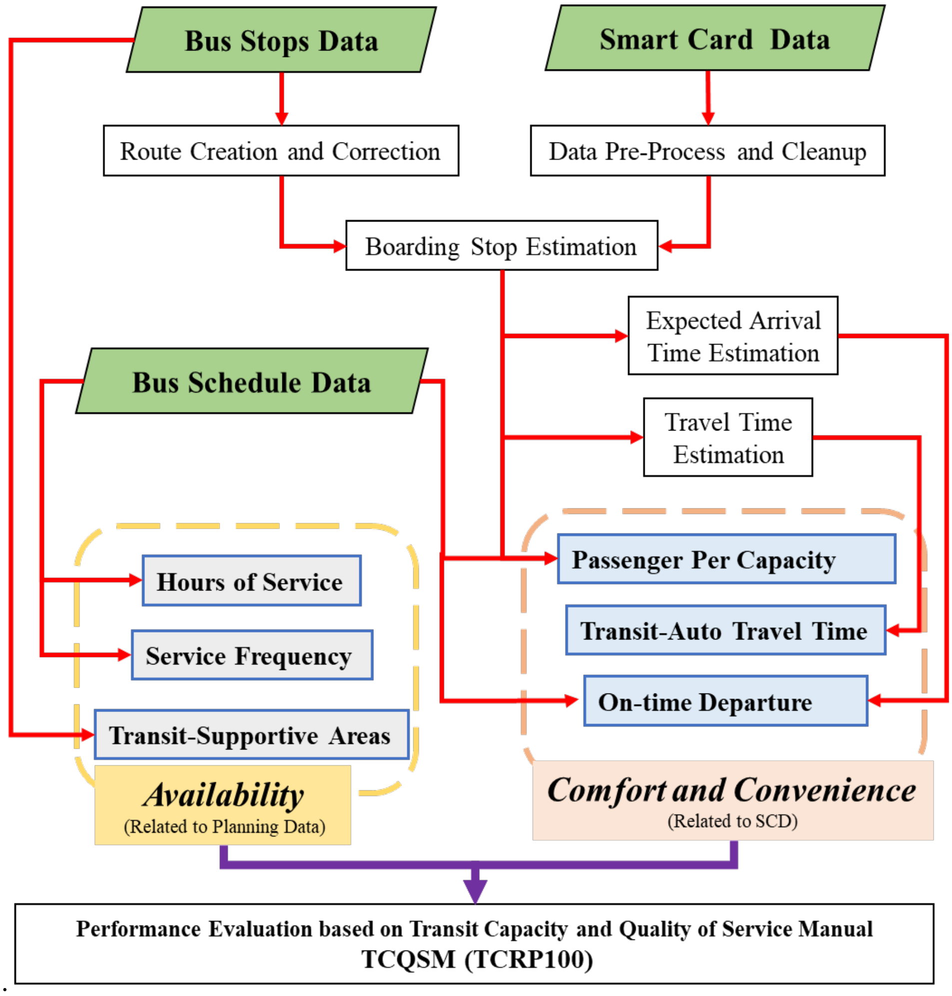


Figure 4.1 Flowchart of Study Framework

4.2 Data Quality Evaluation

Data cleaning and filtering are crucial steps in data processing, holding significant importance, as even the slightest issue during a transaction can lead to errors when constructing a passenger’s trip chain. Generally, data may contain errors stemming from system failures or human errors. These could be related to GPS inaccuracy, failure to match transactions with a particular service, and errors by drivers. The datasets generated from SC systems frequently contain errors, which might arise from software issues like ‘bugs’ in the system, missing requirements, and synchronization problems. Hardware-related problems can include incorrect GPS location information and malfunctioning readers or SCs. Furthermore, user-related issues such as sharing cards, failure to tap on or off, and losing cards can contribute to errors.

The comprehensive assessment of the attributes of SCD and the methodical procedure was implemented, as detailed in **Appendix A** and **Appendix B**. It included the following three stages. The data continuity check stage involved reviewing the SCD for missing rows and columns in the raw data and ensuring data availability for each vehicle and line. The review included a consistency check to confirm data continuity across different days and months. Additionally, seasonal patterns were explored to examine the presence of cyclic behavior. Data Consistency Check stage examined the coherence and consistency within the available data. Inconsistencies were identified in the stop sequence and bus line ID, including differences in the sub-line ID. Further differences were noted between the stated bus line ID and the route information declared on the ATUS website. The missing Data Detection stage identifies any missing cells in the raw data, such as absent information for the location of the SCD, line ID, and driver ID. This detection was conducted using R codes. Through this multilayered approach, the data quality was thoroughly examined and optimized, paving the way for accurate analysis and interpretation. It ensures that the integrity of the data is maintained, which is fundamental to obtaining reliable results and insights from it. The list of filters is shown in **Figure 4.1**. (note: i =Transaction number & DCF= Data Clean-up Filter).

Table 4.2 Missing Data Filters

Variable	Description	Condition
DCF_MissX	Filter missing values of X (LATITUDE)	For a transaction “i” If “x_i” is “Missing or 0” DCF_MissX = 1 Otherwise DCF_MissX = 0
DCF_MissY	Filter missing values of Y (Longitude)	For a transaction “i” If “y_i” is “Missing or 0” DCF_MissY = 1 Otherwise DCF_MissY = 0
DCF_MissXY	Filter missing values of X and Y (Latitude, Longitude)	For a transaction “i” If “x_i” and “y_i” is “Missing or 0” DCF_MissXY = 1 Otherwise DCF_MissXY = 0
DCF_MissVID	Filter missing values of VID (Vehicle ID)	For a transaction “i” If “bid_i” is “Missing or 0” DCF_MissVID = 1 Otherwise DCF_MissVID = 0
DCF_MissCID	Filter missing values of CID (SC Serial Number)	For a transaction “i” If “$cid_i \neq 32$ character” DCF_MissCID = 1 Otherwise DCF_MissCID = 0
DCF_MissCT	Filter missing values of CT (SC Ticket Type)	For a transaction “i” If “ct_i” is “Missing” DCF_MissCT = 1 Otherwise DCF_MissCT = 0
DCF_MissLID	Filter missing values of LID (Service Line Identification Number)	For a transaction “i” If “lid_i” is “Missing or 0” DCF_MissLID = 1 Otherwise DCF_MissLID = 0
DCF_MissTS	Filter missing values of TS (TIMESTAMP)	For a transaction “i” If “ts_i” is “Missing or 0” DCF_MissTS = 1 Otherwise DCF_MissTS = 0

4.3 Digitalization of PBT Network

The methodology for correcting the bus route and stop location data is a comprehensive four-part process. In the initial phase, various datasets for bus stops are merged, forming a compiled stop list for each ULID. The accuracy of these stop locations is then heightened by cross-verifying the stop location and SCD within the ArcGIS environment. **Appendices D** and **C** outline the first and second attempts to construct segmented bus routes utilizing ArcGIS and Open Street Map. Despite these efforts, the accuracy was insufficient for the study's needs, leading to a third attempt, detailed in the following. This attempt employs ArcGIS Pro and Google Road Map to sharpen the results, with outcomes cross-checked against SCD data for consistency. The flowchart illustrating the Route and Stop correction process can be seen in **Figure 4.2**.

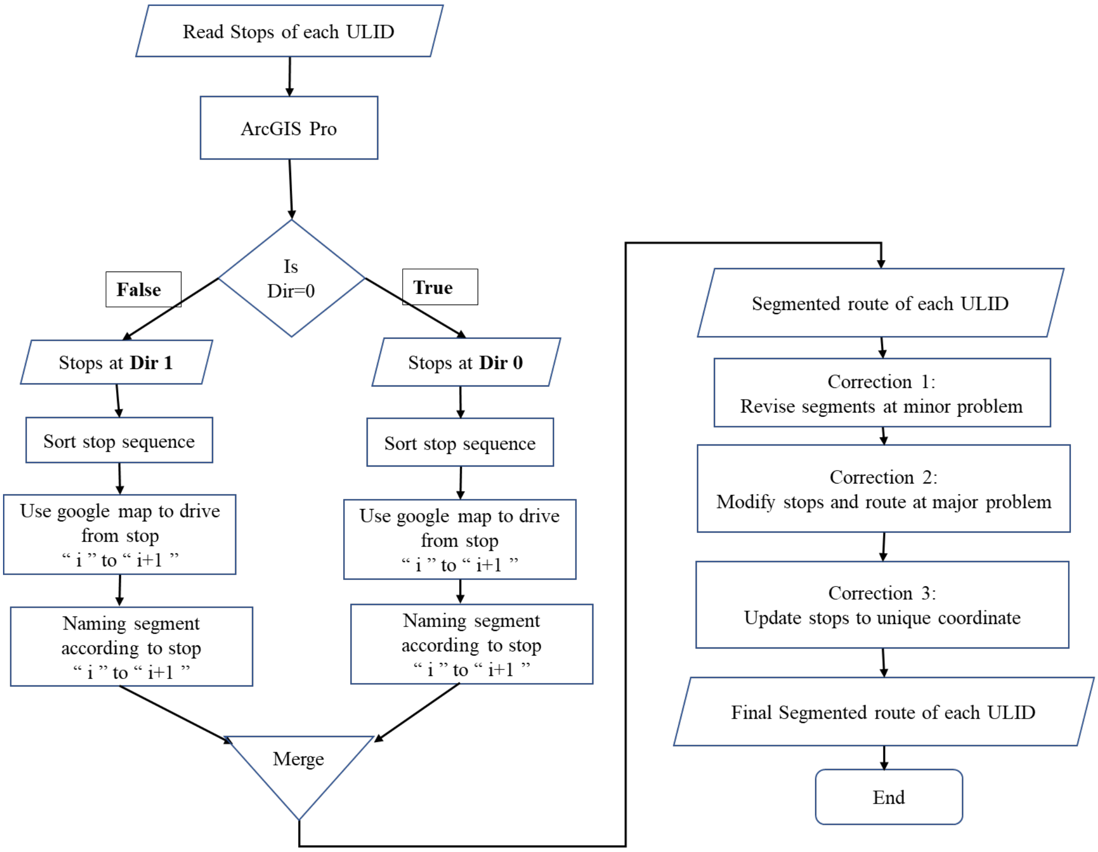


Figure 4.2 Flowchart of Digitalization of PBT Network

GIS Implementation

The attribute table and too many manual corrections were the main problems of the previous attempt, detailed in **Appendices D** and **C**. Therefore, the ArcGIS Pro environment creates a segmented route from bus stops in this step. The reason for choosing ArcGIS Pro for this step is online access to the Google map road network in the Esri server. The ArcGIS Pro model builder tool has been used to create a segmented route. The model contains four main parts: 1) stop each ULID as input, 2) create a segment between stops in part one, 3) name segments according to start and end stops in part two, 4) merge the result, and create one multipart rout. **Figure 4.2** shows the flowchart of the model for the segmented route.

In the first step, the model created in the Model Builder iterates through the stops at each ULID. Stops are divided based on their direction into Dir0 and Dir1 to accommodate two-way routes. The stops within each directional group are then sorted according to their sequence numbers. At this stage, the model utilizes the Google Road Map network available on Esri online to simulate driving, like a car, between stops in their respective sequence, thereby creating a polyline between each pair of stops. Subsequently, in part two of the process, the model begins to label these segments and generate an attribute table. This table includes the sequence, name, direction, latitude, and longitude of the 'From (1st) stop' and 'To (2nd) stop'. In the final step, the outputs from 'Dir 0' and 'Dir 1' are combined, resulting in a single shapefile for each ULID. **Figure 4.3** shows the model created in the ArcGIS Pro Model Builder tool. The model results show that the segments that were created need some improvement and revision. A minor problem arises from the model builder. The code separates the stop into two directions and then merges the results; therefore, the segment cannot be created between the last stop of "Dir 0" and the first stop of "Dir 1". Thus, this segment is added manually to all ULIDs. **Figure 4.4** displays the model's output and minor problems of the created line.

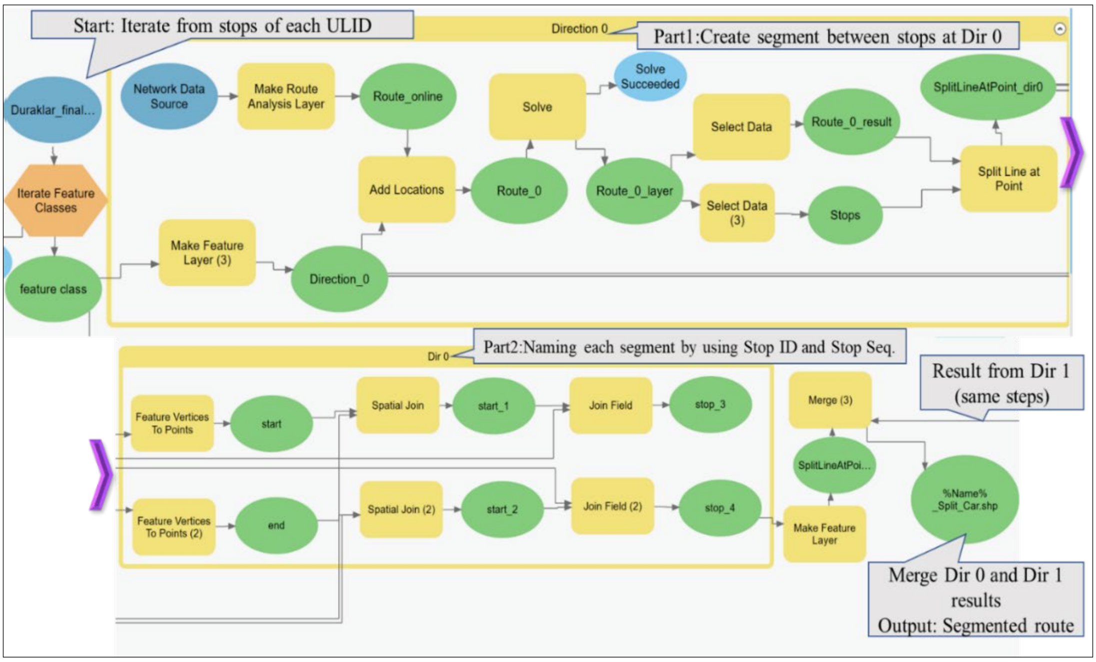


Figure 4.3 Created model in the ArcGIS Pro model builder tool

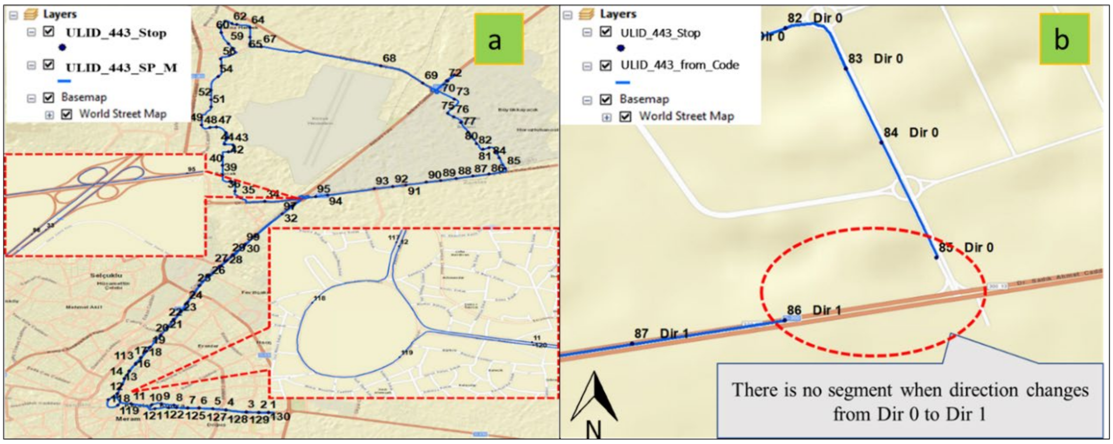


Figure 4.4 a) Output of the model builder b) Minor problem

Moreover, some major problems are detected when bus GPS and SCD exist in the base map, but there is no line or stop at that part(for more detail, see Afshar et al. 2020). To solve these problems, the bus GPS was first animated according to timestamp, and then new stops were added to the ULID stop list. Then, the rerun model builder was to create a new segmented route with new stop lists. **Figure 4.5** indicates these major problems and the revised version. At the end of the improvement, the snapping tool of ArcGIS was used to relocate all stops to the end of each segment, which is shown in **Figure 4.5**.

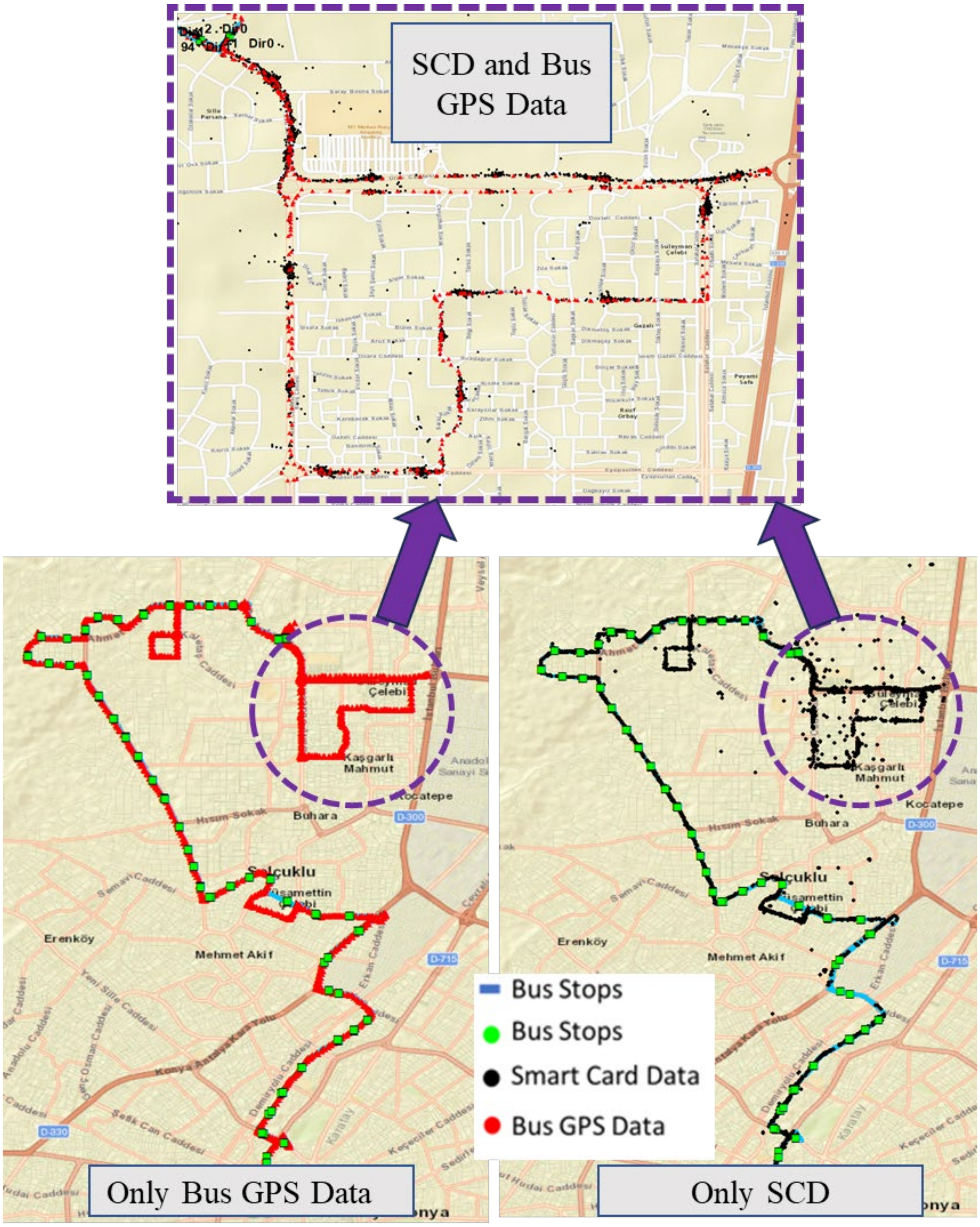


Figure 4.5 The major problem

Following merging the provided datasets into one, the satellite base map within the ArcGIS environment showed that bus stops were approximately around actual stop locations. Using the ArcGIS edit tool, these stops were snapped to Open Street Map lines around dense SCD, enhancing the location's accuracy. This process is shown in **Figure 4.6**.

Finally, the GIS tool's application unintentionally created duplicated data because segments were slightly adjusted to align with the Bus GPS path. Multiple coordinates for the same stop were produced when stops were snapped to the end of each segment. To resolve this issue stops from all ULIDs were consolidated. The process involved calculating the distance between stops sharing the same name and identifying the most commonly occurring coordinates, which were then revised. This method established a unique stop list with a single coordinate for each Stop name, as shown in **Figure 4.7**.

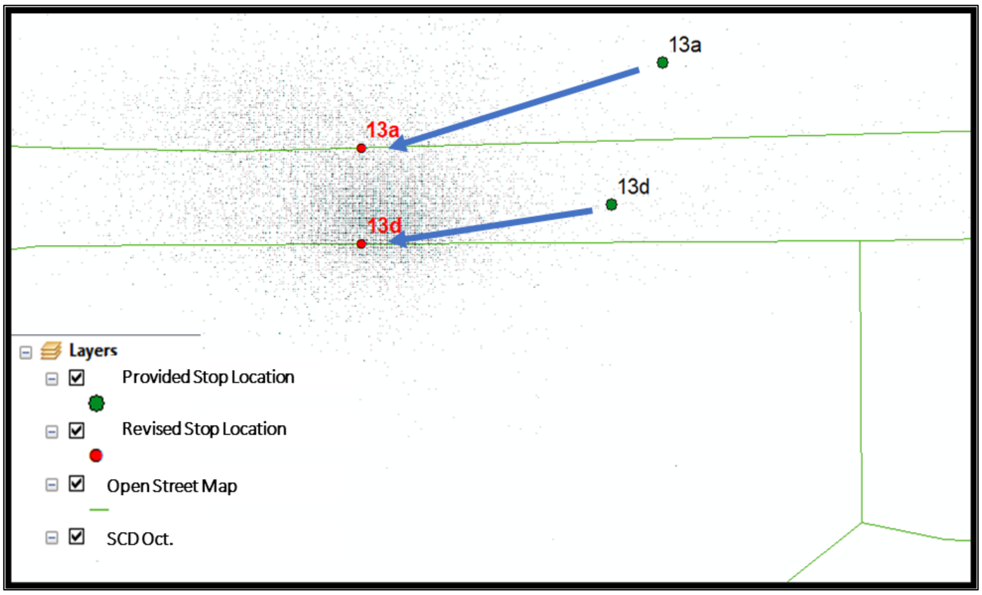


Figure 4.6 Provided and revised stop location

Detailed explanations of each step are provided in **Appendix E**; the following are the steps' overviews. The methodology begins with integrating two primary types of data: Line Data and SCD. The Line Data provides a detailed layout of bus routes and stop sequences. The SCD captures all onboard bus transactions, complete with GPS information. The second stage in this methodology is the Bus Service Shift Determination. In this phase, GPS logs from the SCD are sorted using the resetIndex Function. The sorting process is conducted first by Vehicle ID and then by Timestamp, assigning a unique index to each GPS log. When paired with the Vehicle ID, this index creates a ShiftID for each bus trip, marking the beginning of each journey's data analysis.

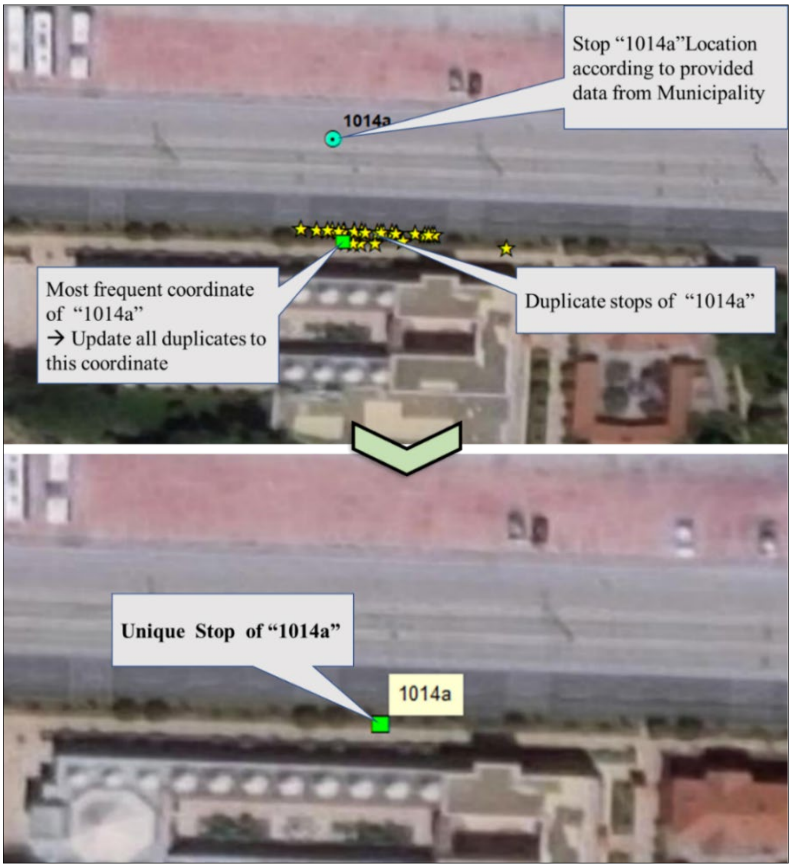


Figure 4.7 Sample of duplicate stops and correction

4.4 Boarding Stop Estimation

The methodology for determining boarding stops from SCD is a multi-step process that accurately captures passenger boarding points. This process is crucial for evaluating PBT systems' efficiency and service quality. The methodology contains several stages. First, bus line data and SCD are uploaded. Next, bus service shifts are established. The third stage involves the determination of the move group for each segment. Subsequently, the direction of the bus service is determined. The fifth stage consists of defining the bus service's trip direction. Finally, boarding stops are assigned based on the information processed in the preceding stages. All these steps are implemented using Python. The general procedure of the boarding stop assignment is shown in **Figure 4.8**.

Figure 4.8 Flow Chart for Boarding Stop Assignment

Following this, Move Group Determination for Segments employs the createSegmentBase function to establish a 100-meter buffer zone around each bus route segment. This step determines whether the GPS coordinates from SCD are within these zones, linking them to specific route segments. Next, the direction of the bus service is determined through a combination of functions: getLocalStop and getDirections. These functions analyze the sequence of transactions at stops, providing insights into the bus's travel direction. Then, in the Trip Detection phase, the data is filtered to isolate individual bus trips using the getTripID Function. This function assigns each trip a unique ID, reflecting its starting time.

The final phase of the process is the Bus Boarding Stop (AsgnStopID) Assignment. This involves the assignScData function, which creates a 50-meter buffer around each bus stop segment. SCD within this buffer are linked to their respective boarding stops. The assignment process is based on two key assumptions: the presence of at least five distinct SCD points for each bus trip and sufficient variance in GPS coordinates to indicate the bus's direction of travel. The chosen buffer zones – 100 meters for segments and 50 meters for stops – consider potential inaccuracies in GPS data due to factors like urban infrastructure interference and minor deviations in bus stop locations. Upon completing these stages, the system can display the success rate of boarding stop assignments, achieving an accuracy rate of 97.63%. However, challenges such as route deviations, errors in GPS data entry, or insufficient SCD can impact this accuracy, potentially leading to incorrect boarding stop assignments. **Table 4.3** shows the summary of each step in the Boarding Stop Assignment.

Table 4.3 Summary of each step in the Boarding Stop Assignment

No.	Stage	Description
1	Data Merging	Combining Line Data (bus route and stop sequences) and SCD (record of boardings with GPS location and timestamp).
2	Bus Service Shift Determination	Sorting GPS data from SCs by Vehicle ID and Timestamp, assigning a unique index to each entry, and creating a ShiftID for each bus trip.
3	Move Group Determination for Segments	Create a 100-meter buffer around each bus route segment using the createSegmentBase Function and check if SC GPS data is within this buffer.
4	Bus Service Direction Determination	Using functions getLocalStop and getDirections to analyze stop transaction sequences and determine the bus's travel direction.
5	Bus Service Trip Detection	Isolate individual bus trips using the getTripID Function and assign each trip a unique ID based on its start time.
6	Bus Boarding Stop	Create a 50-meter buffer around bus stop segments and link SCD within this buffer to the appropriate boarding stops. Based on the

	(AsgnStopID) Assignment	assumption that multiple data points per trip indicate the bus's direction.

4.5 PBT Arrival Time Estimations

The methodology for ATE in PBT begins with an initial ‘Static Route Data Analysis’ for each bus line. In this stage, bus lines are converted into "bus route feature classes," transforming the sections between stops into "polyline m objects (routes)" using LR techniques. Additionally, this phase calculates the distance in kilometers between bus stops (St Km) through LR tasks. Following this, each bus service's Dynamic Bus Line Service Analysis phase takes place. This phase includes preprocessing SCD within a GIS environment. Subsequently, LR and Dynamic Segmentation (DynSeg) techniques are applied to the daily dataset, generating route and trip-specific station kilometers (ST) for both SC and bus trajectory data. This phase is followed by post-processing steps that aim to clean and reorganize the data for clarity. The final stage of this methodology concentrates on ATE for PBT. This process merges SCD with bus stop information and calculates the expected arrival times at each stop. This calculation is achieved through linear interpolation, utilizing both the distance (in kilometers) and time stamps. The comprehensive methodology culminates in producing Time-Space diagrams and metrics of average travel speeds. This detailed approach to extracting arrival and travel times using SCD and GIS is illustrated in **Figure 4.10.** The following subsection provides an in-depth exploration of the GIS implementation techniques used in ATE.

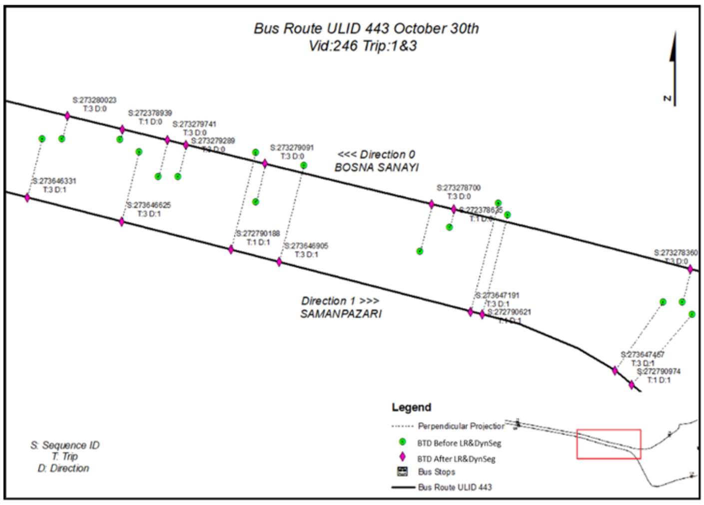


Figure 4.9 Before and After the Linear Referencing

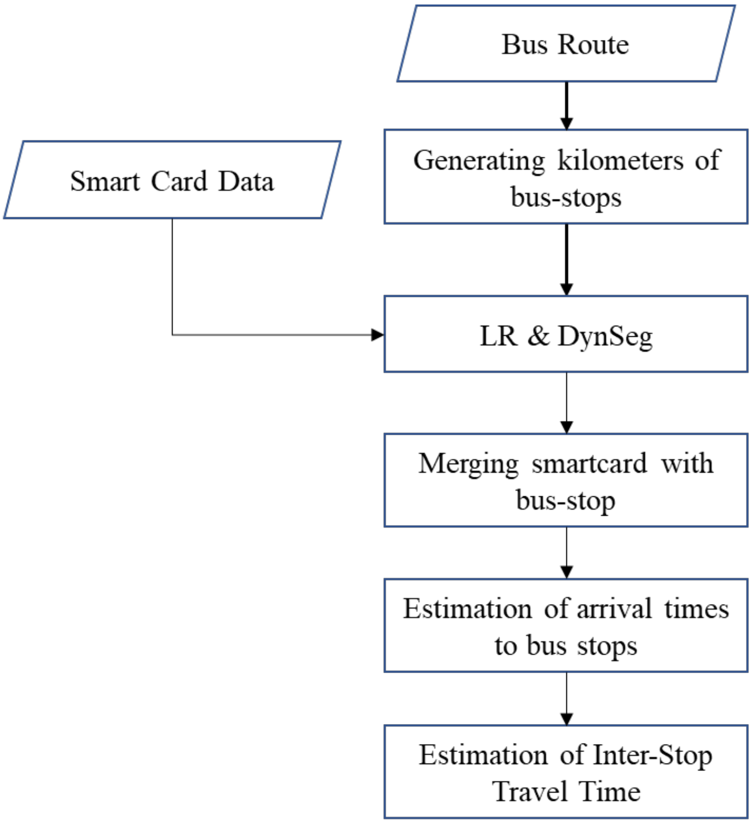


Figure 4.10 Flowchart of Arrival Time Estimations

GIS Implementation

The GIS Implementation section is divided into three distinct phases. In the first phase, Static Route Data Analyses, vehicle trajectory data are transformed from traditional latitude/longitude coordinates into the 'measure' domain. This transformation is facilitated using GIS methodologies such as LR and DynSeg. These techniques help calculate the cumulative kilometers traveled by a bus. The second phase, Dynamic Bus Line Service Analyses, is further categorized into two sub-stages: LR of SCD Feature Classes and DynSeg of the Event Table. This phase ensures the alignment of SCD with the spatial route data, thus establishing a comprehensive spatial outline. The last section is the ATE phase. This phase estimates bus stop arrival times using linear interpolation and extrapolation methods. These calculations are directed in Microsoft Excel. Regarding the coordinate system used, the initial SCD is provided in geographic coordinates, specifically in latitude and longitude, according to the WGS84 Datum. It is essential to use a projected coordinate system to perform accurate geoprocessing tasks and precisely depict the locations of SCDs. In this context, TUREF_TM33, an ITRF-based geodetic datum aligned with the central meridian of Konya, is utilized.

