GIS-BASED TOOL TO ASSESS THE IMPACT OF UNREGULATED PARKING ON URBAN ROAD CAPACITY

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ABSTRACT

A GIS-BASED TOOL TO ASSESS THE IMPACT OF UNREGULATED PARKING ON URBAN ROAD CAPACITY

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Limited off-road parking capacities in urban regions leads to increasing roadside parking demand in Turkey, which sometimes occurs in illegal or hazardous patterns. In the absence of strict parking management policies and regulation, lack of enforcement for illegal parking results in unregulated parking demand occupying road capacity, which is threatening the traffic management and safety in cities. Before parking management policies are developed, it is crucial to monitor the impact of roadside parking on urban road capacity, which is the focus of this thesis. Data collected for different patterns of roadside parking is processed to calculate the resulting net road width (NRW) utilizing advanced Geographic Information Systems (GIS) technologies. Video data of parked vehicles taken at the same time with the GPS track record of the observation vehicle is used with a custom-developed Windows Forms application tool, which allows semi-automatic detection of parked vehicles and violations on both divided and undivided corridors. As travel demand changes over space and time in a day, so does the parking demand; thus, the NRW indicator becomes a parameter which can be mapped dynamically. A case study in 100. Yıl neighborhood in Ankara, showed that due to parking, some road segments were narrowed to a NRW less than one lane, while along some corridors parking on both sides of the divided road segments led to traffic flow capacity of one-lane. Simple structure of the approach supported by Python scripts, enables quick analysis of roadside parking and its impact.

Keywords: GIS, Illegal Parking, Net Road Width Calculation, Smart Urban Planning

ÖZ

KENTSEL YOL KAPASİTESİ ÜZERİNDEKİ DÜZENSİZ PARKLAMANIN ETKİSİNİ DEĞERLENDİRMEK İÇİN COĞRAFİ BİLGİ SİSTEMİNE DAYALI BİR ARAÇ

Ünsal, Ozan
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Kent bölgelerinde sınırlı otopark kapasiteleri, Türkiye'de yol kenarı park talebini artırmakta ve bu durum bazen kural dışı veya tehlikeli parklanma şeklinde gerçekleşmektedir. Katı park denetim politikaları ve düzenlemelerinin olmaması, kural dışı parklanma yaptırımlarının eksikliği nedeniyle düzensiz park talebinin yol kapasitesini işgal etmesine yol açmakta ve bu durum şehirlerdeki trafik yönetimi ve güvenliğini tehdit etmektedir. Park yönetim politikaları geliştirilmeden önce, yol kenarı parklanmasının kentsel yol kapasitesi üzerindeki etkisinin izlenmesi bu tezin odak noktasıdır. Yol kenarı parklanmalarının farklı türleri için toplanan veriler, ileri Coğrafi Bilgi Sistemleri (CBS) teknolojileri kullanılarak net yol genişliği (NYG) değerlerini hesaplamak için kullanılmaktadır. Park halindeki araçların video verileri, gözlem aracının GPS izinin kaydı ile eş zamanlı alınmakta ve bölünmüş ve bölünmemiş koridorlarda park halindeki araçları ve ihlalleri yarı otomatik olarak tespit eden özel geliştirilmiş bir Windows Forms uygulama aracı kullanılmaktadır. Ankara'daki 100. Yıl mahallesinde yapılan bir vaka çalışması, park sebebiyle bazı yol segmentlerinin bir şeritten az bir NYG ile daraldığını, bazı koridorlarda ise bölünmüş yol segmentlerinin her iki tarafında yapılan parkın trafik akış kapasitesini bir şeride kadar indirdiğini göstermiştir. Yaklaşımın basit yapısı, Python betikleriyle desteklenmekte ve yol kenarı parkının ve etkilerinin hızlı bir şekilde analiz edilmesini sağlamaktadır.

Anahtar Kelimeler: CBS, Parklanma, Net Yol Kapasitesi Hesaplama, Akıllı Kent Planlaması

To Ada Liya, Kağan and Özlem…

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CHAPTER 1

INTRODUCTION

City roads play a key role in urban transportation of people and goods; however, they are also used as parking spaces due to lack of off-road parking capacities. Thus, management of roadside parking is also very critical in the management of urban road capacity. This issue gets even more challenging when roadside parking is not controlled or enforced, which is often the case in developing countries.

The problem of unregulated, or sometimes illegal, roadside parking is often not addressed proportionally to the problems it causes: For instance, roadside parking along 2-lane streets serving both directions will automatically force a shift of the centerline of the road and reduce the lane width (and thus, capacity). Streets with a slightly larger lane width values, are under a bigger threat of parking on both sides, which practically leaves capacity for barely only one vehicle in each direction. This reduction in road capacity leads to slower traffic, more traffic jams, traffic safety problems for vehicles as well as bicycles, etc. Traffic jams caused by reduced road space led to vehicles spending more time idling, which in turn increases air pollution. This pollution affects the health of city residents. Parked vehicles can obstruct the view of both drivers and pedestrians, leading to accidents.

The problem can be more critical for large vehicles, such as public transit buses, which need larger lanes and radii for turning movements. Delivery trucks stuck in traffic may take longer to distribute goods, affecting the supply chain and increasing operational costs. The ability of emergency services to operate effectively is compromised. When ambulances and fire trucks cannot navigate through the streets swiftly, the safety of the public is at risk. For instance, a fire truck delayed by blocked roads could result in catastrophic outcomes during an emergency. The presence of illegally parked vehicles can create bottlenecks at critical points along the road network. These bottlenecks can occur near intersections, bus stops, and areas with high pedestrian traffic, where the road narrows due to unauthorized parking. This situation not only affects vehicular traffic but also jeopardizes the safety of pedestrians.

1.1 Aim of the Study

Unregulated and illegal roadside parking presents a multifaceted challenge to urban roads, which has to be addressed properly and systematically. This research centers around a detailed investigation of locations and extents of road capacity reductions caused by illegal or hazardous parking. By doing so, it aims to provide valuable information that can help urban planners and policymakers create more effective traffic management and urban planning strategies. Aggressive roadside parking leads to illegal parking at or near intersections, at pedestrian crossings, bus stops, etc, which are defined in traffic legislation. At a bigger share than these behaviors, there is a large amount of hazardous parking, which cannot be defined as illegal due to lack of legislative definitions or operational delineation or markings, such as parking on both sides of a two-lane undivided road leaving a capacity for one-vehicle, which can cause severe delays or conflicts of movements in the traffic flows.

The first step would be the monitoring of current roadside parking situation and assessing its impact on the road network capacity, which is the main focus of this study. However, as in the case of traffic demand, which fluctuates over space and time, parking demand also changes spatiotemporally. Consequently, it is necessary to analyze roadside parking patterns at different time periods for a selected corridor. Secondly, automatization of this process via satellite images or drone-based data collection may not be effective, as they are not always practical for urban regions. Satellite images are not taken frequently within a day, they may not provide detailed parking data due to clouds, trees, buildings, etc. Drone usage for urban areas can be more practical, however, the increased demand for drone usage in urban regions resulted in severe restrictions; it is very difficult to get permissions for simple processes such as parking management. It is also not very cheap.

1.2 Objective of the study

Surpassing the complexities of traditional data collection methods, which are often cumbersome and impractical in dense urban environments, it employs an innovative technological solution: for the generation of roadside parking input data, the new approach utilizes a simple video camera and a GPS tracker smartphone app. By mounting a video camera on a car and using a GPS tracker app that collects point data in terms of latitude and longitude, as the car travels on the road surface, the GPS tracker app captures floating points along the car's track. The point data and video footage is synchronized and processed to accurately estimate the locations of parked vehicles. A custom-developed Windows Forms Desktop application, which utilizes GPS and video data inputs, serves as the cornerstone of this approach.

This application facilitates the semi-automatic digitization of parking data, outputting precise geographic coordinates and categorizing types of illegal or hazardous parking. After the generation of point data, which includes consistent location and tabular information of parked cars, GIS takes the handling of the analysis and visualization. However, point data alone are insufficient for calculating the net road width (NRW). The transformation of points into polygons, which depict each car's occupied area, should also be performed. To speed up this conversion, which is very time consuming to be done completely manual, Python scripts are utilized. This capability for rapid processing is essential for handling large volumes of data and providing timely recommendations to urban planners and policymakers. Flexible structure of the tool can be easily adapted to work with data from other sources in the future.

Numerical results are obtained for a study region in Ankara, which has seen rapid growth in population and car ownership similar to many metropolitan regions in

Turkey, while the lack of needed road parking lots capacity grows. A case study was conducted in the 100. Yıl neighborhood of Ankara. This area was selected due to its representation of complex and diverse parking trends, attributed to the presence of hospitals, schools, governmental buildings, residential complexes, and commercial establishments. These various amenities contribute to a wide range of parking behaviors within the area. The proposed methods and processing techniques were assessed using this pilot area, which spans over four kilometers in length.

1.3 GIS support in the Study

The integration of Geographic Information Systems (GIS) is pivotal in analyzing and visualization needs of roadside parking. GIS offers robust capabilities for handling and interpreting spatial and tabular data, enabling a comprehensive analysis of how illegally or hazardously parked vehicles impact road capacity. For the calculation of NRW, which is the core metric for understanding spatial distribution of road blockages, using advanced GIS technologies is essential. GIS allows for precise mapping and analysis of how much actual road space is available for vehicular movement after accounting for parked cars. This analysis can show variations in available road width at different locations. Utilizing GIS technologies aids in visualizing how parking impacts traffic flow. It can help in identifying specific areas where unregulated parking is causing significant reductions in road capacity. This visual representation can be crucial for urban planners and traffic managers in making informed decisions. Within this context, due to the variability of parking and traffic demand, utilizing GIS to monitor and map the NRW becomes indispensable. This approach provides a clear visual tool for understanding and managing the impacts of unregulated parking on road capacity effectively.

The simplicity of the data acquisition process, relying on common and easy-to-reach technologies, revolutionizes the study of urban traffic. This methodology not only makes it feasible to gather large volumes of data efficiently but also ensures that the study can be replicated in varied urban settings. By demonstrating the effectiveness of this approach in large cities, especially in developing countries, this thesis aims to contribute valuable insights that could guide the development of targeted regulations and control measures to lessen the effects of illegal parking.

1.4 Layout of the thesis

Layout of the thesis is as follows: roadside parking and its impact on urban mobility are introduced in Chapter 1, followed by a review of relevant literature in Chapter 2 to frame the study within existing research. Methods and technologies utilized in the study are detailed in Chapter 3, and the results are discussed in Chapter 4, analyzing how illegal parking influences road capacity and traffic. Finally, the thesis is concluded in Chapter 5, where the findings are summarized and directions for future research and policy development are suggested.

CHAPTER 2

BACKGROUND

The issue of roadside parking reducing the effective capacity of roads is well-known in urban planning and traffic management. Research consistently shows that vehicles parked improperly along roadsides can significantly reduce the width available for moving traffic, leading to congestion and a higher likelihood of accidents. Key studies in this field have focused on determining the actual usable road width, taking into account the space taken up by parked vehicles. This is essential for understanding how much road space is really available for driving. Additionally, research into how roadside parking affects traffic has emphasized the need for effective regulations. These regulations might include improved parking management or stricter parking rules to help alleviate the problems caused by reduced road space. Studies have also looked at how different strategies can optimize the use of road space, thereby improving traffic efficiency and safety.

2.1 Parking Behaviors and Studies in the Literature

The issue of unregulated roadside parking is a critical concern in urban traffic management and planning. It is possible to evaluate the relation between roadside parking and urban traffic management into sub-sections of

i. Types of Roadside Parking
ii. Primary Effects of Unregulated Roadside Parking on Urban Road Capacity and Traffic Flow
iii. Methodologies and Data Sources in Roadside Parking Studies
iv. Technological Tools and Techniques in Roadside Parking Studies

2.1.1 Types of Roadside Parking

Different types of roadside parking, such as double parking and parking on both sides of the street, significantly impact road capacity and safety. Here are some key findings from various studies:

- Curb Parking: Curb parking reduces the effective lane width, which decreases road capacity and affects traffic flow volumes. The presence of parked vehicles influences the capacity of the parking lane and the adjacent lane, leading to increased traffic congestion. Also, curb parking can create traffic conflicts and reduce stopping sight distance, affecting both motor vehicle and pedestrian safety (Cao et al., 2017).
- Double Parking: Double parking creates significant obstacles for moving traffic, leading to severe congestion and delays. It blocks one or more lanes of traffic, which can drastically reduce the road's capacity and cause bottlenecks (Yousif & Purnawan, 1999). Also, double parking increases the risk of accidents as it forces drivers to maneuver around the parked vehicles, often into oncoming traffic lanes, which increases the likelihood of collisions.
- Parking on Both Sides of the Street: When vehicles are parked on both sides of a street, the remaining space for moving traffic is significantly reduced, leading to a decrease in road capacity. The effects are compounded in narrow urban streets, where the available lane width is further restricted (Madushanka et al., 2020). Also, the maneuvering of vehicles into and out of parking spaces on both sides of the street creates delays for through traffic, causing a ripple effect of congestion and increased travel times (Pan et al., 2023).
- Illegal Parking: Obstruction of Traffic Flow: Vehicles parked illegally, especially in non-designated areas, obstruct the normal flow of traffic. This leads to sudden stops and lane changes, which can cause traffic jams and accidents (Yousif & Purnawan, 1999).

Different types of roadside parking, such as curb parking, double parking, and parking on both sides, have notable impacts on road capacity and safety. These effects include reduced lane width, increased congestion, traffic delays, and increased risk of accidents. Effective traffic management measures and parking regulations are essential to mitigate these impacts and improve overall road safety.

2.1.2 Roadside Parking and Traffic Flow and Capacity

Unregulated roadside parking significantly impacts urban road capacity and traffic flow by reducing effective lane width, increasing traffic delays, reducing speeds, exacerbating congestion, and raising safety concerns. Implementing proper parking regulations and urban planning measures can help mitigate these negative effects.

- Reduction in Road Capacity: Unregulated roadside parking significantly reduces the effective lane width available for moving traffic, which directly decreases road capacity. Studies indicate that capacity can drop by approximately 17% when there are frequent parking maneuvers (Pan et al., 2023). The presence of parked vehicles along the roadside obstructs traffic flow, reducing the available space for vehicles to move smoothly. This can lead to a decrease in capacity by up to 33.92% in some urban settings (Alkaissi & Kamoona, 2021)
- Increased Traffic Delays: The process of vehicles entering and exiting parking spaces creates delays and disrupts the flow of traffic, leading to the propagation of shockwaves during high traffic periods. This causes additional delays and reduces overall traffic efficiency (Madushanka et al., 2020).
- Impacts on Traffic Speed: Vehicles parked along the roadside reduce the speed of moving traffic as drivers need to navigate around parked cars. The speed reduction is more pronounced during peak traffic periods and in highly congested areas (Cao et al., 2017).

- Traffic Congestion: The obstruction caused by roadside parking leads to traffic congestion, particularly in urban areas with high parking demand and limited road space. This congestion is exacerbated by vehicles cruising for parking spots, which can increase travel times and reduce overall traffic flow efficiency (Srivastava & Kumar, 2023; Tsakalidis & Tsoleridis, 2015)
- Safety Concerns: Roadside parking can increase the likelihood of traffic conflicts and accidents. The presence of parked vehicles can obstruct the visibility of pedestrians and other vehicles, increasing the risk of collisions (Cao et al., 2017).

2.1.3 Methodologies and Data Sources in Roadside Parking Studies

The impacts of roadside parking on urban traffic are analyzed using traffic simulation models, field data collection, spot field investigations, remote sensing, GIS, and statistical models. These methodologies provide detailed insights into traffic flow, congestion, and safety, underscoring the necessity of effective parking management in urban planning.

Traffic Simulation Models: Micro simulation models, such as the PTV-VISSIM software, simulate the impact of roadside parking on traffic flow characteristics by modeling detailed vehicle interactions. For example, a study used VISSIM to observe that road capacity dropped by approximately 17% due to frequent parking maneuvers (Madushanka et al., 2020). Macroscopic models provide a broader view of traffic flow and parking interactions. They aggregate data over larger spatial and temporal scales, reducing computational costs. For instance, a study integrated on-street and garage parking decision models to analyze their impacts on traffic performance in Zurich (Jakob & Menendez, 2019).

Field Data Collection: Collecting real-time traffic data using GPS-enabled devices, license plate recognition (LPR), and other sensors helps in estimating traffic dynamics and emissions. For instance, a study utilized taxi GPS data and LPR data to map traffic emissions in Hangzhou, China (J. Liu et al., 2019).

Spot Field Investigations: On-site observations and data collection at specific locations provide insights into the impact of roadside parking. This includes measuring traffic speed, flow, and vehicle interactions. For example, a study in Kunming, China, used field investigations to analyze the impact of unsafe driving behaviors, including illegal parkin g, on traffic flow (Hu et al., 2017).

Remote Sensing and GIS for roadside parking: Using Geographic Information Systems (GIS) to analyze spatial patterns and the impact of roadside parking on traffic congestion and emissions. For example, a study in Xi'an, China, used GIS to explore the relationship between land use, parking availability, and traffic congestion (Shen et al., 2020).