4.5.1 Static Route Data Analyses

The objective of this process is centered on creating a route feature class, which is essential for the LR of both bus-stop locations and SCD. In the initial "Route" analysis stage, the existing polyline feature classes need to be converted into full bus route feature classes. This conversion takes multi-part polyline feature classes, characterized by segments between bus stops, as inputs. In outputs, it produces both single-part and multi-part route feature classes.

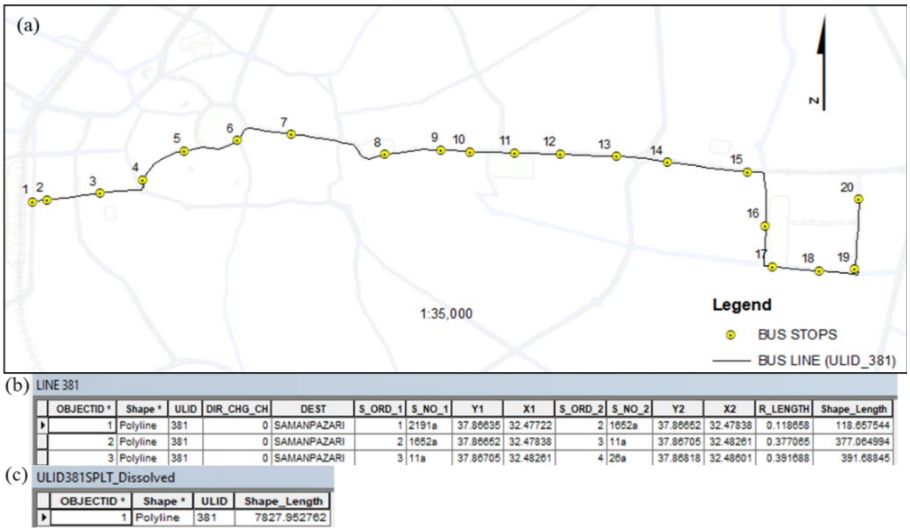
As provided at the onset of the process, the initial bus line object comprises multiple polyline-type objects between bus stops, as shown in **Figure 4.11** (a). The shape field within the primary attribute table, shown in **Figure 4.11** (b), reveals that these segments are classified as polyline objects. These polylines are identified by their attribute values, including the bus stops' names and sequence orders at each segment's end. These polyline objects also include direction attributes, labeled as "0" for routes heading inbound and "1" for those outbound, as detailed in the attribute table. The characteristics of the initial and final bus routes are outlined in **Table 4.4**.

Table 4.4 Initial and resulting field attributes of bus lines

Polyline Field Name	***Attribute Description***	***Notes***
Initial Data		
ULID	Unique Line ID	LID*10+SLID
DIR_CHG_CH	Direction Value (Inbound/Outbound)	0/1
DEST	Destination	-
S_ORD_1	Order Value of the Current Bus Stop	1, 2, 3, …
S_NO_1	Number of the Current Bus Stop	-
Y1	Latitude of the segment origin	-
X1	Longitude of the segment origin	-
S_ORD_2	Order Value of the Next	2, 3, 4, …
S_NO_2	Number of the Next Bus Stop	-
Y2	Latitude of the segment destination	-
X2	Longitude of the segment destination	-
Resulting Data		
FMEAS	Cumulative Km from Bus Stop	-
TMEAS	Cumulative Km to Bus Stop	-

The composition for the route feature classes includes "polyline m" type objects segmented between bus stops, with each segment extending ST progressively. Nevertheless, directly forming a route feature class from these initial classes could potentially lead to losing critical attributes. Moreover, it becomes challenging to obtain essential fields like "from measure" (FMEAS) and "to measure" (TMEAS), which represent cumulative measure values in the attribute field of the subsequent route feature class. These are vital in subsequent LR processes for accurately aligning the SCD with the appropriate polyline object between bus stops. To overcome this, an intermediate single-part route feature class is necessary. This intermediate class is then used in the next phase of the methodology to develop the required final route. The GIS environment's geoprocessing steps to formulate this intermediate class are as follows:

1. The initial step involves using the "Dissolve" tool from the "Data Management" toolbox to produce a single-part polyline feature class. The input for this is the segmented polyline feature class of the bus line. The outcome is a consolidated single-part polyline feature class of the bus line, as illustrated in **Figure 4.11** (c).
2. Subsequently, the "Create Route" tool from the "Linear Referencing" toolbox establishes a single-part route feature class, serving as an intermediate product. Here, the single-part polyline feature class of the bus line is used as input, and the resulting product is a single-part route feature class, as shown in **Figure 4.12**.



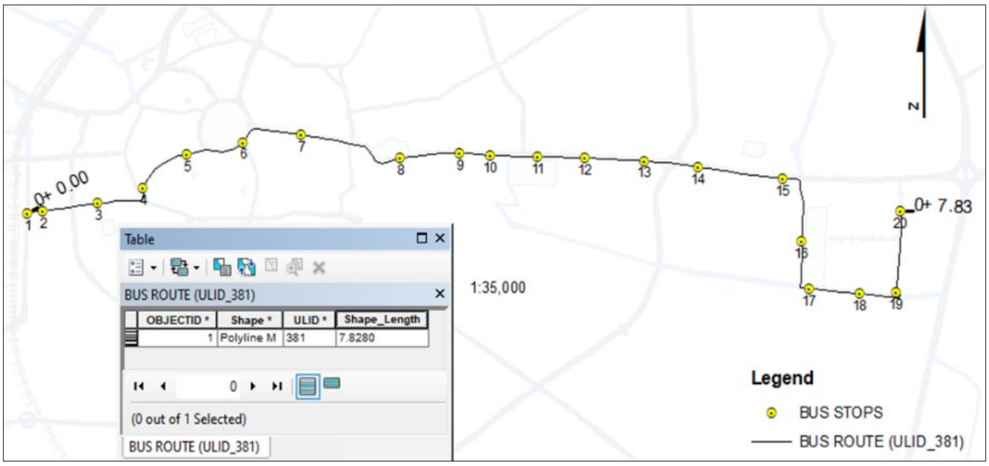
LINE 381

OBJECTID *	Shape *	ULID	DIR_CHG_CH	DEST	S_ORD_1	S_NO_1	Y1	X1	S_ORD_2	S_NO_2	Y2	X2	R_LENGTH	Shape_Length
1	Polyline	381	0	SAMANPAZARI	1	2191a	37.86635	32.47722	2	1652a	37.86652	32.47838	0.118658	118.657544
2	Polyline	381	0	SAMANPAZARI	2	1652a	37.86652	32.47838	3	11a	37.86705	32.48261	0.377065	377.064994
3	Polyline	381	0	SAMANPAZARI	3	11a	37.86705	32.48261	4	26a	37.86818	32.48601	0.391688	391.68845

ULID381SPLT_Dissolved

OBJECTID *	Shape *	ULID	Shape_Length
1	Polyline	381	7827.952762

Figure 4.11 Initial (a) inter-stop segmented bus line and (b) attribute table, (c) resulting attribute table of a single part (non-segmented) bus line (polyline)

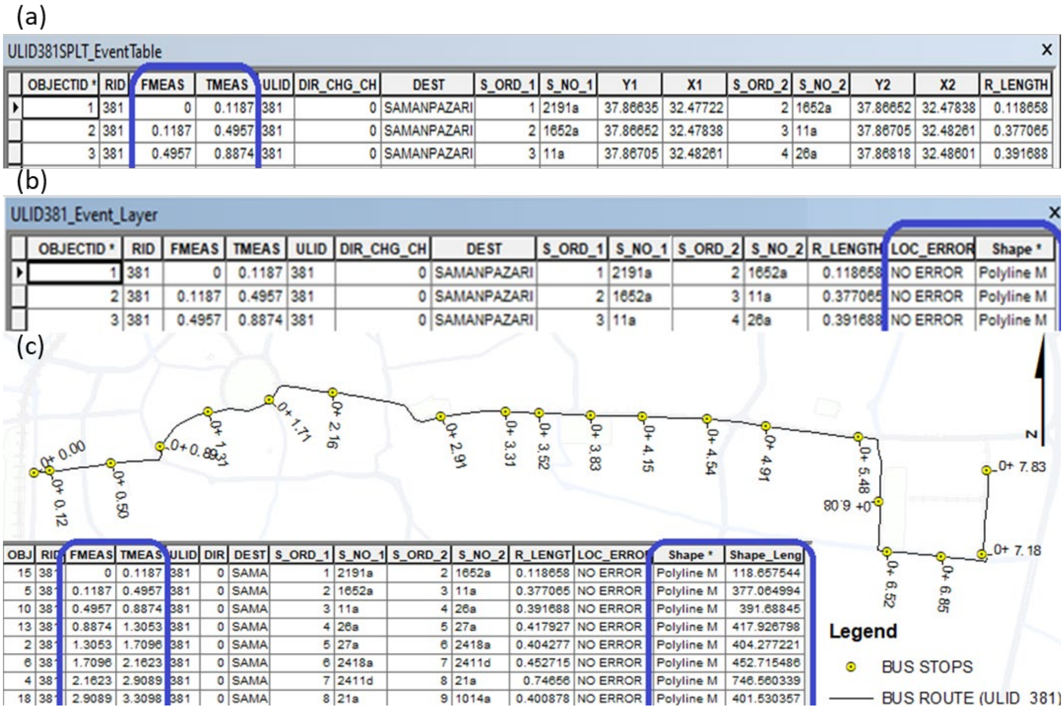


OBJECTID *	Shape *	ULID *	Shape_Length
1	Polyline M	381	7.8280

(0 out of 1 Selected)

Figure 4.12 Single-part (non-segmented) route feature class and attribute table (polyline m).

After creating the intermediate single-part route feature class, the next phase in the GIS process involves executing LR and DynSeg tasks to develop the final route feature class. The process begins with generating an event table representing the segments of the route between bus stops. This step utilizes the LR toolbox, requiring the segmented polyline feature class of the bus line and the newly created single-part route feature class as inputs. The resulting product of this step is an Event Table detailing the segments between bus stop locations, as shown in **Figure 4.13**(a). The DynSeg process is applied to this Event Table in the next step. Inputs for this phase include the Event Table and the single-part route, creating an Event Layer for the inter-stop segmented route feature class, as shown in **Figure 4.13** (b). The subsequent action involves converting the Event Layer into a feature class. For this transformation, the Event Layer of the segmented route is used as the input, and the outcome is the inter-stop segmented route of routes, shown in **Figure 4.13** (c). This figure demonstrates that the segments can now be marked with cumulative "hatches" (kilometer markers) at the beginning and end of each inter-stop segment. Such a configuration allows each SCD occurring near an inter-stop segment to be accurately referenced to the correct location based on its cumulative kilometers from the start of the route.



(a)

ULID381SPLT_EventTable

OBJECTID *	RID	FMEAS	TMEAS	ULID	DIR_CHG_CH	DEST	S_ORD_1	S_NO_1	Y1	X1	S_ORD_2	S_NO_2	Y2	X2	R_LENGTH
1	381	0	0.1187	381	0	SAMANPAZARI	1	2191a	37.86635	32.47722	2	1652a	37.86652	32.47838	0.118658
2	381	0.1187	0.4957	381	0	SAMANPAZARI	2	1652a	37.86652	32.47838	3	11a	37.86705	32.48261	0.377065
3	381	0.4957	0.8874	381	0	SAMANPAZARI	3	11a	37.86705	32.48261	4	26a	37.86818	32.48601	0.391688

(b)

ULID381_Event_Layer

OBJECTID *	RID	FMEAS	TMEAS	ULID	DIR_CHG_CH	DEST	S_ORD_1	S_NO_1	S_ORD_2	S_NO_2	R_LENGTH	LOC_ERROR	Shape *
1	381	0	0.1187	381	0	SAMANPAZARI	1	2191a	2	1652a	0.118658	NO ERROR	Polyline M
2	381	0.1187	0.4957	381	0	SAMANPAZARI	2	1652a	3	11a	0.377065	NO ERROR	Polyline M
3	381	0.4957	0.8874	381	0	SAMANPAZARI	3	11a	4	26a	0.391688	NO ERROR	Polyline M

(c)

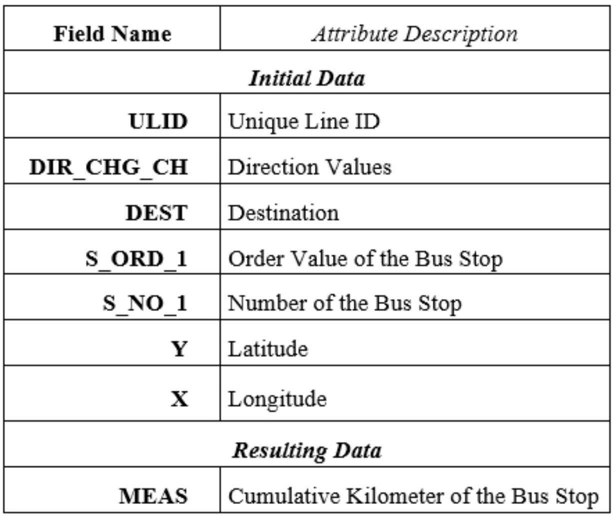
OBJ	RI	FMEAS	TMEAS	ULID	DIR	DEST	S_ORD_1	S_NO_1	S_ORD_2	S_NO_2	R_LENGT	LOC_ERRO	Shape *	Shape_Leng
15	38	0	0.1187	381	0	SAMA	1	2191a	2	1652a	0.118658	NO ERROR	Polyline M	118.657544
5	38	0.1187	0.4957	381	0	SAMA	2	1652a	3	11a	0.377065	NO ERROR	Polyline M	377.064994
10	38	0.4957	0.8874	381	0	SAMA	3	11a	4	26a	0.391688	NO ERROR	Polyline M	391.68845
13	38	0.8874	1.3053	381	0	SAMA	4	26a	5	27a	0.417927	NO ERROR	Polyline M	417.926798
2	38	1.3053	1.7096	381	0	SAMA	5	27a	6	2418a	0.404277	NO ERROR	Polyline M	404.277221
6	38	1.7096	2.1623	381	0	SAMA	6	2418a	7	2411d	0.452715	NO ERROR	Polyline M	452.715486
4	38	2.1623	2.9089	381	0	SAMA	7	2411d	8	21a	0.74656	NO ERROR	Polyline M	746.560339
18	38	2.9089	3.3098	381	0	SAMA	8	21a	9	1014a	0.400878	NO ERROR	Polyline M	401.530357

Figure 4.13 (a) Event table, (b) event layer, and (c) resulting attribute table and route feature class after the LR & DynSeg processes for the generation of inter-stop segmented route

4.5.2 Generation of Bus Stop with ST

This detailed process uses points containing bus stop order numbers and directional information. The primary goal of this process is to calculate the ST for each bus stop. The original dataset for bus stops includes stop order numbers and their respective directions, as shown in **Figure 4.14**(a). This operation aims to establish the ST for each bus stop, as illustrated in **Figure 4.14**(d), which is vital for future steps involving processing SCD data and forecasting bus arrival times. **Table 4.5** shows the attributes from the initial bus stop data and the results obtained from this process.

Table 4.5 Attribute descriptions for the initial data

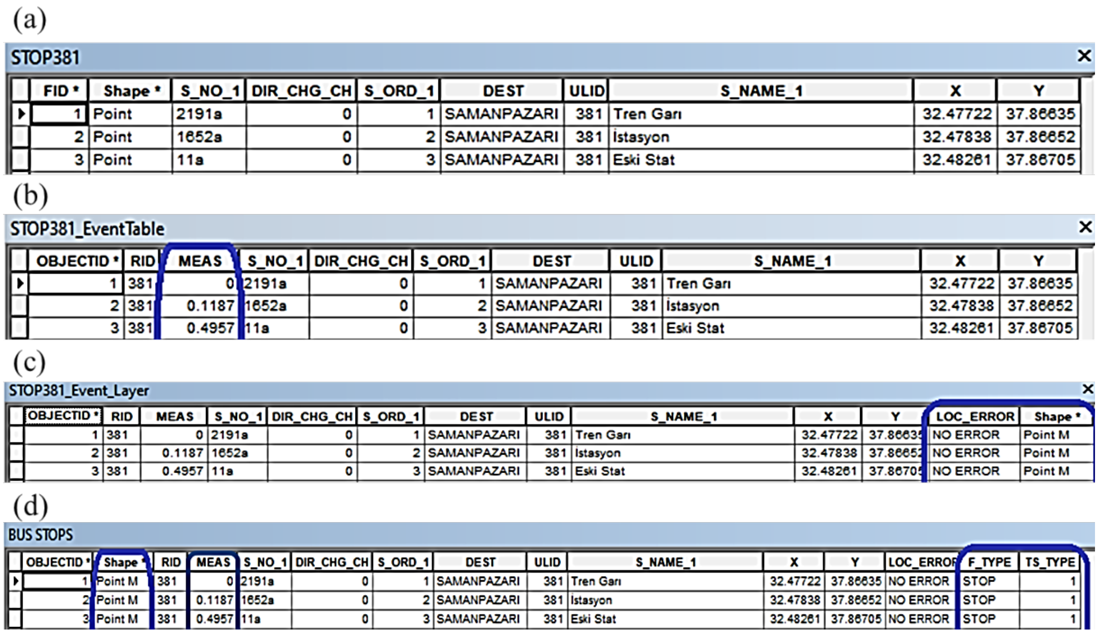


Field Name	*Attribute Description*
Initial Data	
ULID	Unique Line ID
DIR_CHG_CH	Direction Values
DEST	Destination
S_ORD_1	Order Value of the Bus Stop
S_NO_1	Number of the Bus Stop
Y	Latitude
X	Longitude
Resulting Data	
MEAS	Cumulative Kilometer of the Bus Stop

Generating ST data for each bus stop involves executing a series of LR and DynSeg tasks within the GIS environment. The first step in this process is to create an event table for bus-stop ST. This is done using the LR tool with inputs. The outcome of this step is an event table displaying the bus-stop ST, as shown in **Figure 4.14**(b). Subsequently, this event table undergoes DynSeg using the "Locate Features Along Route" tool, which requires the event table of bus-stop kilometers and the inter-stop segmented route as inputs. The result of this step is an event layer that maps bus-stop locations onto the route, each marked with kilometer attributes, as indicated in **Figure 4.14**(c).

The final step in this phase involves exporting the generated event layer into a feature class. The input for this process is the event layer of the bus-stop feature class, which creates a bus-stop feature class that includes kilometer attributes, as shown in **Figure 4.14**(d). Following the export, the attribute table of the newly formed event layer mirrors the contents of **Figure 4.14**(d), resulting in a "Point M" type bus-stop feature class. This class contains progressively increasing kilometer values from the route's start point in the "MEAS" field. Adding the "F_TYPE" and

"TS_TYPE" fields to the final bus stop feature class is also essential. These added fields are crucial as they help differentiate bus-stop data from SCD during ATE.



(a)

STOP381

FID *	Shape *	S_NO_1	DIR_CHG_CH	S_ORD_1	DEST	ULID	S_NAME_1	X	Y
1	Point	2191a	0	1	SAMANPAZARI	381	Tren Garı	32.47722	37.86635
2	Point	1652a	0	2	SAMANPAZARI	381	Istasyon	32.47838	37.86652
3	Point	11a	0	3	SAMANPAZARI	381	Eski Stat	32.48261	37.86705

(b)

STOP381_EventTable

OBJECTID *	RID	MEAS	S_NO_1	DIR_CHG_CH	S_ORD_1	DEST	ULID	S_NAME_1	X	Y
1	381	0	2191a	0	1	SAMANPAZARI	381	Tren Garı	32.47722	37.86635
2	381	0.1187	1652a	0	2	SAMANPAZARI	381	İstasyon	32.47838	37.86652
3	381	0.4957	11a	0	3	SAMANPAZARI	381	Eski Stat	32.48261	37.86705

(c)

STOP381_Event_Layer

OBJECTID *	RID	MEAS	S_NO_1	DIR_CHG_CH	S_ORD_1	DEST	ULID	S_NAME_1	X	Y	LOC_ERROR	Shape *
1	381	0	2191a	0	1	SAMANPAZARI	381	Tren Garı	32.47722	37.8663	NO ERROR	Point M
2	381	0.1187	1652a	0	2	SAMANPAZARI	381	Istasyon	32.47838	37.8665	NO ERROR	Point M
3	381	0.4957	11a	0	3	SAMANPAZARI	381	Eski Stat	32.48261	37.8670	NO ERROR	Point M

(d)

BUS STOPS

OBJECTID *	Shape *	RID	MEAS	S_NO_1	DIR_CHG_CH	S_ORD_1	DEST	ULID	S_NAME_1	X	Y	LOC_ERROR	F_TYPE	TS_TYPE
1	Point M	381	0	2191a	0	1	SAMANPAZARI	381	Tren Garı	32.47722	37.86635	NO ERROR	STOP	1
2	Point M	381	0.1187	1652a	0	2	SAMANPAZARI	381	Istasyon	32.47838	37.86652	NO ERROR	STOP	1
3	Point M	381	0.4957	11a	0	3	SAMANPAZARI	381	Eski Stat	32.48261	37.86705	NO ERROR	STOP	1

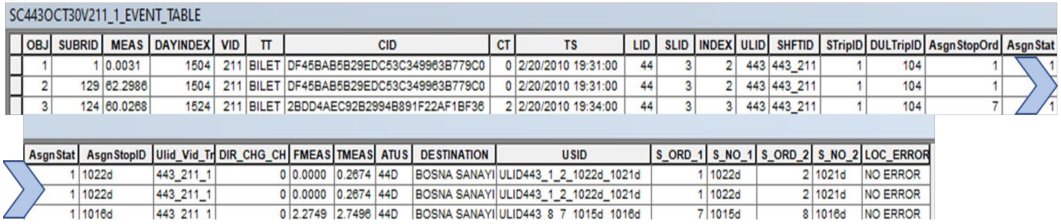
Figure 4.14 (a) Initial, (b) event table, (c) event layer, and (d) resulting attribute tables the generation of bus-stop kilometers

4.5.3 Dynamic Bus Line Service Analyses

This step concerns producing kilometer measurements from SCD, ensuring the coordinates extracted from SCD precisely match specific bus route segments. This accuracy is achieved through the use of specialized GIS tools, particularly during the stages of preprocessing and LR. During the preprocessing stage within a GIS environment, SCD is used alongside specific trip data to create distinct feature classes for each trip. This step is crucial for the subsequent LR of the SCD Feature Classes phase. In this phase, the SCD input is divided into daily segments, setting the stage for a detailed trip-by-trip analysis. Essential to this process are tools such as "Select Layer by Attribute" and "Locate Features Along Route" from the LR

Toolbox. These tools are instrumental in generating an Event Table that accurately reflects the kilometers corresponding to each SCD, as shown in **Figure 4.15.**

(a)



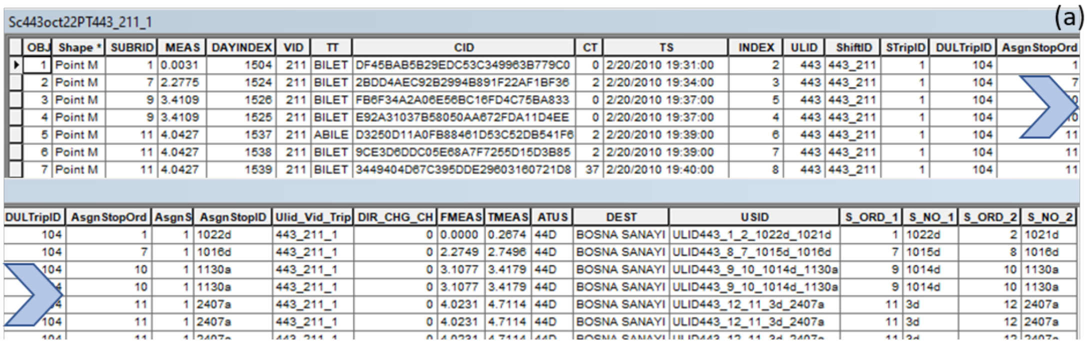
SC443OCT30V211_1_EVENT_TABLE

OBJ	SUBRID	MEAS	DAYINDEX	VID	TT	CID	CT	TS	LID	SLID	INDEX	ULID	SHFTID	STripID	DULTripID	AsgnStopOrd	AsgnStat
1	1	0.0031	1504	211	BILET	DF45BAB5B29EDC53C349963B779C0	0	2/20/2010 19:31:00	44	3	2	443	443_211	1	104	1	1
2	129	62.2986	1504	211	BILET	DF45BAB5B29EDC53C349963B779C0	0	2/20/2010 19:31:00	44	3	2	443	443_211	1	104	1	
3	124	60.0268	1524	211	BILET	2BDD4AEC92B2994B891F22AF1BF36	2	2/20/2010 19:34:00	44	3	3	443	443_211	1	104	7	1

AsgnStat	AsgnStopID	Ulid_Vid_Tr	DIR_CHG_CH	FMEAS	TMEAS	ATUS	DESTINATION	USID	S_ORD_1	S_NO_1	S_ORD_2	S_NO_2	LOC_ERROR
1	1022d	443_211_1	0	0.0000	0.2674	44D	BOSNA SANAYI	ULID443_1_2_1022d_1021d	1	1022d	2	1021d	NO ERROR
1	1022d	443_211_1	0	0.0000	0.2674	44D	BOSNA SANAYI	ULID443_1_2_1022d_1021d	1	1022d	2	1021d	NO ERROR
1	1016d	443 211 1	0	2.2749	2.7496	44D	BOSNA SANAYI	ULID443 8 7 1015d 1016d	7	1015d	8	1016d	NO ERROR

Figure 4.15 Resulting event tables for (a) SCD after LR

Moving to the Dynamic Segmentation of the Event Table, the focus shifts to converting the LR-derived event table into a practical feature class. This vital transformation is carried out using the "Make Event Layer" tool from the LR toolbox. The tool merges the Event Table with the segmented bus route feature class, resulting in a comprehensive Event Layer of the SCD, as shown in **Figure 4.17**. The accuracy of this layer is improved by selectively filtering out unnecessary CID values, ensuring only relevant data is included. Completing this process allows for the exact projection of selected data points onto the correct bus line segments, as shown in **Figure 4.18**. Furthermore, **Figure 4.16** displays a sample attribute table, which includes detailed kilometer ("MEAS" field) readings from the start of the bus route, providing a thorough overview of the journey.



Sc443oct22PT443_211_1

OBJ	Shape *	SUBRID	MEAS	DAYINDEX	VID	TT	CID	CT	TS	INDEX	ULID	ShiftID	STripID	DULTripID	AsgnStopOrd
1	Point M	1	0.0031	1504	211	BILET	DF45BAB5B29EDC53C349963B779C0	0	2/20/2010 19:31:00	2	443	443_211	1	104	1
2	Point M	7	2.2775	1524	211	BILET	2BDD4AEC92B2994B891F22AF1BF36	2	2/20/2010 19:34:00	3	443	443_211	1	104	7
3	Point M	9	3.4109	1526	211	BILET	FB6F34A2A06E56BC16FD4C75BA833	0	2/20/2010 19:37:00	5	443	443_211	1	104	10
4	Point M	9	3.4109	1525	211	BILET	E92A31037B58050AA672FDA11D4EE	0	2/20/2010 19:37:00	4	443	443_211	1	104	10
5	Point M	11	4.0427	1537	211	ABILE	D3250D11A0FB88461D53C52DB541F6	2	2/20/2010 19:39:00	6	443	443_211	1	104	11
6	Point M	11	4.0427	1538	211	BILET	9CE3D6DDC05E68A7F7255D15D3B85	2	2/20/2010 19:39:00	7	443	443_211	1	104	11
7	Point M	11	4.0427	1539	211	BILET	3449404D67C395DDE2960316O721D8	37	2/20/2010 19:40:00	8	443	443_211	1	104	11

DULTripID	AsgnStopOrd	AsgnS	AsgnStopID	Ulid_Vid_Trip	DIR_CHG_CH	FMEAS	TMEAS	ATUS	DEST	USID	S_ORD_1	S_NO_1	S_ORD_2	S_NO_2
104	1	1	1022d	443_211_1	0	0.0000	0.2674	44D	BOSNA SANAYI	ULID443_1_2_1022d_1021d	1	1022d	2	1021d
104	7	1	1016d	443_211_1	0	2.2749	2.7496	44D	BOSNA SANAYI	ULID443_8_7_1015d_1016d	7	1015d	8	1016d
104	10	1	1130a	443_211_1	0	3.1077	3.4179	44D	BOSNA SANAYI	ULID443_9_10_1014d_1130a	9	1014d	10	1130a
104	10	1	1130a	443_211_1	0	3.1077	3.4179	44D	BOSNA SANAYI	ULID443_9_10_1014d_1130a	9	1014d	10	1130a
104	11	1	2407a	443_211_1	0	4.0231	4.7114	44D	BOSNA SANAYI	ULID443_12_11_3d_2407a	11	3d	12	2407a
104	11	1	2407a	443_211_1	0	4.0231	4.7114	44D	BOSNA SANAYI	ULID443_12_11_3d_2407a	11	3d	12	2407a

Figure 4.16 Resulting SCD attribute table after DynSeg.

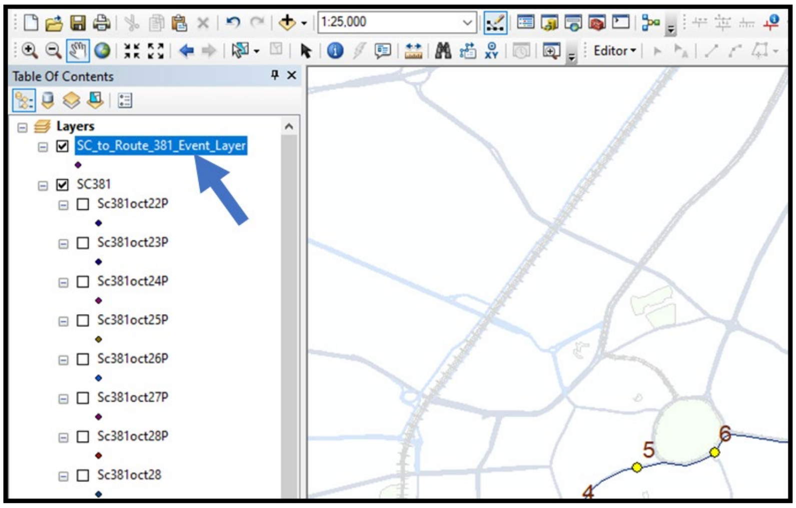


Figure 4.17 Resulting event layer in the table of contents

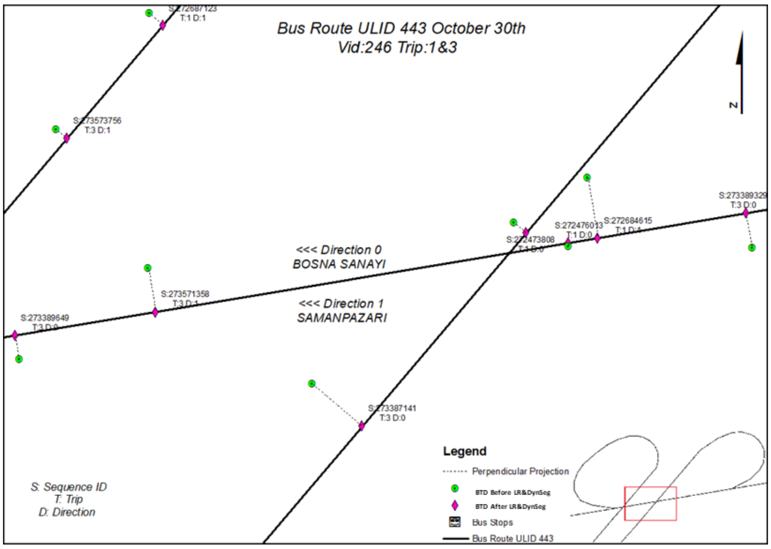


Figure 4.18 Before and after the LR in a bi-directional route segment

4.5.4 Arrival Time Estimations

This step involves creating an Excel spreadsheet that combines the bus stop and SCD data, complete with ST for each trip conducted within a day. This step's input includes the single trip SCD with ST and the corresponding bus stop with their ST.