Statistical Models for Roadside Parking: Regression Models help identify relationships between traffic variables and roadside parking impacts. For example, a study used Bayesian generalized mixed linear models to analyze the effect of speed limit reduction and roadside parking on traffic behavior in Montreal (Heydari et al., 2014). A combination of traffic simulation models, field data collection, remote sensing, and statistical methods is employed to study the effects of roadside parking on urban traffic. These methodologies provide comprehensive insights into traffic flow, congestion, and safety.

2.1.4 Technological Tools and Techniques in Roadside Parking Studies

Advanced technologies enhance the monitoring and analysis of parking behaviors. Video surveillance, Internet-of-things (IoT), smartphone-based sensing, machine learning, automated license plate recognition (ALPR), and remote monitoring systems optimize parking management.

Video Surveillance and Computer Vision: Deep learning models use convolutional neural networks (CNN) and other deep learning techniques to detect, track, and analyze parked vehicles. This includes systems like ParkMaster which uses smartphones to estimate parking space availability by analyzing video feeds (Grassi et al., 2017).

<u>IoT and Wireless Communication:</u> Intelligent parking systems use sensors, cameras, and wireless technologies to monitor parking spaces in real-time. Data is sent to cloud servers where it is processed and analyzed, providing users with real-time parking availability and usage statistics (Iqbal et al., 2019).

<u>Smartphone-Based Sensing:</u> Wi-Fi beacon sensing detects unparking events by analyzing the change in Wi-Fi signals around parked vehicles. This technique leverages the existing Wi-Fi infrastructure to monitor parking behaviors with minimal energy consumption compared to GPS-based methods (Nawaz et al., 2013).

<u>Machine Learning and Data Analytics:</u> Occupancy estimation models utilize logistic regression, deep learning, and gradient boosting models to estimate parking occupancy based on payment transactions and camera data. This helps in understanding payment behaviors and optimizing parking resource allocation (Assemi et al., 2022). Behavior Analysis uses machine learning techniques like neural networks and random forests to analyze driving behaviors within parking spaces, improving parking management and safety (Lindow et al., 2020).

<u>ALPR:</u> Detection of illegal parking employs deep learning-based object detection algorithms such as YOLOv3 to detect and track illegally parked vehicles. ALPR systems then capture license plate information for enforcement actions (Z. Liu et al., 2019).

<u>Remote Monitoring with Sensors and Cameras:</u> Parking monitoring systems use a combination of high-resolution cameras and various sensors to monitor parking spaces. These systems can track vehicle movements and occupancy, providing real-time data to users via dashboards (Sukhinskiy et al., 2016).

These technologies collectively enhance the monitoring and analysis of parking behaviors, helping to optimize parking management, reduce congestion, and improve urban mobility.

The reviewed studies collectively highlight the significant impacts of unregulated roadside parking on urban traffic flow and road capacity. By reducing lane width, causing delays, decreasing traffic speeds, and increasing congestion and safety risks, roadside parking poses substantial challenges to urban mobility. The methodologies and technological tools discussed in this chapter provide comprehensive insights and solutions for monitoring, analyzing, and mitigating these impacts. Implementing effective parking management strategies and leveraging advanced technologies can enhance urban traffic flow, improve safety, and ensure more efficient use of urban road networks.

2.2 Road Types

Highway design approach mostly defines road types based on the geometric features and traffic flow conditions on it. Basically, it is crucial to distinguish between the divided and undivided roads (urban or rural), as physical separation between the traffic flows on a carriageway is the main parameter in traffic management and safety. It also effects the parking behavior and capacity, directly.

<u>Divided Roads:</u> In transportation infrastructure, a divided road (Figure 2.1a) is a road that has a physical barrier or median separating lanes that go in opposite directions. This separation prevents vehicles from crossing into oncoming traffic, enhancing safety and improving traffic flow. Divided roads often feature dual carriageways, making them distinct from simpler undivided roads.

On divided roads, parking attitudes may vary due to the presence of physical barriers that separate opposite flows of traffic. These barriers can affect drivers' choices about where to park, potentially leading to a preference for parking in right of the right lane rather than leftmost side of the road. In extreme situations drivers may choose the left of leftmost lane but this may be categorized as rare and can be neglected.

Undivided Roads: On un-divided roads (Figure 2.1b), where there is no physical barrier between lanes moving in opposite directions or single direction roads, similar parking categories apply, but the implications can be more significant in terms of traffic flow, safety and parking attitudes. For single side parking on un-divided roads can limit road capacity due to narrow nature of this type due to opening doors or pedestrians crossing behind parked cars. Double side parking on un-divided roads may significantly reduce the effective width of the roadway available for moving traffic, increasing the likelihood of traffic congestion and collisions, particularly in high-traffic areas. Special regulatory measures, such as time-restricted or permit-only parking, may be necessary to mitigate these risks.

In both divided and un-divided road contexts, the design and management of parking must balance the maximization of available parking spaces with the minimization of traffic disruption and safety risks. Effective parking management strategies, tailored to the specific road type and traffic patterns, are essential for maintaining full potential of the road, the net road width (NRW) in this thesis context.

In contrast, un-divided roads, which lack a physical separation between opposite directions of traffic, present unique challenges. This type of roads can be in form of single direction or muti-direction. Drivers might exhibit different parking behaviors, such as parking on either side of the road, which can lead to increased traffic congestion, potential safety hazards and dramatically minimized NRW. In some situations, NRW can reach to zero that means road is no longer available due to congestion led by illegal parking.

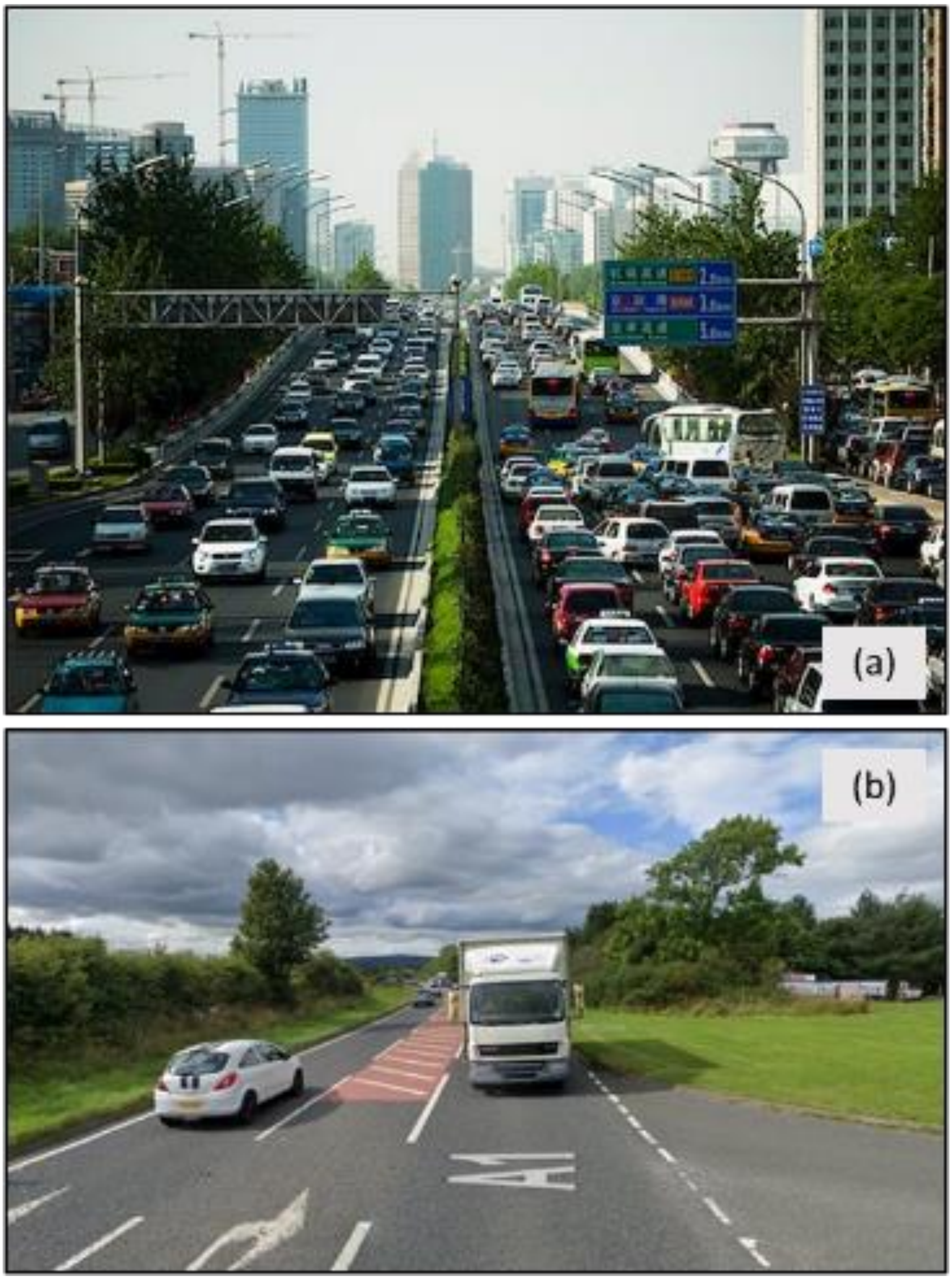


Figure 2.1 Examples of (a) divided and (b) undivided roads.

2.3 Parking Design and Types in Turkey

2.3.1 Parking Types

The parking types in Turkey are similar to those in the global context including:

- Regular (Parallel) Parking: Parallel parking (Figure 2.3c and Figure 2.3d) involves vehicles parking in line with the flow of traffic, aligned parallel to the road. This configuration is typically found on city streets where the available space is longitudinally along the curb. Parallel parking maximizes the length of curb space utilized for parking and fits seamlessly into existing road layouts. However, it is generally more challenging for drivers to maneuver into and out of these spaces and usually provides fewer parking spots compared to other configurations, given the amount of road space used.

- Angled Parking: Angled parking (Figure 2.3b), also known as echelon parking, places parking spaces at an angle to the curb, commonly between 30 to 60 degrees. This setup is often employed in commercial parking lots and on wider streets where space allows. Angled parking is easier for drivers to enter and exit than parallel parking and can accommodate more vehicles than parallel configurations, thereby increasing the total capacity of the parking area. However, it may require more space for maneuvering when entering or leaving, which can affect traffic flow, especially if the design does not account for adequate vehicle movement space. Additionally, this configuration usually supports one-way traffic flow, which could restrict access flexibility.

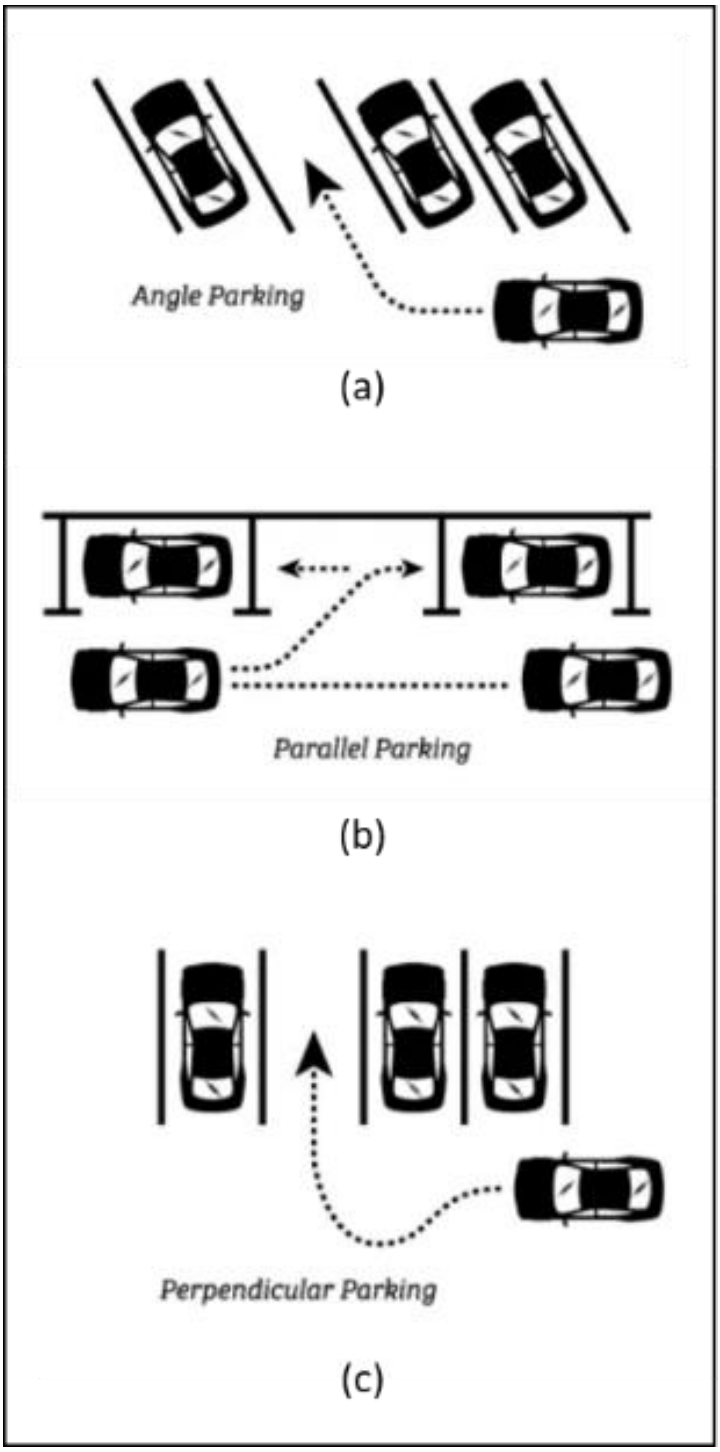


Figure 2.2 Parking types in design standards: (a) angle parking, (b) parallel parking and (c) perpendicular parking.

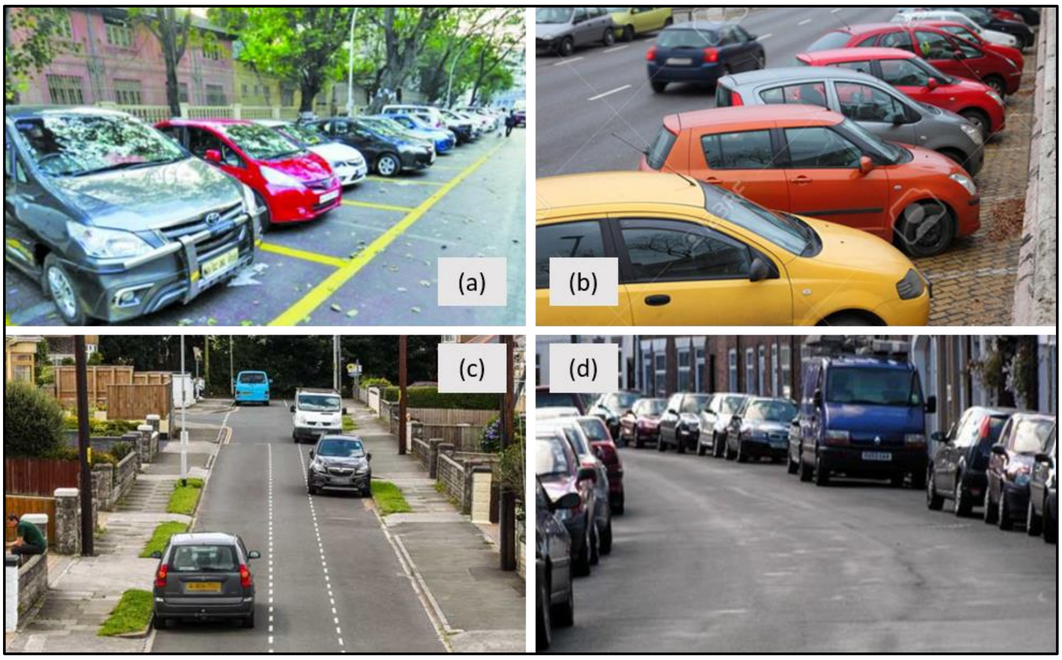


Figure 2.3 a) Perpendicular Parking, b) Angled Parking, c) Parallel Parking on a one-way Street, d) Parallel Roadside Parking

- Perpendicular Parking: In perpendicular parking (Figure 2.3a), spaces are set at a 90-degree angle to the curb or driving lanes. This layout is the most common in commercial and institutional parking lots where maximizing the number of parking spaces is a priority. Perpendicular parking increases the number of available parking spaces and makes it easier for drivers to see other vehicles and pedestrians when pulling out. However, it requires wider aisles for safe maneuvering, increasing the total area needed for the parking lot. There is also an increased risk of collisions with oncoming traffic as vehicles back out, necessitating careful planning of pedestrian pathways and traffic control measures.

2.3.2 Parking Space Standards in Turkey

In 1993, Turkey established parking space standards for the first time, which were later updated in 2018 through the Official Gazette No. 30340 (Resmi Gazete - Otopark Yönetmeliği, 2018). According to these regulations, the minimum parking space size, including the maneuvering area for each vehicle, is set at 20 square meters. Additionally, the Istanbul Metropolitan Municipality specifies that the length of parking spaces for passenger cars must be at least 5 meters, and the width no less than 2.5 meters. These regulations help ensure that there is sufficient space for vehicles to park and maneuver safely within parking areas.