The output is a merged Excel table of SCD and bus stop, with ST for daily trips. After preparing the required spreadsheet tables, estimating the ATEs becomes the next task. These estimations are derived from the merged tables, consisting of bus stop and SCD data, including ST for each trip conducted during the day. The outcome of this phase is the ATEs of bus stops across each bus service. Equation 4.1 shows the interpolating or extrapolating formula for calculating ATE.

$$T_i=T_{i-1}+[\{(S_i-S_{i-1})*(T_{i+1}-T_{i-1})\}/(S_{i+1}-S_{i-1})] \qquad \textbf{4.1}$$

Where T_i *: the estimated time of arrival at the current bus stop*

T_{i-1}*: the time of arrival at the previous bus stop*

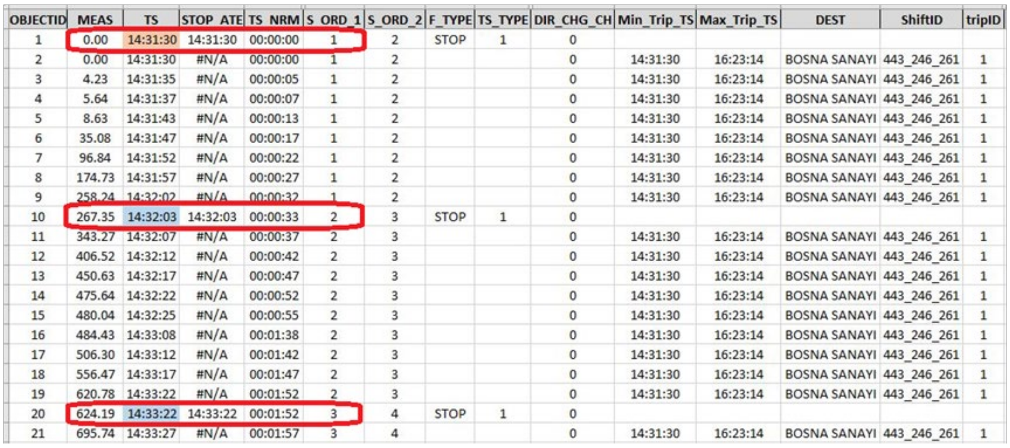
T_{i+1}*: the time of arrival at the next bus stop*

S_i *: the cumulative kilometer value at the current bus stop*

S_{i-1} *: the cumulative kilometer value at the previous bus stop*

S_{i+1} *: the cumulative kilometer value at the next bus stop*

Estimating bus stop arrival times along a route is accomplished through interpolating or extrapolating time stamps based on the ST and time stamps derived from preceding and subsequent SCD. This task employs a linear interpolation method to compute these estimations in a sequence corresponding to the SCD and the kilometers at each bus stop, referred to as MEAS. Due to the lack of a linear interpolation tool in ArcGIS, this step utilizes Excel's "Forecast Linear" function for interpolation and extrapolation calculations. Also, Excel's "Match" and "Offset" functions are used to identify and align the closest preceding and following records necessary for accurate linear interpolation. ATEs are extrapolated for bus stops at the start of a route, where preceding SCD is absent. Similarly, ATEs are also determined through extrapolation for bus stops at the end of a route without subsequent SCD data. The results of performing the processes outlined in **Figure 4.10** can be seen in **Figure 4.19**. Rows specified by a polygonal shape contain data belonging to the bus stops, which are calculated through linear interpolation and extrapolation.



OBJECTID	MEAS	TS	STOP_ATE	TS_NRM	S_ORD_1	S_ORD_2	F_TYPE	TS_TYPE	DIR_CHG_CH	Min_Trip_TS	Max_Trip_TS	DEST	ShiftID	tripID
1	0.00	14:31:30	14:31:30	00:00:00	1	2	STOP	1	0					
2	0.00	14:31:30	#N/A	00:00:00	1	2			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
3	4.23	14:31:35	#N/A	00:00:05	1	2			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
4	5.64	14:31:37	#N/A	00:00:07	1	2			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
5	8.63	14:31:43	#N/A	00:00:13	1	2			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
6	35.08	14:31:47	#N/A	00:00:17	1	2			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
7	96.84	14:31:52	#N/A	00:00:22	1	2			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
8	174.73	14:31:57	#N/A	00:00:27	1	2			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
9	258.24	14:32:02	#N/A	00:00:32	1	2			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
10	267.35	14:32:03	14:32:03	00:00:33	2	3	STOP	1	0					
11	343.27	14:32:07	#N/A	00:00:37	2	3			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
12	406.52	14:32:12	#N/A	00:00:42	2	3			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
13	450.63	14:32:17	#N/A	00:00:47	2	3			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
14	475.64	14:32:22	#N/A	00:00:52	2	3			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
15	480.04	14:32:25	#N/A	00:00:55	2	3			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
16	484.43	14:33:08	#N/A	00:01:38	2	3			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
17	506.30	14:33:12	#N/A	00:01:42	2	3			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
18	556.47	14:33:17	#N/A	00:01:47	2	3			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
19	620.78	14:33:22	#N/A	00:01:52	2	3			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1
20	624.19	14:33:22	14:33:22	00:01:52	3	4	STOP	1	0					
21	695.74	14:33:27	#N/A	00:01:57	3	4			0	14:31:30	16:23:14	BOSNA SANAYI	443_246_261	1

Figure 4.19 Resulting ATE tables from SCD.

CHAPTER 5

USE of SCD for PERFORMANCE EVALUATION OF PUBLIC BUS TRANSIT (PBT) LINES IN KONYA, TÜRKİYE

5.1 PBT Services in Konya

Konya is a large province in Türkiye with a significant population. According to the 2018 results of the Address-Based Population Registration System (ABPRS), Konya has a population of 2,205,609 people, making up 2.7% of Türkiye's population and ranking 7th among the provinces. The population density of Konya is 57 people per square kilometer. **Figure 5.1** displays Konya's location in Türkiye.

Figure 5.1 Location of Konya (Google Map, 2022)

PBT services in Konya mainly consist of public buses, minibuses (locally known as 'dolmuş'), various para-transit options, taxis, trams, and work-school shuttles catering to a substantial shared-ride demand. The city boasts two tram lines, encompassing 280 bus routes and 4878 stops. The first tram line links the Central

Business District to Selcuk University and includes 35 stops. In contrast, the second line connects the CBD to the Konya Courthouse with nine stops. The tram network operates with 112 trams, offering a one-way trip capacity for 12,000 passengers. About 750 vehicles service the 280 bus lines during the day, with 106 lines dedicated to urban areas and 174 catering to the suburbs. Since 2000, Konya has implemented a SC fare collection system for buses and trams. Alongside the SC system, a GPRS technology vehicle tracking system is integrated into all public buses and the tram network. The transition to an entirely SC-based fare collection for PBT services occurred in 2006, further enhanced by the introduction of a PBT information system application. This application provides vital information, including bus line and stop locations, timetables, and fare details. A web-based trip planner and an online service displaying real-time bus locations are also available.

The SC system, initiated in 2000, has seen widespread adoption, with almost 550,000 SC in circulation. As of August 1, 2019, a flat rate of 2.10 TL (approximately $0.37) is charged per trip for a full fare, with various discounts available based on card types, such as for students, seniors, and disabled individuals. The student fare, discounted by 26%, is 1.55 TL per trip. Transfers within 60 minutes between tram stops are free, with a 40% discount applied to transfers between other services, like tram-bus and bus-bus connections. An unlimited pass service is also available with a total deposit of 135 TL (equivalent to 65 full trip fares) on the SC. The SC readers are installed on buses for boarding validation, while tram stations have readers at entrances. The city's fare system is not distance-based, so the SCD primarily records boarding activities. Analysis of six months' smartcard data from 2018 revealed an average of 6.5 million monthly transactions. This figure, however, excludes transactions by free users, who typically do not use a card while boarding buses. Figure 5.2 indicates the location of bus lines and bus stops in Konya.

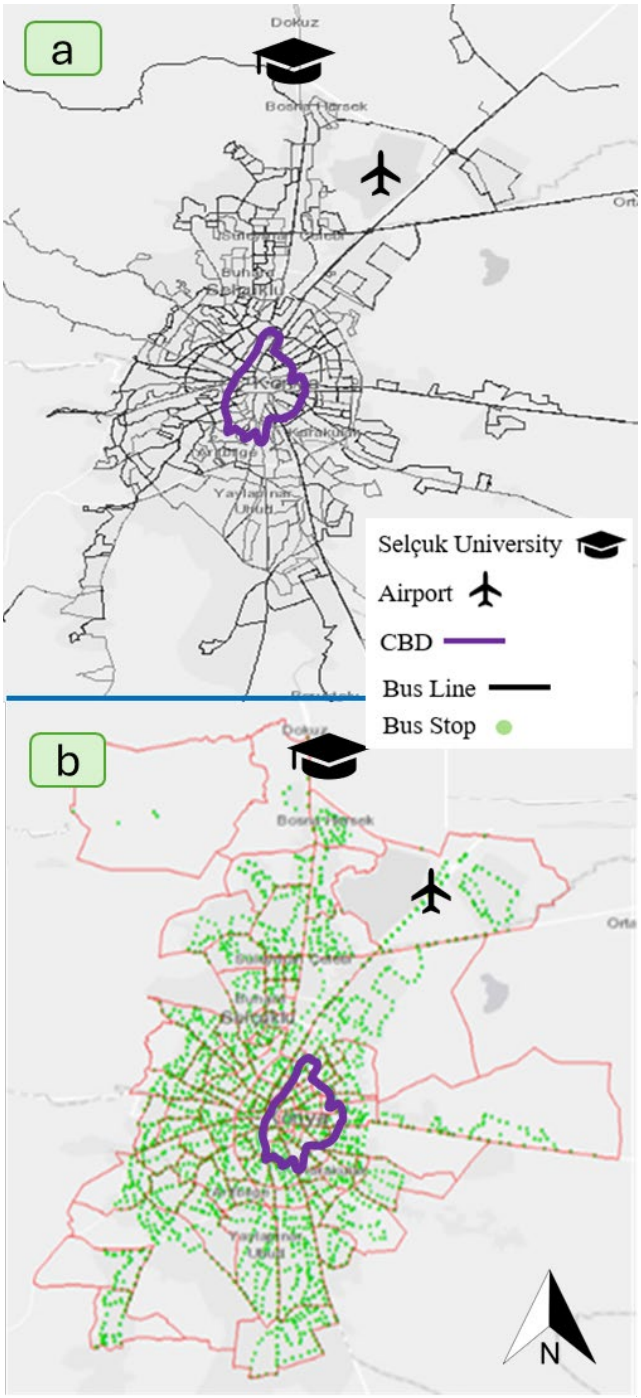


Figure 5.2 Konya a) bus lines b)bus stops

When SCD is evaluated in terms of monthly ridership levels, it is seen that the average ridership per month is about 6.5 million passengers (regarding seven months) (**Figure 5.3**). As can be seen from these figures, the highest number of users was observed in November 2018, followed by October 2018 and May 2018. During the summer months, the number of total users seems to diminish. This can be explained as follows the summer break of schools. Many citizens may be leaving for holidays, eventually affecting the number of PBT users.

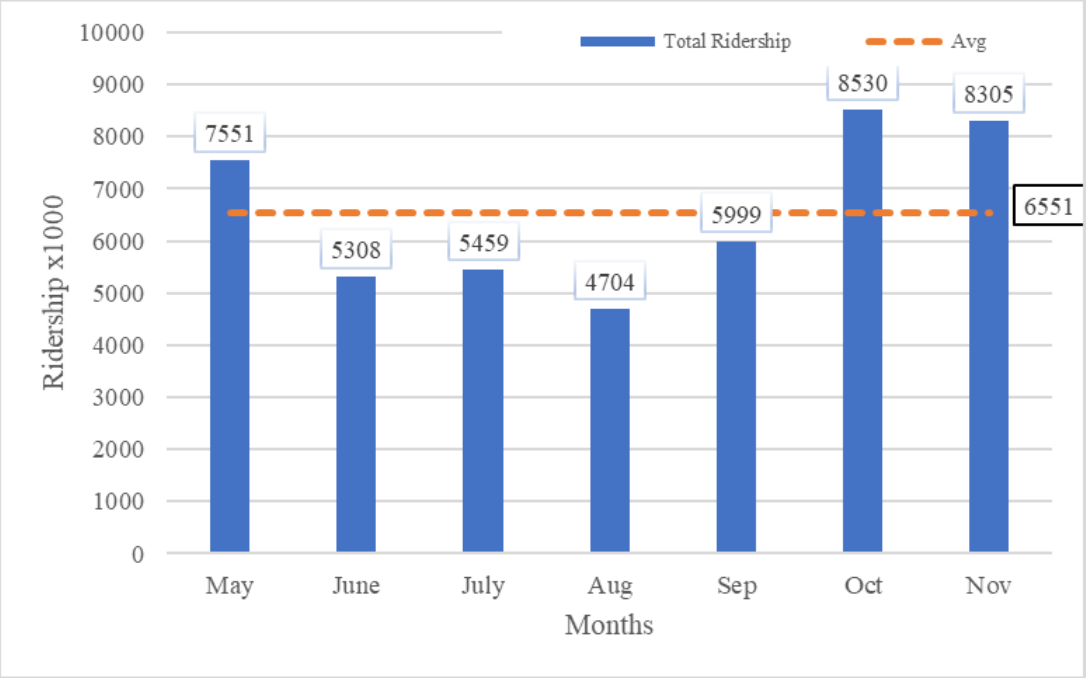


Figure 5.3 Monthly ridership

According to data from Konya municipality, a seven-month (May to November) PBT ridership is available. The pattern of ridership data shows that October has the highest ridership (8.53 million). Also, daily ridership in October shows a similar pattern each week. Therefore, the first week (Monday to Sunday) of October 2018 was selected for evaluating QOS according to the TCQSM manual. **Figure 5.4** shows the daily ridership of October.

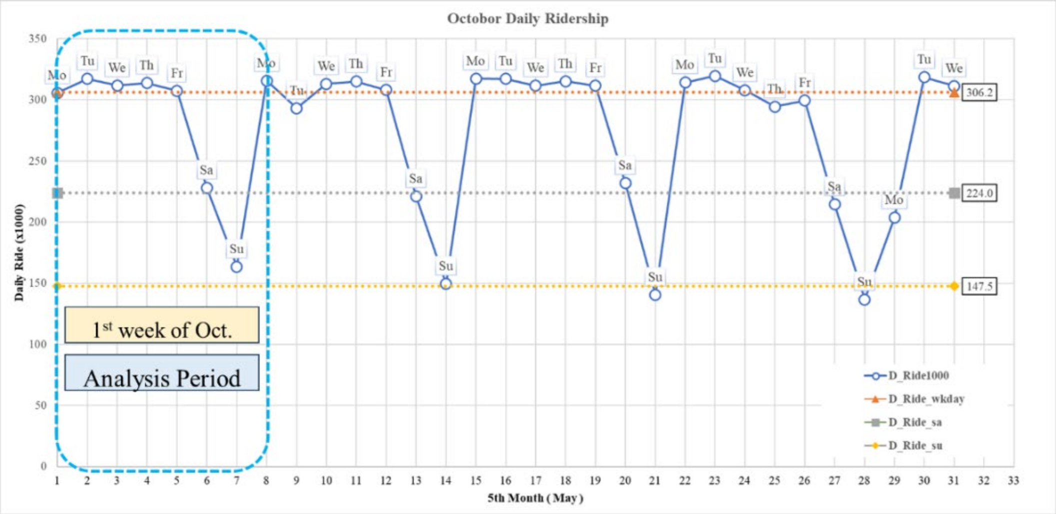


Figure 5.4 Daily ridership of October 2018

5.2 Transit-Supportive Areas

While commonly used for assessing transit coverage performance, service areas are not always the most reliable indicators due to the varying land uses and differences in population and job densities across different transit systems. Urban transit systems, for example, often extend into large undeveloped areas that do not contribute to immediate transit usage. Therefore, this study focuses solely on calculating service areas and assessing the extent of transit system coverage. Utilizing ArcGIS software, the study outlines the transit service coverage by mapping all regions within a 400-meter radius of transit stops. Areas along routes that lacked pedestrian access from nearby regions were excluded from the service coverage area.

The initial step in this analysis involved calculating the area of Konya city in ArcGIS to determine the Transit Service Area. Subsequently, bus stops from all unique line IDs (ULIDs) were combined into a single layer, with outlier stops being removed via the Clip tool in ArcMap. A 400-meter buffer was applied around each stop, and the extent of the area covered by transit was calculated. This analysis estimated that about 78% of the system area was served by transit. This estimate was benchmarked against the threshold values for fixed-route service coverage QOS as detailed in the TCQSM manual. The study concluded that Konya’s fixed-route service coverage QOS was rated as “C”, indicating that approximately three-quarters of the high-density areas were adequately served by transit. **Figure 5.5** graphically illustrates the coverage of Konya's PBT system, highlighting how effectively it spans across the city.

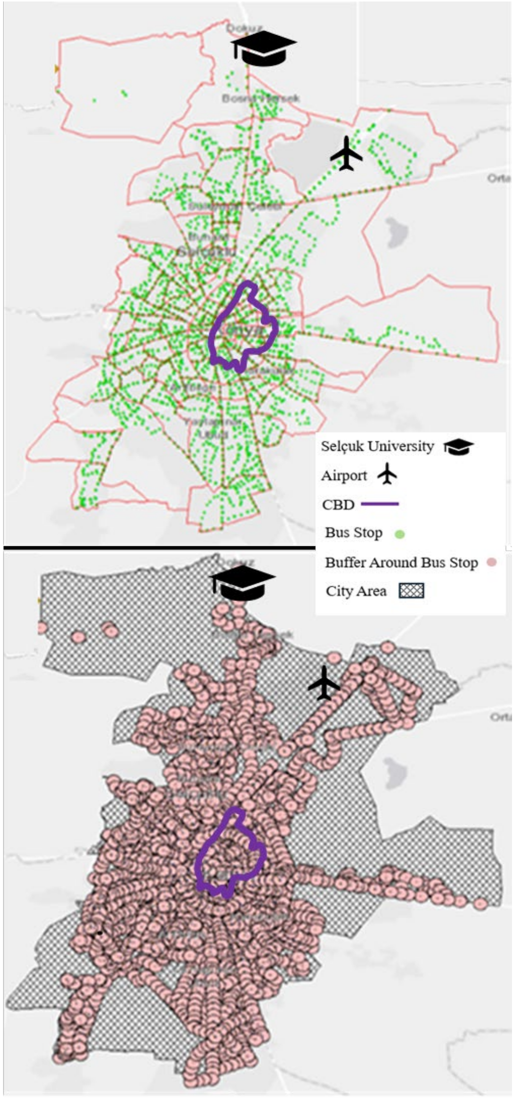
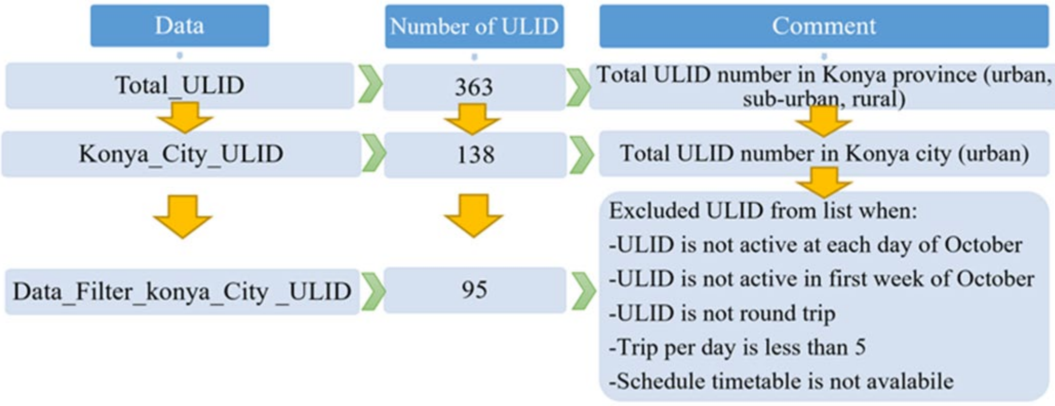


Figure 5.5 Quality of services of Konya in terms of TSA

5.3 Sampling PBT lines

As detailed in Section 5.1, a specific week was chosen for the evaluation to examine various bus routes closely. Initial steps included applying filters to these routes and ranking them based on their ridership numbers in October, as detailed in **Table 5.1.** Subsequently, the average ridership for the month was computed. This led to the categorization of bus routes into three groups based on ridership levels: High, Moderate, and Low. From each category, three bus routes were selected for further study. The selected routes included ULIDs 650, 10, and 450 for High Ridership; 600, 260, and 300 for Middle Ridership; and 900, 940, and 430 for Low Ridership, as represented in **Figure 5.7** to **Figure 5.9** illustrates the route map for each ULID within these groups, while **Figure 5.6** presents the ridership data for each line. Data derived from SCD was aggregated hourly to analyze passenger demand. This analysis aimed to capture and visualize the spatial-temporal variations in passenger demand across different routes. The resulting descriptive statistics, outlining weekly passenger demand, are comprehensively displayed from **Figure 5.10** to **Figure 5.11**.

Table 5.1 Data filter for ULID



Data	Number of ULID	Comment
Total_ULID	363	Total ULID number in Konya province (urban, sub-urban, rural)
Konya_City_ULID	138	Total ULID number in Konya city (urban)
Data_Filter_konya_City _ULID	95	Excluded ULID from list when: -ULID is not active at each day of October -ULID is not active in first week of October -ULID is not round trip -Trip per day is less than 5 -Schedule timetable is not avalabile

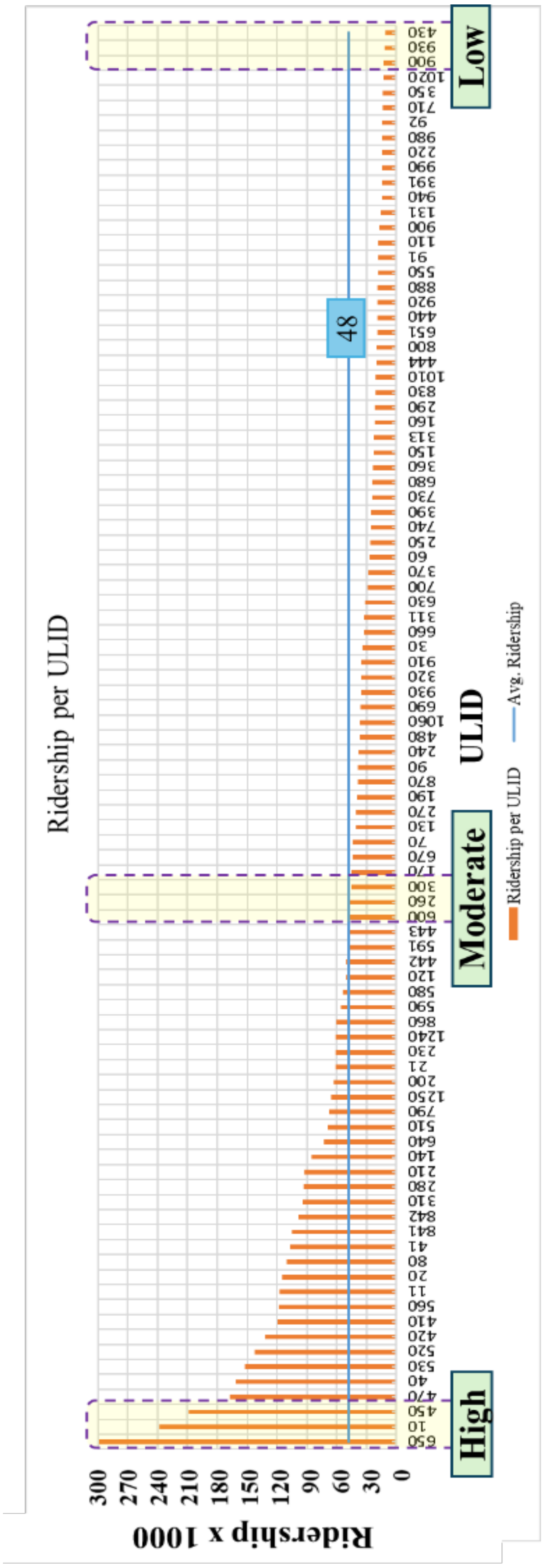


Figure 5.6 Ridership per each study PBT Line in October,2018

Table 5.2 Study Week Ridership

ULID	Study Week Ridership (x1000)			
	WeekD_Tot	**WeekD_Avg.**	**Sat**	**Sun**
High Ridership				
650	52.8	10.6	9.3	6.6
10	42.8	8.6	3.9	3.3
450	36.7	7.4	6.4	4.7
Moderate Ridership				
600	9.3	1.9	1.0	0.8
260	8.6	1.8	1.6	1.2
300	8.2	1.7	1.5	0.7
Low Ridership				
900	3.2	0.7	0.5	0.4
940	3.0	0.6	0.4	0.1
430	2.2	0.5	0.4	0.2

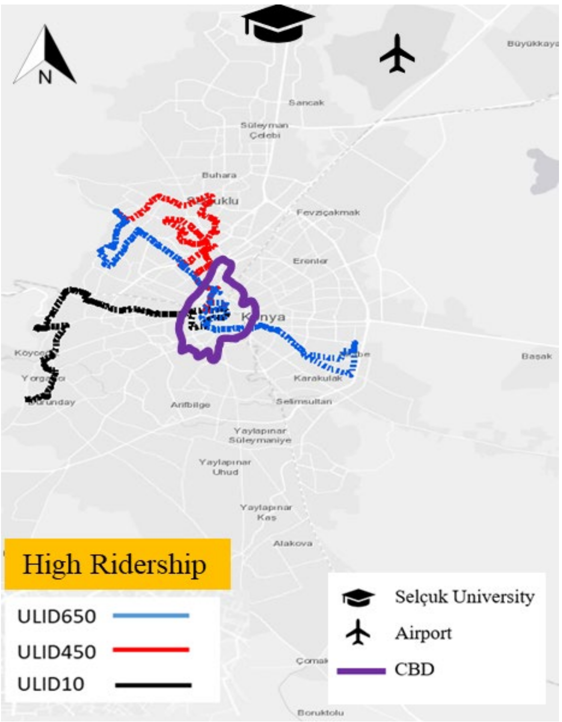


Figure 5.7 Bus route of High Ridership

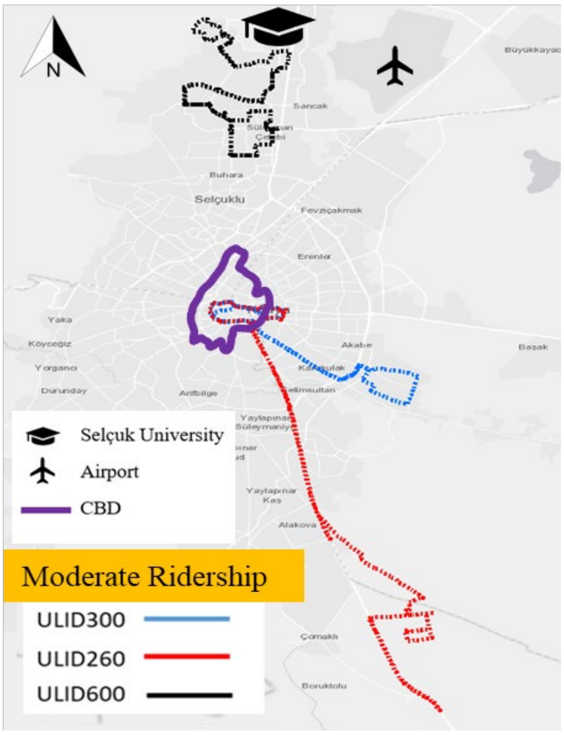


Figure 5.8 Bus route of Moderate Ridership

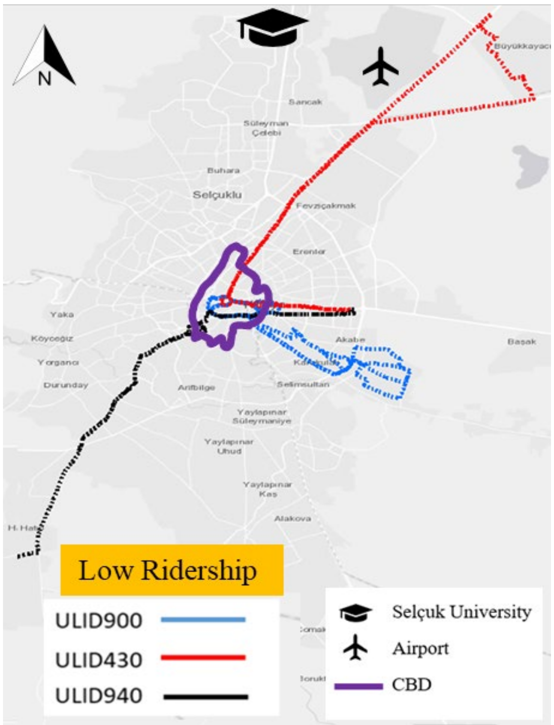


Figure 5.9 Bus route of Low Ridership

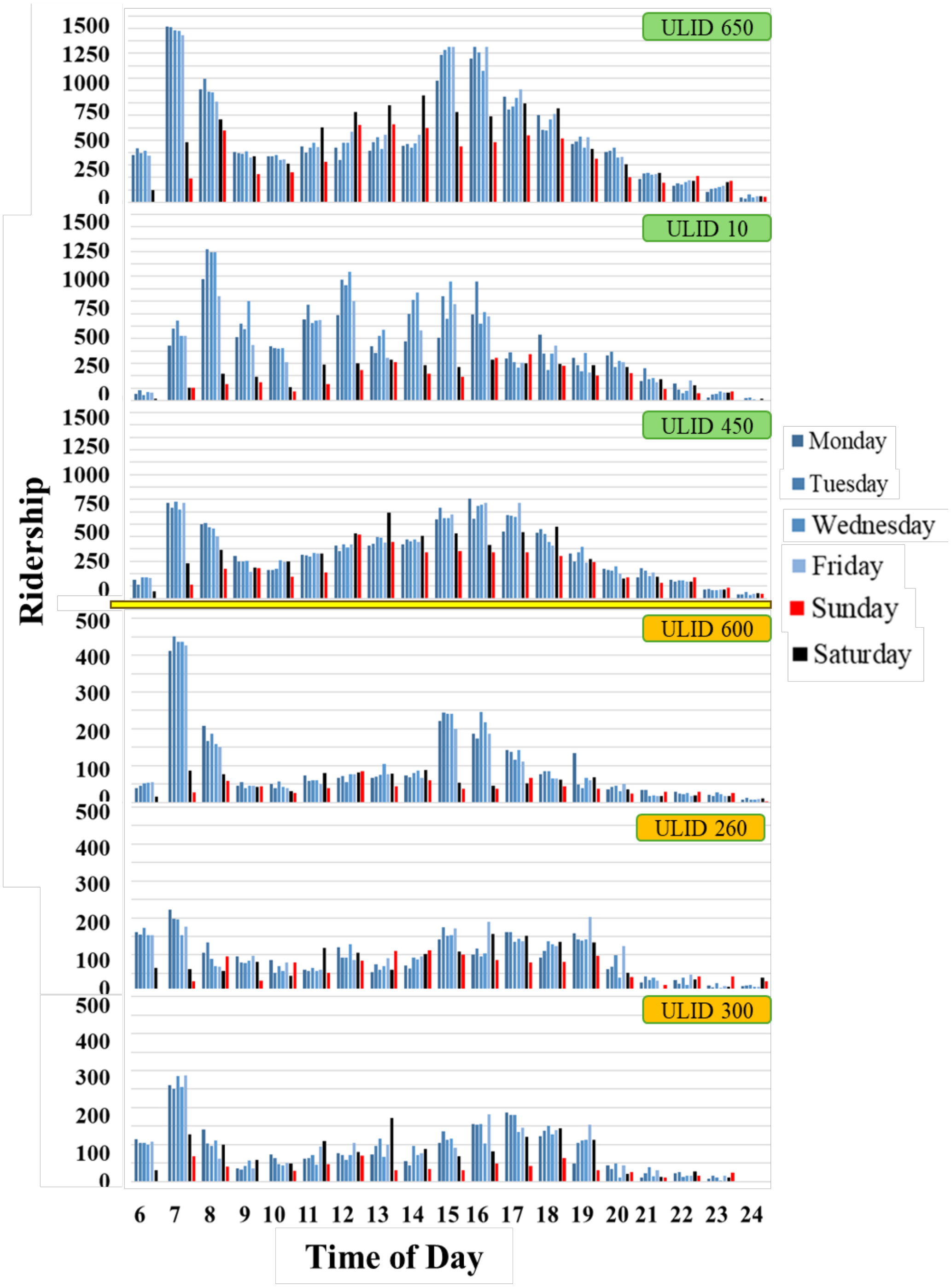


Figure 5.10 Analysis of High and Moderate Ridership Patterns

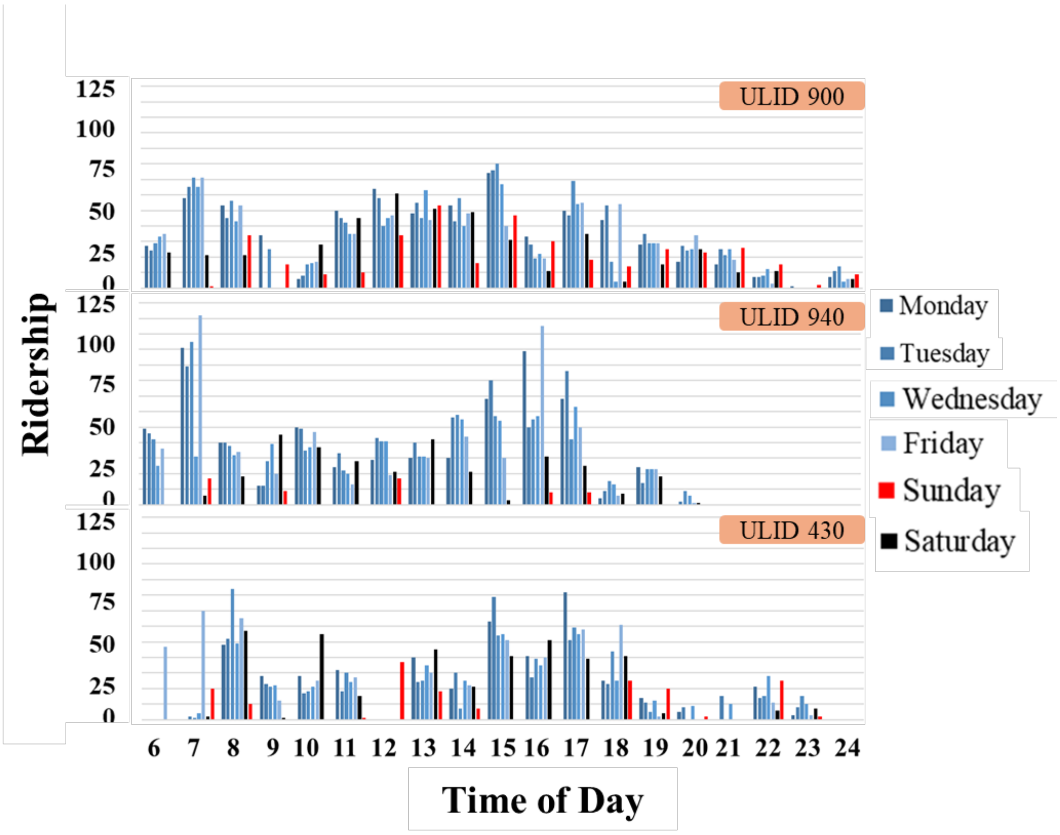


Figure 5.11 Analysis of Low Ridership Patterns

5.4 PBT Planning Data for Study PBT Lines

After selecting nine bus lines for analysis within a specific study week, the study requires two sets of data: SCD and planning data provided by the municipality. This planning data includes critical operational details such as bus schedules, route lengths, and the number of stops on each route. This information is instrumental in assessing the HS and SF for each selected bus line. Schedule data provided by the municipality indicates that the HS and SF for each ULID differ between weekdays and weekends, necessitating separate evaluations for these periods. The HS reflects the operational timeframe of each bus line, indicating service availability from the earliest to the latest trips scheduled for each day. The SF reflects the service frequency of each bus line, analyzing the interval between consecutive bus departures. Average headways for selected ULIDs were computed to assess QOS in line with TCQSM.