2.4 Planning Roadside Parking

Safety is the most important concern in designed roadside parking. This includes adequate spacing between parked cars and moving traffic, clear signage, and well-marked spaces to guide drivers. Safety measures also involve ensuring good visibility for both drivers and pedestrians, reducing the risk of accidents related to vehicles entering or exiting parking spaces.

Designed roadside parking refers to the deliberate planning and structuring of parking spaces along roadways with careful consideration for various urban and traffic requirements. Unlike non-regulated parking along curbs, designed roadside parking is systematically integrated into urban planning to ensure it serves the needs of the community efficiently and safely.

Designed roadside parking is thoughtfully integrated into the urban layout, taking into account the overall street design, pedestrian pathways, and nearby facilities. It aims to complement other elements of the streetscape, such as bus stops, bike lanes, and sidewalks, ensuring that all modes of transportation can coexist harmoniously.

Properly designed roadside parking is configured to minimize its impact on traffic flow. Planners consider the density of traffic, the type of road, and peak traffic times to determine the most appropriate parking configurations—whether parallel, angled, or perpendicular. (see Figure 2.5) The goal is to facilitate easy access to parking spaces while avoiding significant disruptions to ongoing traffic.

Designed roadside parking obeys to local regulations and standards, which may include surveys on the size of parking spaces, the distance from intersections or crosswalks, and accessibility requirements. Compliance ensures that parking areas are not only efficient but also legally completing all requirements and other regulatory guidelines. Finally, designed roadside parking often utilizes technology and policy to maximize the efficiency of parking spaces. This could involve the use of parking meters, timed parking limits to increase turnover, or dynamic pricing models that adjust parking fees based on demand. These strategies help manage parking availability, making it easier for drivers to find spaces when they need them.

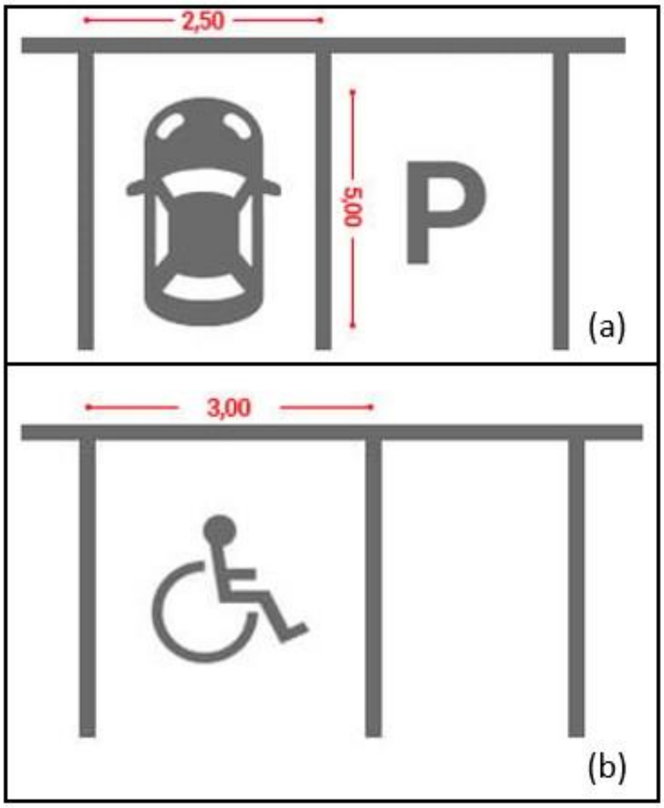


Figure 2.4 Parking Design Standards for (a) regular vehicles and (b) handicapped parking in Turkey

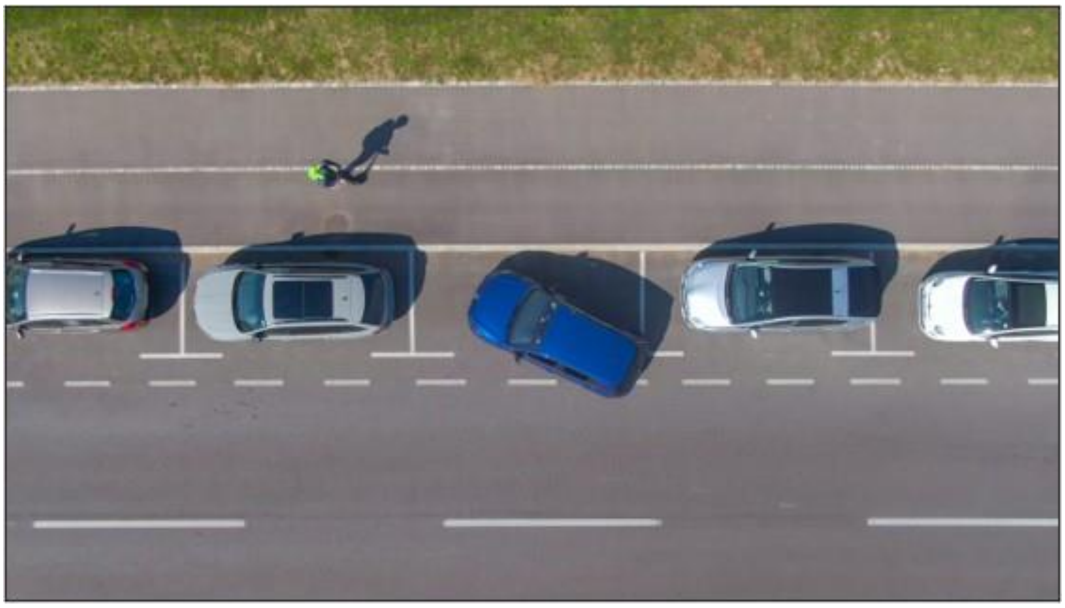


Figure 2.5 Designed Roadside Parking

2.5 Roadside Parking Behaviors

2.5.1 Unregulated Use of Roadside Parking

In designing roadside parking without a dedicated parking lot, strategic location and frequency are crucial to minimize disruption to traffic flow and maximize user convenience. Each parking space should be clearly marked and sized according to expected vehicle types, ensuring that they do not impede the roadway's operational efficiency. Regulations and time restrictions are often enforced to optimize parking space usage, including metered parking or short-term limits during peak hours.

A good example of those like parking design without a parking lot is presence near the Grand Stadium of Inonu belongs to Besiktas. Shortage in parking spaces and amorphic topography leads to design call parking spaces without a parking lot design. This face of urban area is maximized by this without effecting road safety and the flow of traffic.

Safety considerations are paramount, including adequate lighting and signage to inform drivers of parking rules, alongside design features that protect pedestrians, such as curb extensions or raised crosswalks. Accessibility must be considered, with provisions for disabled parking located near key destinations and accommodating accessibility needs.

Integration with public transit can enhance connectivity, providing park and ride options or designated drop-off zones that complement transit access. The environmental impact of roadside parking should also be considered, implementing green infrastructure elements like permeable pavements or bioswales to manage stormwater runoff.

Effective enforcement mechanisms must be in place to ensure adherence to parking regulations, preventing issues such as double-parking or the blocking of emergency routes. Designing roadside parking requires a nuanced approach to balance the needs of vehicle owners, pedestrians, and the overall urban environment, with each design tailored to the specific characteristics of the roadway and surrounding area.

2.5.2 Parking Hazardous to Motorized Traffic

Parking attitudes encompass a broad spectrum of driver perceptions and behaviors towards parking, which vary widely from one individual to another. These attitudes are shaped by a variety of factors, including personal experiences, cultural background, and the specific parking norms of different cities or towns. For example, in areas where parking spaces are scarce, drivers may exhibit a more competitive attitude towards finding a spot, whereas in areas with ample parking, the approach may be more relaxed. This diversity in parking attitudes can significantly influence parking patterns and compliance with local traffic regulations. Understanding these differences is crucial for urban planners and policymakers who aim to design effective parking management systems that accommodate the unique needs and behaviors of all drivers.

In crowded metropoles, the challenge of finding a parking space becomes significantly more acute. The dense population and high volume of vehicles create a chronic shortage of available parking, leading to problematic behaviors such as parking at intersections or even within crosswalks. This not only disrupts the flow of traffic but also poses serious risks to pedestrian safety. The frustration of navigating congested city streets often compels drivers to make hasty decisions to park in prohibited areas, exacerbating the congestion further and leading to a cycle of inefficiency and increased hazards. Such practices strain the infrastructure and require urgent attention to develop more effective traffic and parking management strategies in these urban environments.

In cities with a large working-class population, there is a noticeable increase in the occurrence of illegal parking, particularly during the busiest times of the day. This is often due to everyday activities such as dropping off or picking up children from school. Even though this illegal parking might last only a short while, it tends to happen during peak traffic hours, leading to significant congestion. In a similar way, people who are trying to catch a bus or train might park their cars illegally for a few minutes near transit stations, causing disruptions in these critical areas. Another common scenario is around local markets, where drivers might quickly stop in no-parking zones to grab items, adding to the traffic congestion during busy periods. This type of short-term illegal parking, especially during rush hours, can greatly disrupt traffic flow and contribute to urban congestion. All terms in this section related to “Parking” should be considered in “illegal” or “not permitted” manner unless otherwise stated.

If the local authority does not define the roadside parking regulations clearly (marking the spots, putting necessary signs, etc.) it creates a gray zone for drivers, which would be filled based on the perception and behavior of them. Main types of parking illegally on these areas are: parallel, angled, perpendicular, two-sided parking and double parking. Among all of these double parking is a special case of parking due to the high blocking potential. Therefore, more importance and detail given to this type within this thesis.

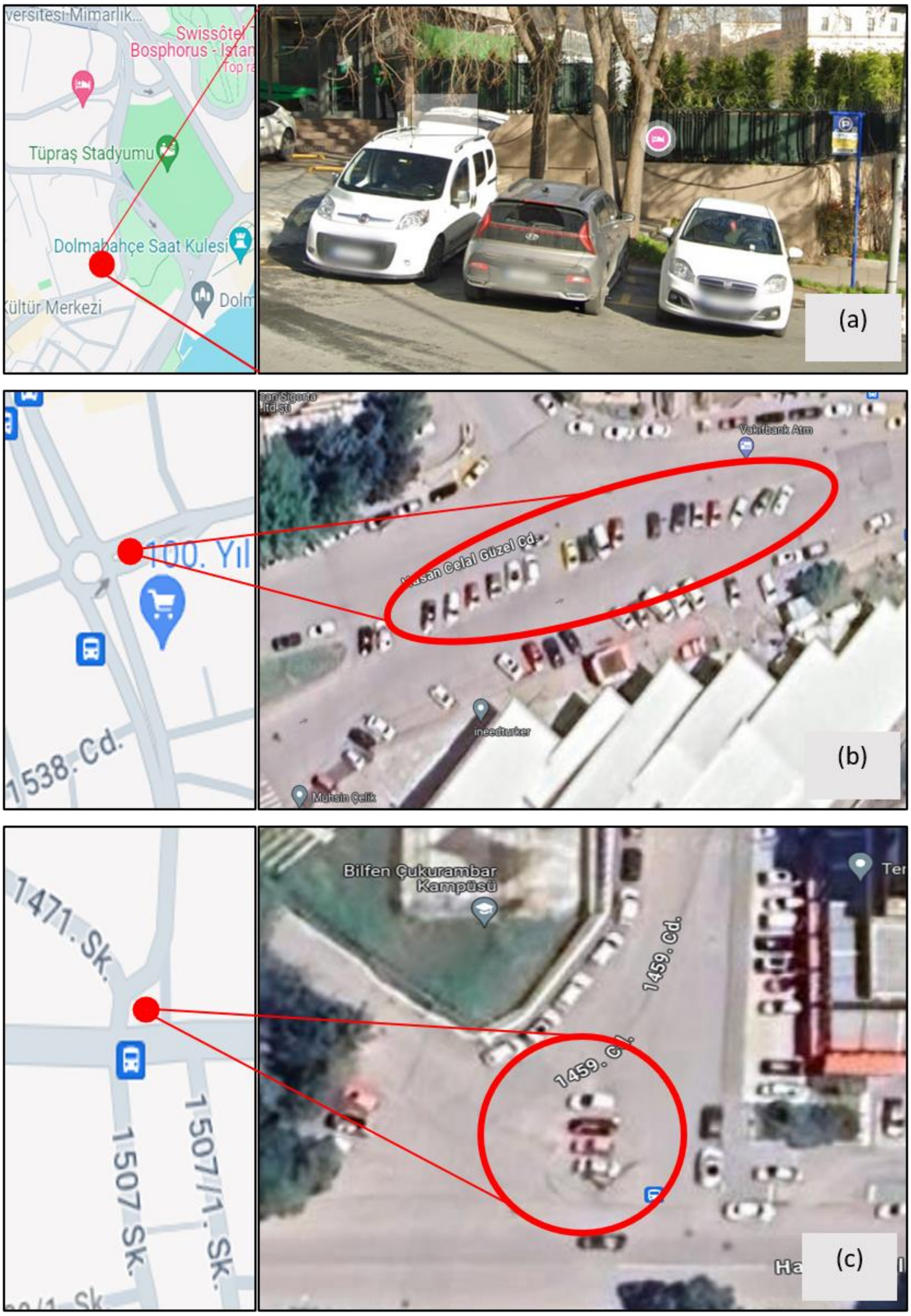


Figure 2.6. Examples of unregulated parking cases of (a) roadside parking near Besiktas Tüpraş Stadium, Istanbul, (b) parking in the junction at Hasan Celal Guzel Street and 1516 street and (c) 1471. Street and Hasan Celal Guzel Street in 100.yıl Ankara

Illegal Parallel Parking: Parallel parking along the direction of the road, limiting the roads' capacity. Figure 2.7a shows a vehicle illegally parked in a clearly marked no-standing zone, parallel to curb, obstructing potential traffic. This represents a typical instance of parking in an illegal manner.

Illegal Angled Parking: Parking violations are angled relative to the curb, which can increase the number of cars that can be parked compared to regular parallel parking. (Figure 2.7b) It also tends to be easier for drivers to maneuver into and out of angled spaces. This behavior limits road capacity more than regular road side parking

Perpendicular Parking: **(**Figure 2.7**c)** depicts an instance that a car parked at a 90-degree angle to the curb. This attitude generally stems from the concept of maximizing the number of vehicles that can be accommodated. It's commonly used and effective in parking lots but can be challenging in terms of space efficiency on street-parked scenarios. Perpendicular Park is the type that degreases NRW most.

Parking Blocking Traffic: In the context of urban planning and traffic management, parking in a manner that prevents a vehicle from passing refers to a situation where vehicles are parked in such a way that they obstruct the flow of traffic. This typically occurs when vehicles are parked illegally or inappropriately along the roadside (Figure 2.8a), on the curb totally or partially (Figure 2.8b), inside intersections (Figure 2.8c) and other places on the carriageway reducing the available road width to an extent (Figure 2.8d) that makes it impossible for other vehicles to pass through. This kind of parking is problematic as it not only disrupts traffic flow but also raises safety concerns, particularly in emergencies when rapid access through the roadway is necessary. Figure 2.8 shows an example that how summing up of all instances of illegal parking will lead to a total congestion.

Figure 2.7 Illegal (a) parallel parking, (b) angled parking, (c) perpendicular parking[1]

Two-Sided Parking: Vehicles are parked on both sides, on a road, has not been fully addressed by legislation, creating a regulatory gray area. However, this practice leads to significant issues both in terms of traffic flow and road capacity, often resulting in problematic situations that affect the efficiency of the transportation infrastructure. Two-sided parking has different effects in terms of narrowing potential due to the road type. Two-sided parking on un-divided (physically un-separated) roads (Figure 2.9a) both directions will be affected due to blockage. On divided roads (Figure 2.9b) because of the physical separation only one direction will be affected while road width of the other direction preserved.

Figure 2.8 Parking blocking traffic (a) along the roadside, (b) on the curb, (c) inside intersections

Double Parking

Illegal parking types generally refers to a parking violation that occurs when a vehicle is parked on an empty roadside or on a sidewalk, thereby narrowing the roadway. But double parking has significant frequency especially covering crowded areas in the means of vehicle population. Figure 2.10 shows examples of double parking, that a vehicle is stopped or parked on the roadway alongside other vehicles that are parallel parked.

Double parking states single side double parking on most cases. Drivers often have a tendency to park on the right side of the road, close to an already parked car, rather than on the uncontrolled left side of a divided roads. Reverse is true for countries with traffic flowing on the left side. This behavior stems from a perception of safety, as parking near other vehicles may feel more secure and orderly. This term could refer to parking near an already parked vehicle forming two vehicles side by side in most cases.

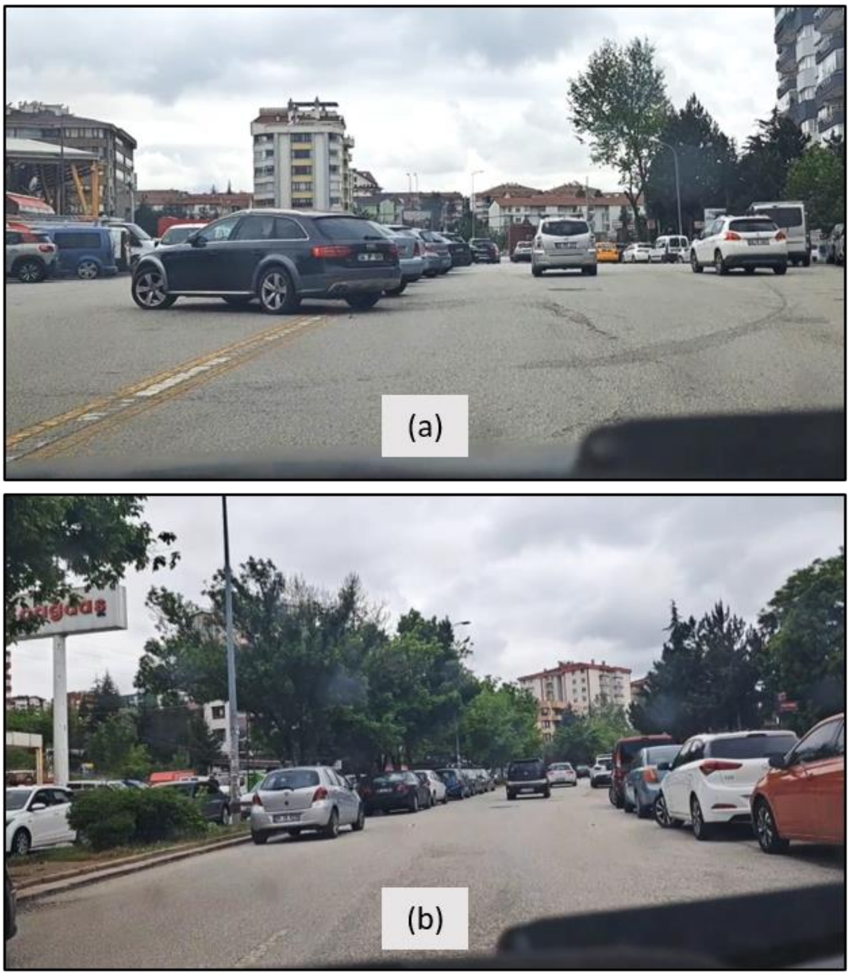


Figure 2.9 Two-sided parking on (a) un-divided road and, (b) divided road.

Figure 2.10 Illegal double-parking examples.

2.5.3 Parking Hazardous to Non-Motorized Traffic

Illegally parked vehicles present a significant threat to non-motorized road users by obstructing designated pathways and creating unsafe conditions. When cars encroach on sidewalks, pedestrian crossings, or cycle lanes, they force pedestrians and cyclists to divert from their intended paths, often pushing them into vehicle traffic. This displacement heightens the risk of accidents, as non-motorized users are compelled to navigate alongside moving vehicles in spaces not designed for their safety. For example, a car parked on a sidewalk can disrupt the mobility of individuals, particularly those with disabilities or those using strollers, leading them to detour onto busy roads. In the case of cyclists, illegal parking in bike lanes can compel them to merge into faster-moving traffic, increasing the potential for collisions and reducing the overall safety of the cycling environment.

The image below highlights several instances of hazardous parking affecting non-motorized traffic. In Figure 2.11a, a vehicle is shown parked inside a pedestrian crossing, forcing pedestrians to step onto the roadway to navigate around the obstruction. This creates a dangerous situation, especially for children, the elderly, and individuals with limited mobility. In Figure 2.11b, a car parked on a bicycle lane forces cyclists to swerve into the main traffic flow, increasing the risk of accidents.

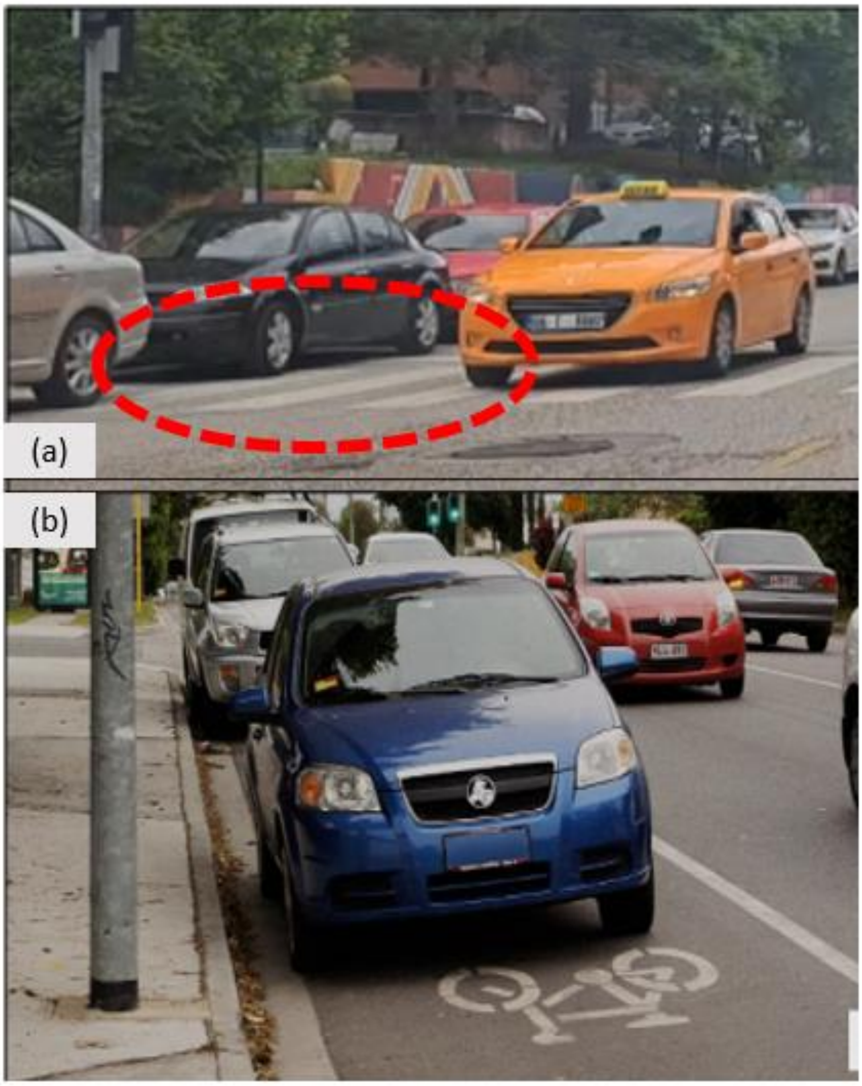


Figure 2.11 (a) Parking inside pedestrian crossing, (b) on a bicycle lane.

CHAPTER 3

METHODOLOGY

The road networks in GIS mostly consider graphical representation of the road segments with polylines representing the centerline of the road. However, the real geometric features (number of lanes, lane widths, medians, islands, etc.) are important features to consider when roadside parking focus is selected. To monitor and evaluate the level of roadside parking in urban regions, it is necessary, first, to transfer the necessary road network detail to GIS environment, which could be defined as road network digitization stage. Later, parking area usage along roadsides must be defined geographically. Data collection requirements are determined for simple videorecording and GPS track data. The developed Windows Forms Application tool is described, which is producing parking point coordinates data, the main input for roadside parking detection. Comparing the parking locations and digitized road network features produces the net road with (NRW) estimations which can provide insights about the capacity losses on urban corridors due to parking, as well as thematic maps to visualize the risks it creates.

3.1 Road Netwok Digitization

Road network digitization must be handled in two parts: a) digitization of intersection areas and b) digitization of road corridors. But, urban road corridor characteristics (width, road type, number of lanes, parking restrictions, etc.) may vary significantly in short distances. Thus, a further process of the network digitization is necessary, which slices the corridor into smaller and more homogenous sub-parts, called segments.

3.1.1 Intersection Area Digitization

The digitization process begins with the digitization of intersections due to their complex structure. (Figure 3.1) The definition of corridors is made by using segments that connect one intersection to another. To properly define connections, the digitization of cross-sections is essential. A systematic approach was adopted for the creation and digitization of cross-sections, with intersections divided based on the principle of designating one lane for entry and another for exit. According to this scheme, each approach at a roundabout is divided into two segments.

In the construction of the digital model of an actual roundabout, efforts were made to preserve its true form. Efforts were also made to simulate the presence of roundabouts where none physically existed by employing a zero radius to intersect the midpoints of converging roads. This approach aimed to align the digital model with the functional layout of intersections as closely as possible.

Figure 3.1 Creation and Digitization of Intersections

For undivided roads, the entire road layout was taken into account when defining intersections, ensuring all potential turning movements were taken into account. This comprehensive methodology facilitated accurate simulations of traffic flow and the identification of potential congestion points.

In the case of divided roads, right lane designated as the turning lane. Consequently, the left lane was not influenced by the turning movements, thus it was important to mark it distinctly in the model. This distinction is crucial for understanding traffic dynamics and planning appropriate road infrastructure modifications to improve traffic management and safety at intersections.

3.1.2 Road Corridor Digitization

Corridor digitization begin with the precise digitization of the left and right boundaries of the roads using Google Earth base maps, providing a detailed and accurate layout of the roadway geometry. Visualization of these elements is conducted in QGIS, offering easy-to-use tools and open-source environment in a clear and straight forward manner. QGIS is also used for further analysis and decision-making processes. This step is critical as the actual road width is going to be calculated directly using this digitized data. Accurate road geometry (esp. road boundary) extraction ensures that subsequent analysis is based on solid and reliable foundational data. (Figure 3.2)

Figure 3.2 Creation and Digitization of Corridors

3.1.3 Road Corridor Segmentation and Slicing

To evaluate road capacities affected by illegal parking, a detailed corridor segmentation and slicing methodology was employed. Corridors were divided into segments and analyzation conducted within each segment. Calculation of actual road capacity at each segment gives the chance of to calculate and analyze the actual road widths’ left after illegal parking.

Assessment granulity determines the precision of evaluation. Sampling interval of corridors may be selected as desired. Typically selecting this interval under the distance of one car is not meaningful. Besides the distances under one car length increases data and process volume dramatically, it has no meaning and does not increase the precision because of the fact that the effective capacity does not influence by sampling distance within a car.

In this study three meters of sampling distance, enables precise measurements and evaluations. For each segment, the NRW was calculated and documented in a structured tabular format.

Generation of Segments

The transition from polygon data representing corridors to line data representing actual NRW measurements begins approximating the rough midline of the road. Although this midline does not directly contribute to calculations, it serves a crucial role in defining the segments for further analysis. “Points along geometry” tool of QGis has been used to segmentate. In the QGIS User Manual (2024) it is stated as follows: “*This algorithm creates a points layer, with points distributed along the lines of an input vector layer. The distance between points (measured along the line) is defined as a parameter. Start and end offset distances can be defined, so the first and last point will not fall exactly on the line's first and last nodes”.* Offset distance has been used to eliminate the location that is exactly at the line which corridor and intersection areas share. Giving an offset distance makes sure that segmentation point surely falls in the corridor itself.

Drawing perpendicular lines from these points is a critical step for measuring road width across different sections of the corridor. To execute this slicing, Python code is used to draw lines perpendicular to the midline at each slicing point. These lines intersect with the corridor polygon where the areas occupied by parked cars have been previously subtracted. By the end of this process, each line slice represents the NRW at a linear resolution of 3 meters along the corridor. This method of segmenting and analyzing the road in detailed slices provides an accurate depiction of how parking impacts capacity of the road.

Lastly, the perpendicular lines falling within the bounds of the corridor polygon were cut. This action facilitated to analyze and make the distinction between the space occupied by parked vehicles and the remaining available road, leading to precise calculations of NRW, the key metric. (Figure 3.3)

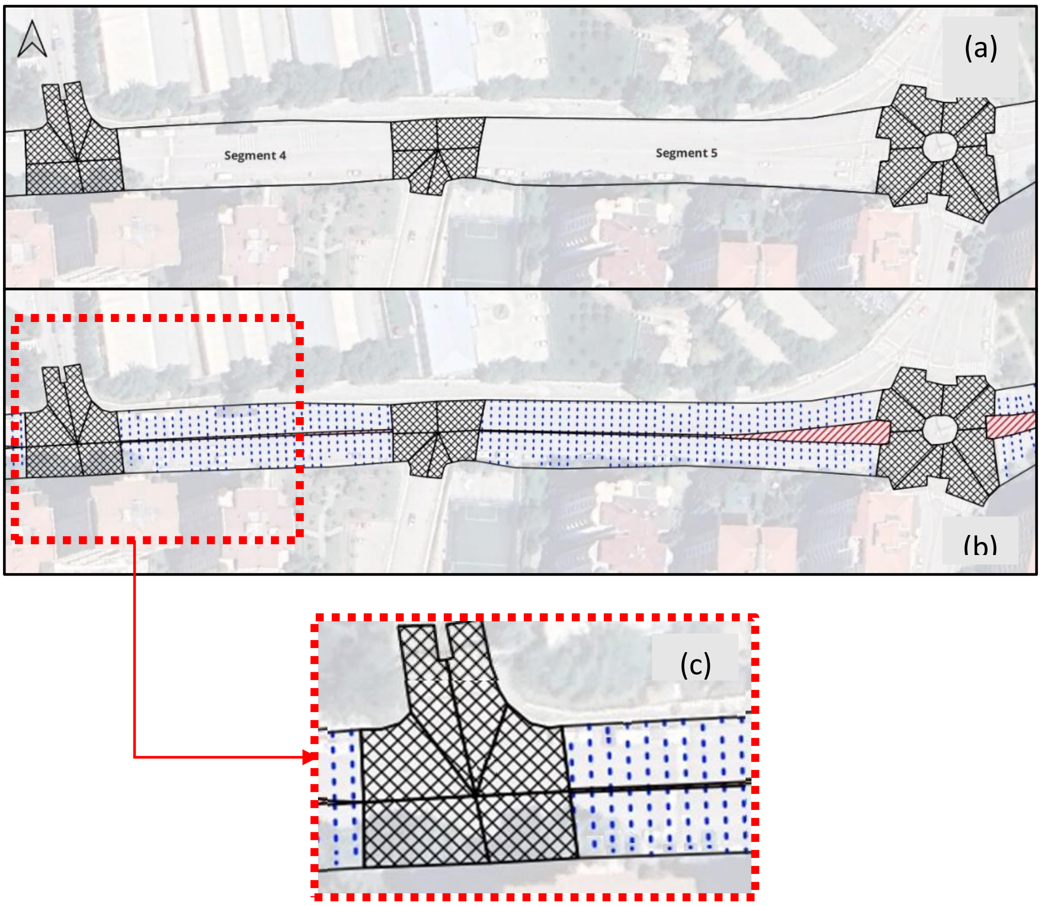


Figure 3.3 Example of Road (a) Segmentation (b, c) slicing

3.2 Roadside Parking Area Usage and Definition

When a vehicle is parked illegally, it doesn't just take up its own physical space. The presence of the vehicle affects a larger area, which is magnified when its doors are open — a factor that must be accounted for. Moreover, its presence renders nearby areas unusable for other motorists. The sum of all space that cannot be used due to the vehicle existence defines the obstruction area. Identifying these areas (Figure 3.4) is crucial for calculating the distance that they made unavailable.

Occupation Area: The term "occupied area" is defined as the portion of the roadway occupied by any parked vehicle. This specifically refers to the space directly beneath where the vehicle is stationed. Such area has a minimum direct impact on traffic lanes by reducing the available road width for moving vehicles, which can lead to congestion and decreased traffic flow.

Impact Zone: The "impact zone" is defined as the area where improperly parked vehicles significantly disrupt traffic flow or compromise safety. Typically, it is not feasible for a vehicle to park directly adjacent to another vehicle or flush against a curb without leaving any space. A minimal "Curb Aligning Distance" of approximately 0.20 meters is generally maintained between the vehicle and the curb. (Figure 3.5) This term encompasses not only the area directly under the vehicle but also includes this curb aligning distance.

Additionally, it is important to consider the space required when car doors open, which can extend an additional 0.5 meters into the roadway. This "door opening distance" significantly contributes to the impact zone and should be factored into any assessments of parking impact on traffic and pedestrian safety. By accounting for these dimensions, we can more accurately evaluate how parked vehicles affect their surroundings and implement more effective traffic management strategies.

Dead-Zones: In addition to the impact zone, the obstruction caused by parked vehicles extends further due to the need for other drivers to maintain a safe distance from these vehicles. This requirement results in the formation of triangular areas both in front of and behind the parked vehicle. These spaces, which other vehicles must avoid using to ensure safety, are referred to as "dead zones." (Figure 3.4)

Dead zones are crucial for traffic safety as they provide necessary clearance for maneuvering and emergency responses, preventing potential accidents. The presence of a vehicle and its associated impact zone effectively increases the road space it occupies, compounding the disruption to traffic flow. Thus, these dead zones are not merely unused spaces but are essential safety buffers that facilitate smoother traffic movement around parked vehicles.