5.4.1 Hours of Service

According to data from Konya's municipality, the HS for each ULID varies on weekdays and weekends. Therefore, the weekday and weekend schedules are evaluated separately. The result shows that the routes with High ridership have higher service hours. **Table 5.3** shows the HS of each ULID.

Table 5.3 Hours of Service of each ULID

ULID	Length (Km)	No. of Stops	WeekD		Sat		Sun	
			OP	**HS**	**OP**	**HS**	**OP**	**HS**
High Ridership								
650	39	103	6:00-24:00	19	6:00-24:00	19	7:00-24:00	18
10	31	85	6:00-24:00	19	6:00-24:00	19	7:00-24:00	18
450	24	90	6:00-24:00	19	6:00-24:00	19	7:00-24:00	18
Moderate Ridership								
600	44	116	6:00-23:00	18	6:00-23:00	18	7:00-23:00	17
260	63	129	6:00-24:00	19	6:00-24:00	19	7:00-23:00	17
300	22	95	6:00-24:00	19	6:00-24:00	19	7:00-24:00	18
Low Ridership								
900	32	80	6:00-23:00	18	6:00-23:00	18	7:00-22:00	16
930	64	63	6:00-23:00	18	6:00-23:00	18	7:00-22:00	16
430	65	122	6:00-22:00	17	6:00-22:00	17	7:00-22:00	16

5.4.2 Service Frequency

The timetable data for each ULID was obtained from ATUS. This information was pivotal in determining the QOS for SF across all transit lines. This analysis, guided by the methodology in TCRP100, focuses on assessing how frequently transit services are available to users within an hour. SF is crucial in gauging the convenience of transit services, influencing rider choices, and contributing to the overall transit trip time. Typically, this assessment involves calculating the average headway, essentially the inverse of the average frequency. For this study, average headways were computed for nine bus lines in Konya. These calculated values were then used to establish the SF of QOS for these bus lines. **Table 5.4** shows the SF of each ULID.

Table 5.4 Service Frequency; in minutes of each ULID

ULID	**WeekD**		**Sat**		**Sun**	
	Mean(SD)	(Min,Max)	Mean(SD)	(Min,Max)	Mean(SD)	(Min,Max)
High Ridership						
650	18(7)	(10,60)	19(9)	(10,60)	21(7)	(15,45)
10	29(3)	(10,30)	29(3)	(15,30)	31(5)	(20,35)
450	30(8)	(20,60)	30(8)	(20,60)	40(14)	(30,60)
Moderate Ridership						
600	58(21)	(30,105)	58(21)	(30,105)	57(22)	(50,60)
260	61(26)	(25,120)	61(26)	(25,120)	68(21)	(60,120)
300	64(15)	(25,90)	64(15)	(25,90)	80(25)	(45,120)
Low Ridership						
900	110(35)	(60,150)	110(35)	(60,150)	132(41)	(90,180)
940	77(43)	(15,175)	77(43)	(15,175)	285(21)	(270,300)
430	160(64)	(100,270)	160(64)	(100,270)	300(88)	(200,370)

5.5 Study PBT Line characteristics from SCD

The study uses SCD after necessary preprocessing to analyze PBT's operational dynamics, focusing on PPC, OTD, and TAT. Hourly boarding data at each PBT Line, obtained from SCD, highlights passenger trends. Also, departure times are estimated using SCD timestamps at stops. Additionally, bus speed and travel time are analyzed through timestamp and location data from SCD, offering insights into the travel time difference between PBT and private vehicle (PV) use.

5.5.1 Passenger Per Capacity

The PPC analysis for Konya's city bus service began with collecting bus schedules from ATUS. This schedule outlined the hourly frequency of buses on each route, known as headway. **Table 5.4** provides an overview of the SF, while **Figure 5.10** to **Figure 5.11** presents an analysis of ridership for each ULID, showing the passenger demand across high, moderate, and low ridership levels during the first week of October. The seating capacity of buses was calculated by multiplying the frequency of buses on each route by their seating capacities. According to data from bus system operators, each bus can accommodate up to 100 passengers, consisting of 27 seats and 73 standing spaces. The study further calculated the ratio of passenger ridership per hour against the bus's seating capacity, deriving an hourly PPC value for each route. These values were then averaged to determine the mean PPC value for weekdays and weekends for each ULID. Based on these calculated mean PPC values, the QOS for weekdays, Saturdays, and Sundays was determined for each ULID. **Figure 5.12** to **Figure 5.13** indicates the PPC for each ULID.

Table 5.5 Passenger per Capacity (in traveler) for each ULID

ULID	**PPC (traveler per capacity)**					
	WeekD		**Sat**		**Sun**	
	Mean(SD)	(Min,Max)	Mean(SD)	(Min,Max)	Mean(SD)	(Min,Max)
High Ridership						
650	1.87(1.08)	(0.15,4.17)	1.64(0.73)	(0.26,2.65)	1.58 (0.88)	(0.42,3.13)
10	1.19(0.74)	(0.07,3.05)	0.57(0.23)	(0.08,0.82)	0.49 (0.23)	(0.03,0.94)
450	2.05(1.01)	(0.29,4.04)	1.78(0.88)	(0.29,3.46)	1.82(0.78)	(0.30,3.42)
Moderate Ridership						
600	0.85(0.70)	(0.08,2.45)	0.46(0.24)	(0.11,0.88)	0.4(0.19)	(0.03,0.85)
260	0.97(0.28)	(0.05,0.88)	0.45(0.28)	(0.05,0.88)	0.43(0.17)	(0.24,0.85)
300	0.95(0.67)	(0.03,2.87)	0.78(0.51)	(0.11,1.72)	0.34(0.14)	(0.15,0.69)
Low Ridership						
900	0.30(0.21)	(0.00,0.71)	0.20(0.17)	(0.00,0.49)	0.27(0.19)	(0.01,0.53)
940	0.41(0.32)	(0.04,1.22)	0.20(0.18)	(0.00,0.45)	0.14(0.05)	(0.08,0.17)
430	0.29(0.20)	(0.00,0.84)	0.34(0.25)	(0.00,0.57)	0.27(0.07)	(020,0.37)

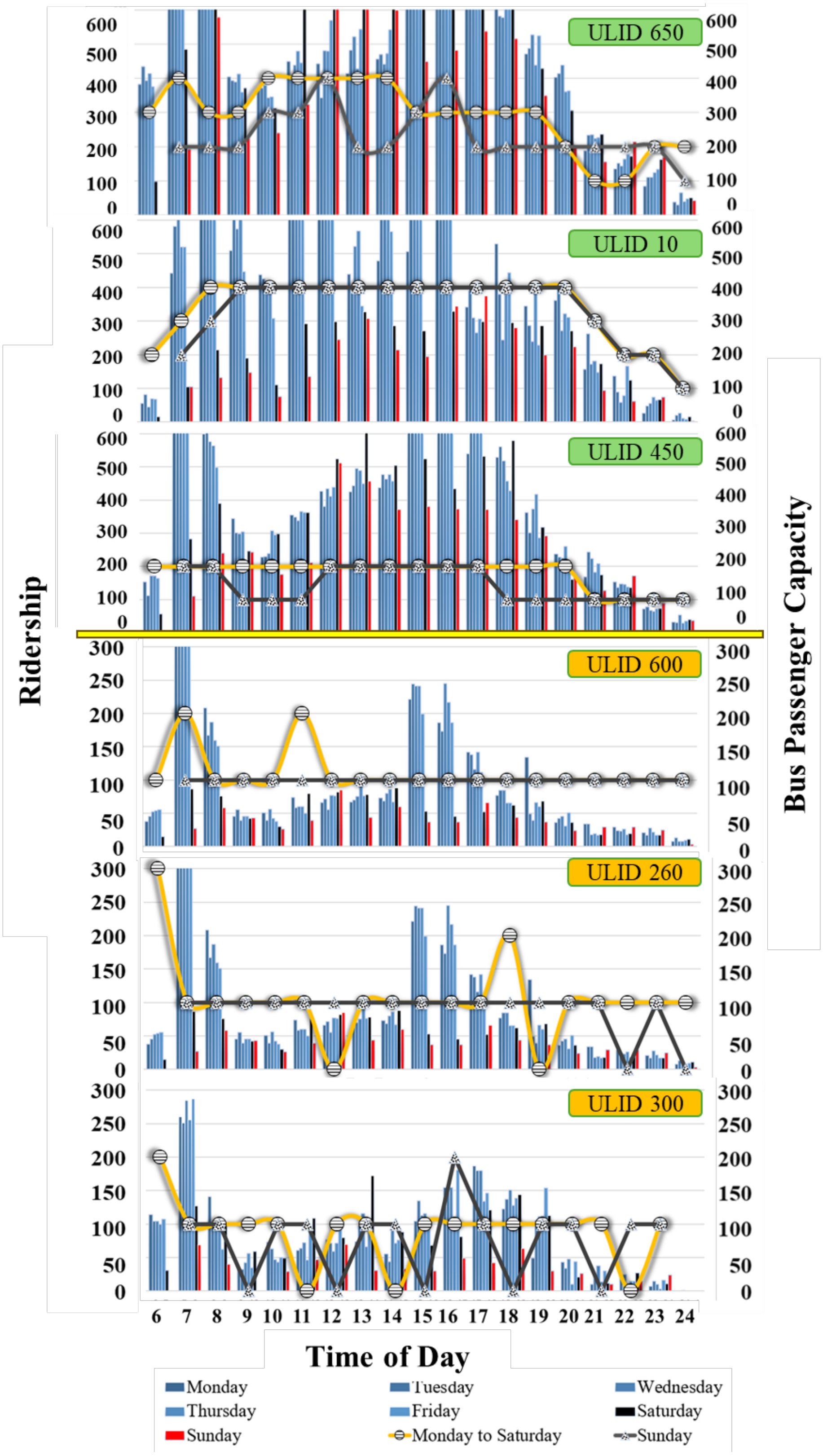


Figure 5.12 PPC for High and Moderate ridership

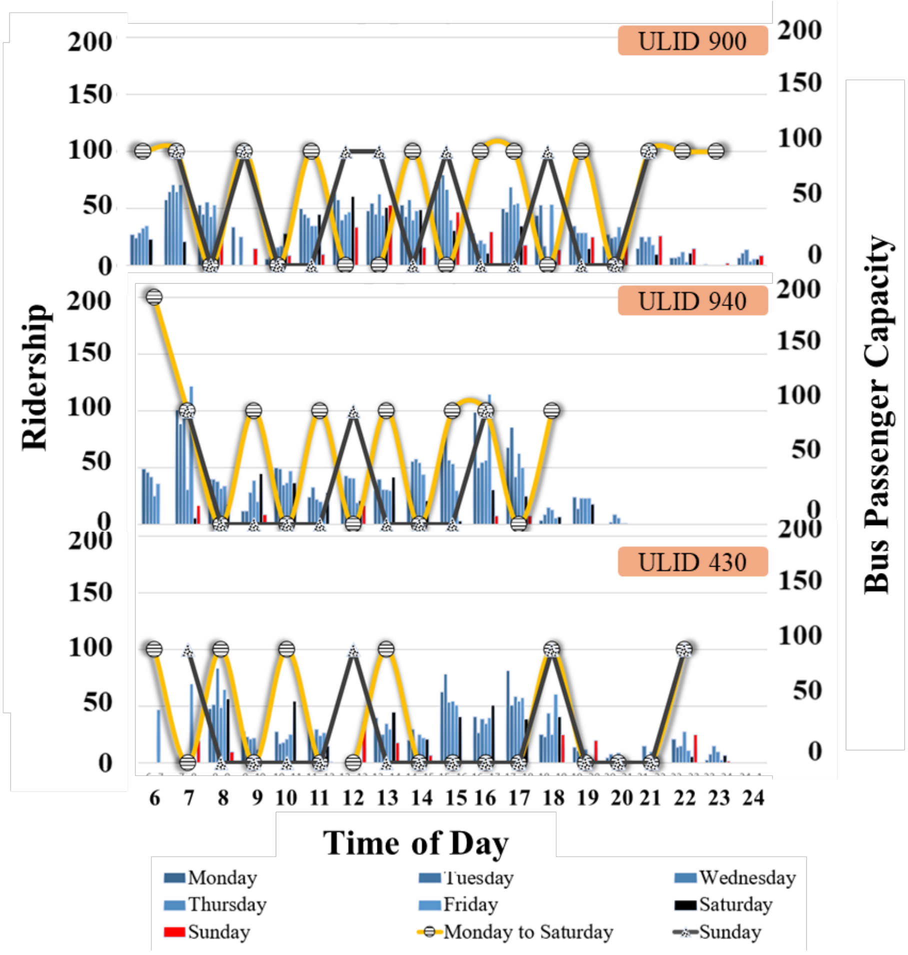


Figure 5.13 PPC for low ridership

5.5.2 On-time Departure

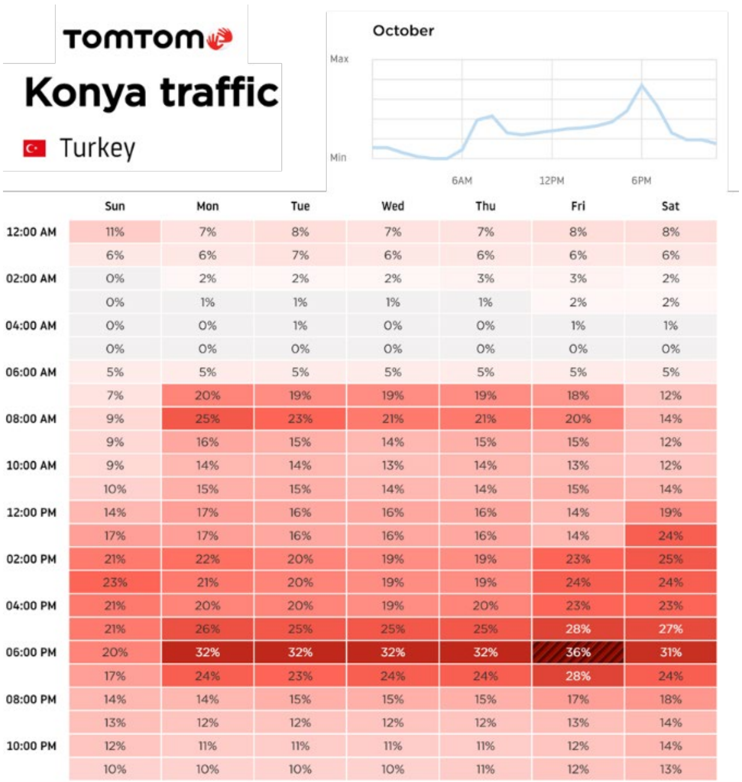
The ATUS was used to obtain the scheduled departure time for each ULID. Also, the real-time departure time was calculated for each ULID using SCD in the "Linear referencing" section. Each departure of each ULID is labeled as "on-time" or "late. Reliability QOS considers "on-time" for fixed-route service to be a departure from a published timepoint 0-5 minutes after the scheduled time of arrival at the end of the route no more than 5 minutes after the scheduled time. **Table 5.6** shows the On-time and Late trips criteria of each ULID.

Table 5.6 Departure Statistics a) delay(minutes) b) On-time Departure

ULID	**Departure Delays (min) - b -**		**On-time Departure % - c -**		
	Mean(SD)	(Min,Max)	#On-time Departure	#Late Departure	**%**
High Ridership					
650	5(4)	(0,29)	1084	118	**0.89**
10	5(4)	(0,25)	655	118	**0.84**
450	8(5)	(0,20)	805	189	**0.81**
Moderate Ridership					
600	8(5)	(0,20)	400	172	**0.70**
260	7(5)	(0,21)	347	110	**0.76**
300	9(5)	(0,19)	202	28	**0.88**
Low Ridership					
900	10(6)	(0,19)	121	26	**0.82**
940	12(6)	(0,22)	80	36	**0.69**
430	5(5)	(0,15)	83	12	**0.85**

5.5.3 Transit-auto Travel time

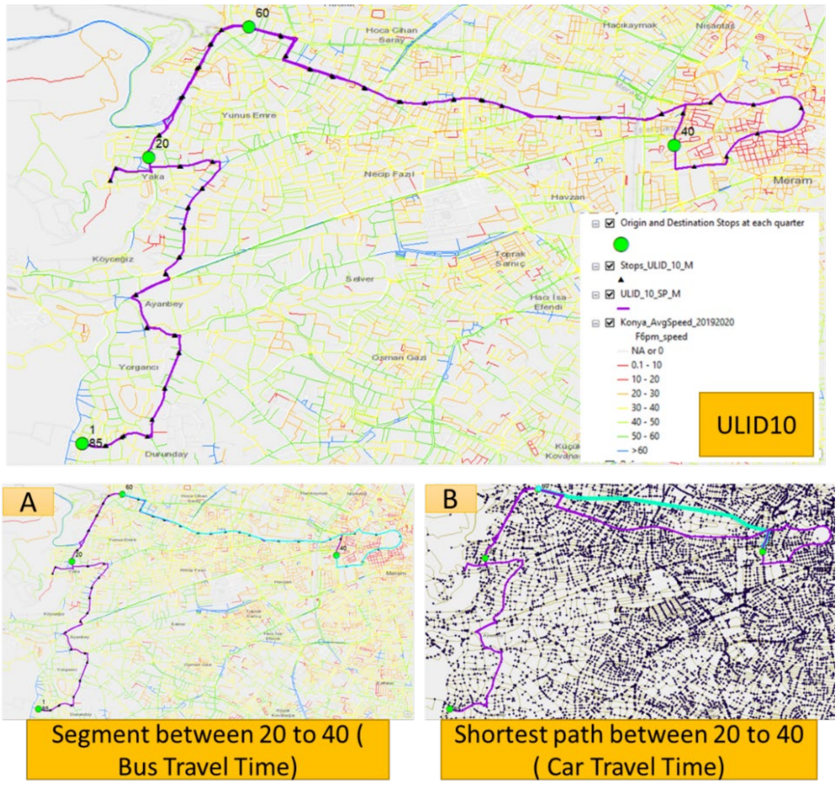
An essential factor in a potential transit user's decision to regularly use PBT is the comparative duration of the trip against an automobile journey. The QOS metric measures this as the door-to-door difference in travel times between automobiles and transit, including walking, waiting, and transfer times (if applicable) for both modes. This metric assesses whether a trip by transit is longer (or sometimes shorter) than by car. The overall trip length is less crucial than the total travel time. Since TAT is a comprehensive system measure, it requires more extensive data than individual transit stop and route segment metrics. Like many other service measures, TAT can be evaluated at various times of the day, including peak and off-peak periods. Due to peak-hour traffic congestion often delaying car journey times, QOS is generally better for transit during these peak hours than at other times. Consequently, historical data from TomTom was used to identify Konya's peak hours. According to this data, as illustrated in **Figure 5.14**, the morning peak hour is between 8-9 AM, and the evening peak hour is between 6-7 PM.



	Sun	Mon	Tue	Wed	Thu	Fri	Sat
12:00 AM	11%	7%	8%	7%	7%	8%	8%
	6%	6%	7%	6%	6%	6%	6%
02:00 AM	0%	2%	2%	2%	3%	3%	2%
	0%	1%	1%	1%	1%	2%	2%
04:00 AM	0%	0%	1%	0%	0%	1%	1%
	0%	0%	0%	0%	0%	0%	0%
06:00 AM	5%	5%	5%	5%	5%	5%	5%
	7%	20%	19%	19%	19%	18%	12%
08:00 AM	9%	25%	23%	21%	21%	20%	14%
	9%	16%	15%	14%	15%	15%	12%
10:00 AM	9%	14%	14%	13%	14%	13%	12%
	10%	15%	15%	14%	14%	15%	14%
12:00 PM	14%	17%	16%	16%	16%	14%	19%
	17%	17%	16%	16%	16%	14%	24%
02:00 PM	21%	22%	20%	19%	19%	23%	25%
	23%	21%	20%	19%	19%	24%	24%
04:00 PM	21%	20%	20%	19%	20%	23%	23%
	21%	26%	25%	25%	25%	28%	27%
06:00 PM	20%	32%	32%	32%	32%	36%	31%
	17%	24%	23%	24%	24%	28%	24%
08:00 PM	14%	14%	15%	15%	15%	17%	18%
	13%	12%	12%	12%	12%	13%	14%
10:00 PM	12%	11%	11%	11%	11%	12%	14%
	10%	10%	10%	10%	11%	12%	13%

Figure 5.14 Konya peak hour

To enhance the precision of the data, bus stops within each ULID were segmented into four categories. Individual morning and evening travel times were then calculated for each group. The average travel time for peak-hour bus journeys was computed, as shown in **Figure 5.15**, part A. The TomTom travel time and speed map were also employed to calculate automobile travel times. The road network of Konya, sourced from Open Street Map, was analyzed using ArcGIS's network analysis tool to determine the shortest path between two stops. The travel time of these shortest paths was then calculated using the ArcGIS Spatial Join tool and TomTom map data, as depicted in **Figure 5.15** part B. **Table 5.7** details the TAT criteria for each ULID.



Segment between 20 to 40 (Bus Travel Time)

Shortest path between 20 to 40 (Car Travel Time)

Figure 5.15 TAT calculation A) segment between two stops by using bus route B) segment between two stops by using the shortest path

Table 5.7 Travel time (in minutes) comparisons for selected lines

ULID	Bus	Auto	Difference
High Ridership			
650	62	29	33
10	41	24	17
450	50	19	31
Moderate Ridership			
600	51	18	33
260	67	29	38
300	48	17	31
Low Ridership			
900	42	16	27
940	64	39	26
430	57	25	33

5.6 QOS Evaluation

Applying the TCQSM manual to the Konya transit system provides a multifaceted view of its operational performance. A detailed portrait of the system's effectiveness emerges by examining service hours, frequency, PPC, OTD, and TATs. Konya's transit network demonstrates strong availability regarding service hours, particularly on weekdays and Saturdays. This suggests a system geared toward accommodating the routine commuting patterns of its ridership. However, the service hours experience a noticeable decline on Sundays, with lines such as 900, 940, and 430 experiencing a more significant decrease in service. This pattern reveals a potential gap in service that could affect weekend commuters, suggesting an opportunity to enhance service to meet the needs of Sunday travelers.

Frequency stands out as a particular challenge within the Konya transit system. Routes like 10, 450, and 260 encounter issues that likely impact their attractiveness to potential riders. Inconsistent service can decrease reliability and convenience, possibly prompting passengers to look for alternatives. This inconsistency risks the system's goal of maintaining and boosting ridership. The assessment of the PPC balance highlights disparities on routes such as 650 and 450, indicating a misalignment between the services provided and the actual needs of passengers. This imbalance suggests adjustments may be necessary to optimize service delivery, potentially by reallocating resources to match the demand patterns on these routes better.

The variability in OTD across the network is noteworthy. Some routes, like 650 and 10, show a strong punctuality record, reflecting a dependable service that passengers can trust. Conversely, routes 450, 600, and 260 exhibit less-than-ideal punctuality, signaling an area where improvements are essential. Delays and inconsistencies can significantly affect rider satisfaction and the perceived reliability of the transit system, making it imperative to address these shortcomings. Lastly, comparing TATs indicates that buses in Konya are generally competitive with automobile travel times. Most routes hold their own against the convenience of car travel, with line 10 notably surpassing expectations in efficiency. This competitive edge is vital in convincing potential riders to choose PBT over personal vehicles, especially in urban areas where traffic congestion can be a significant concern. **Table 5.8** shows the results of the QOS for PBT in Konya. Moreover, in terms of individual line analysis:

High Ridership:

Line 650: This line boasts excellent service hours, ensuring broad weekly availability. However, the frequency is only average, potentially leading to longer wait times for passengers. A significant imbalance between PPC indicates that the line may either be under-serving or over-serving passengers at different times or locations. Nevertheless, the line's punctuality is good, so they tend to keep to their schedule when the buses run. The average TATs suggest that while competitive with automobile travel, there is room for improvement to make it a more attractive option.

Line 10: Line 10 maintains excellent service hours, offering consistent availability. The frequency is below average, which might discourage some potential riders who prefer more frequent service. The PPC balance is improving towards the weekend, suggesting adjustments could be tailored to different days of the week. Punctuality is average, indicating a reliable service but not outstanding. The TATs are better than average, making it a competitive choice against private car use, especially during peak travel times.

Line 450: With excellent service hours, Line 450 is widely available to passengers. The frequency, however, is below average, which could be a limiting factor for increasing ridership. The line experiences significant PPC imbalances, reflecting a mismatch between service provision and passenger needs. Punctuality is below average, which could negatively impact the line's reliability in commuters' eyes. TATs are average, which does not significantly disadvantage the line against car travel but doesn't offer a clear advantage.

Moderate Ridership:

Line 600: Line 600 has good service hours, indicating a decent level of availability, though not as comprehensive as some other lines. The frequency is poor, likely leading to longer waits and potential overcrowding during operating hours. The PPC balance is improving, reflecting recent efforts to better align services with passenger needs. However, the line's punctuality is poor, undermining service reliability and could be a significant factor in passenger dissatisfaction. TATs are average, providing no incentive for car users to switch to PBT.

Line 260: This line offers excellent service hours, suggesting a high commitment to providing service throughout the week. The frequency, however, is very limited, which could severely affect the line's usability. The PPC balance is on the upswing, indicating an awareness of and response to the needs of passengers. Punctuality is very poor, which is a critical area for immediate improvement. Below-average TATs further challenge the attractiveness of this line compared to private vehicles.

Line 300: Line 300 provides excellent service hours, ensuring passengers can access the line when needed. The frequency is very limited, which may not meet the needs of those requiring more flexible travel times. The steady PPC balance suggests that current service levels adequately meet the existing demand. Punctuality is average, indicating a level of reliability. TATs are also average, suggesting that travel by this line is neither particularly fast nor slow compared to cars.

Low Ridership:

Line 900: This line has good service hours overall but experiences a drop on Sundays, which could affect weekend travelers. The frequency is extremely limited, which may significantly impact ridership, as potential passengers may turn to other options that offer more frequent services. The excellent PPC balance indicates that buses are well-utilized when running. Punctuality is below average, which may discourage use, especially for those with time-sensitive commitments. Average TATs mean this line is neither particularly faster nor slower than car travel.

Line 940: Line 940's service hours are good, though there is a noticeable dip on Sundays. Frequency is very limited, which can be a major limitation for potential riders. Despite this, the excellent PPC balance suggests that current services are well-matched to rider demand. Punctuality is poor, a significant concern for PBT services, and an area needing improvement. TATs are average, offering no distinct advantage over private car use.

Line 430: Service hours for Line 430 are good, but like other lines, there is a decline on Sundays, which could be a potential inconvenience for weekend travelers. The frequency is very limited, which may deter passengers who require more flexible travel times. The PPC balance is excellent, indicating efficient use of the services provided. Punctuality is average, suggesting a reasonable level of reliability. However, below-average TATs could influence some passengers to choose car travel over PBT for time savings.

Table 5.8 Quality of Services

ULID	HS			SF			PPC			OTD	TAT
	WeekD	Sat	Sun	WeekD	Sat	Sun	WeekD	Sat	Sun		
High Ridership											
650	A	A	B	C	C	D	F	F	F	C	D
10	A	A	B	D	D	E	E	D	B	D	C
450	A	A	B	D	D	E	F	F	F	D	D
Moderate Ridership											
600	B	B	B	E	E	E	C	A	A	E	D
260	A	A	B	F	F	F	C	A	A	E	D
300	A	A	B	F	F	F	C	B	A	C	D
Low Ridership											
900	B	B	C	F	F	F	A	A	A	D	C
940	B	B	C	F	F	F	A	A	A	F	C
430	B	B	C	F	F	F	A	A	A	D	D

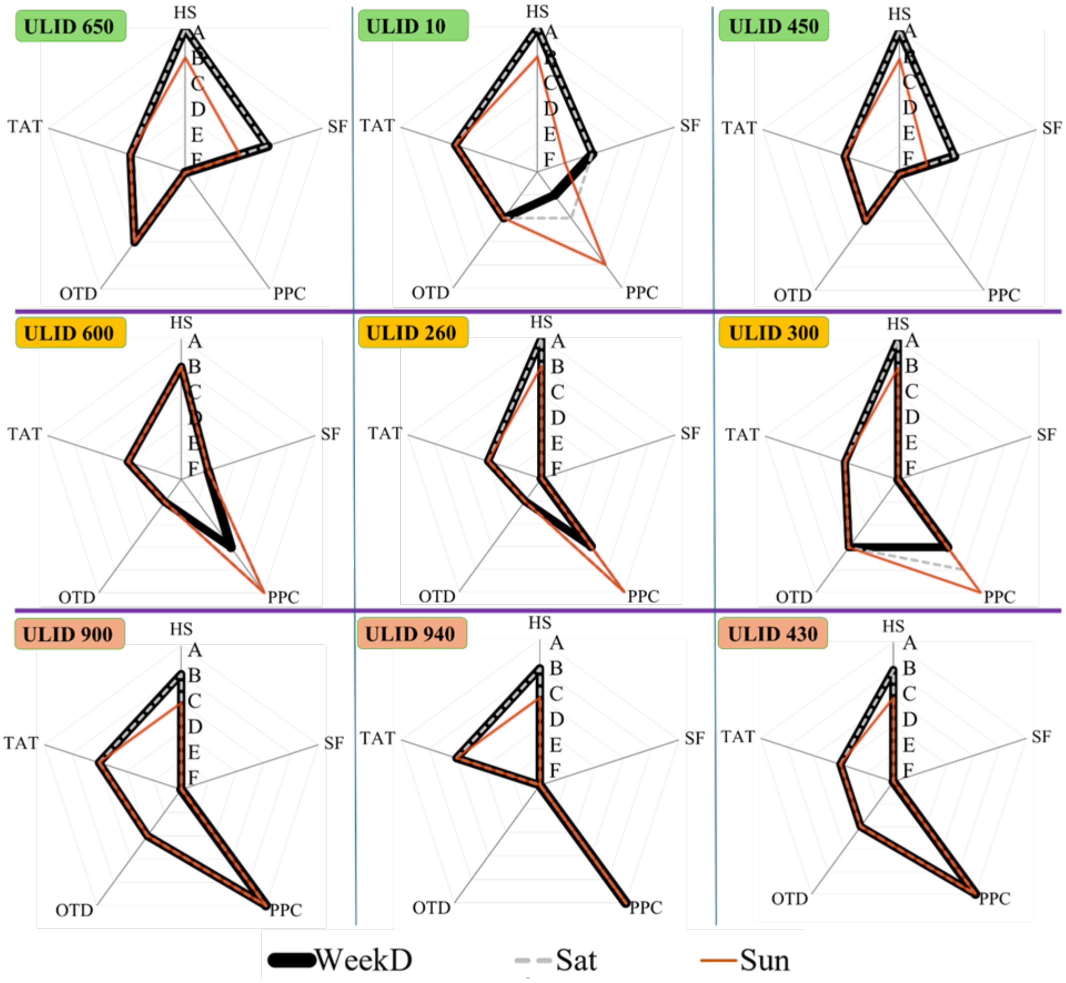


Figure 5.16 Radar chart of Results

CHAPTER 6

CONCLUSION AND FUTURE RECOMMENDATIONS

6.1 Major Findings

The evaluation of PBT performance in Konya, using SCD and TCQSM guidelines, reveals significant operational challenges and improvement opportunities across high, moderate, and low ridership levels. Insights into HS, SF, PPC, OTD, and TAT underscore the complex dynamics between service provision and user satisfaction. High ridership routes exhibit strong HS but insufficient SF, leading to overcrowding and a diminished PPC. Despite adequate HS, moderate ridership routes suffer from poor SF and OTD, affecting their attractiveness and utilization. Meanwhile, with acceptable HS, low ridership routes face severe underutilization due to poor SF and OTD, indicating a disconnect between service offerings and user needs.