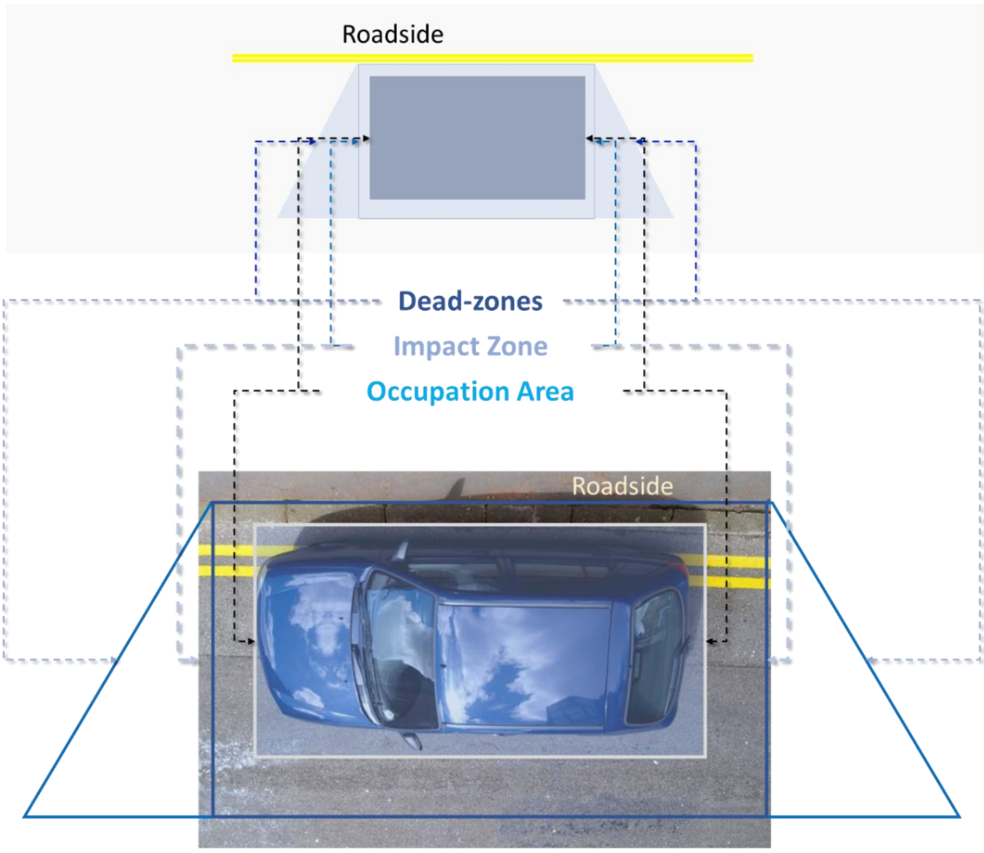


Figure 3.4 Obstruction Area of a Parked Vehicle

Figure 3.5 Curb Aligning Distance

Obstruction Area: The concept of obstruction area encompasses the occupied area, impact zone, and dead zones associated with a parked vehicle. This cumulative area represents the total road capacity disabled by a single parked car and should be carefully considered in urban planning and traffic management. (Figure 3.4) The occupied area refers to the space directly occupied by the parked vehicle, while the impact zone includes additional space affected by activities such as the opening of doors. Dead zones, which are the triangular areas in front of and behind the parked vehicle, must remain clear to allow for safe maneuvering and emergency access. Together, these components form the obstruction area, which significantly reduces the effective road capacity. Understanding and quantifying this obstruction area is crucial when assessing the impact of parking on traffic flow and road usability.

3.3 Roadside Parking Data Collection Using GPS and Video Recording

3.3.1 Needs and Restrictions

Video recording combined with GPS data (Gpx records) has emerged as the most rapid and effective method for data collection in the context of parking studies. This approach provides a dynamic and comprehensive capture of real-time parking behaviors, which is superior to other methods such as on-foot coordinate collection or drone surveillance.

Collecting coordinates by walking is notably time-consuming and labor-intensive. It limits the amount of data that can be collected in a single session and is highly dependent on the physical endurance and accuracy of the data collector. This method also poses significant challenges in terms of accessing all areas equally, particularly in dense urban environments where navigating on foot can be obstructive.

Similarly, while drones offer a bird's-eye view that can cover large areas quickly, they come with their own set of disadvantages. Drone operations require clear weather conditions and are subject to strict regulatory restrictions, especially in urban areas. The noise and privacy concerns associated with drones can also be significant, limiting their use in populated or sensitive areas.

In contrast, video recording using a video camera, paired with GPS data, offers a less intrusive and more flexible approach. Smartphones are ubiquitous, relatively inexpensive, and require minimal setup for use in data collection. When equipped with video and GPS functionalities, they can provide accurate location data along with visual records, allowing for mapping of parking spaces and patterns with enough precision.

Therefore, the development of a software application that combine and calculate latitude and longitude information of parked vehicles along with details, sides, and types of parking in tabular form has emerged. Video and recording of Gpx data capabilities of smartphones is crucial for overcoming the limitations posed by traditional data collection methods. This application not only addresses the needs of efficient data collection but also aligns with the restrictions of accessibility and user-friendliness, paving the way for data collection of more sustainable and scalable urban traffic management solutions.

3.3.2 Gathering Data

The data gathering and digitization process begins with clearly defining the route for analysis. Upon deciding on the path, the team prepares to embark on the data collection trip with a smartphone camera and a Gpx tracker application called "Geo Tracker". (see Figure 3.6a)

For this operation, two individuals are necessary: one to drive the vehicle and the other to handle the video and gps track recording. With both the video recording and the Gpx tracker activated simultaneously, they ensure an almost synchronized start. Precise synchronization handled by software application later. The driver navigates the vehicle along the designated route while the second team member focuses on capturing stable, clear footage of the roadside. To achieve this, a phone gimbal (see

Figure 3.6b) is used to counteract any potential shakiness in the video, which is crucial as shaky footage could severely compromise the quality and usability of the video data.

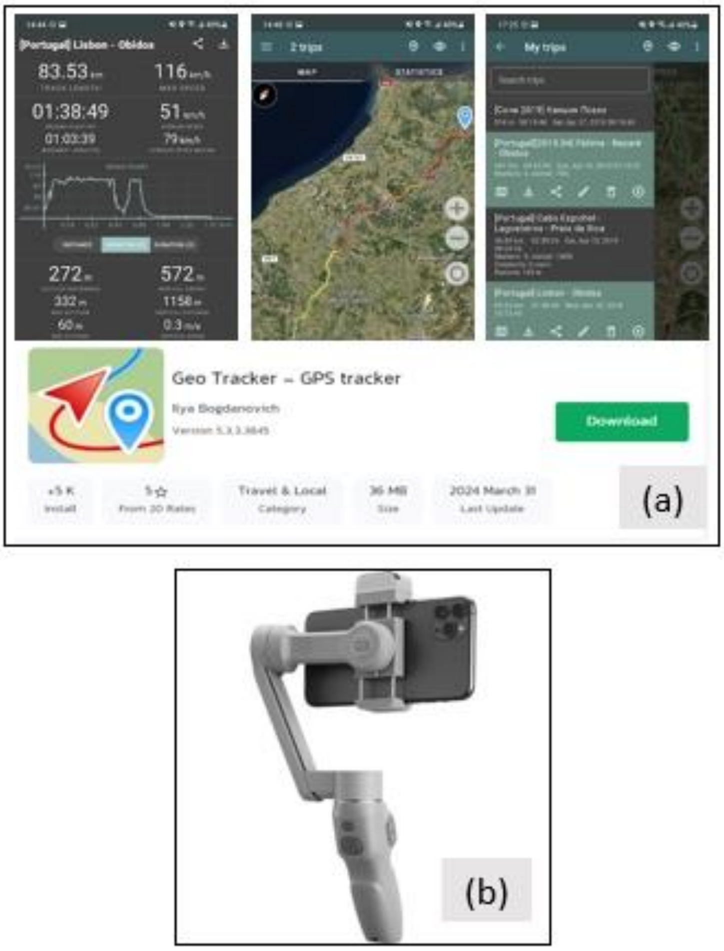


Figure 3.6 (a) GeoTracker Application (b) Gimbal

Traffic stoppages or variations in driving speed are unimportant in terms of the data collection process. The Gpx tracker diligently records the coordinates alongside the corresponding time stamps, ensuring that each point is accurately logged regardless of such fluctuations.

Upon completion of the route, both the video and the Gpx recordings are stopped. The data files are then transferred to a computer but are not ready to be loaded into the application for the next phase - digitization.

Video and GPX durations differ, as do their starting times. The app uses the total durations of both the GPX and video to synchronize the times at which the points' latitudes and longitudes are collected. Thus, these two discrepancies must be eliminated. An initial rough synchronization is performed to maintain the highest possible accuracy.

A typical “gpx duration to video duration ratio” (G/V ratio) of 1.005 results in an 8-second difference for a 15-minute-long video footage. By assuming that the data collection car travels at an average speed of 30 km/h, it covers 8 meters per second. Consequently, an 8-second discrepancy results in a 64-meter difference. Therefore, to achieve the best possible accuracy, the G/V ratio should be kept below a certain threshold.

At this point, the open-source video editing app DaVinci Resolve was used. Records provide the exact starting times of the GPX and videos at the sub-second level. A two-step synchronization methodology is proposed:

1. Synchronization of starting moments.

2. Synchronization of durations.

Both are done by adding the missing seconds using a screen displaying a "Sync Time" message. It is crucial to add missing seconds in the correct order. First, seconds are added at the beginning of the video to precisely match the starting times. Then, to eliminate the total duration error, the difference in durations is added to the end of the video. This concludes the synchronization process, and new videos are rendered using DaVinci Resolve.

At this stage, using powerful open-source software like DaVinci Resolve (Figure 3.7) allows for corrections in color, sharpness, and contrast. This enhances the visibility for digitizing operators and makes the process more error-free.

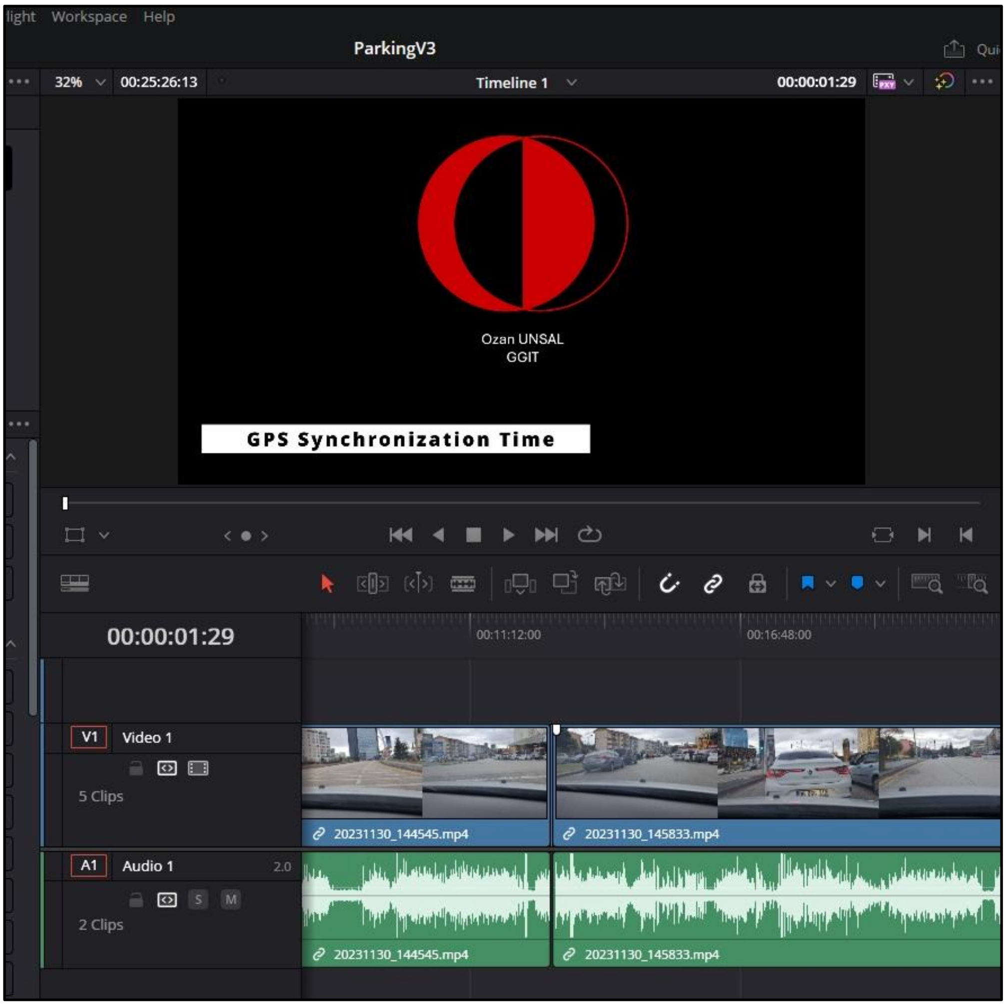


Figure 3.7 Video Editing Software Davinci Resolve

3.4 Roadside Parking Data Processing via a Custom Windows Forms Application

For the gathered data, there is no pre-existing software or app available. Recognizing the need to digitize and process this data, a Windows Forms app was developed. This app is designed to take video and Gpx data, allowing an operator to watch the video and, upon clicking a button, calculate the exact geographic coordinates using the Gpx data.

This app scenario presents some challenges. The first is a synchronization issue because users cannot start the Gpx recorder and video recording simultaneously. The app includes functionality to adjust this time shift. Secondly, the app should be user-friendly, storing data about which side of the street to digitize and featuring buttons for each type of parking. Lastly, it should allow users to navigate within the video and digitize as desired without errors or confusion due to back-and-forth digitization.

3.4.1 Working Principal and Algorithm

The software application is meticulously designed to digitize and synchronize parking data captured through video and GPS recordings. Due to the need to design software capable of solving all these above problems, the following rules, algorithms, and working principles were established.

- Video Duration Reading: The application reads the total duration of the uploaded video file, providing a framework for subsequent synchronization with GPS data.
- GPX Duration Reading: Similarly, it reads the total duration of the Gpx file, which contains the GPS data, to ensure alignment with the video's timeline.
- Synchronization Constant Calculation: The software calculates a synchronization constant, a crucial factor that aligns video and GPS timestamps, allowing for accurate location pinpointing corresponding to the visual data. Even though the Gpx and video were started simultaneously, there is still a gap between their start and end times. To eliminate this discrepancy, some calculations were necessary. These calculations were completed in two steps. The first step converts video time to Gpx time. Since both datasets were started nearly at the same time, the total duration of Gpx data is almost the same as the total duration of video data.

This relationship is established through a basic ratio calculation by dividing the total Gpx duration by the total video duration and then multiplying by the video time we wish to convert to Gpx time. (Equation 3.1)

$$Gpx_{Time} = \frac{\sum GPX}{\sum Vid} \times Vid_{Time} \tag{3.1}$$

After determining the time equivalent of video time, another issue arises due to the nature of Gpx recordings. Gpx records a set of latitude, longitude, and height triplets every second. If the required Gpx second falls within a fraction of a second, it means there is no exact match in the Gpx data. This issue is resolved through 'Gpx time interpolation' for coordinates at non-measured seconds. (Equation 3.2) The mathematical model for this interpolation is akin to triangulated irregular network models that use three-point coordinates to interpolate points in space.

$$\frac{(T_A - T_1)(x_2 - x_1)}{T_2 - T_1} + x_1 = x_A \tag{3.2}$$

This formula calculates the X-coordinate for a given video time by finding the ratio of two known coordinates and interpolating to find the distance to an unknown point. By applying a similar formula for the Y-coordinate, the desired Y-coordinate at that specific time can be determined. This method allows for precise interpolation of fractional video seconds from known Gpx coordinates.

- Video Time Capture: When user clicks a button within the "Park to Point Converter" (Figure 3.8) section, application captures the current time from the video.

- Time Synchronization: This captured video time is then multiplied by the synchronization constant to determine the equivalent time in the Gpx data timeline.
- Coordinate Matching: The application checks if there is a recorded GPS coordinate at that specific second.
- Time Interpolation: If there is no exact match, it locates the GPS data points recorded just before and after the video time instance.
- Coordinate Interpolation: The software interpolates between these before and after coordinates to find the precise location at the exact Gpx time, filling in the gaps to maintain data accuracy.
- String Writing: The resulting coordinates are formatted into a string for ease of use and readability.
- Data Categorization and Listing: This string is then appended with the parking category which taken from the name of the button pressed and written to the list box within the interface, which compiles and displays the data entries.
- Repetition and Calculation: The process is designed to be repeated for each instance of parking observed, building a comprehensive list of time-stamped, geolocated parking events. This workflow allows for a robust, user-friendly experience, streamlining the complex task of matching video and GPS data to create an accurate and usable dataset for urban parking analysis.

3.4.2 User Interface and Workflow of Data Processing App

The user interface of the application is designed considering efficiency and ease of use in the digitization and analysis of parking data. The main window is divided into two sections (Figure 3.8):

1. Video display and digitization buttons area on the left.
2. Digitized GPS data list on the right.

The video display area is intended to play recorded footage that users can analyze to identify instances of parking. The playback controls located below the display area, including play, pause, stop, and seek functions, provide users with full control over video navigation, which is essential for accurately pinpointing the time frames of interest. The use of Windows Media Player controls creates a sense of familiarity among users, which makes the software advantageous.

On the right, the digitized data log presents the information in a tabular format. Each row includes timestamped GPS coordinates and a corresponding code denoting the type of parking observed and the side of the road which this vehicle belongs. This dual-pane approach with remove button allows users to go back and forth in video and digitize precisely correct location where video time and Gpx time corresponds.

Below the video area, there are options for loading video and GPS data. Video and Gpx loader 'Load Video' and 'Load Gpx' buttons, and an 'Export' button which suggests functionality for exporting processed data for further analysis are generated respectively. The path to the data files is clearly shown or asked, ensuring that users can verify anytime of the source or destination of the data being loaded or saved.

The bottom portion of the interface features a set of color-coded buttons in a stack called "Park to Point Converter". There is "Park", "Double Park", "Park Inside the Bus Stop", "Angled Parking" and Perpendicular Parking" buttons that each representing a different parking scenario. These buttons likely serve as quick tools for users to categorize the parking instances they observe in the video feed, aligning with the types of parking patterns being analyzed.

The interface also includes a selection for the user to indicate which side of the road they are digitizing – 'Right' or 'Left', which is critical for accurate mapping of the parking situation. GPS data can fluctuate with in few meters and this can lead to misunderstanding about the correct side of the road that vehicle parks. In order not to lead this type of confusion digitizing operator declares the side of the road which he/she makes the digitization for.

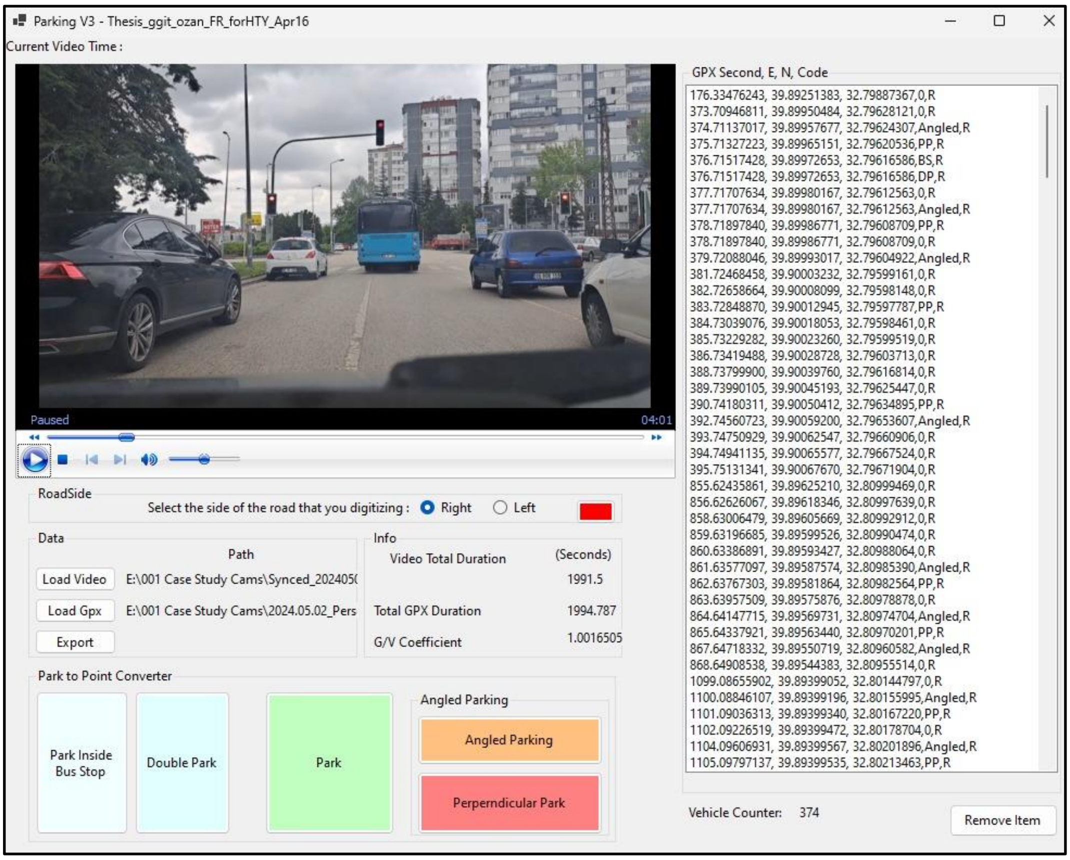


Figure 3.8 User Interface

Overall, the application's interface arranged to facilitate the collection, digitization, and categorization of parking data, with a clear focus on enhancing the user's ability to process and interpret large volumes of video and GPS information efficiently.

Digitization Workflow from the Operators Point of View

Operator loads the video and the Gpx file. Selects the road side to digitize from radio buttons. Conducts the digitization process using video pane and buttons. Some back and forth digitization is available. User can digitize any portion of the video at any time. In case of an error, he/she deletes and edits digitized data. In the end of the whole digitization process user can get the output file using export button. (see Figure 3.9)

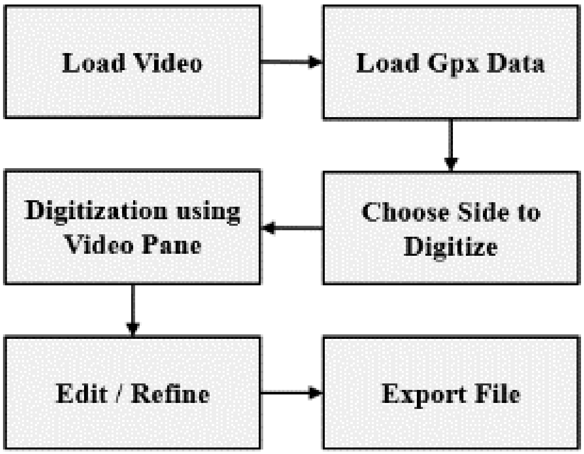


Figure 3.9 Workflow (Operator Point of View)

Within the interface of the application, operator selects which side of the road to digitize first. As the video plays, the operator observes for instances of illegal parking. Upon identification, he/she presses the corresponding button in the application, which automatically logs the incident, along with its coordinates, into the list box displayed on the user interface.

Once digitization of all observed vehicles is complete, the operator uses the export function to compile data, which is now primed for processing with GIS software. At this juncture, data, collected directly from the field, is assembled and ready to undergo further analysis in GIS.

3.5 Net Road Width (NRW) Estimation Using GIS

Polygons were created to digitally represent the edges of roads, as well as the locations and orientation of vehicles. This digital representation is crucial as it lays the groundwork for further analysis within the GIS environment.

The GIS tools were then utilized to calculate the NRW. (Figure 3.10) With these two sets of data, a difference algorithm is applied to subtract the space occupied by improperly parked vehicles from the total road capacity. The result is an adjusted road capacity that reflects the actual usable space on the roads, accounting for the areas lost to these obstructions defined as “Net Road Capacity”.

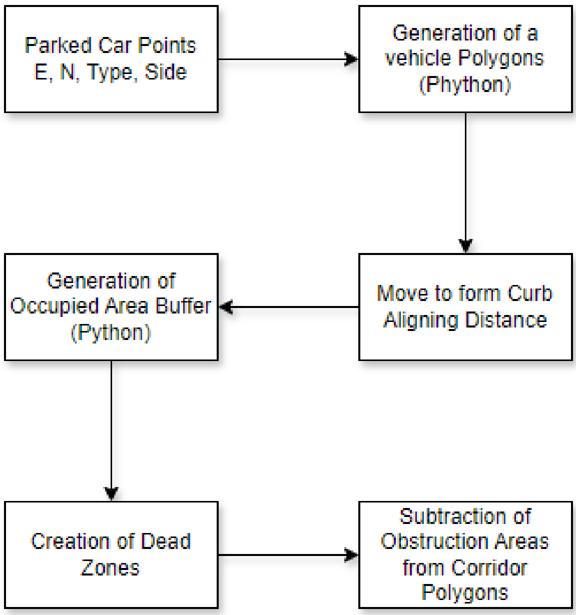


Figure 3.10 Net Road Width Estimation Workflow

The digitization process results in a series of points data that represent the location of parked vehicles. To accurately depict the physical presence of these vehicles on the road, these points must be transformed into rectangular geometries that reflect the typical size of a vehicle. Standard vehicle dimensions are represented by rectangles that have 2.5 meters to 4.5 meters dimensions. A Python code was created to facilitate the conversion of a large number of points into these rectangle shapes, which embody the "occupied area" as previously defined.

The algorithm for this transformation takes each point, assumes it as the center, and expands it outwards to form a rectangle of the vehicle's dimensions. Here’s a simplified representation of the algorithm:

i. For each point, determine the orientation of the road.
ii. Create a rectangle centered on the point with lengths corresponding to the average vehicle size (2.5m x 4.5m).
iii. Align the longer side of the rectangle parallel to the direction of the road.

After the rectangles which represents vehicles are created, they are adjusted to simulate the typical distance maintained from the curb. In reality, vehicles do not park flush against the curb; a gap is always present. For the purposes of this study, a typical gap of 0.20 meters is assumed and accounted for in the model. The Python code's algorithm for this adjustment involves:

iv. Shifting each rectangle away from the road line by 0.20 meters.
v. Ensuring that this shift is perpendicular to the road's orientation to maintain accurate road alignment.

To generate the "impact area" of the vehicles, which takes into account the additional space taken when car doors are open, a simple buffer tool is employed. This tool expands the rectangle by the necessary distance, reflecting the space a vehicle occupies when doors are open, in accordance with the earlier definition of the impact area. Subsequently, "dead zones" are also created. These are triangular areas that cannot be used for traffic movement, situated at the front and rear of the parked vehicle, forming a dual-area pattern. To determine the net usable road area, first subtract the areas obstructed by parked vehicles, identified as obstruction areas, from the polygons that represent the road corridors. This step is essential for calculating the actual available space for vehicular traffic, providing a clear picture of how much road capacity is reduced by parked vehicles.

The methodology outlined in this section offers a structured approach to representing parked vehicles in a manner that reflects their real-world impact on road capacity.

Through the use of precise algorithms and Python scripting, the study provides a quantifiable representation of how parking behaviors translate into reducing physical space on urban roads. Practical workflow of the NRW calculation and visualization begin with the input of the text file that contains the geographic location, type, and side of each parked car generated with the presented software. Point data is imported into QGIS using the 'Import Delimited Text' function in the “Data Source Manager”, generating point data for parked cars.

By using points data, rectangular polygons representing occupied areas of cars are drawn. At this level points are assumed as the center point of the rectangles. A Python code was written to generate all rectangular shapes representing vehicles in a matter of seconds, using the size of 2.5 meters to 4.5 meters to represent occupied areas. At this stage, each occupied area represents parked cars' shifted positions where the operation vehicle has passed. All cars are shifted to the sides of the road using both side data and roadside line data at the attribute table. Again, a Python code is deployed for this batching this process, including a procedure that generates 20 centimeters of curb-aligning distance accordingly. Impact zones are generated using the QGIS buffer tool, and a 0.5-meter buffer is created for each vehicle. This polygon represents the impact zone of each car, taking into account the effect of curb-aligning distance and represents the space impacted by the vehicle in terms of calculating NRW.

The next step was to generate triangular obstruction areas located at the front and back of each car. A Python code was written, but due to inconsistencies in processing the triangular areas, the batch generation of dead zones failed. For the sake of the study, these triangular areas were generated manually to ensure correctness. After calculating and generating all zones that affect NRW, all areas are joined together using the “Dissolve” tool. By finding the difference between the road corridor polygon and the dissolved obstruction areas polygon, the polygon representing the net road width of the road is obtained. After determining the NRW in terms of polygons, segmentation and slicing steps were conducted. For this purpose, the rough middle of the road should first be found. The “v.voronoi.skeleton” algorithm is used for roughly defining the middle line of the road. This middle line does not need to be the exact middle of the road corridor as it is only used for linear segmentation and road slicing. Using the “Points Along Geometry” tool of QGIS, segments are generated as points along the rough midline, spaced every 3 meters. This three-meter distance represents the examination and sampling distance for the NRW estimation. After linear segmentation, perpendicular lines are drawn using a Python script. This script draws lines passing through a given point, which are perpendicular to a given geometry. However, as a side effect, the drawn lines can only be distance-specific. To obtain the correct line length representing actual NRW, the generated long lines need to be cut. NRW polygons are used as a clipping mask to trim these lines. In this way, each line now accurately represents the NRW at that specific point on the corridor. Visualization and thematic mapping were subsequently established, utilizing NRW line geometry (Figure 3.11) as the primary input for visualization. The comprehensive details of this process, including the methodologies and techniques employed, are provided in the following section.

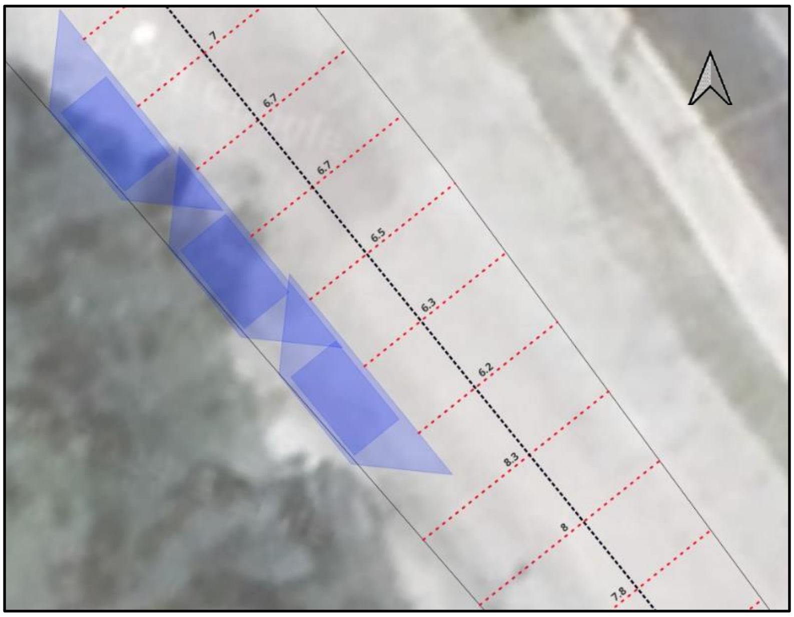


Figure 3.11 NRW Line Geometry

3.6 GIS Based Visualization and Thematic Mapping

To visually interpret findings, a thematic color-graded map was created. This map uses color coding to indicate varying levels of road congestion due to narrowing caused by illegal parking:

- Dark Red: Areas where the NRW ranges from 0 to 2.5 meters are highlighted in dark red, indicating total congestion. In these segments, the width is insufficient for any vehicle to pass, signaling complete blockage and a high likelihood of severe congestion.
- Red: Segments where the NRW is between 2.5 meters and 4 meters are marked in red. These dimensions allow only one vehicle to pass at a time. If two vehicles meet head-on, one must wait for the other to pass, thereby introducing delays or "latencies emerge" in traffic flow. Prolonged demand on these roads could lead to total congestion.
- Yellow: Segments with an NRW of 4 meters to 7 meters are marked in yellow. These are indicative of potential bottlenecks where two cars can pass side by side, yet the space is limited and may lead to minor congestion.
- Green: Areas where the NRW is between 7 and 10 meters are denoted with green, representing safe zones with adequate space to mitigate road congestion linked to illegal parking.
- Light Blue: Lastly, areas with an NRW of 10 meters or more are colored blue. These segments are typically spacious enough that their road capacity is not significantly impacted by illegal parking but rather by the inherent size and presence of the road infrastructure.