Addressing these challenges requires improvements within Konya's PBT system. Enhancing SF could mitigate overcrowding for high ridership routes, improving PPC and passenger experience. Moderate ridership routes require improvements in both SF and OTD to boost their utilization and reliability. Similarly, strategic enhancements in SF and OTD for low ridership routes are critical for increasing their attractiveness and efficiency, encouraging higher usage. These adjustments are pivotal for aligning the PBT system with the demands and expectations of its diverse user base.

The study highlights a critical need for better capacity and demand management, especially on high ridership routes where insufficient SF makes passengers uncomfortable and deterred. Addressing this issue requires strategic bus numbers or schedule adjustments to match demand more effectively. Additionally, improving service reliability across all ridership levels by improving OTD can significantly affect passengers' willingness to rely on PBT for their daily commute. Finally, increasing the SF and reliability of services, particularly on underutilized low ridership routes, could transform these lines into more attractive and efficient options.

6.2 Response to Research Questions

The research questions mentioned in the introduction chapter have been answered along the thesis methodology and analysis. As responses to the research questions:

i. How to use SCD to evaluate PBT performance?

In the thesis, chapters 3 and 4 address the use of SCD to evaluate PBT performance through a defined framework. Initially, 'Data Pre-processing and Cleanup' is undertaken to establish a clear understanding of the SCD's structure by detecting and eliminating missing data and resolving any discrepancies, ensuring a reliable dataset for subsequent stages. Following this, the 'Creation of Bus Routes from Bus Stops' stage is implemented, where datasets are merged to form a compiled stop list for each ULID, with the accuracy of stop locations verified within the ArcGIS environment against SCD. These efforts, including attempts with ArcGIS and Open Street Map, are vital for achieving the study's precision needs. The subsequent step, 'Estimation of Boarding Stops and Trip Direction,' involves determining the specific stops at which passengers board and the direction of the bus for each trip, shedding light on passenger flow and route usage. 'Estimation of Arrival Time and Travel Time' then calculates the expected arrival time of buses, the travel duration between stops, and the bus's average speed, using the SCD system timestamps. The final phase, 'Evaluation of PBT Performance,' employs the TCQSM framework to measure service quality, considering factors affecting passenger comfort and convenience and service availability factors like frequency and coverage. These combined measures comprehensively evaluate the PBT system's service quality.

ii. **What challenges are related to using SCD in PBT performance? And what solutions can be implemented to address these challenges?**

When SCD was utilized to assess PBT performance, several challenges emerged. A primary issue was the varied quality and structure of the data collected from different municipality divisions, which led to inconsistencies and errors in the dataset. Data preprocessing and applying error data filters were vital to address this, as highlighted in the Data Quality Evaluation phase. These methods helped fix discrepancies, remove erroneous entries, and ensure the overall reliability of the data used for analysis. Another significant challenge was the absence of GIS-based information for bus routes, which is essential for accurate mapping and analysis of transit systems. To overcome this, existing bus stop data was integrated with ArcGIS Pro to digitalize the PBT Network process. This approach enabled the creation of detailed digital representations of bus routes.

Additionally, the SCD often lacked clear information on the direction of trips and boarding stops, which is critical for understanding passenger flow and service utilization. To overcome this challenge, Python code was utilized in the Boarding Stop Estimation phase to algorithmically determine the boarding stops and trip directions. This coding solution helped extrapolate the needed information from the available data, enriching the SCD with more actionable insights.Lastly, the challenge of missing data on bus speeds and arrival times significantly hindered performance evaluation. The solution implemented involved the use of LR techniques in ArcGIS during the ATE stage. This method allowed for the interpolation of arrival times and speed calculations, thereby filling the gaps in the data and providing a more complete picture of the transit service's efficiency. By employing these specific solutions—data preprocessing, GIS digitalization, Python coding for data enrichment, and LR for data interpolation—the challenges associated with using SCD in PBT performance evaluation were effectively addressed, resulting in more accurate and reliable assessments.

iii. What is the limitation of SCD in PBT performance evaluation?

SCD offers valuable insights into PBT usage patterns, yet it presents several limitations when used for performance evaluation. In its raw form, the data is not immediately suitable for analytical purposes; it necessitates substantial preprocessing to transform it into a usable format for meaningful analysis. One key challenge is the diversity of payment methods; not all users rely on smart cards, with some preferring mobile apps or alternative fare options, which leads to gaps in the dataset captured by smart cards alone. This limitation can result in an incomplete representation of transit usage.

Additionally, the reliability of data provided by municipalities, often assumed to be accurate, can sometimes be questionable. There can be notable discrepancies between the scheduled data and the actual operational performance, particularly if the data is not regularly updated to reflect real-time changes. Consequently, SCD does not offer real-time insights, which poses significant challenges in evaluating immediate transit performance or addressing operational issues promptly.

Furthermore, transaction data may not always be correctly assigned. Instances such as buses deviating from their designated routes, drivers inaccurately entering route identifiers, or passengers boarding from unscheduled locations like garages can all lead to errors in data recording. The algorithms used to assign boarding stops to transactions are also limited, especially when the data is sparse. If there are fewer than five transactions for a particular trip or if all transactions for a trip are clustered in the same geographic location, the algorithm may incorrectly determine the boarding stop. In these cases, the system struggles to accurately identify the bus's direction, which is crucial for correct stop assignment.

Estimating arrival times presents another set of challenges when working with sparse SCD sets. A high volume of evenly distributed smart card readings across the entire route is necessary to obtain accurate estimates. As the distance for interpolation or extrapolation increases, the accuracy of the time estimates decreases, leading to potential exclusions of less reliable data from the analysis.

6.3 Further Research and Recommendations

Despite Despite the TCQSM framework's strengths in evaluating PBT systems, it has limitations, including the absence of an overall performance rating, a lack of consideration for passenger numbers in performance metrics, a uniform weighting system that might not reflect passenger priorities, and a difficulty in comparing PBT performance across cities. To address these issues, this study introduces a novel framework to provide a more comprehensive measure of transit service quality. This approach advances the evaluation of PBT systems through a multi-stage process, encompassing service quality assessment, converting qualitative grades to numerical values, weighting based on user perception and passenger numbers, and calculating an average performance rate. This method addresses TCQSM's limitations and better aligns with transit users' needs and experiences. However, the study's reliance on a relatively small survey sample from Konya, with 323 respondents, presents a limitation, as it may not fully capture the diversity of user experiences and perceptions across different demographics and geographies. Despite the promising initial findings and the potential benefits of the method, further research with a more comprehensive and diverse survey population is essential to validate and refine the proposed model. **Appendix F** provides detailed information for an in-depth exploration of the methodology and findings.

Future research should focus on several key areas to enhance the comprehensiveness and accuracy of the performance assessment for Konya's PBT system and beyond. Expanding the evaluation to encompass all PBT lines in Konya will provide a more holistic view of the system's performance. This expansion is crucial for identifying strengths and opportunities for improvement across the entire network, thereby facilitating the development of targeted strategies to elevate the overall quality of transit services.

Temporal assessment of performance rates on a daily, monthly, and seasonal basis will offer valuable insights into the dynamics of transit service quality, helping to identify patterns of performance fluctuation. Such analysis enables transit authorities to adjust services proactively during peak times, holidays, or seasonal changes to maintain high service standards. Finally, the design of the evaluation platform as an Intelligent Transportation System (ITS) represents a forward-thinking approach to monitoring and comparing transit performance. An ITS-based platform would facilitate the real-time collection and analysis of performance data, allowing for immediate adjustments to service delivery and dynamic comparisons of transit performance across different cities. This technology-driven approach promises to enhance the efficiency and responsiveness of transit systems. It promotes innovation and best practice sharing among cities globally.

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APPENDICES

A. SCD Structure

SCD consists of BTD that is recorded once for each SC reading during boarding. This means that Fare Collection Systems is the only tap-in type of system, and tap-out information is not provided. These records are provided in CSV file format daily for a ULID. Attributes of daily SCD are listed below in **Table A.1**.

Table A.1 Raw SCD attribute list

ATTRIBUTE	FIELD NAME	Attribute Description	Notes
VEH_ID	VID	Vehicle ID	Vehicle ID shows which vehicle is on trip.
TXN_TYPE	TT	Type of Transaction from SC	Txn_type is seen as ABILET, BILET, GBILET, KBILET, TBILET, GLBILET, GDBILET, BKM in smart card data
CARD_ID	CID	Smart Card Serial Number	Character length = 32 Total unique card id = 551470
CARD_TYPE	CT	Smart Card Ticket Type (There are 40 types)	Ticket types are shown in numerical values as 0, 1, 2, 8, 9,10..
LATITUDE	Y	Latitude	Provided in decimal format
LONGITUDE	X	Longitude	Provided in decimal format
TIMESTAMP	TS	Date and Time of Smart Card Use	Provided in yyyy-mm-dd hh:mm:ss format
LINE_ID	LID	Service Line Idendification Number	Identification Number for a Service
SUB_LINE_ID	SLID	Sub_Line Idendification Number	The number showing the small change in routes under the same LID (i.e: 36-0, 36-1 in a particular place going from an upper street)
TYPES	T	Public Transport types	Types show public transportation modes. Tram=0, bus=1

B. Missing Data Detection

In the first stage, different rules were applied to SCD to identify the different types of errors. Based on the literature and typical applications, some filters are created to detect missing values. According to data characteristics, the missing values are NaN, NULL, no value, and NA. also, in some parts of the data, such as latitude and longitude, zero values are not acceptable. **Figure B.1** shows the framework of SCD cleaning.

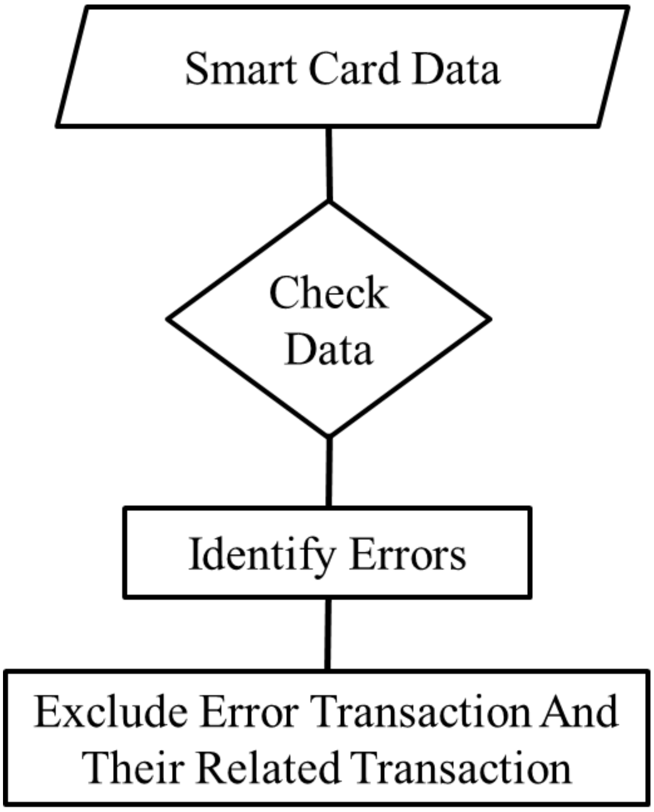


Figure B.1 Framework of SCD cleaning

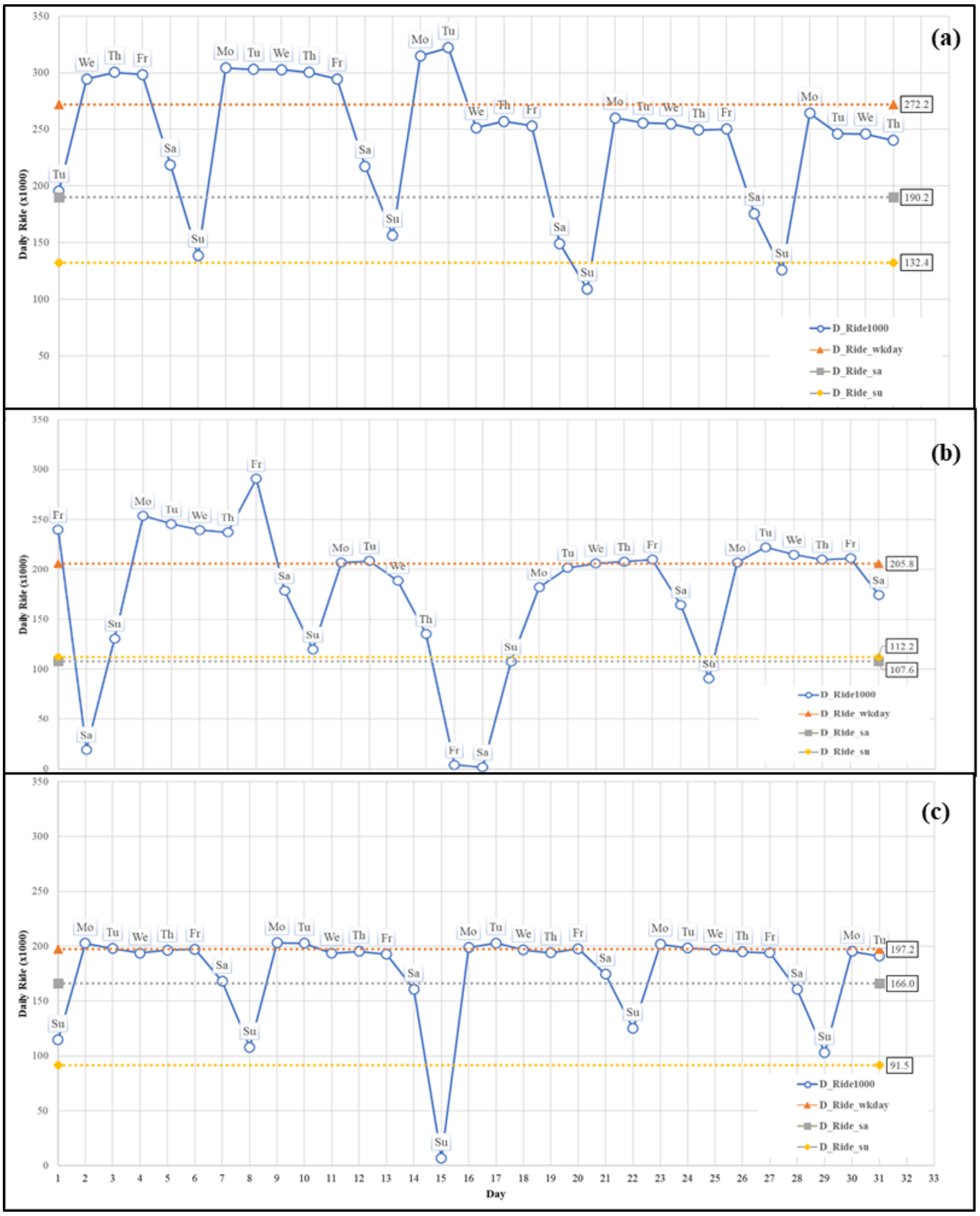


Figure B.2 Daily Ridership Levels for a) May b) June c) July Months

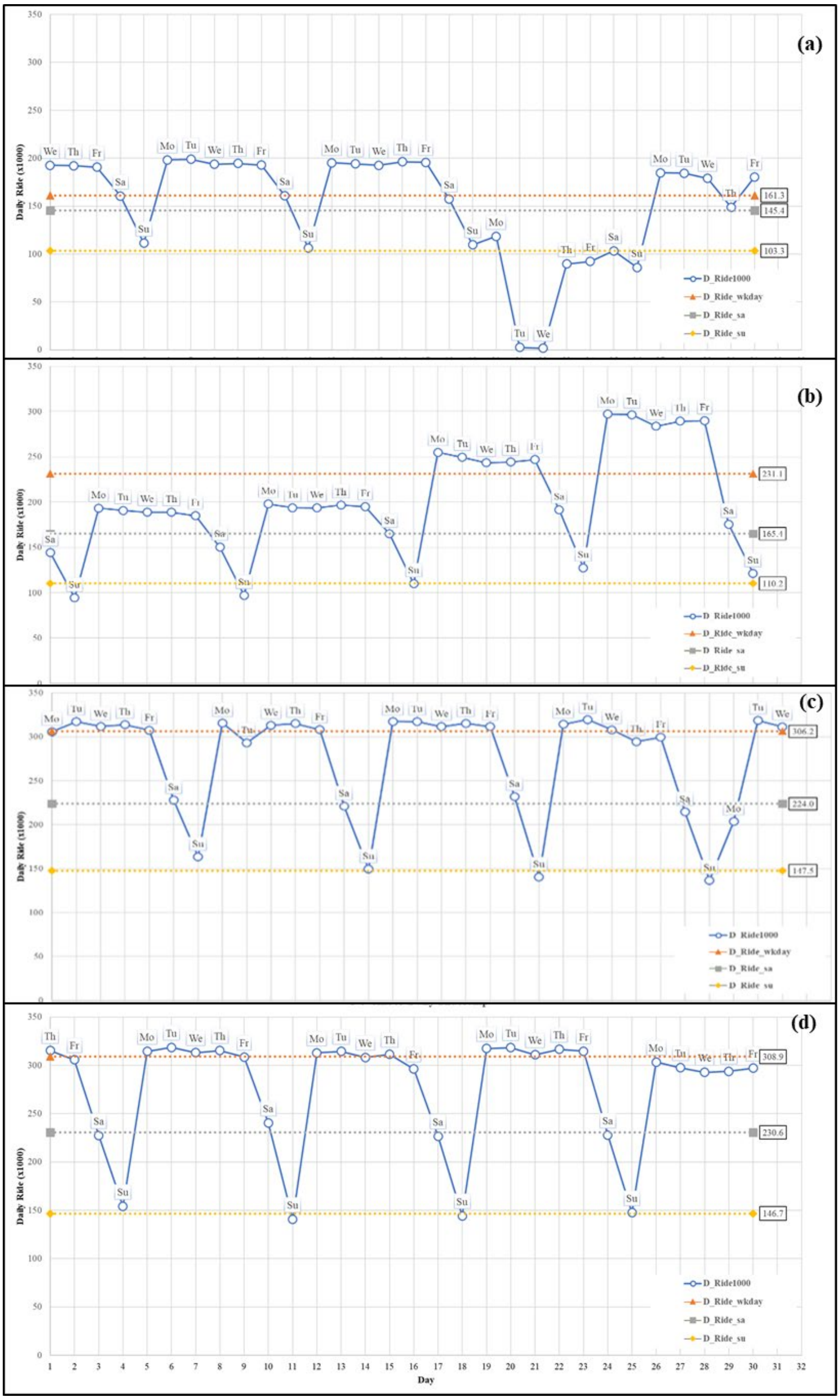


Figure B.3 Daily Ridership Levels for a) August b) September c) October and d) November

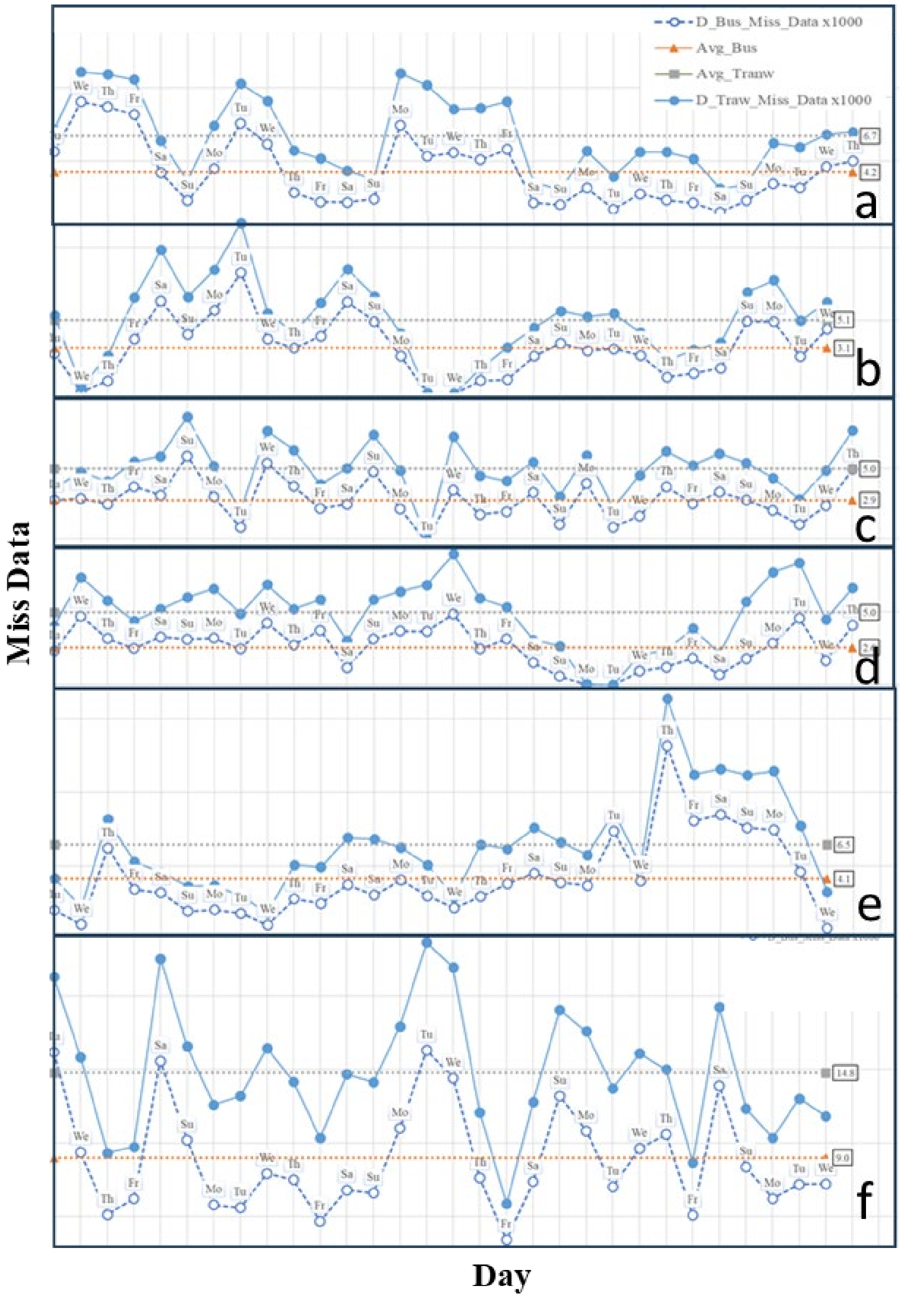


Figure B.4 Missing Data Distribution by Day for a) May b)June c) July d) August e) September c) October f) November Months

C. Definition of GIS Tools and Concepts

Along with the tools under the LR tasks, many other standard GIS tools have been used throughout this study. The definitions of these GIS tools are listed in **Table C.1**, and the concepts related to these tools are listed in **Table C.2**.

Table C.1 Definition of GIS tools

GIS Tools	Definitions
Add Field	It is used to add a new attribute column.
Dissolve	It is used to combine or separate objects.
Create Route	It is used to produce polyline m objects.
Locate Features Along Route	It is used to generate kilometers.
Make Route Event Layer	It is used for the mapping of the generated kilometers.
Sort	It is used to put attributes in a specific order.
Field Calculator	It is used to calculate field values.
Calculate End Time	It is used to generate from-to timestamps and kilometers
Feature Class to Feature Class	It is used to export data and change the table structure
Select Layer by Attribute	It is used to select target data by attribute values.
Select Layer by Location	It is used to select target data by location specifications.
Add Join	It is used to joins a layer to another layer or table based on a common field.
Join Field	It is used to join one or more fields of a table to another table based on a common attribute field.
Summary Statistics	Calculates summary statistics for field(s) in a table.
Feature Class to Feature Class	Converts a feature class in the form of selected fields to another one.
Make feature Layer	Creates a temporary feature layer from an input feature class.
Add Field	Adds a new field to the feature class.
Remove Join	Removes a join established before.

Table C.2 Definition of GIS concepts

Concepts	Definitions
Feature Class	In ArcGIS, a collection of geographic features with the same geometry type (such as point, line, or polygon), the same attributes, and the same spatial reference.
Multipart Feature Class	A Feature Class defined as one feature since it references one set of attributes.
Feature Dataset	In ArcGIS, a collection of feature classes that share the same spatial reference are stored together.
Polyline Feature	A digital map feature that represents a place or thing that has length but not area at a given scale.
Polyline M Feature Class	A polyline feature class has the ability to store m-values (measurement values) or distance from a starting point along a given line.
Single Polyline Feature Class	A polyline feature class having one part associated with a single record in the attribute table.
Multiple Polyline Feature Class	A polyline feature class having more than one part associated with related records in the attribute table.
Single Polyline M Type Of Feature Class	A polyline feature with one part associated with a single record in the attribute table can also store m-values.
Multiple Polyline M Type Of Feature Class	A polyline feature with more than one part associated with related records in the attribute table can also store m-values.
Point Feature Class	A map feature that has neither length nor area at a given scale, such as a city on a world map or a building on a city map.
Point M Feature Class	A point feature class can store m-values.
Event Table	A data source containing location information in tabular format (called events) that is used to create a spatial dataset. For example, an event table might contain x,y coordinates, measures or routes.
Event Layer	A layer created from an event table
Field	A column in a table or attribute table of a feature class that stores the values for a single attribute.
Projected coordinate system	A reference system used to locate x, y, and z positions of point, line, and area features in two or three dimensions. A projected coordinate system is defined by a geographic coordinate system, a map projection, any parameters needed by the map projection, and a linear unit of measure.

D. Creation and Correction of PBT Lines

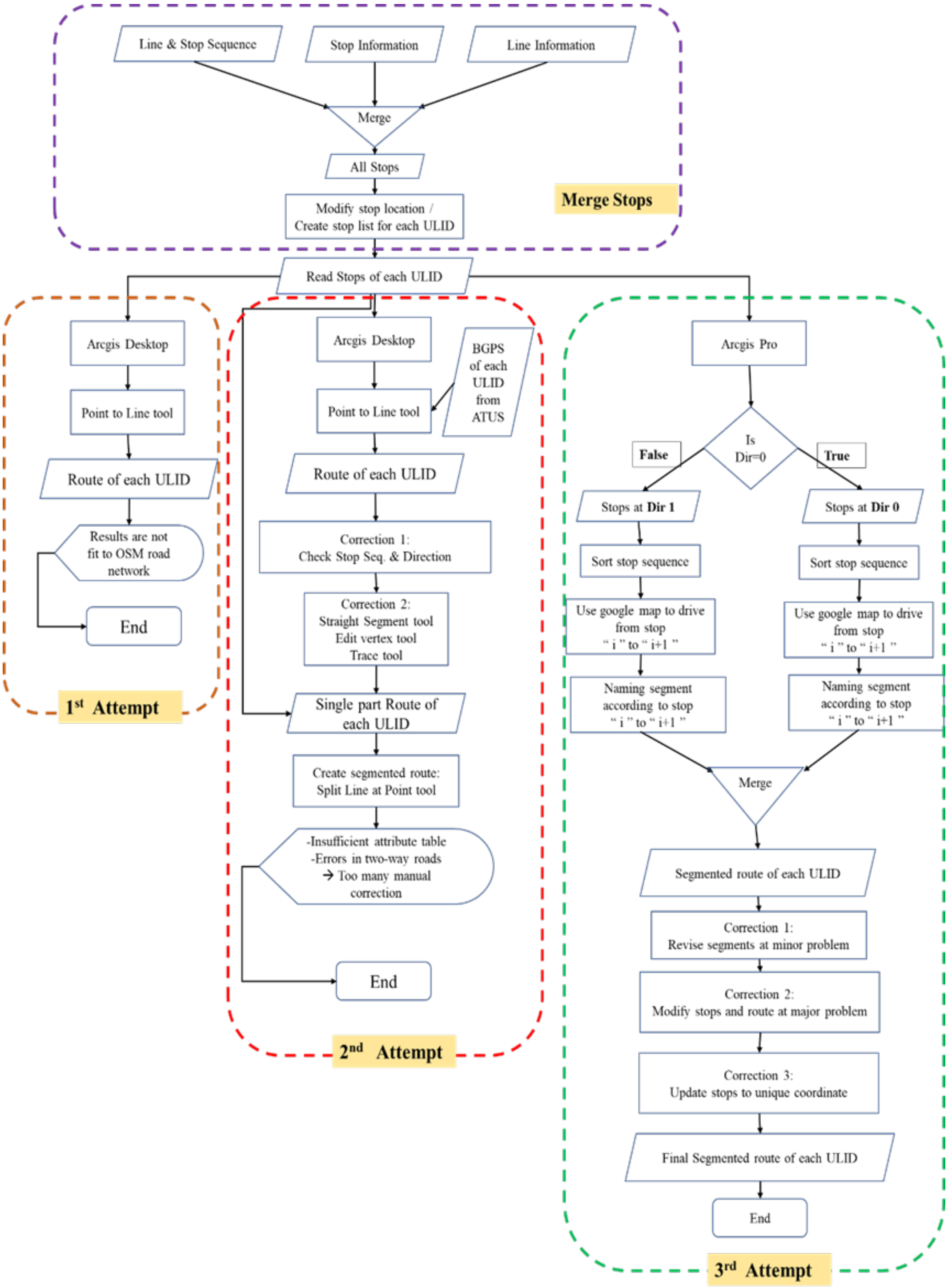
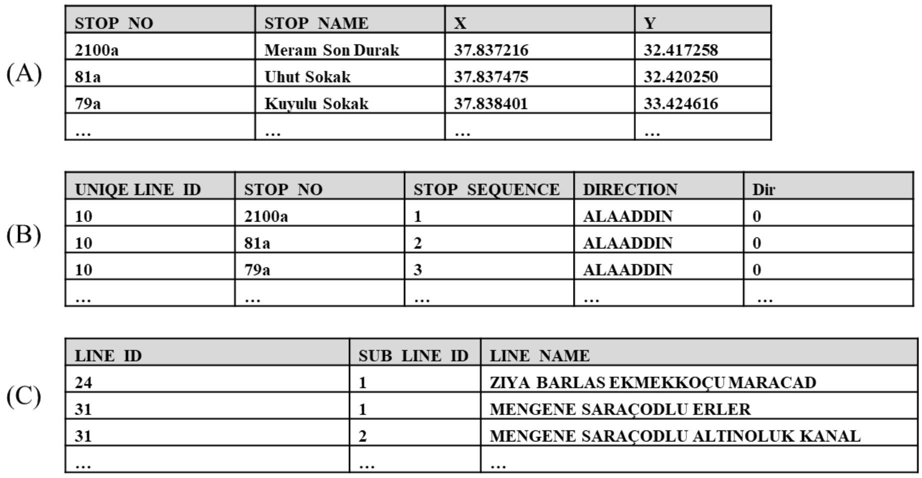


Figure D.1 Flowchart of Route and Stop Correction

Konya municipality provided three Excel datasets for stops and one KML dataset for service line data. The first Excel dataset includes the data of stop information, which contains: stop No, stop name, latitude, and longitude. The second dataset contains the data of stop and line sequence, which contains contain: ULID, stop No, stop sequence, and direction. The "Dir" value of bus stops with "ALAADDIN" direction is "0"; otherwise, it is "1".The reason behind this numbering is that "ALAADDIN" is the city center and most of the bus routes start from "ALAADDIN", so the bus stops in the going trip (from Alaaddin) are coded as "0" and the bus stops in the returning trip (to Alaaddin) coded as "1". The third dataset includes the bus route data that contains: line ID, subline ID, and line name. to show the sample data of each dataset. **Figure D.2** shows the attribute of provided datasets.