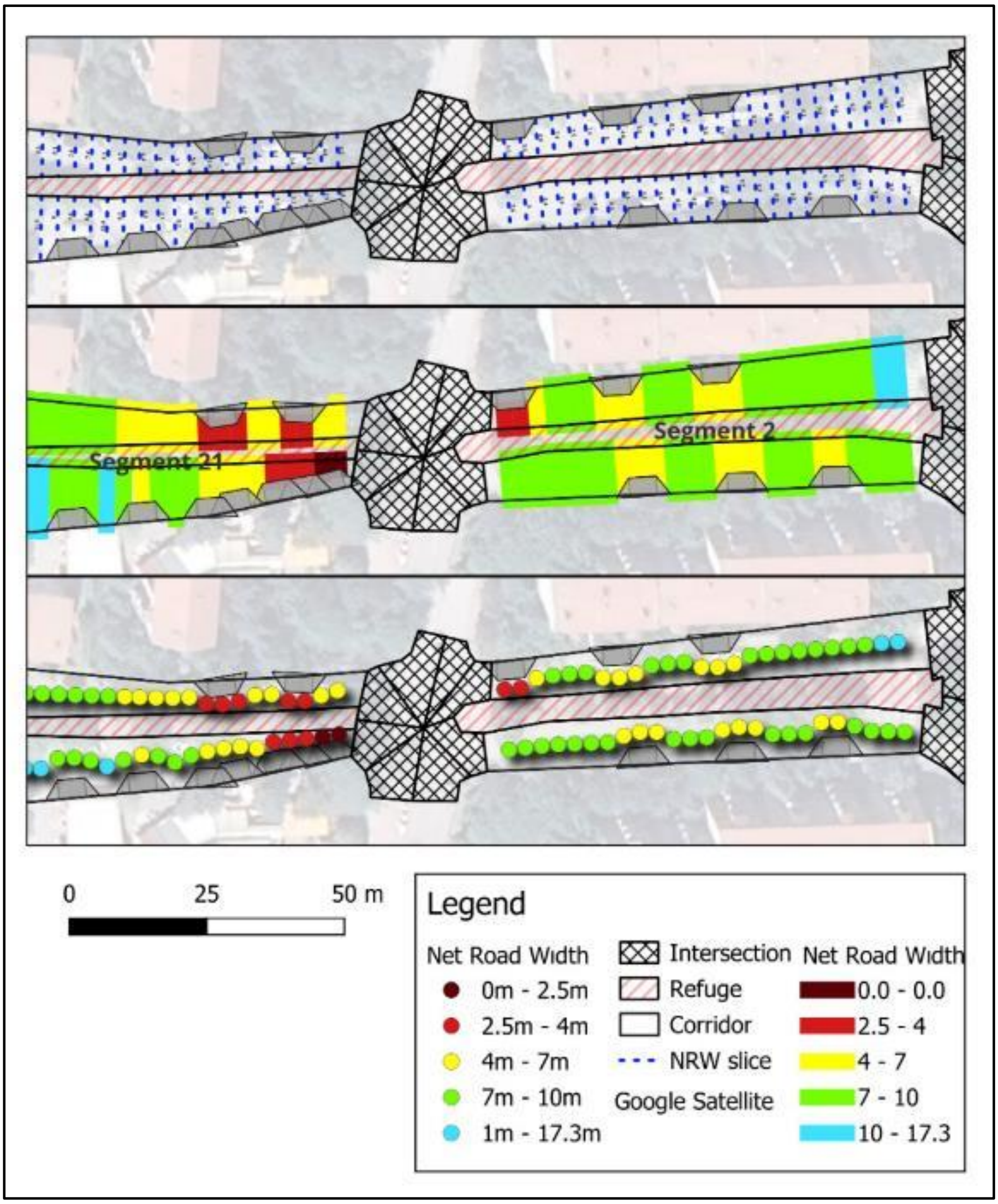


Figure 3.12 Visualization of Net Road Width
(a) Line representation, (b) Colored area representation, (c) Circle representation with which the distance to the road center depicts also NRW

The thematic map serves as a tool for identifying specific areas of concern and helps in visualizing the spatial distribution of narrowed road capacities due to illegal parking, effectively. A color-coded thematic map has been selected as the optimal tool for visualizing the effective road capacity impacted by illegal parking. This map highlights various traffic conditions using distinct colors, each signifying a different level of road usability due to parking behaviors.

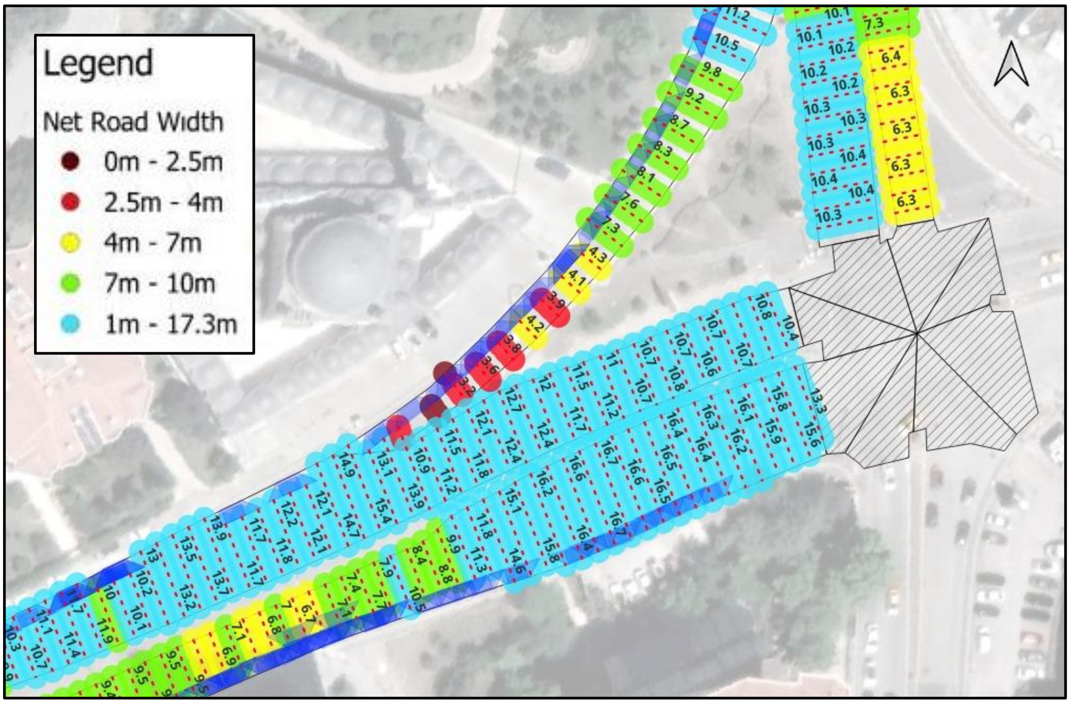


Figure 3.13 Visualization of Net Road Width (NRW)

CHAPTER 4

CASE STUDY

The case study focuses on the impact of illegal parking on urban road capacity, specifically investigating the spatial distribution and severity of parking violations using Geographic Information System (GIS) technology. This study is set in a busy metropolitan area and examines how these parking practices reduce road space availability, consequently affecting traffic flow and urban mobility. The objectives include identifying problematic areas, assessing the effectiveness of current enforcement strategies, and suggesting improvements to enhance traffic management and urban planning.

4.1 Study Area

The study area spans through the neighborhoods of Kızılırmak, Çukurambar, and İşçi Blokları quarters in Ankara's Çankaya district. These neighborhoods exhibit diverse demographic and socio-cultural characteristics, which are significant from an urban traffic planner's perspective. Kızılırmak and Çukurambar are known for their mixed residential and commercial zones, contributing to varying traffic patterns. İşçi Blokları, often characterized by more residential features, shows different peak traffic hours, which might be influenced by local schools and business hours. Understanding these dynamics is crucial for addressing traffic congestion and designing effective parking management strategies in these densely populated areas. The socio-economic activities in these neighborhoods also influence the demand for parking spaces, underscoring the need for tailored traffic regulations and infrastructure improvements to accommodate the unique needs of each area. (Figure 4.1)

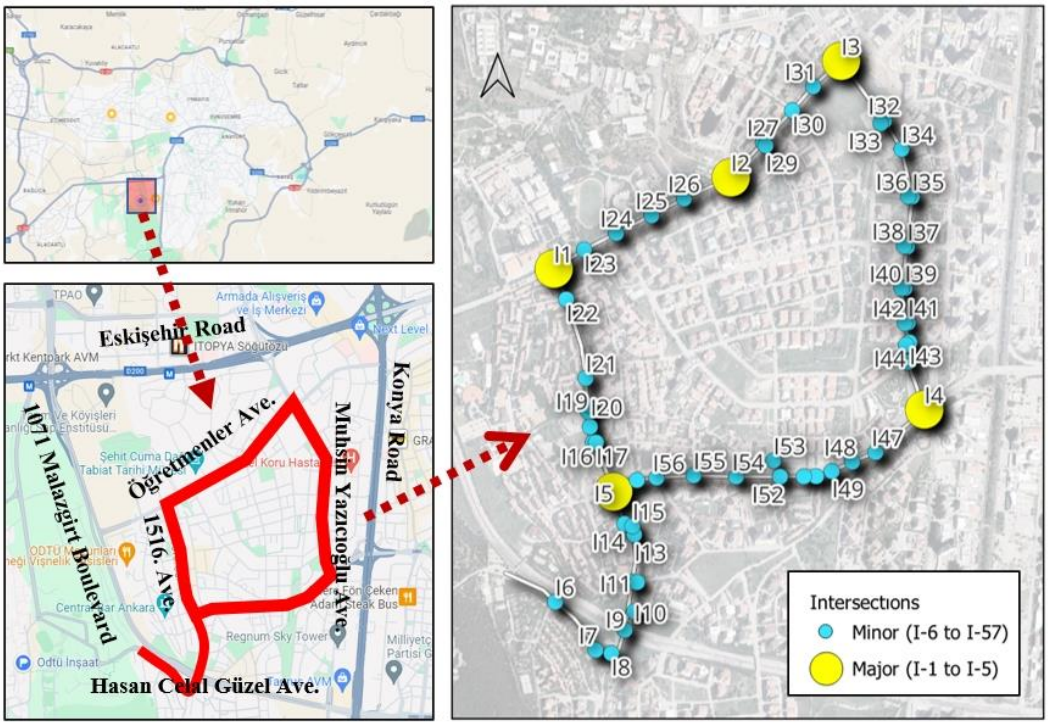


Figure 4.1 Study area and intersections

The study area involves roads including Hasan Celal Güzel, Muhsin Yazıcıoğlu, 1516th Avenue, and Öğretmenler Caddesi, covering a total length of 4,350 meters. This area encompasses 28 intersections and 27 corridors, providing a comprehensive setting for examining traffic dynamics and parking behavior. The spatial layout and the number of intersections is critical in understanding the flow of traffic and identifying key points for detailed traffic and parking analysis within the urban landscape.

The underlying issues leading to traffic congestion in the study area are multifaceted, stemming from its unique position at the confluence of commercial, residential, educational, and governmental activities. The presence of schools, government buildings, and hotels within the area adds significantly to the daily traffic volume, not only from those who reside and work there but also from visitors and service providers. Compounding this, the area serves as a critical transit route for vehicles traveling to neighboring districts. Many drivers perceive this route as an alternative to the major thoroughfares such as Mevlana Bulvari (former Konya Yolu) and İnönü Bulvarı (former Eskisehir Road), which are key arterial roads in Ankara (Figure 4.1).

Eskisehir Road, a major west-east axis, features a dual carriageway with three lanes on each side and a wide median, accommodating substantial traffic flow. Similarly, Konya Road, facilitating the north-south traffic, mirrors this capacity and traffic volume. These roads, while designed to handle heavy traffic, often push overflow traffic into the study area, especially when drivers seek shortcuts during peak congestion times. The study area's proximity to significant avenues and carriageways, along with hospitals, residential blocks, and commercial entities, makes it a preferred shortcut for those aiming to bypass congestions at major intersections. This tendency significantly elevates the demand on the local road network, worsening congestion and complicating traffic management efforts. The strategic positioning and the resultant traffic dynamics are illustrated in Error! Reference source not found., which provides a close-up view of how the area is enveloped by these critical infrastructures, underscoring the pressing need for targeted traffic solutions in this urban locale.

4.2 Digitization of the Study Area

Google Earth satellite images were utilized as base maps to provide a precise and up-to-date representation of the study area road sides. The first step involved the detailed digitization of intersections as polygons. This initial focus on intersections allowed for an accurate mapping of these critical areas, which are central to understanding traffic flow dynamics and congestion points within the study area.

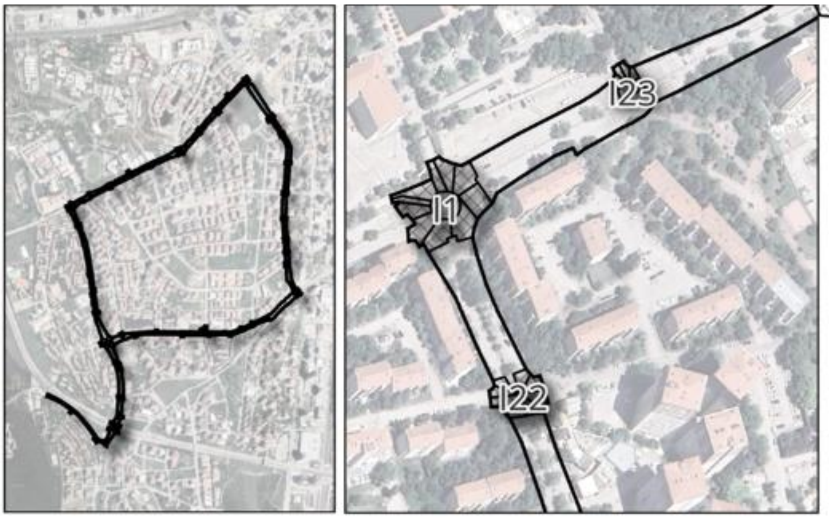


Figure 4.2 Digitized Study Area

4.2.1 Segmentation

Segmentation refers to the division of road corridors into smaller, more manageable sections to facilitate detailed analysis of traffic flow and parking behavior. Each corridor, which is the portion of the road between intersections, is divided into segments. These segments are defined by their direction and specific characteristics, allowing for a more focused examination of each section of the road.

Following the intersections, corridors were digitized as polygons. This method facilitated a clear delineation of the road portions between intersections, known as "corridors," which were then further divided into "segments" that separate road directions, enabling a comprehensive analysis of traffic movement and parking behavior. The polygonal representation of both intersections and corridors (by means of segments) forms the foundational geographic data necessary for subsequent analysis. (Figure 4.2) A table of details about digitization process is given in the table 4.1

In quantifying the scope of the study area, the following key metrics have been recorded. Specifically, the area includes 51 intersections and 79 segments, highlighting the complexity and density of the corridors being analyzed. Details about the digitization process are provided in tables 4.1, 4.2, 4.3, 4.4 and 4.5. Additionally, the detailed slicing process resulted in 2,709 slices perpendicular to segments representing net road widths (NRW) for precise analysis.

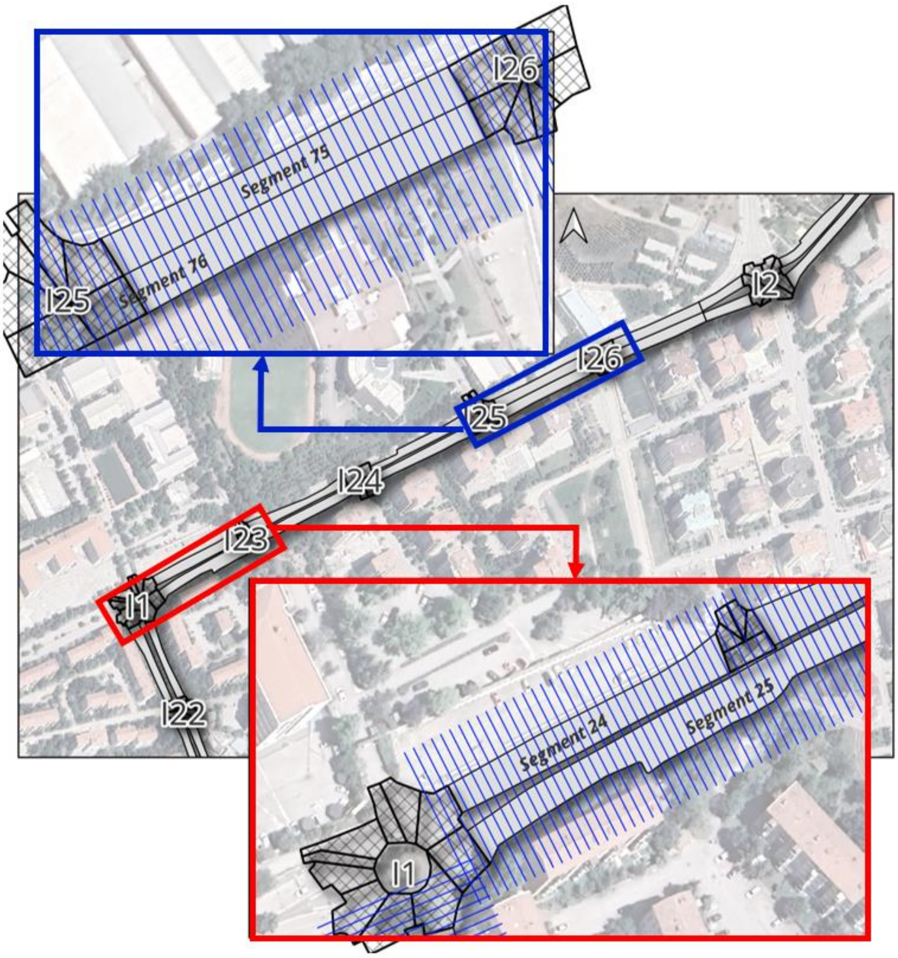


Figure 4.3 Segmentation and slicing between major intersections of I1, I23 and I25, I26.