(A)

STOP NO	STOP NAME	X	Y
2100a	Meram Son Durak	37.837216	32.417258
81a	Uhut Sokak	37.837475	32.420250
79a	Kuyulu Sokak	37.838401	33.424616
…	…	…	…

(B)

UNIQE LINE ID	STOP NO	STOP SEQUENCE	DIRECTION	Dir
10	2100a	1	ALAADDIN	0
10	81a	2	ALAADDIN	0
10	79a	3	ALAADDIN	0
…	…	…	…	…

(C)

LINE ID	SUB LINE ID	LINE NAME
24	1	ZIYA BARLAS EKMEKKOÇU MARACAD
31	1	MENGENE SARAÇODLU ERLER
31	2	MENGENE SARAÇODLU ALTINOLUK KANAL
…	…	…

Figure D.2 a)Stop Information , b) Stop Sequence, c) Bus Route Data

The provided service line data contains the bus route for each Line ID. The subline Information is not available in this dataset. Moreover, all available routes of each line ID are merged into one line. Similarly, this dataset does not include any direction information, and all lines are single-part lines. Besides, this study's data accuracy is insufficient because the lines derived from bus GPS points can degrade accuracy by satellite signal blockage or reflect due to buildings. Therefore, this dataset was excluded from the study. **Figure D.3** shows the existing bus line route and provides data for LID 44. Sample "A" shows that all six subline IDs of line 44 combined in one shapefile, which is unacceptable for this study. In order to analyze SC data at each day and trip and for future study in LR and Trip chaining, bus stops of each ULID and segmented routes of each ULID are needed. Therefore, the attempts and processes to create segmented routes are described in **Figure D.1.**

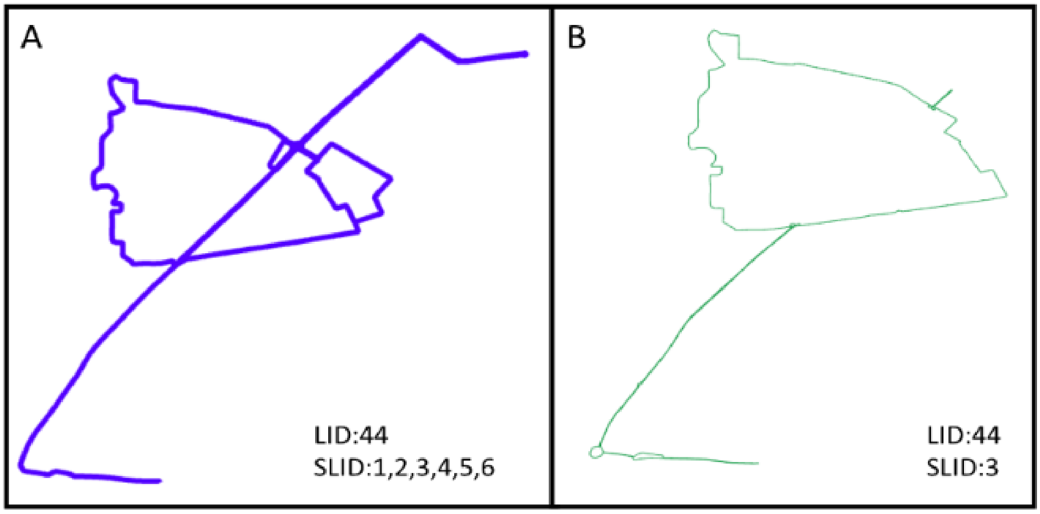


Figure D.3 a) provided KML file for LID 44 a) route of ULID 443

a. Merge Stop Datasets

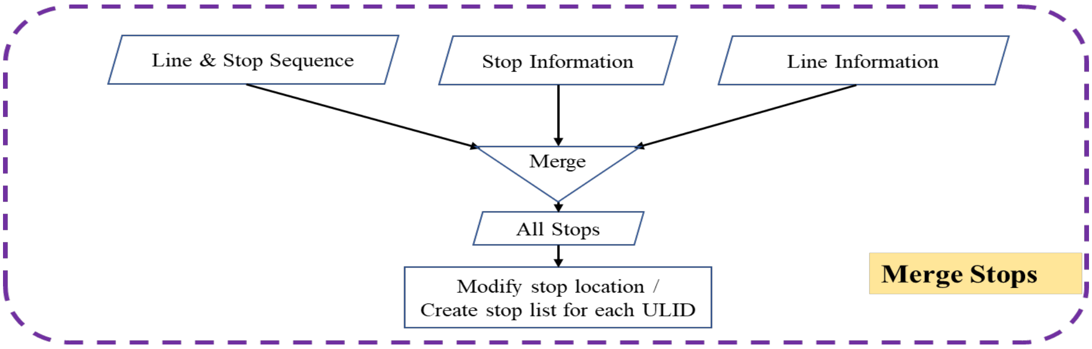


Figure D.4 Framework of merge stop datasets

At this step, the provided datasets of bus stops are merged into one dataset according to "Stop_No" because each dataset contains a different specification of stops. The output data contains Stop No, Stop Name, Latitude, Longitude, ULID, Stop Sequence, and Direction. Checking stop coordinates with the satellite base map in the ArcGIS environment shows that the bus stops were approximately around a real stop location. Therefore, using the ArcGIS edit tool, the bus stop was snapped to Open Street Map lines around dense SCD to increase the accuracy of the stop location. After that, the merged file has been split by ULID to create a stop list for each ULID. Table **Figure D.5** indicates the sample attribute of the merged dataset.

Figure D.5 Sample of merged stop

STOP _NO	STOP _NAME	X	Y	ULID	STOP _SEQ	DIRECTION	Dir
2100a	Meram Son Durak	**37.837216**	**32.417258**	**10**	**1**	**ALAADDIN**	**0**
2100a	Meram Son Durak	**37.837216**	**32.417258**	**11**	**1**	**ALAADDIN**	**0**
2100a	Meram Son Durak	**37.837216**	**32.417258**	**20**	**1**	**ALAADDIN**	**0**
…	**…**	**…**	**…**	**…**	**…**	**…**	

b. First Attempt: Create Bus Route in ArcGIS Desktop

The bus stops of each ULID have been created in Step 1. This step describes the first attempt at creating a bus route from bus stops(see **Figure D.6**). In order to create a bus route, the "Point to Line" tool of ArcGIS Desktop was used, shown in **Figure D.7**. This tool connects bus stops to each other according to the stop sequence. This tool creates a straight line between two points, and there is no direction information in the attribute table; therefore, the created routes are not accurate enough to use in this study**. Figure D.8** shows the result of the point-to-line tool and some examples of inaccuracy.

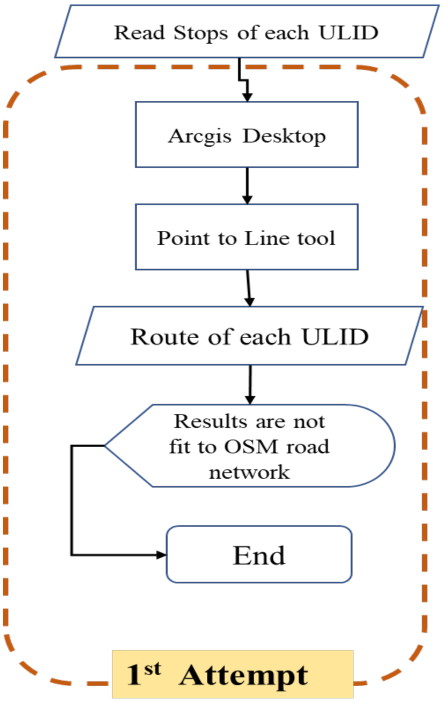
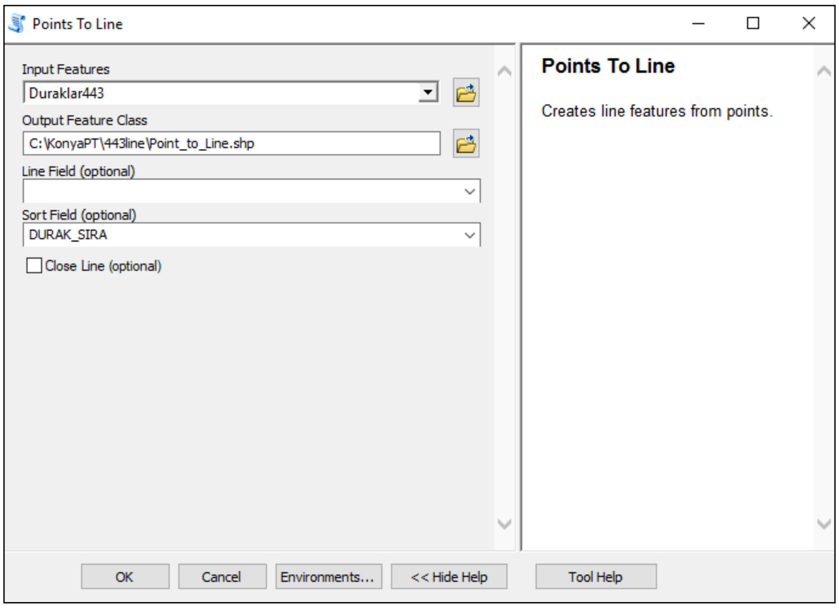


Figure D.6 Framework of the first attempt



Input Features: Duraklar443

Output Feature Class: C:\KonyaPT\443line\Point_to_Line.shp

Line Field (optional):

Sort Field (optional): DURAK_SIRA

☐ Close Line (optional)

Points To Line

Creates line features from points.

Figure D.7 Point to Line tool in ArcGIS

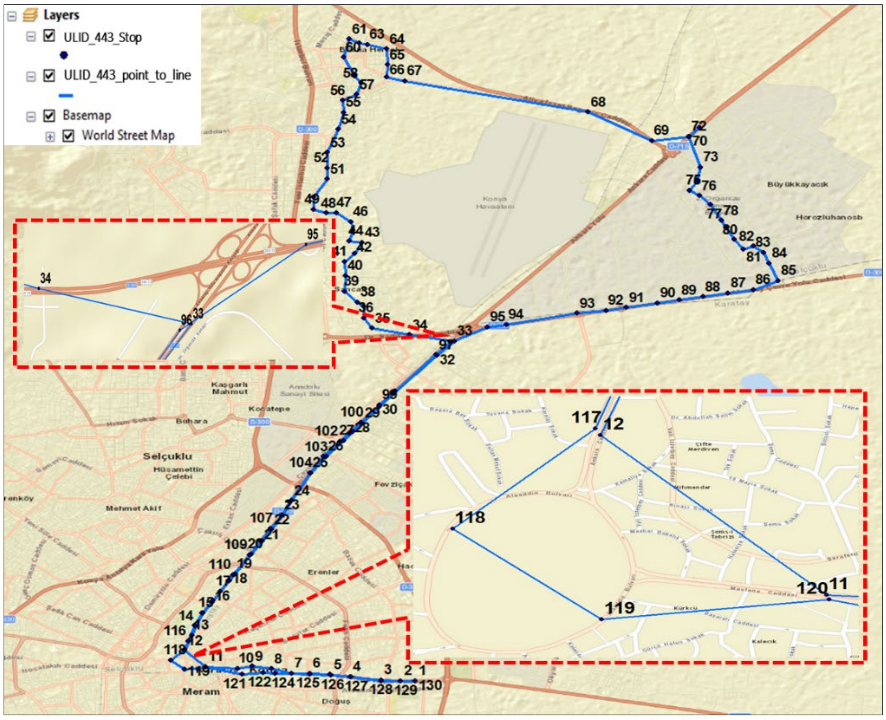


Figure D.8 Result of "Point to Line" tool of ArcGIS at ULID_443

c. Second Attempt: Create Bus Route from ATUS

According to previous attempt results, the point-to-line tool is not working with the stop dataset because of long-distance between two points. In this attempt, data from ATUS was used as input to the "Point to Line" tool because the distance between two GPS points is small. Also, it is real-time data collected from GPS devices in buses. As the first step of this attempt, the ATUS website has been used to collect data on each ULID. **Figure D.9** shows the framework of the second attempt.

The municipality of Konya tried to collect the whole system under one umbrella and named it ATUS which means Intelligent PBT System. This system can be accessible in the web browser and mobile app. **Figure D.10** shows the ATUS website, which contains details about the city of Konya, real-time bus location information, location to reload SC, SC online reload system, school services location, bike line, fare information, railroad information, and online tramway information. **Figure D.11** indicates the Bus route in the ATUS website for ULID 443.

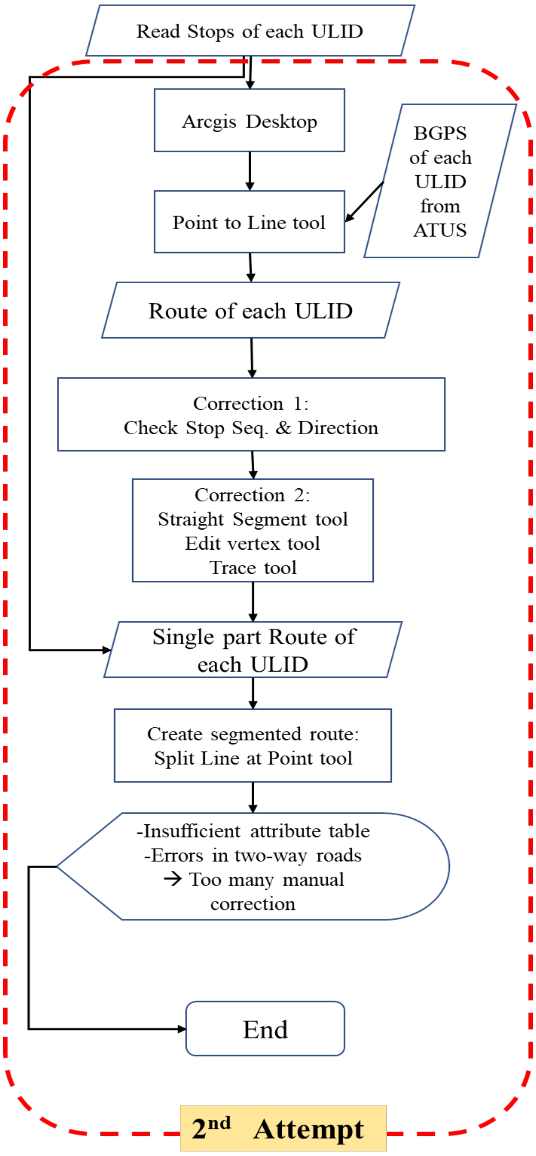
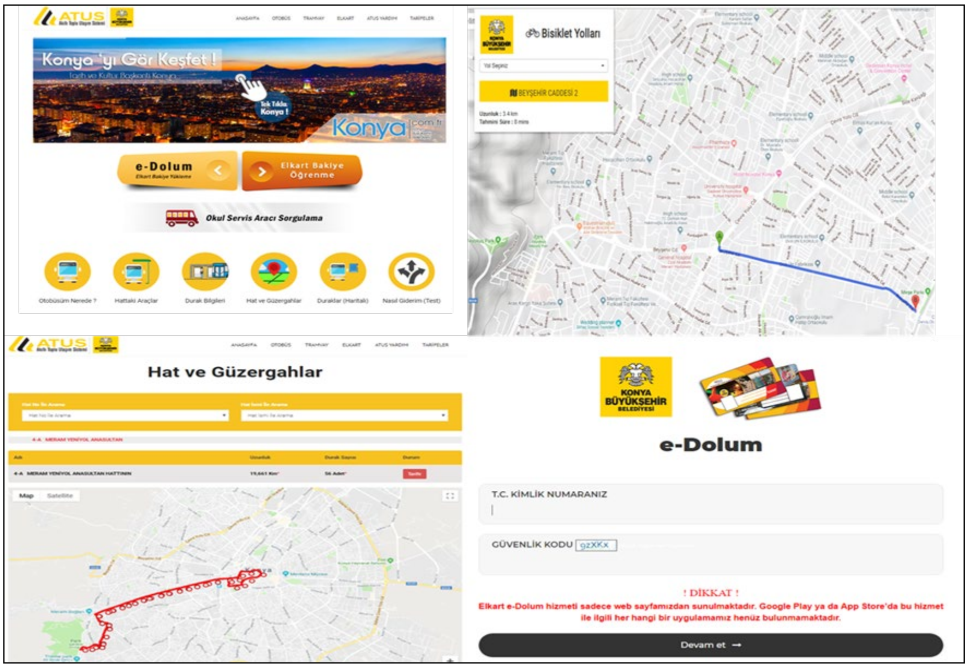


Figure D.9 Framework of the second attempt



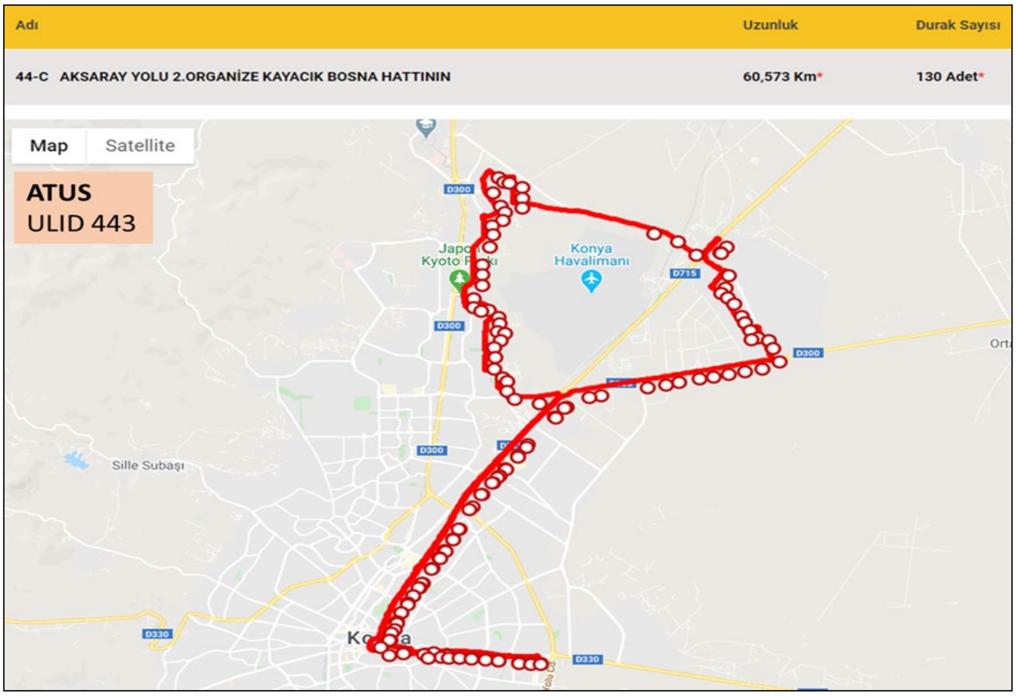
T.C. KİMLİK NUMARANIZ

GÜVENLİK KODU gzXKx

! DİKKAT !

Elkart e-Dolum hizmeti sadece web sayfamızdan sunulmaktadır. Google Play ya da App Store'da bu hizmet ile ilgili her hangi bir uygulamamız henüz bulunmamaktadır.

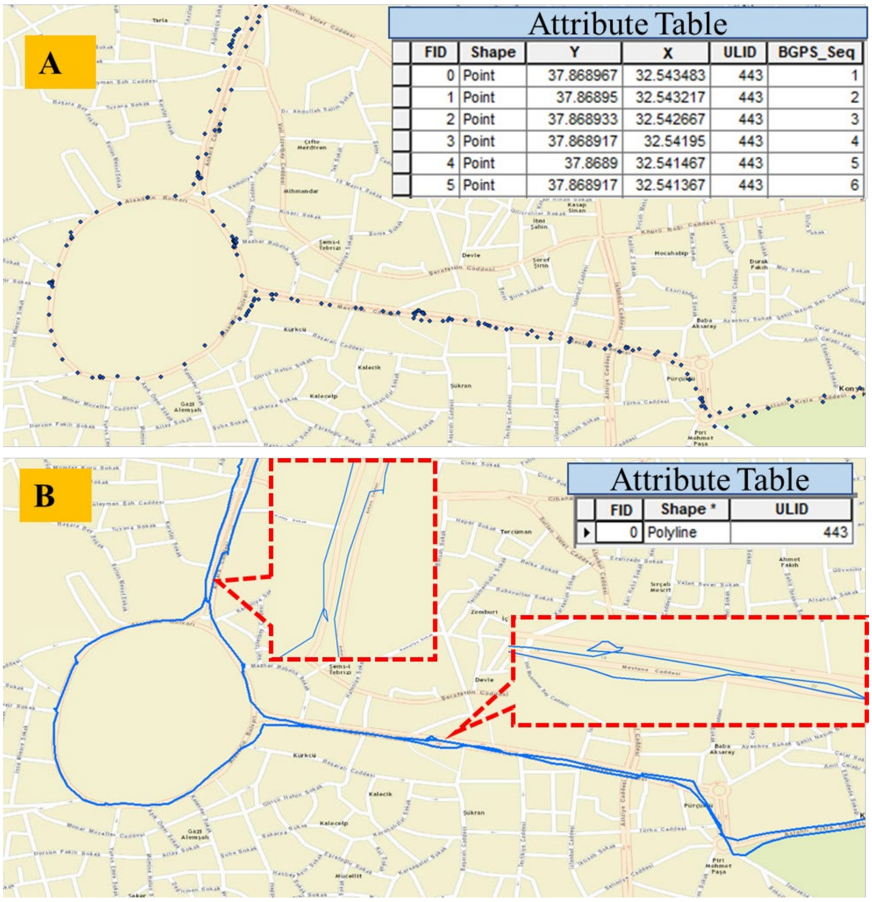
Figure D.10 examples of ATUS website



Adı	Uzunluk	Durak Sayısı
44-C AKSARAY YOLU 2.ORGANİZE KAYACIK BOSNA HATTININ	60,573 Km*	130 Adet*

Figure D.11 Bus route in ATUS website for ULID 443

The attribute of bus GPS data contains the coordinate and sequences of each GPS point. Then the "Point to Line" tool of ArcGIS was used to create a route for each ULID from a sequence of GPS points. The accuracy of created routes is low because of the nature of GPS data. The Accuracy of GPS points can degrade by satellite signal blockage or reflect due to buildings. Therefore, to increase the precision of lines, some modifications were applied to each ULID route. **Figure D.12** shows the bus GPS and point-to-line results for ULID 443.



Attribute Table

FID	Shape	Y	X	ULID	BGPS_Seq
0	Point	37.868967	32.543483	443	1
1	Point	37.86895	32.543217	443	2
2	Point	37.868933	32.542667	443	3
3	Point	37.868917	32.54195	443	4
4	Point	37.8689	32.541467	443	5
5	Point	37.868917	32.541367	443	6

Attribute Table

FID	Shape *	ULID
0	Polyline	443

Figure D.12 a) bus GPS and b) point-to-line results for ULID 443

In this step, stop direction and sequence correctness at each ULID has been checked by opening the stop list and OSM base map in the ArcGIS environment. If the sequence and direction are not matched with the base map, the stops relocate to the correct location. **Figure D.13** shows the sample of stop correction according to the direction and stop sequence.

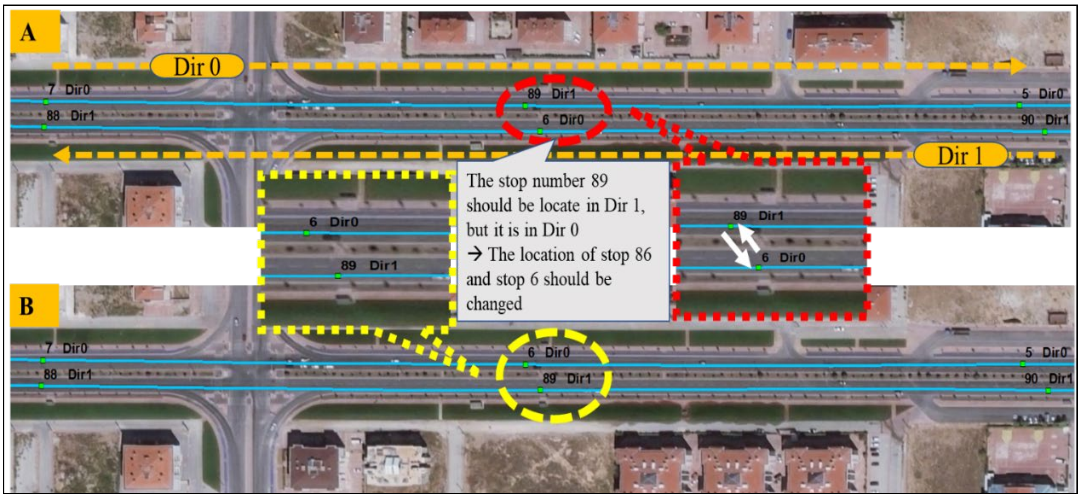
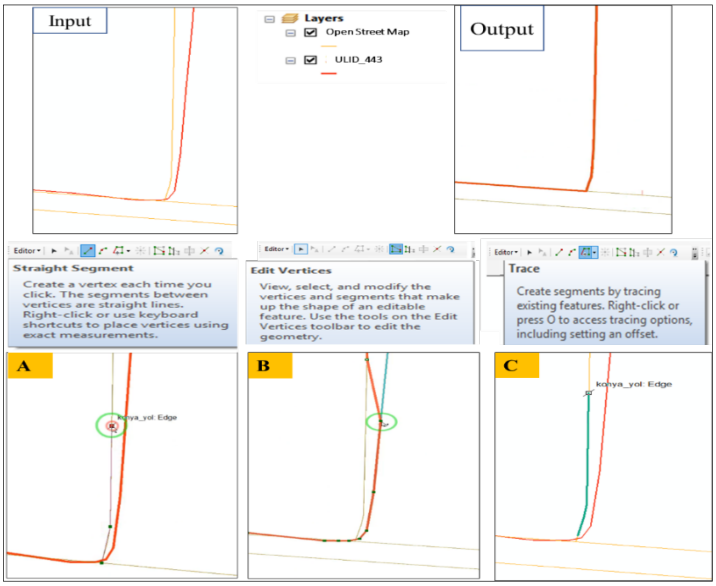

The stop number 89 should be locate in Dir 1, but it is in Dir 0
→ The location of stop 86 and stop 6 should be changed

Figure D.13 Sample of stop correction according to the direction and stop sequence

Afterward, three different tools of ArcGIS were used to snap lines to the OSM network. According to the error type of each line, at least one of the correction methods has been used to modify the line. The "straight Segment" is one of the editing tools that creates a straight line between two clicked points. This tool created a new line on the OSM road network analogous to existing lines. Another editing tool is "Edit Vertices.". Using this tool, the current lines are modified, moved, and snaped to the OSM network. The" Trace" tool is one of the most used tools. Tracing the mouse on the OSM network creates a new line along with the current line. All ULIDs were modified concerning stop sequence and direction. **Figure D.14** shows the three different tools used for route modification. The output of each ULID is saved as a shape file with one attribute table, which shows the shape type and ULID number. **Figure D.15** indicates the final output of ULID 443 after modification.



Straight Segment

Create a vertex each time you click. The segments between vertices are straight lines. Right-click or use keyboard shortcuts to place vertices using exact measurements.

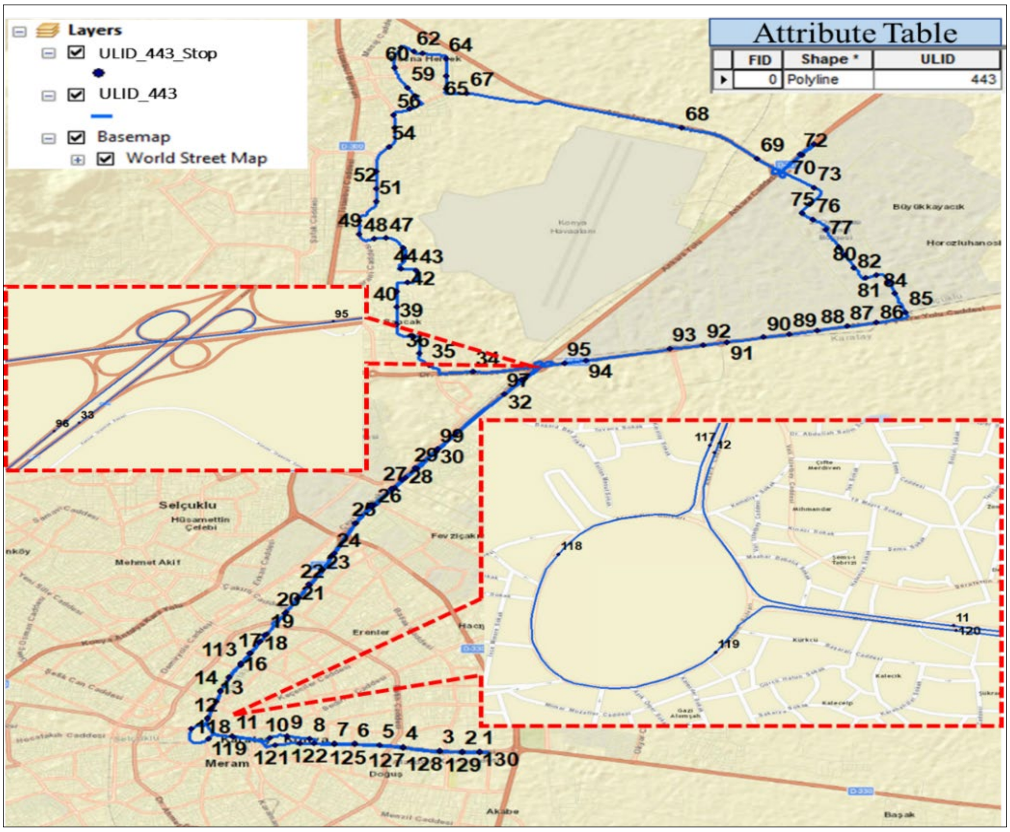
Edit Vertices

View, select, and modify the vertices and segments that make up the shape of an editable feature. Use the tools on the Edit Vertices toolbar to edit the geometry.

Trace

Create segments by tracing existing features. Right-click or press O to access tracing options, including setting an offset.

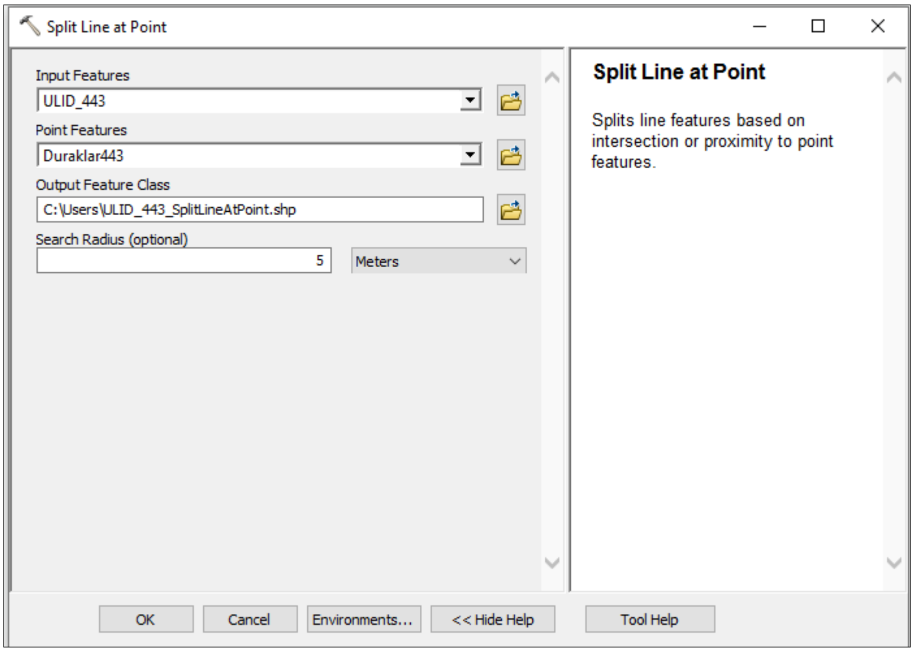
Figure D.14 Three different tools used for route modification



FID	Shape *	ULID
0	Polyline	443

Figure D.15 Final output of ULID 443 after modification

At this point, the single-part route of each ULID is created and revised according to the OSM road network. The segmented line between stops is the following needed data. Moreover, the attribute of the segmented line should contain the sequence, name, latitude, longitude, and direction of "From (1st) stop" and "To (2nd) stop". In order to split the route at stops and create a multipart ULID route, the "split Line at Point" tool of ArcGIS has been used.**Figure D.16** shows the "split line at point" tool in ArcGIS.



Split Line at Point

Input Features: ULID_443

Point Features: Duraklar443

Output Feature Class: C:\Users\ULID_443_SplitLineAtPoint.shp

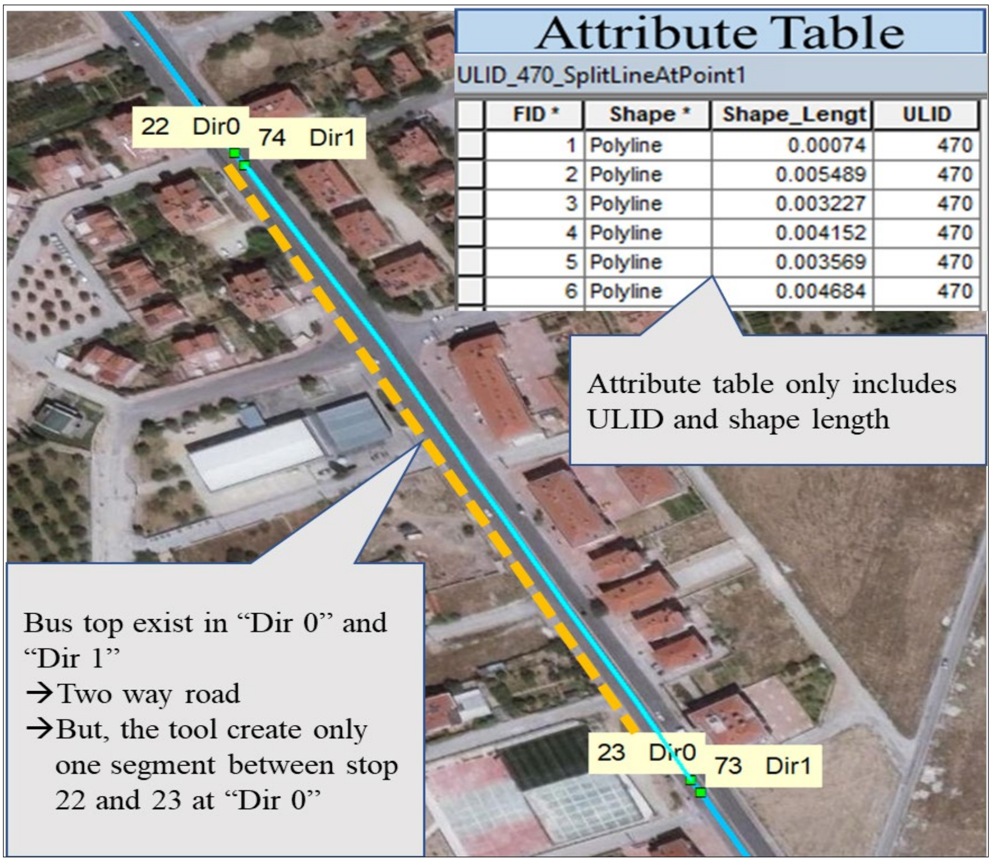
Search Radius (optional): 5 Meters

Split Line at Point

Splits line features based on intersection or proximity to point features.

Figure D.16 The "split line at point" tool in ArcGIS.

Using this tool created the segmented line between stops, but two significant problems were faced in the results. The first problem is that the attribute table of the created line did not include any information about each segment's start and end stop. Moreover, the tool did not work correctly at one link in two directions. **Figure D.17** shows the sample of two significant problems in the results for ULID 470. The correction process for the results needs much manual work; thus, another method tried to create more accurate results.



Attribute Table

ULID_470_SplitLineAtPoint1

FID *	Shape *	Shape_Lengt	ULID
1	Polyline	0.00074	470
2	Polyline	0.005489	470
3	Polyline	0.003227	470
4	Polyline	0.004152	470
5	Polyline	0.003569	470
6	Polyline	0.004684	470

Attribute table only includes ULID and shape length

Bus top exist in “Dir 0” and “Dir 1”

→Two way road

→But, the tool create only one segment between stop 22 and 23 at “Dir 0”

Figure D.17 The sample of two significant problems in results for ULID 470

E. Boarding Stop Estimation

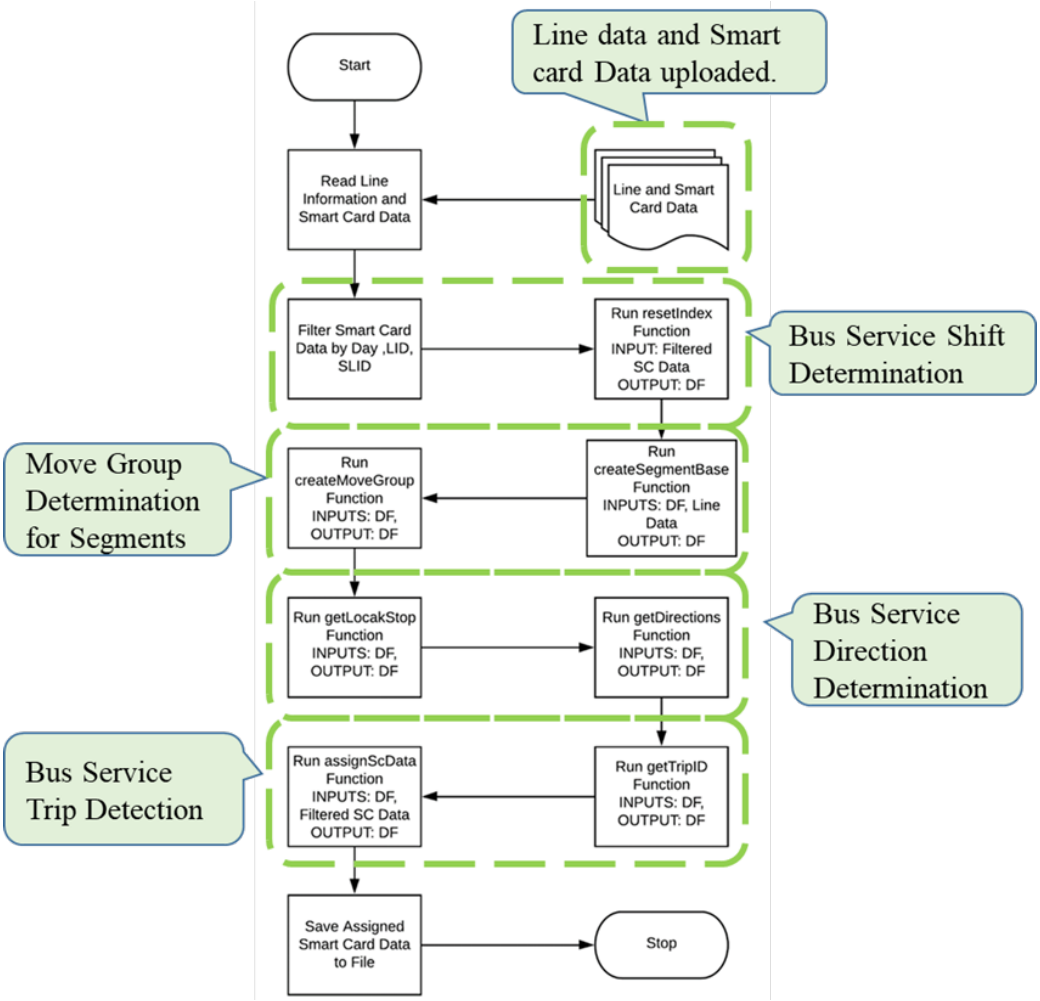


Figure E.1 Flowchart of Boarding Stop Estimation

a. Bus Service Shift Determination

Once the data is filtered, the resetIndex Function goes into action. This function uses the filtered GPS data from the SC as input. The flow chart for the resetIndex Function is included in **Figure E.3**. The data is sorted into groups based on the VID during the function. Timestamp then sorts each group. The SC's GPS information is given an index starting from 1. The ShiftID, a combination of ULID and VID, is also written for each data set. After executing the function, INDEX and ShiftID columns are added to the data. The sample of the resetIndex Function's output is in **Table E.1**.

Table E.1 Short Version of Output of resetIndex Function Execution

VID	TS	LID	SLID	ShiftID	INDEX
246	2018-10-01 07:29:26	44	3	443_246	1
246	2018-10-01 07:29:28	44	3	443_246	2
246	2018-10-01 07:31:08	44	3	443_246	3
246	2018-10-01 07:31:09	44	3	443_246	4

For example, **Figure E.2** displays the index values of the initial six SCD. The blue line on the graph represents the bus route, while the yellow area indicates a 100 m buffer around the bus route line. Additionally, the black dots signify stops, and the red diamonds indicate the location of the SCD. The first two transactions occurred outside of the designated route.

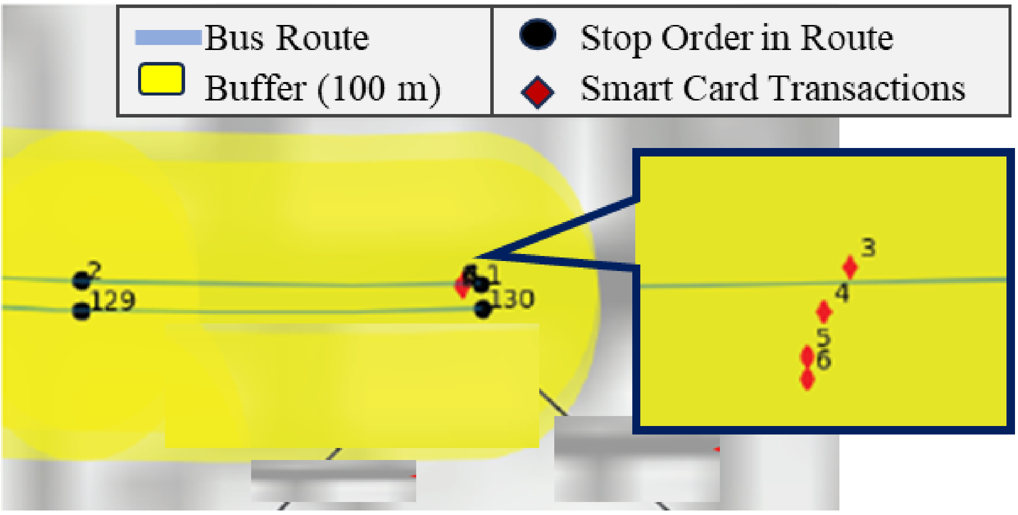


Figure E.2 SCD Indexes

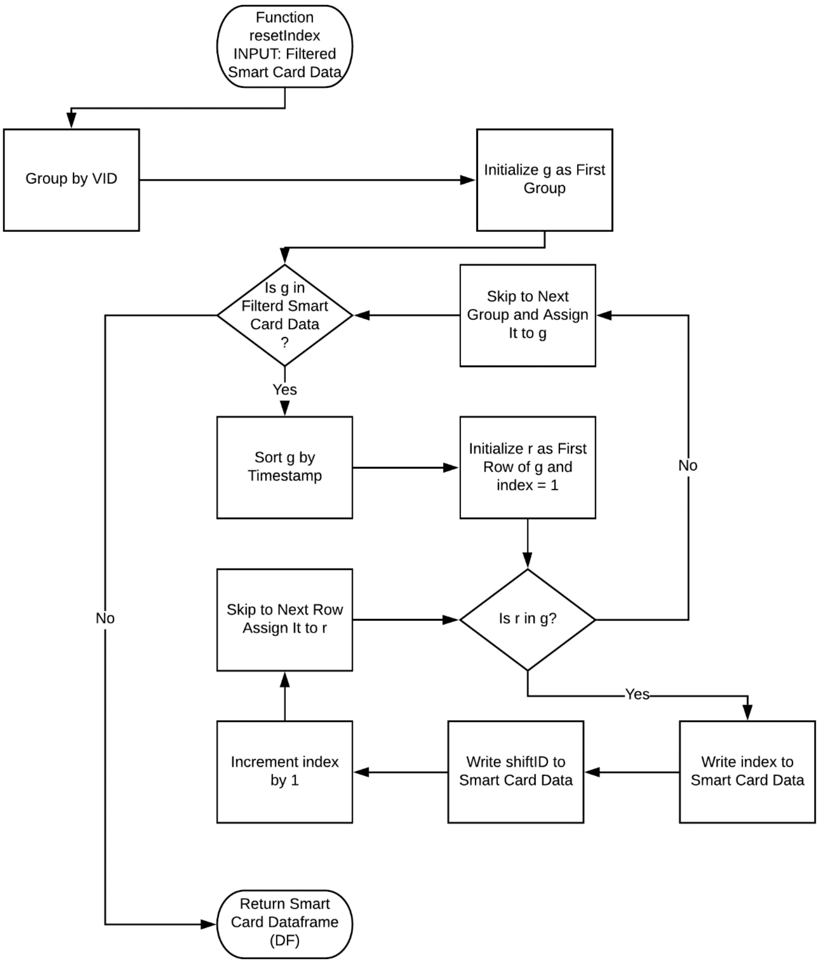


Figure E.3 Flow Chart for resetIndex Function

b. Move Group Determination for Segments

After executing the resetIndex Function, the createSegmentBase Function takes two inputs. The first input is the output of the resetIndex Function, and the second is Line Data, which contains all bus line information in Konya. The flowchart for this function is displayed in **Figure E.4**. The createSegmentBase Function adds a 100m buffer zone to each segment in the line. A segment refers to a polyline between two consecutive stops. ShiftID groups the first input. The function checks if sc data is within the segment buffer zone for each group and row in those groups. If sc data falls within that buffer zone, a new data frame containing segment-based SC information is created. An example output of this function is presented in **Table E.2**.

Table E.2 Output of createSegmentBase Function

INDEX	**VID**	**ShiftID**	**STOP_ORDER_1**	**STOP_ORDER_2**	**STOP_ID_1**	**STOP_ID_2**
8	211	443_211	2	3	1021d	1020d
8	211	443_211	3	4	1020d	1019d
8	211	443_211	127	128	1019a	1020a
8	211	443_211	128	129	1020a	1021a

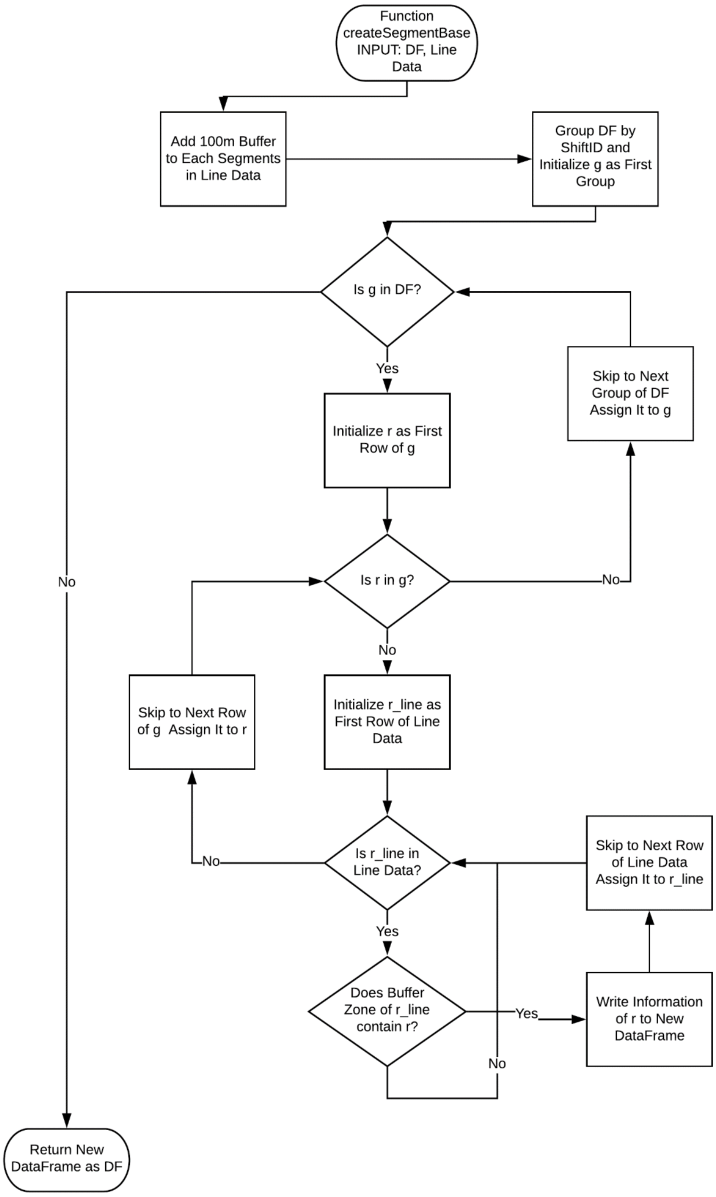


Figure E.4 Flow Chart for createSegmentBase Function

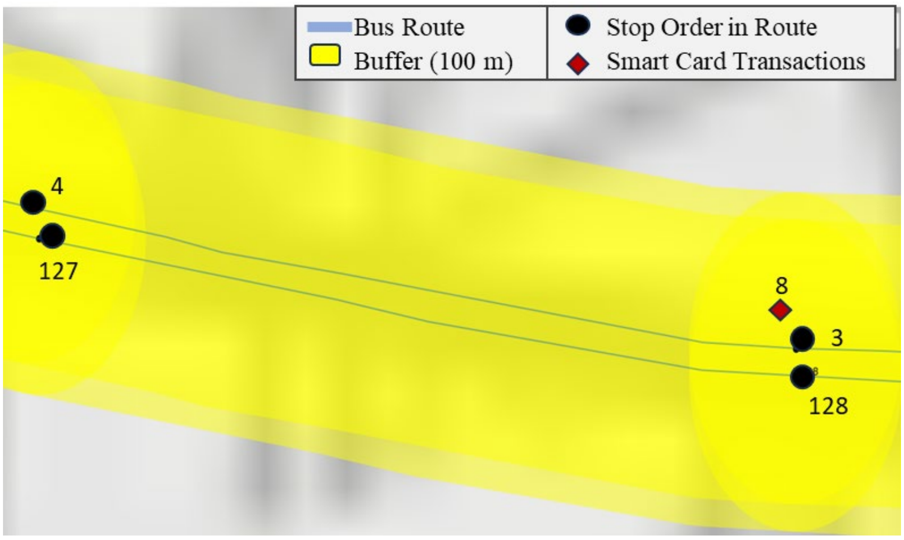


Figure E.5 SCD in Segments

In **Figure E.5**, SCD with index number 8 belongs to 4 segments. Since it is in a buffer zone of 4 segments, these segments are from stop order 2 to 3, from stop order 3 to 4, from stop order 127 to 128, and from stop order 128 to 129.

The USID is a unique identifier for a segment. In **Table E.3**, it is evident that a SCD with an index number of 8 is present in two different segments due to overlapping regions caused by a 100 m buffer. Once the createSegmentBase function is completed, the createMoveGroup function is executed, which requires the output of the previous function as input. USID and VID group the input data frame, and for each group, consecutive SCD with a jump in their INDEX numbers indicates the start of another move group in that segment. The function adds the move group to the data; the output is displayed in **Table E.3**

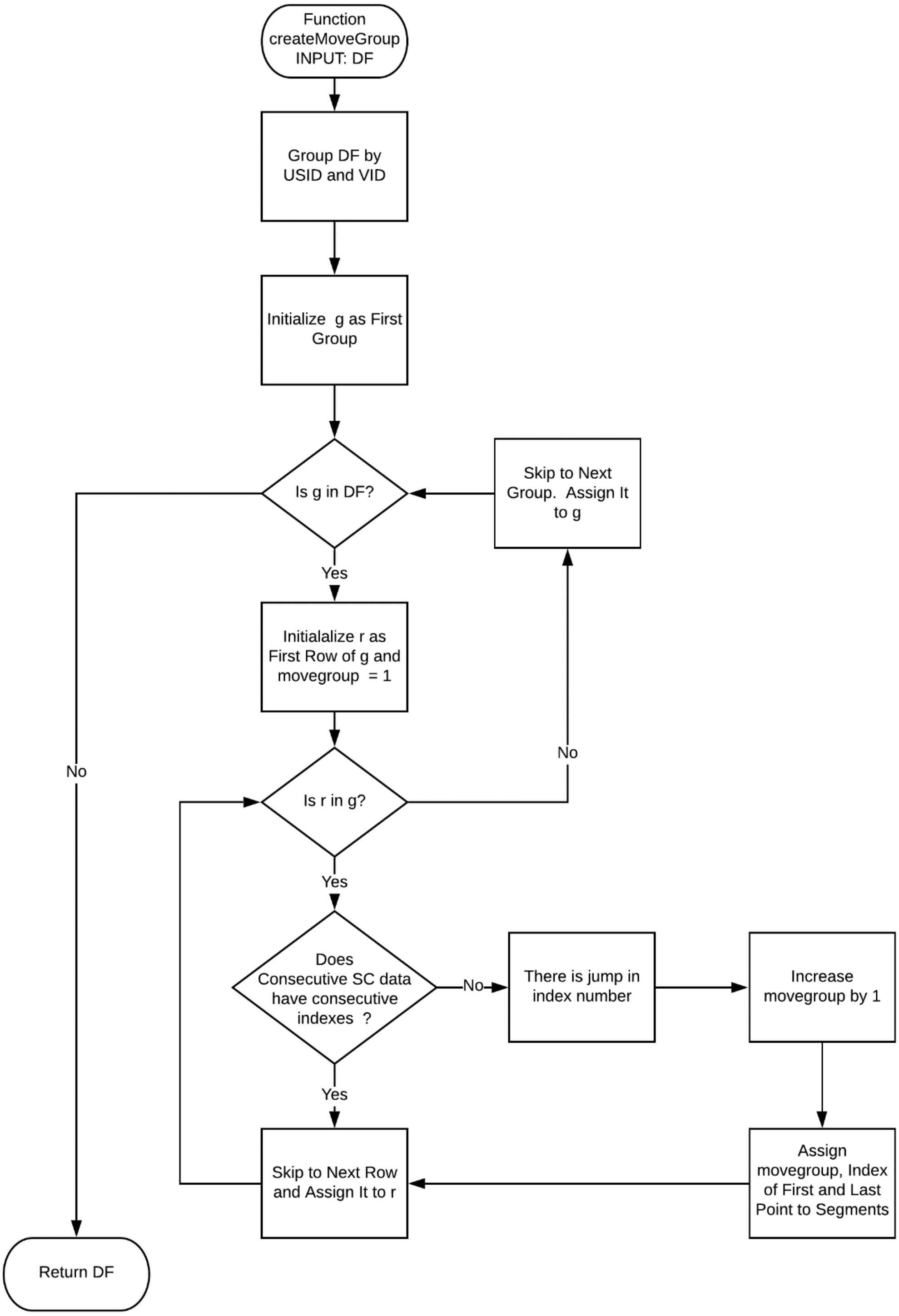


Figure E.6 Flow Chart for createMoveGroup Function

Table E.3 Some Columns of Output of createMoveGroup Function

FP_LAT	**FP_LON**	**F_IND**	**L_IND**	**LP_LAT**	**LP_LON**	**ShiftID**	**MVGRP**
37,92604	32,52847	79	83	37,92809	32,53046	443_211	1
37,92819	32,53014	217	267	37,92809	32,53006	443_211	2
37,92601	32,52851	362	370	37,92802	32,5305	443_211	3

The F_IND and L_IND index numbers of the segment's first and last SCD. FP is a shortcut for the first point, representing the first SCD within the segment. Similarly, LP denotes the last point within the segment. **Table E.3** shows that the SCDs with index numbers 79, 80, 81, 82, and 83 are part of the segment and form move group 1. **Figure E.7** displays the index numbers of SCDs in **Table E.3** that are part of the same segment. However, due to the discontinuity in index numbers, they have different move group numbers. In **Figure E.8**, the move group numbers of the same SCD can be seen.

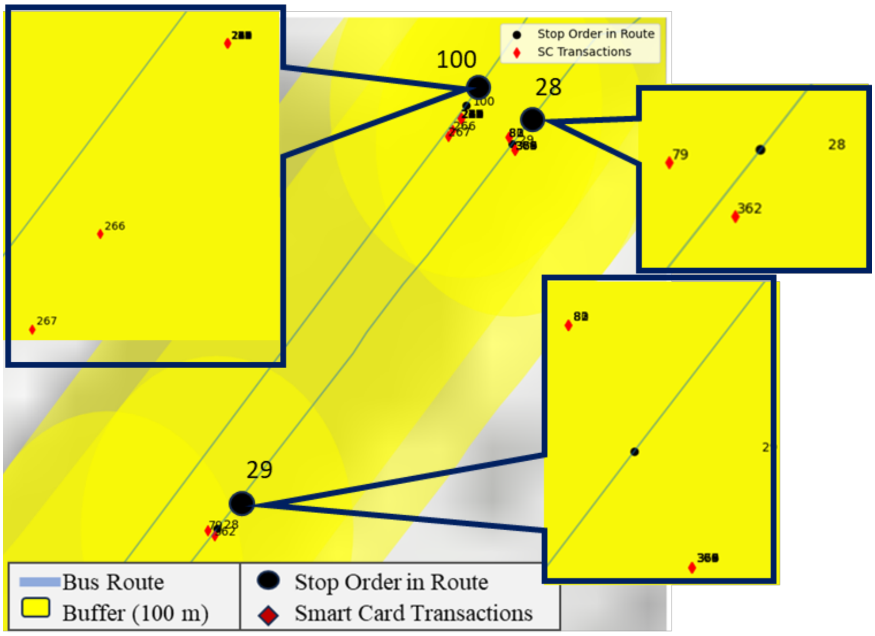


Figure E.7 SCD Index Numbers in Segments, Which is between Stop Order 100 and 101

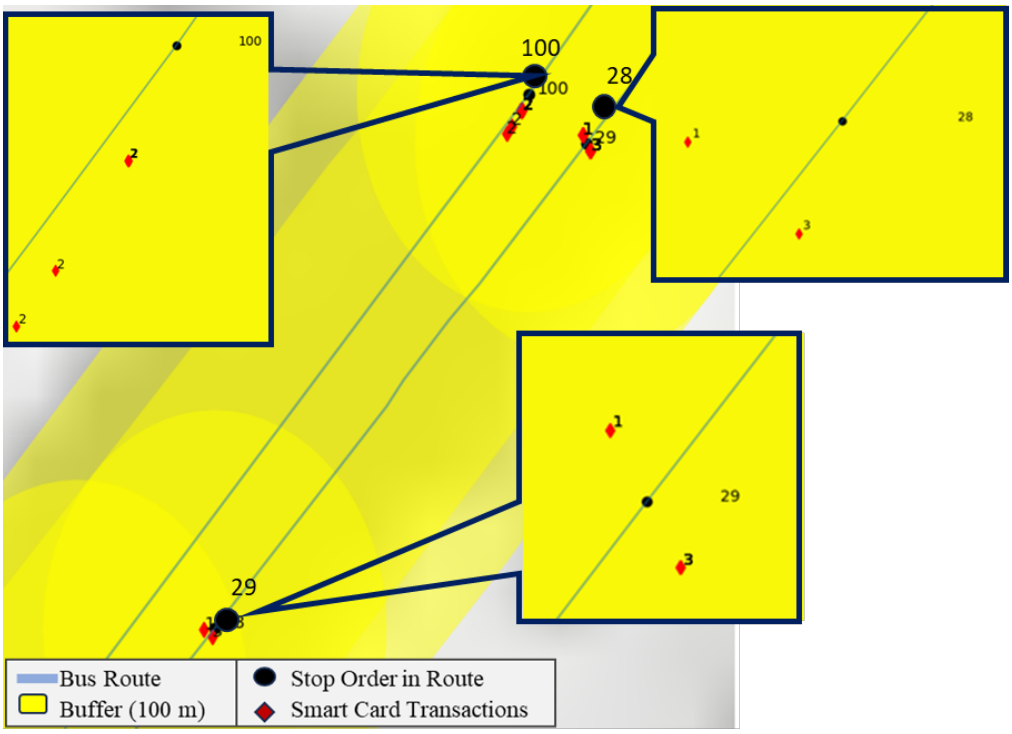


Figure E.8 SCD Movegroup Numbers in Segments, Which is between Stop Order 100 and 101

c. PBT Service Direction Determination

Afterward, the getLocalStop function is executed, with the output of the previous function serving as its input. This function adds the first and last stop order as column names ST1 and ST2 for each row in the input data frame. **Figure E.9** shows the flow chart of this function. **Table E.4** shows the Output of getLocalStop Function.

Table E.4 Some Columns of Output of getLocalStop Function

ShiftID	MVGRP	ST1	ST2
443_211	1	100	101
443_211	2	100	101
443_211	3	100	101

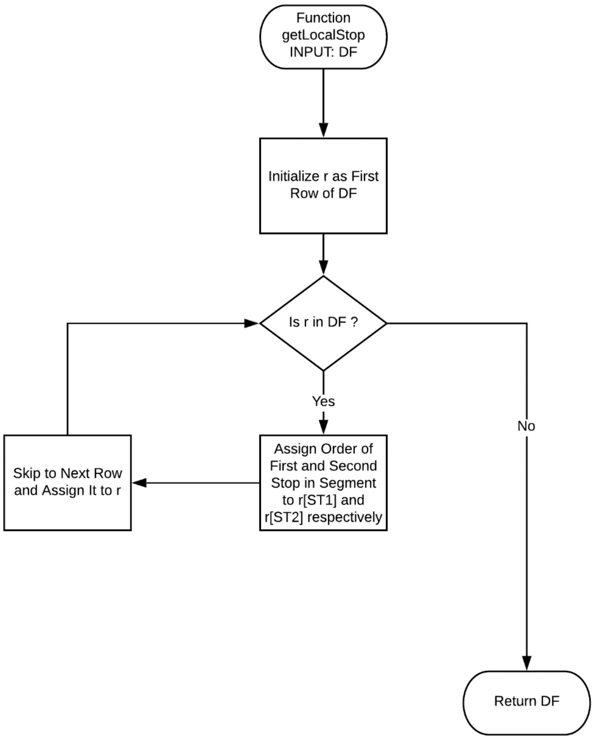


Figure E.9 Flow Chart for getLocakStop Function

Next, the getDirections function is utilized with the previous function's data frame as input. The first step is to set all SCD directions as -1, indicating the reverse direction. The function then simulates data based on time and location to determine the direction of the SCD. For a detailed explanation of the code, refer to **Figure E.10**. A direction column is added to the data frame, and **Table E.5** displays some of the output file's columns.

Table E.5 Some Columns of Output of getDirections Function

F_IND	L_IND	ShiftID	MVGRP	ST1	ST2	Direction
79	83	443_211	1	100	101	-1
217	267	443_211	2	100	101	1
362	370	443_211	3	100	101	-1

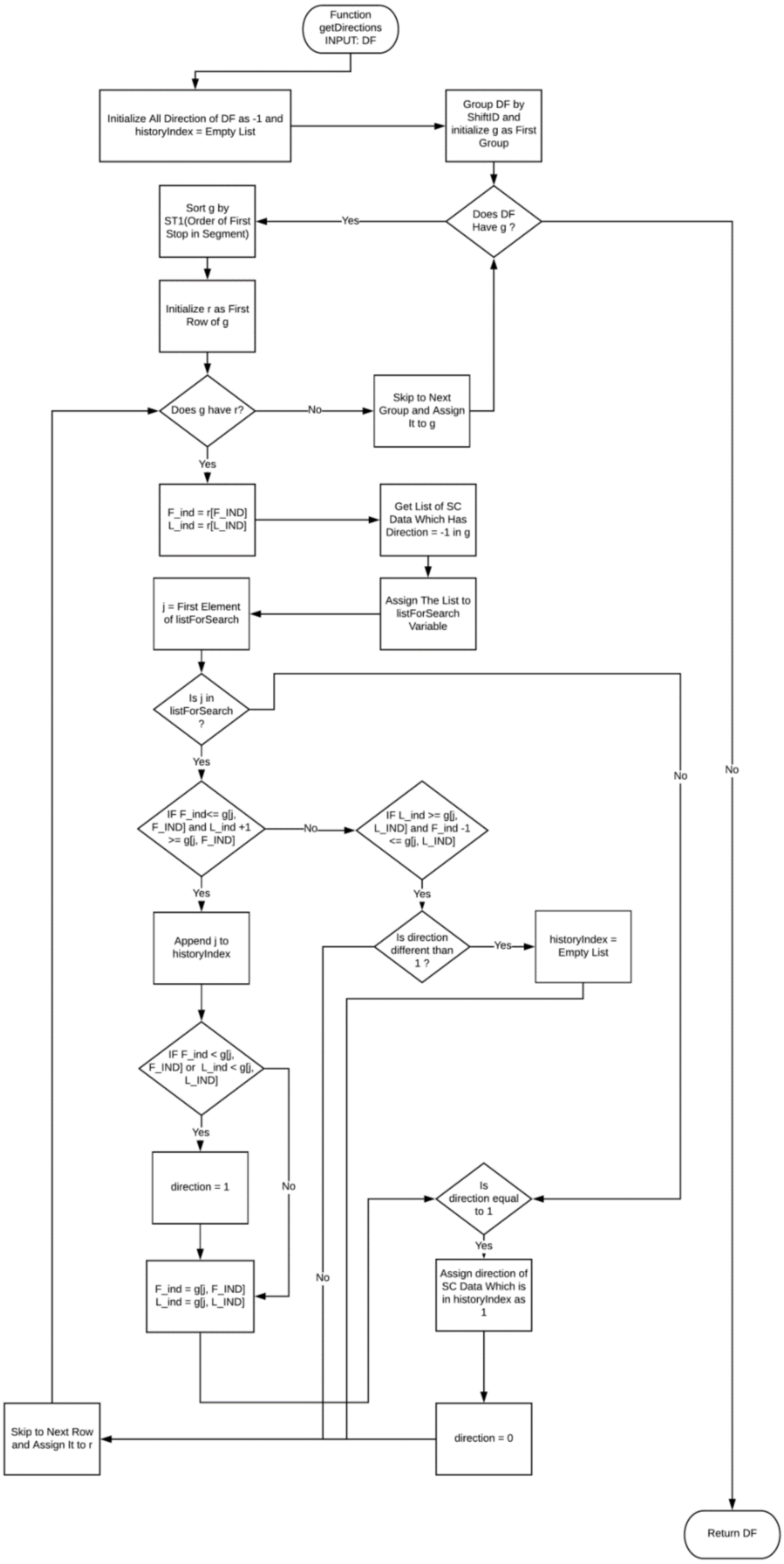


Figure E.10 Flow Chart for getDirections Function

Figure E.11 displays the direction values of SCD within the segment spanning stop orders 100 and 101. Within this segment are three move groups, with only move group number 2 having the correct direction, going from stop order 100 to 101. Move group numbers 1 and 3. On the other hand, from stop orders 28 to 29.

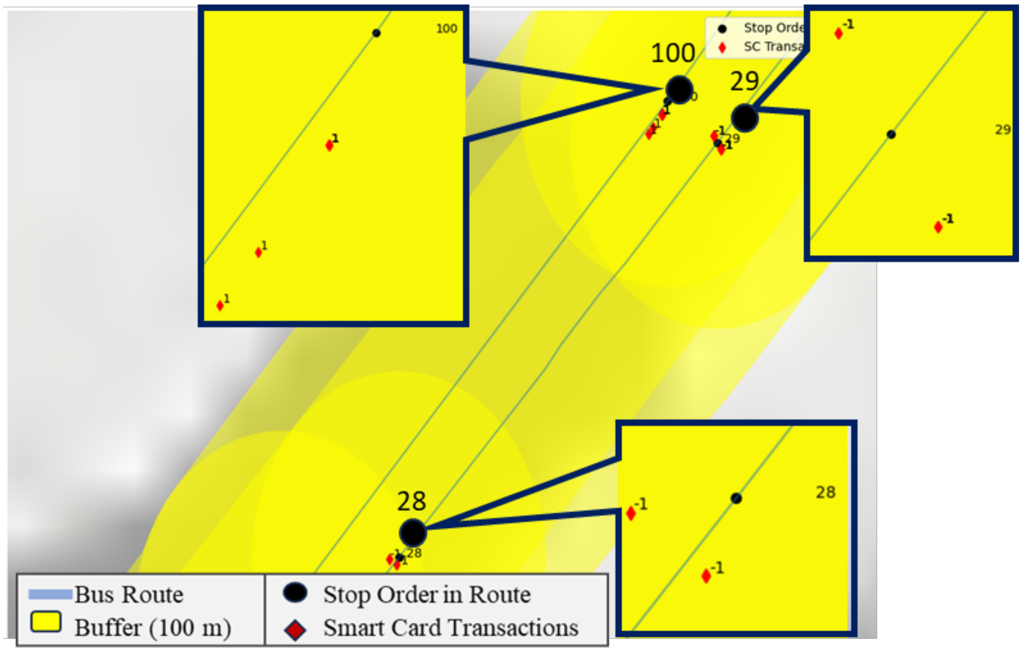


Figure E.11 SCD Directions in Segments Which is between Stop Order 100 and 101

d. PBT Service Trip Detection

After running the previous function, the getTripID Function is executed. This function filters the input and selects data with a direction value 1. ShiftID then groups the filtered data, assigning trip IDs to all shifts. The function's flow chart is provided **Table E.6**. Initially, the function identifies the shifts' trips, and the trip IDs start from 1. If there is more than one bus trip during a shift, the trip IDs are assigned as 1, 2, 3, and more. Additionally, the function calculates the daily unique line trip

ID (DULTripID) using each trip's start time for the whole day. DULTripID also starts from 1 and increments as 1, 2, 3, and more.

Table E.6 Some Columns of Output of getTripID Function

ShiftID	MVGRP	ST1	ST2	Direction	ShiftTripID
443_211	2	100	101	1	1
443_246	2	100	101	1	3
443_248	2	100	101	1	1

e. Bus Boarding Stop (AsgnStopID) Assignment

Assigning boarding stops can be easily accomplished with the assingScData function. This function requires two inputs: the output of the previous function and the filtered raw SCD obtained before using the resetIndex function. It is known which SCD is in which segment buffer zone, with a 50m buffer added to stop points of segments. If the SCD is within the buffer zone of the stop, then it is assigned to the boarding stop with AsgnStat=1. If the SCD is not within the buffer zone of the stop, it is en route and assigned to the previous boarding stop in order with AsgnStat=2. SCDs not within the segment buffer zone (100m) will not be assigned to a boarding stop, and their AsgnStat will be 0.

This algorithm operates under two assumptions. Firstly, it assumes that there are more than five SCD points for each bus trip. Secondly, it assumes that the SCD does not have identical coordinates to determine the bus's direction. The segment buffer length is set at 100m, which is sufficient due to the urban canyons effect that impairs satellite navigation signals. Consequently, the SCD GPS coordinate values may not be entirely accurate. The stop buffer radius is set at 50m because buses may not stop at the exact location but 15m before or 20m after the stop location. If the SCD GPS is within the 50m stop buffer, it is assigned to that stop. Otherwise, it is assigned to the previous stop on that line. Apart from these assumptions, the algorithm is considered ground truth.

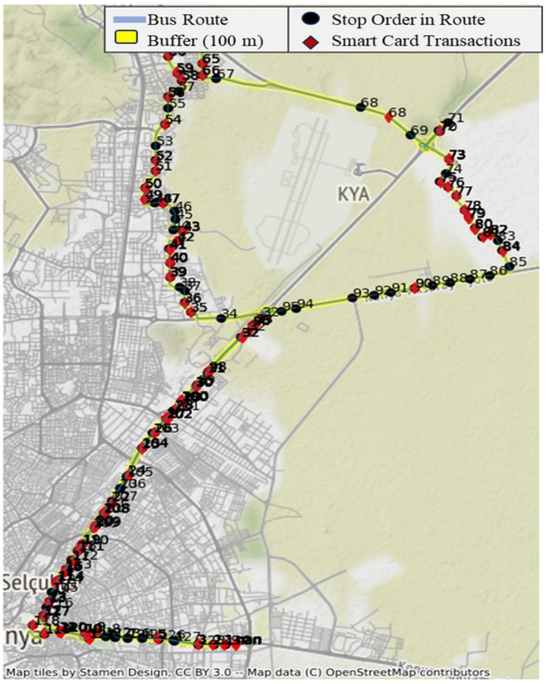


Figure E.12 Assigned SCD which has ShiftID = 443_211

Figure E.12 shows the ULID443 route and assigned SCDs for the boarding stop. **Figure E.13** display a 50m buffer to stops, with SCDs assigned to stop order 114 in **Figure E.14**. One SCD is within the 50m buffer, while the other is not. In **Figure E.15** the AsgnStat values for the same data indicate that the en-route SCD has an AsgnStat value of 2.

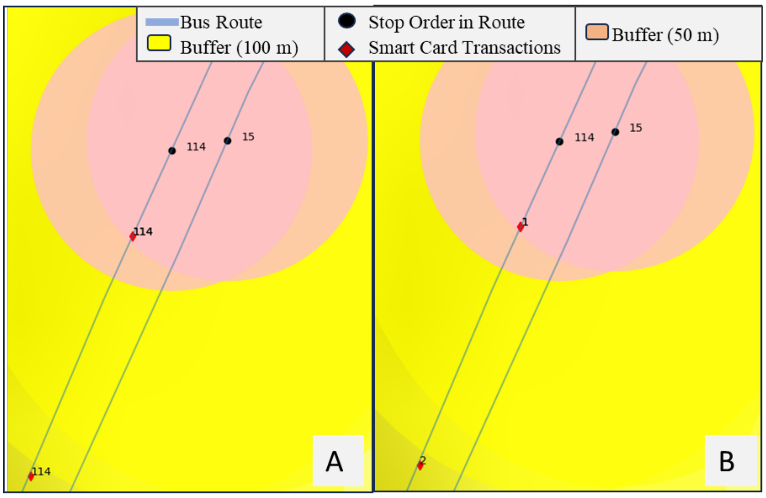


Figure E.13 a)-Stop Order Values of Assigned SCD b) AsgnStat Values of Same SCD

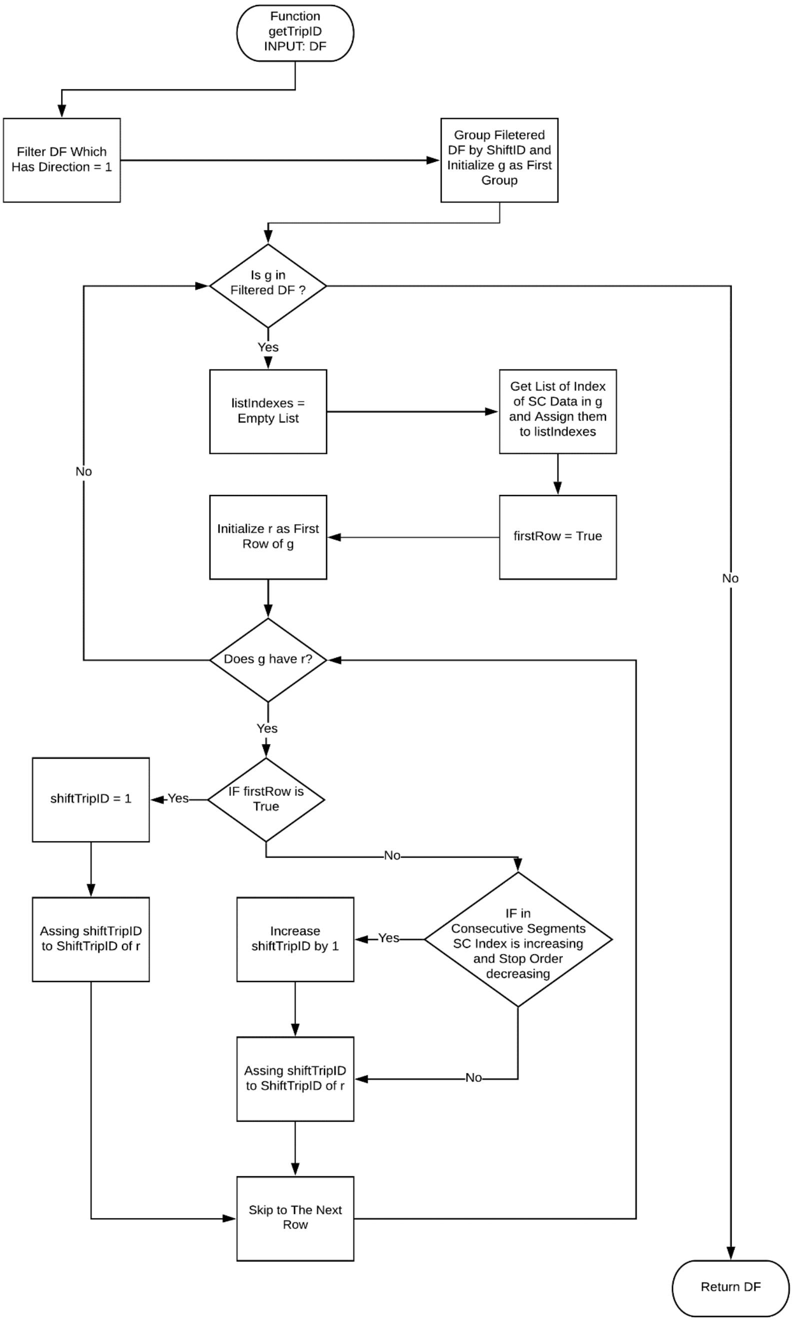


Figure E.14 Flow Chart for getTripID Funtion

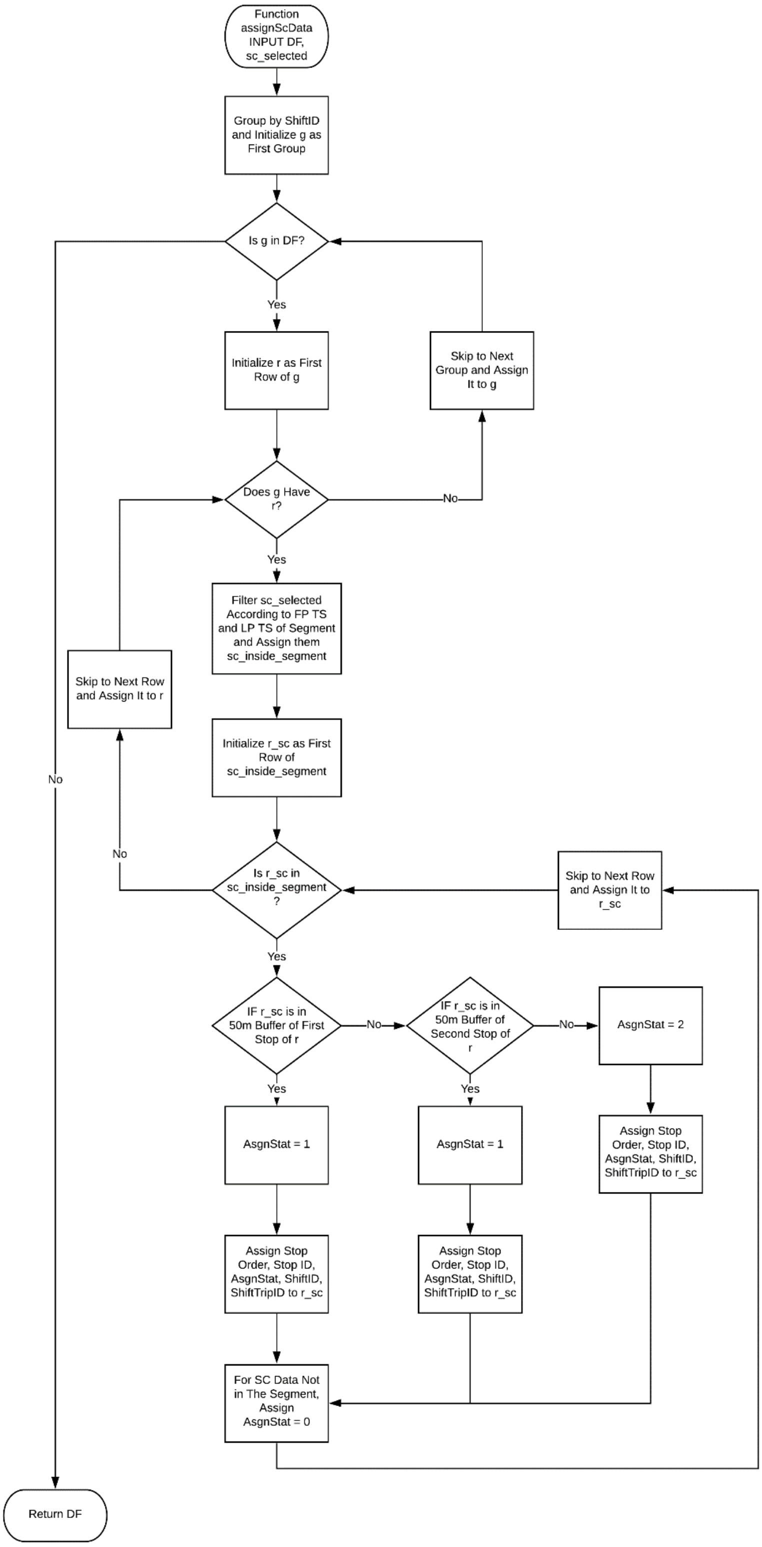


Figure E.15 Flow Chart for assignScData

f. Shift Detection Results

Table E.7 displays a sample of the output for shift detection. The ShiftID for PT SC GPS combines ULID (LID+SLID) and VID.

Table E.7 Shift Detection Output Sample

VID	Y	X	TS	LID	SLID	ShiftID
246	37,86882	32,54431	2018-10-01 07:29:26	44	3	443_246
246	37,86882	32,54431	2018-10-01 07:29:28	44	3	443_246
246	37,86888	32,54144	2018-10-01 07:31:08	44	3	443_246

h. Boarding Stop (AsgnStopID) Assignment Results

Table E.8 displays statistics regarding the assignment of boarding stops. For October, 97.63% of PBT SCD was successfully assigned to a boarding stop. The output sample of boarding stop assignment of PBT bus trips is shown in **Table E 9**.

Table E.8 Statistics on Boarding Stop Assignment

	Bus Stop	En-route	Total
Number of ULID	---	---	146
Number of Stops	---	---	4212
Total no. of transaction (October)	---	---	4931069
Assigned boarding transaction (October)	4614615	199822	4814437
% Assigned boarding transaction (October)	93,58%	4,05%	97,63%
Not assigned boarding transaction (October)	---	---	116632
%Not assigned boarding transaction (October)	---	---	2,37%
Total no. of transaction (30 October)	---	---	197756
Assigned boarding transaction (30 October)	185336	7409	192745
% Assigned boarding transaction (30 October)	93,72%	3,75%	97,47%
Not assigned boarding transaction (30 October)	---	---	5011
%Not assigned boarding transaction (30 October)	---	---	2,53%

Table E 9 Boarding Stop Assignment Output Sample

Date	Time	ShiftID	AsgnStopOrd	AsgnStopID	AsgnStat
2018-10-01	06:30:43	11_312	19	1819a	1
2018-10-01	06:32:25	11_312	22	1816a	1
2018-10-01	06:32:29	11_312	22	1816a	1
2018-10-01	06:34:13	11_312	25	1813a	1

F. A survey on User Priorities among the TCQSCM Criteria

a) Motivation

The motivation behind conducting a survey on user priorities among the TCQSM criteria is deeply rooted in the understanding that QOS dimensions substantially impact PBT evaluation. Determining the appropriate weight for these QOS dimensions is crucial, as it enables the calculation of an overall QOS value. This calculated value is pivotal in reflecting the actual performance and user satisfaction within the public bus system, going beyond simplistic operational metrics to capture the nuanced experiences of users. Recognizing that not all QOS dimensions are equally important to all stakeholders underscores the importance of capturing a broad spectrum of user experiences and expectations. Hence, understanding the variance in priorities across different user demographics and travel patterns is essential.

By incorporating user feedback, the survey seeks to establish a balanced and informed weighting system that represents the diverse needs and preferences of the public bus service's user base. Integral to this process is including passenger numbers at each line, acknowledging that these figures significantly influence perceptions of service quality. Passenger numbers highlight the operational demands placed on different routes and provide insight into user satisfaction levels, with high-demand routes facing challenges such as overcrowding and reduced comfort. These factors are critical in shaping the overall user experience and satisfaction, making considering passenger volumes a key component in the evaluation. Thus, including passenger numbers aims to ensure that the weighting system developed from the survey results reflects the real-world complexities and challenges of providing quality PBT, aligning the evaluation framework more closely with users' actual experiences and priorities.

b) Structure of the Survey

The survey is designed to capture comprehensive insights into user priorities regarding the TCQSM criteria. It is structured into several sections:

Introduction: Briefly explain the purpose of the survey and assure respondents of their privacy and the confidentiality of their responses.

Demographic Information: Gathers basic demographic data such as age, gender, occupation, and frequency of public bus usage. This helps in understanding the background of the respondents.

QOS Dimensions Prioritization: Presents a list of QOS dimensions outlined by the TCQSM, such as service frequency, reliability, comfort, and safety. Respondents are asked to rank these based on their perceived importance.

Open-ended Questions: Allows respondents to provide qualitative feedback on what improvements they wish to see in the PBT based on their experiences.

Closing: Thank respondents for their participation and provide contact information for any follow-up questions.

c) Participant Profile

The demographic details revealed an extensive range of respondents. Male participants spanned diverse age groups. The youngest group of 0-17 years had five respondents, the 18-24 years group comprised 29, the 25-34 years group included 35 respondents, and the 35-44 and 45-54 years groups consisted of 32 and 24 respondents, respectively. The senior groups of 55-65 and 65+ years had 20 and 8 respondents, respectively. The age spectrum among female participants was equally varied. Twelve respondents belonged to the youngest group of 0-17 years. The 18-24 and 25-34 years comprised 18 and 41 respondents, respectively. The 35-44 age group included 37 participants, while the 45-54 age group had 19 respondents. The older age groups, 55-65 years, and 65+ years, had 15 and 9 respondents, respectively. **Figure F 1** shows the age and gender of respondents.

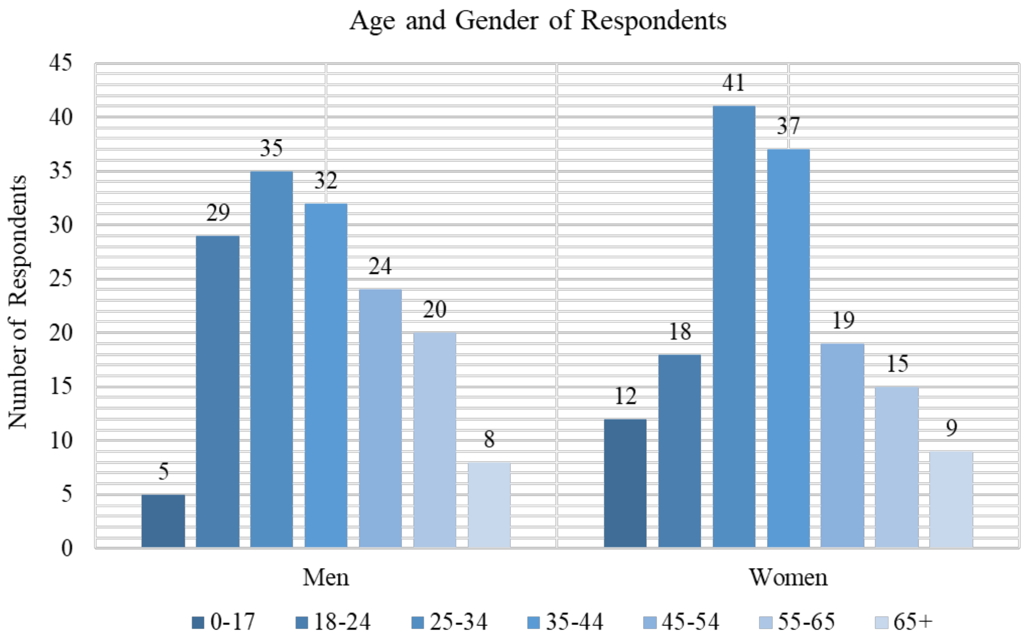


Figure F 1 Age and Gender of Respondents

d) Participant Profile

The proposed solution enhances the TCQSM by incorporating passenger numbers and user perspectives. An extensive survey was conducted to capture user perspectives and attitudes toward each TCQSM performance factor. This survey, disseminated through various platforms such as Facebook, WhatsApp, and Instagram, drew responses from a total of 323 residents of Konya. The survey was divided into two sections. The initial part was dedicated to gathering general demographic information from the respondents, including age, gender, and level of education, as well as understanding their usage patterns of public transport. The subsequent section sought responses to the question: "Which of the following options would you like to improve in PBT services?", allowing participants to select more than one option. The chart titled "User Priorities Among Performance Factors" reveals that service frequency is the top priority for improvement among the respondents, with 204 votes. Passenger demand is the second most significant concern, with 192 responses. Transit-auto travel time received 135 responses, positioning it as the third area of interest. The on-time performance came in next with 115 responses, and hours of service were considered the least priority, gathering 91 responses. These results underscore the areas that users deem essential for improvement in PBT services. **Figure F 2** indicates user priorities among performance factors.

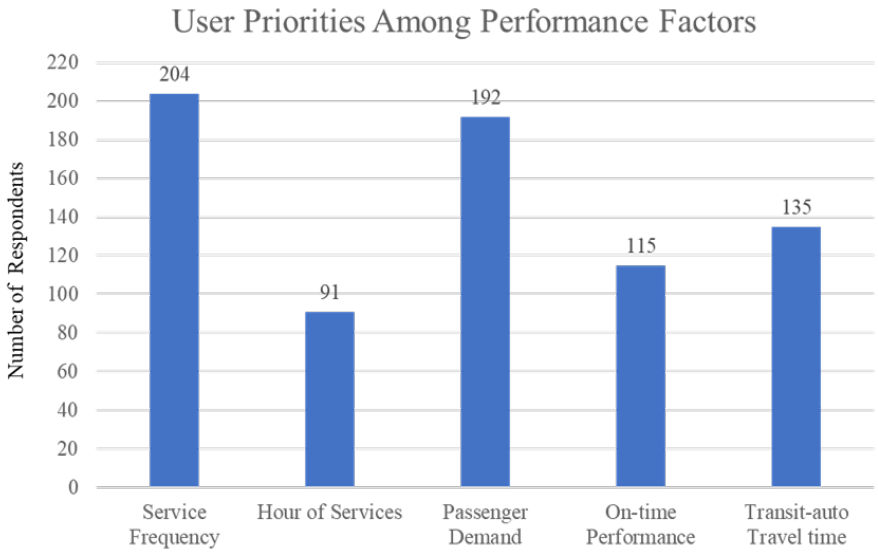


Figure F 2 User Priorities Among Performance Factors

e) Estimating an Overall QOS for PBT

This approach combines various performance indicators into one comprehensive measure to offer a complete view of the transit system's performance, capturing the balance between operational efficiency and user satisfaction. This solution significantly enhances the existing framework, offering a more advanced and complete measure of transit service quality. A multi-stage process has been developed to determine the overall QOS for PBT. The framework is comprehensive and includes the following steps (shown in **Figure F 3**):

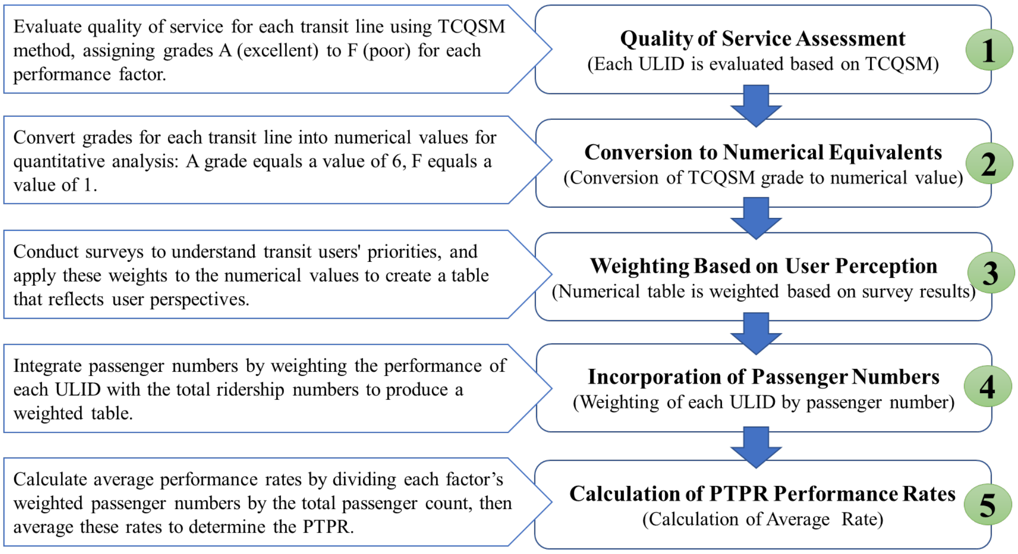


Figure F 3 Framework of the proposed solution

1. Quality of Service Assessment: The evaluation of each transit line's service quality will be conducted by examining various parameters, including Hours of Service, On-time Performance, Passenger Demand, Service Frequency, and Transit-auto Travel Time. This evaluation will adhere to the TCQSM guidelines, which allocate a grade from A (representing excellent service) to F (indicating poor service) for each performance factor.

2. Conversion to Numerical Equivalents: After the assignment of alphabetical grades, these are translated into numerical values to facilitate a more accessible quantitative analysis. Here, an 'A' grade is equated to a numerical value of 6, and an 'F' corresponds to a value of 1. The result of this conversion is a ‘Numerical Value Table’ that provides insight into the performance of each transit line based on different parameters.

3. Weighting Based on User Perception: The third stage prioritizes the perspectives of transit users. By conducting surveys, the framework captures the preferences and priorities of passengers regarding different service quality factors. The feedback obtained informs the weighting of the ‘Numerical Value Table’, resulting in a ‘Weighted Numerical Value Table’ that represents the importance of each performance factor as perceived by the users.

4. Incorporation of Passenger Numbers: To recognize the significance of passenger volumes, the framework includes a step where each transit ULID is weighted according to its passenger numbers. This process multiplies the values in the ‘Weighted Numerical Value Table’ by the total ridership for each ULID during a given period (e.g., October), creating a ‘Weighted Passenger Number Numerical Value Table’.

5. Calculation of Average Performance Rates: the framework involves calculating the average performance rates for each factor. This is done by dividing each factor’s total weighted passenger numbers by the overall number of passengers. To get an average rate, the individual rates from all performance factors are summed and then divided by the number of factors, each weighted per user perception.

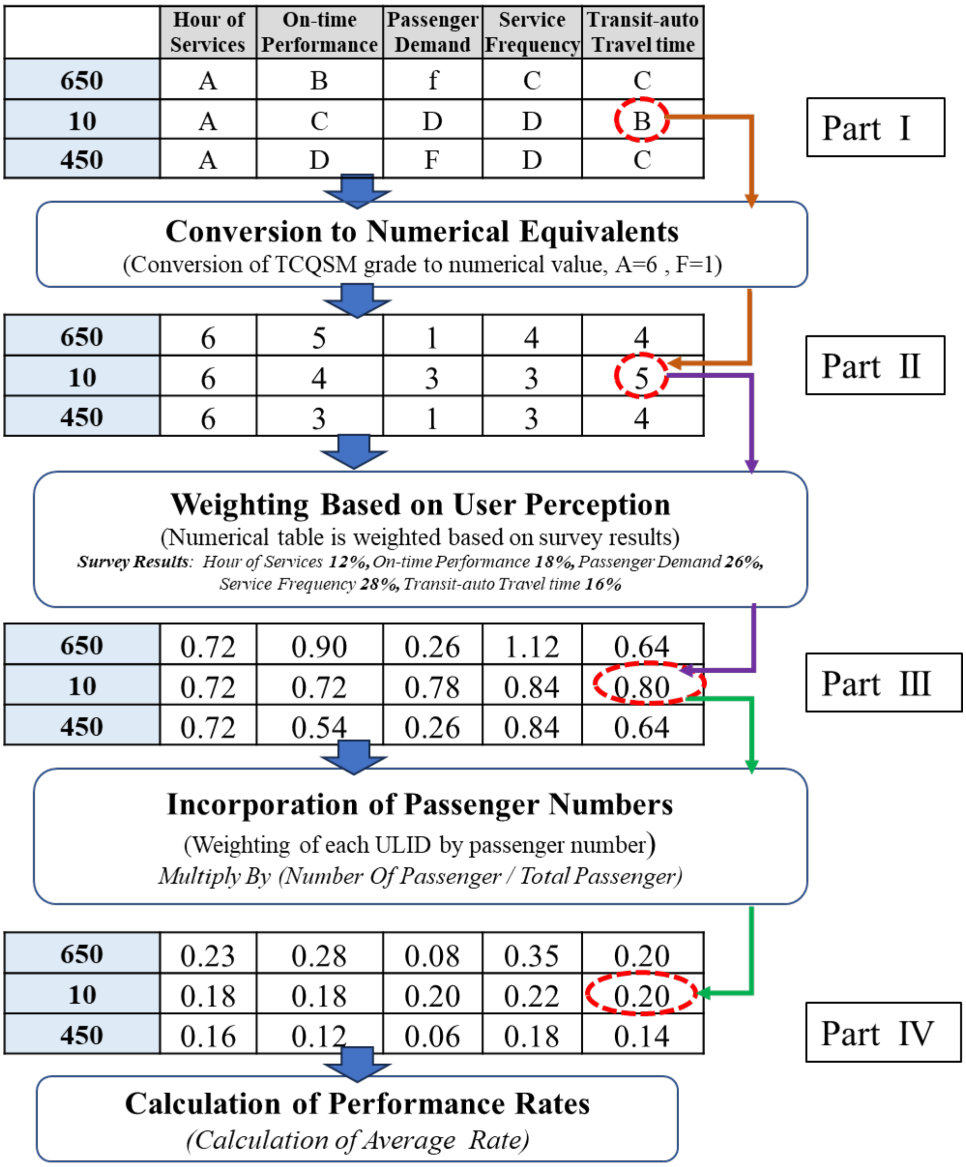
d) Numerical Analysis

It begins with QOS evaluation using the TCQSM method. This involves a detailed analysis of several key parameters for each transit line, including HS, SF, OTD, PPC, and TAT. Each factor is assessed and assigned a grade ranging from A (excellent service) to F (poor service). This step is integral in establishing a baseline for performance evaluation. It is thoroughly detailed in Section 5.4, with representative data illustrated in **Figure F.4** Part I. Next, Following the assignment of grades, these alphabetical representations are converted into numerical values to enhance the ease of quantitative analysis. This conversion sees an 'A' grade being equated to a numerical value of 6 and an 'F' to a value of 1. The outcome is a ‘Numerical Value Table’ that offers a comprehensive insight into the performance of each transit line. An example of this conversion, such as a QOS grade 'B' being translated to '5', is depicted in **Figure F.4** Part II. Next, the stage incorporates user feedback from surveys to weigh the numerical values in the table. The result is a

‘Weighted Numerical Value Table’, reflecting the importance of performance factors from the users’ perspective. For example, the numerical value '5' multiplied by the Transit-Auto travel time survey percentage (16%) results in '0.80', as demonstrated in **Figure F.4** Part III.

Passenger numbers are integrated by weighing each ULID based on its ridership obtained from SCD. The ‘Weighted Numerical Value Table’ values are multiplied by the total ridership for each ULID in a specified period, like October, creating a ‘Weighted Passenger Number Numerical Value Table’. For example, ULID 10’s passenger count divided by the total passengers of all ULIDs (42784/166981 = 0.256) is then multiplied by the value from the previous step (0.80), resulting in '0.20', as depicted in **Figure F.4** Part IV. Finally, the PTPR is determined by calculating the average performance rates for each factor. This involves dividing each factor's total weighted passenger numbers by the overall passenger count. The average rate is obtained by summing the individual rates across all performance factors and dividing by the number of factors, each adjusted according to user perception. **Figure F.4** shows the procedure of proposed solutions for the high ridership group.

The evaluation of PBT performance using the proposed method offers insightful results, shedding light on the effectiveness of integrating diverse factors into the assessment process. Based on the average QOS from the TCQSM, the initial calculation serves as a foundational benchmark for subsequent analyses. When the focus shifts to weighing based on user perception alone, the average rate adjusts to 3.37. This variation highlights the impact of user preferences and experiences on the perception of service quality, indicating a slightly lower satisfaction rate compared to the TCQSM baseline. This underscores the importance of considering user feedback in evaluating transit services. Further analysis involving the weighting based on passenger numbers reveals an increase in the average rate to 3.81. This suggests that transit lines with higher ridership may be perceived as offering better service quality, possibly due to more frequent and reliable services on these routes.



	Hour of Services	On-time Performance	Passenger Demand	Service Frequency	Transit-auto Travel time
650	A	B	f	C	C
10	A	C	D	D	B
450	A	D	F	D	C

650	6	5	1	4	4
10	6	4	3	3	5
450	6	3	1	3	4

650	0.72	0.90	0.26	1.12	0.64
10	0.72	0.72	0.78	0.84	0.80
450	0.72	0.54	0.26	0.84	0.64

650	0.23	0.28	0.08	0.35	0.20
10	0.18	0.18	0.20	0.22	0.20
450	0.16	0.12	0.06	0.18	0.14

Figure F.4 Procedure of Proposed Solutions

The most comprehensive approach combines both user perception and passenger numbers for weighting. This method results in an overall performance factor for the selected lines with a weighted average of 3.46. Interestingly, this figure is somewhat lower than the TCQSM-derived average of 3.64. This comparison demonstrates the proposed method's reliability and effectiveness in capturing a more holistic view of transit performance. By integrating a broader set of performance indicators, including operational data and user insights, the proposed method accurately reflects the transit service quality. Unlike the TCQSM average, which might overlook critical aspects of user experience and ridership data, the proposed approach ensures a comprehensive and user-centric understanding of PT performance. Therefore, applying this multifaceted evaluation method is to understand the quality of PT services. **Figure F.5** shows the expected average and weighted average of the analysis.

Description	Rate
Average QOS from TCQSM	3.64
Weighting Based on User Perception	3.37
Weighting Based on Passenger Numbers	3.81
Weighting Based on User Perception and Passenger Numbers	3.46

Figure F.5 Compare Results

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PUBLICATIONS

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