Table 4.1 Details of Digitization Results Between METU A4 Gate and I5

Segment No.	**From**	**To**	**Length (m)**	**N# Slices**	**Directions**
1	ODTÜ-A4	6	143	48	NW - SE
2	6	7	178	59	NW - SE
3	7	8	19	6	East - West
4	9	8	52	17	South
5	8	9	54	18	North
6	12	9	131	44	South
7	9	10	25	8	North
8	10	12	67	22	North
9	14	11	173	58	South
10	12	13	137	46	North
11	5	14	75	25	South
12	15	5	85	28	North

Table 4.2 Details of Digitization Results Between I5 and I1

Segment No.	**From**	**To**	**Length (m)**	**N# Slices**	**Directions**
13	16	5	142	47	South
14	5	17	141	47	North
15	18	16	28	9	South
16	17	20	99	33	North
17	19	18	29	10	South
18	21	19	90	30	South
19	20	21	70	23	North
20	22	21	257	86	South
21	21	22	255	85	North
22	1	22	77	26	North
23	22	1	79	26	South

Table 4.3 Details of Digitization Results Between I1 and I3

Segment No.	From	To	Length (m)	N# Slices	Directions
24	23	1	91	30	Southwest
25	1	24	212	71	Northeast
26	24	23	105	35	Southwest
27	25	27	102	34	Southwest
28	24	25	103	34	Northeast
30	26	2	93	31	Northeast
31	2	26	48	16	Southwest
32	26	2	47	16	Northeast
33	27	2	131	44	Southwest
34	2	27	138	46	Northeast
35	30	27	122	41	Southwest
36	29	30	127	42	Northeast
37	31	30	76	25	Southwest
38	30	3	207	69	Northeast
39	3	31	106	35	Southwest
75	26	25	96	32	Southwest
76	25	26	95	32	Northeast
77	2	26	92	31	Southwest

Table 4.4 Details of Digitization Results Between I3 and I4

Segment No.	From	To	Length (m)	N# Slices	Directions
40	33	3	224	75	Southeast
41	32	3	220	73	Northwest
42	34	32	84	28	Northwest
43	33	34	80	27	Southeast
44	35	34	142	47	North
45	34	36	141	47	South
46	36	38	141	47	South
47	38	35	146	49	North
48	39	38	117	39	North
49	38	40	117	39	South
50	41	39	90	30	North
51	40	42	90	30	South
52	43	41	42	14	North
53	42	44	44	15	South
54	44	46	28	9	South
55	4	43	207	69	North
56	46	4	138	46	South
79	46	47	124	41	Southwest

Table 4.5 Details of Digitization Results Between I4 and I5

Segment No.	From	To	Length (m)	N# Slices	Directions
57	47	4	194	65	Northeast
58	4	47	187	62	Southwest
59	47	48	34	11	Southwest
60	48	47	33	11	Northeast
61	48	47	28	9	SW - NE
62	48	49	48	21	SW - NE
63	50	49	44	15	SW - NE
64	51	50	31	10	East - West
65	52	51	74	25	East - West
66	54	52	132	44	East
67	53	54	85	28	West
68	54	55	119	40	West
69	55	54	119	40	East
70	56	55	97	32	East
71	55	56	98	33	West
72	56	57	42	14	West
73	5	56	117	39	Northeast
74	57	5	56	19	Southwest
78	52	53	3	1	West

4.2.2 Slicing

Slicing is the process of further subdividing the segmented corridors into smaller, uniform sections to facilitate a more detailed and precise analysis of road capacity and parking behavior. (Figure 4.3) After the corridors are divided into segments, each segment is sliced to capture variations in (NRW) along the corridor accurately. This slicing allows for granular examination of how roadside parking impacts the available road width at different points, enabling the identification of critical areas where parking significantly reduces road capacity, causes congestion, and creates safety issues. By employing this method, the study ensures a comprehensive analysis of the spatial distribution of road capacity reductions due to illegal and unregulated parking.

4.3 Acquisition of Roadside Parking Data

The data for this study was acquired using a car, a smartphone camera video recorder and a GPS tracker application known as "Geo Tracker." (Figure 3.6) Two people were needed. One for driving the car and the other for operation. This setup ensured that detailed geographical and visual data were recorded simultaneously during the data collection drives. The vehicle was driven along the designated study route within the Kızılırmak, Çukurambar, and İşçi Blokları neighborhoods, adhering to the flow of typical traffic. The flexible nature of this data collection method allowed for stops, variable speeds, waits at intersections, and other traffic-related delays, all of which could be accurately synced with the GPS data thanks to the advanced capabilities of the video and GPS synchronization technologies used.

The vehicle was driven along the designated study route within the Kızılırmak, Çukurambar, and İşçi Blokları neighborhoods, adhering to the flow of typical traffic. The flexible nature of this data collection method allowed for stops, variable speeds, waits at intersections, and other traffic-related delays, all of which could be accurately synced with the GPS data thanks to the advanced capabilities of the video and GPS synchronization technologies used. The route was driven twice to ensure comprehensive data coverage, once for the right side of the road and once for the left. This dual approach ensured that all aspects of roadside parking and traffic flow were captured.

4.4 Data Processing with Presented Windows Application

A custom Windows application was introduced for processing video and GPS data (Figure 3.8). The software uses video and GPS data as input and outputs the coordinates of digitized parked vehicles. Due to the user-friendly design of the interface, operating the app is quite straightforward. After opening the app, the first step involves loading the video data and calculating its total duration displayed beside the 'Load Video' button in the digitization panel. (Figure 4.4b) Subsequently, GPX data is loaded, and the total duration of the GPX data is calculated near the 'Load GPX' button. This stage is the end of the preparation process for digitization.

Once all data from the study area are loaded, actual digitization begins. The video is started by pressing the play button on the Windows Media Player control (Figure 4.4a), and when a parked car is observed, the related button is pressed, and the parked car is digitized with its type. There was no extra need to digitize the type of parking because all cases of parking were associated with a related button on the interface. (Figure 4.4b) This enhances ease of use and increases the speed of the digitization process. It also ensures accuracy by visually discriminating types of parking behaviors. After becoming familiar with the software, digitizing a parked vehicle becomes a natural response for the operator and eventually turns into a reflex. This familiarity leads to greater accuracy and efficiency over time. Due to the simplicity of the procedure, the software is particularly suitable for processing a vast number of corridors and distances. Foreach digitization button pressed calculated gpx second, easting and northing coordinates, codes which refer to the parking type will be digitized to the coordinate list in the results panel (Figure 4.4c). The entire digitization process from start to finish took approximately 30 minutes. After digitizing each vehicle, the 'Export' button was used to export the data to a text file that includes northing, easting, type of parking, and side of parking data. Each line of the file represents a single vehicle. At this point, the digitized data is ready for GIS use and import.

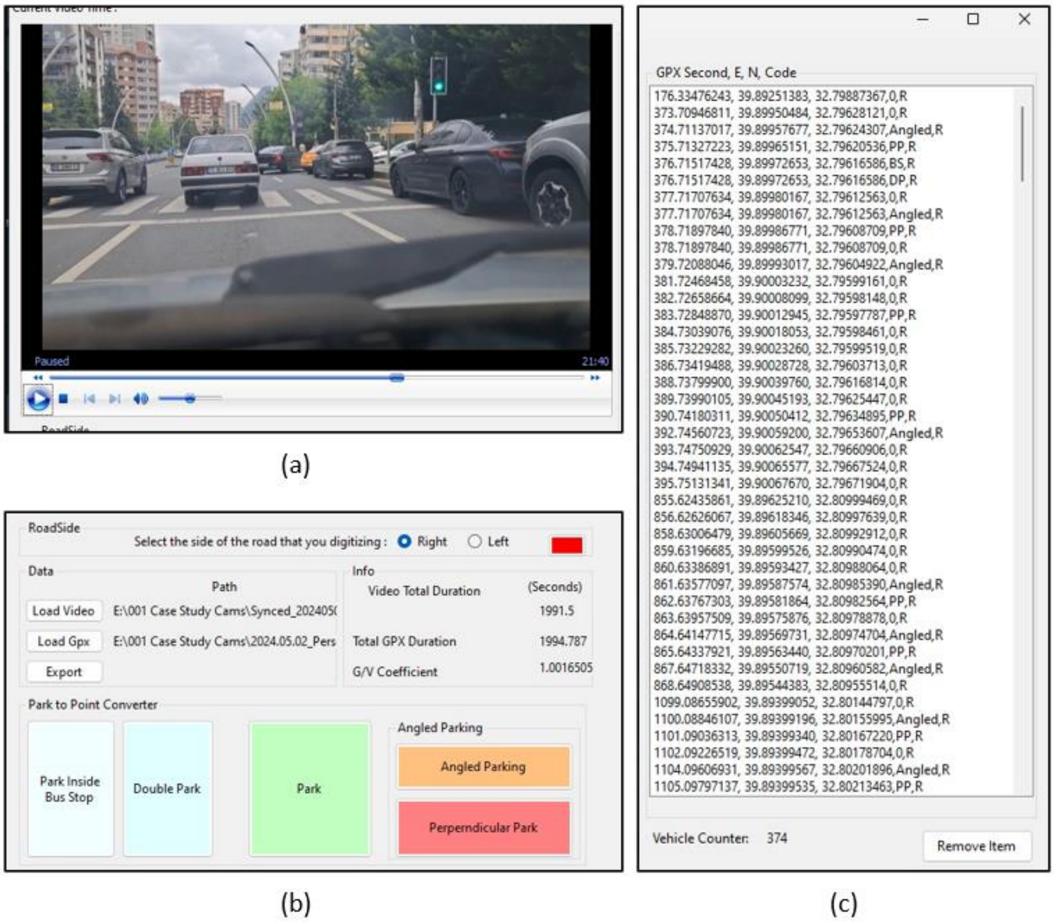


Figure 4.4 User interface portions (a) windows media player control (b) digitization panel (c) results panel

4.5 NRW Estimations and Thematic Maps

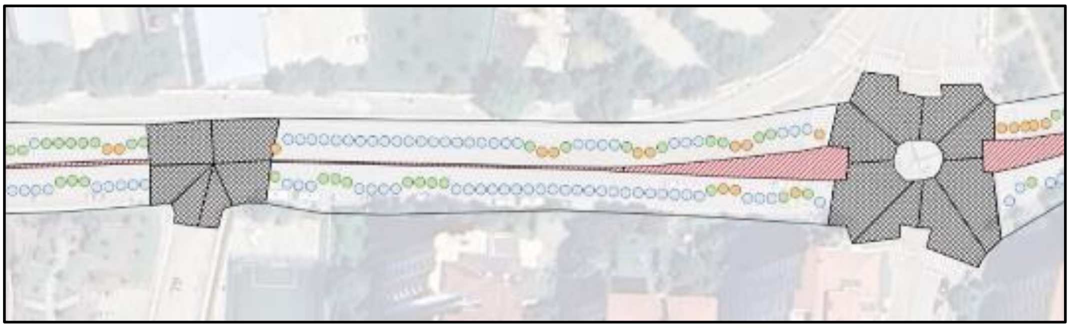


Figure 4.5 Net Road Widths on Undivided Road

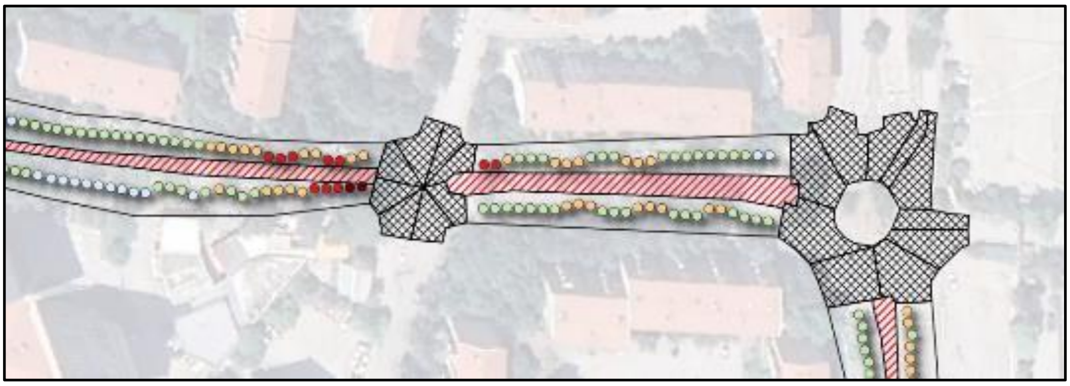


Figure 4.6 Net Road Widths on Divided Road

The entire process was conducted as described formerly. It was observed that in some areas the road merely narrowed, in others it was reduced to a single lane, and in some places, it was completely blocked. The thematic maps used visually highlighted the specific locations of these problems very clearly. While the narrowing on divided roads (Figure 4.6) did not affect the traffic moving in the opposite direction, on undivided roads, (Figure 4.5) the reduction to less than one lane due to parking impacted traffic flowing in both directions, posing a significantly negative effect on traffic safety.

4.6 Evaluation of Roadside Parking in the Study Area

Corridor-based thematic maps were generated for specific portions of the corridors. Intersections were depicted with cross-hatching, while occupied areas were shown in gray. Refuges were indicated on the maps with black contours and red diagonal-hatching when needed else used as lines. NRW was visualized by color-coded points, with the distance from the center of the road indicating road width—meaning the closer the position of the point to the center, the narrower the road. Additionally, a scale bar and a small overview window was introduced at the bottom left corner of the main map window, where a small reddish area indicates the current view within the study area.

Problematic Regions

While roadside parking was observed at almost all corridors, its impact was not the same due to the function and geometry of the road segments. Some corridors were extremely problematic where roadside parking decreased the net road capacity and endangered dual carriage capacity of the road such as the corridor between the METU A4 gate and 100. Yıl entrance (I5). Some locations had severe illegal parking in the intersections and approach legs, where un-channelized capacity in the road network design allowed such as the roundabout at the 100. Yıl Marketplace. Such problematic areas are evaluated in details below:

4.6.1 Parking Problems at the 100. Yıl Marketplace Intersection

The marketplace intersection and the undivided branch demonstrate significant parking challenges throughout the day, as depicted in Figure 4.7. This area was analyzed at four different times (06:30, 08:30, 12:30, and 17:00) to understand the parking patterns and their impact on road capacity and traffic flow. All temporal data superposed (visualized with the same blue color with a %30 of opacity) in the map to reveal the frequency and occupation of the particular roadside portion. The findings reveal widespread parking issues that worsens congestion and arises safety risks. One of the most problematic behaviors observed in this region is mid-road parking. This practice severely disrupts the flow of traffic, particularly on the undivided branch, where vehicles park perpendicularly in the middle of the road. Such parking not only reduces the available road width but also introduces significant safety hazards, as it forces moving traffic to navigate around stationary vehicles, leading to potential collisions and traffic delays.

In particular, the intersections at Segment 72 and Segment 73 exhibit frequent instances of vehicles parked too close to the crossing points. This illegal parking obstructs sightlines for both drivers and pedestrians, increasing the risk of accidents. Also parking directly inside the intersections seen which is a critical problem for traffic safety. Analysis identified instances of double parking in conjunction with perpendicular parking in the middle of the road. This dual-layer parking behavior compounds the problem, creating bottlenecks and further reducing the road's effective capacity. The presence of the marketplace appears to be a significant factor contributing to this parking pattern, as the demand for parking spaces surges during market hours, prompting drivers to park wherever space is available, including inappropriate and hazardous locations.

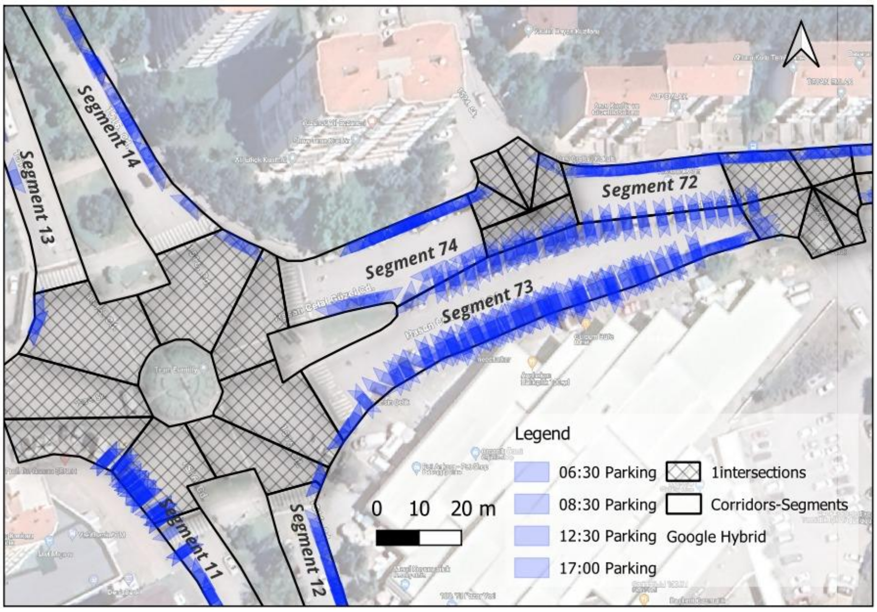


Figure 4.7 Marketplace intersection and mid-road parking

4.6.2 Parking Problems at the Curb Adjacent to Safa Mosque

Segment 79 in (Figure 4.8), which is adjacent to a mosque, faces exceptionally heavy parking during prayer times. During these periods, the net road width nearly falls below the width of a single vehicle, severely restricting the flow of traffic. This reduction in road capacity persists throughout the duration of the prayer times, leading to significant congestion and increased risk of accidents. This illegal parking obstructs sightlines for both drivers and pedestrians, increasing the risk of accidents. To address these issues, it is essential to redesigning the intersections to discourage illegal parking.

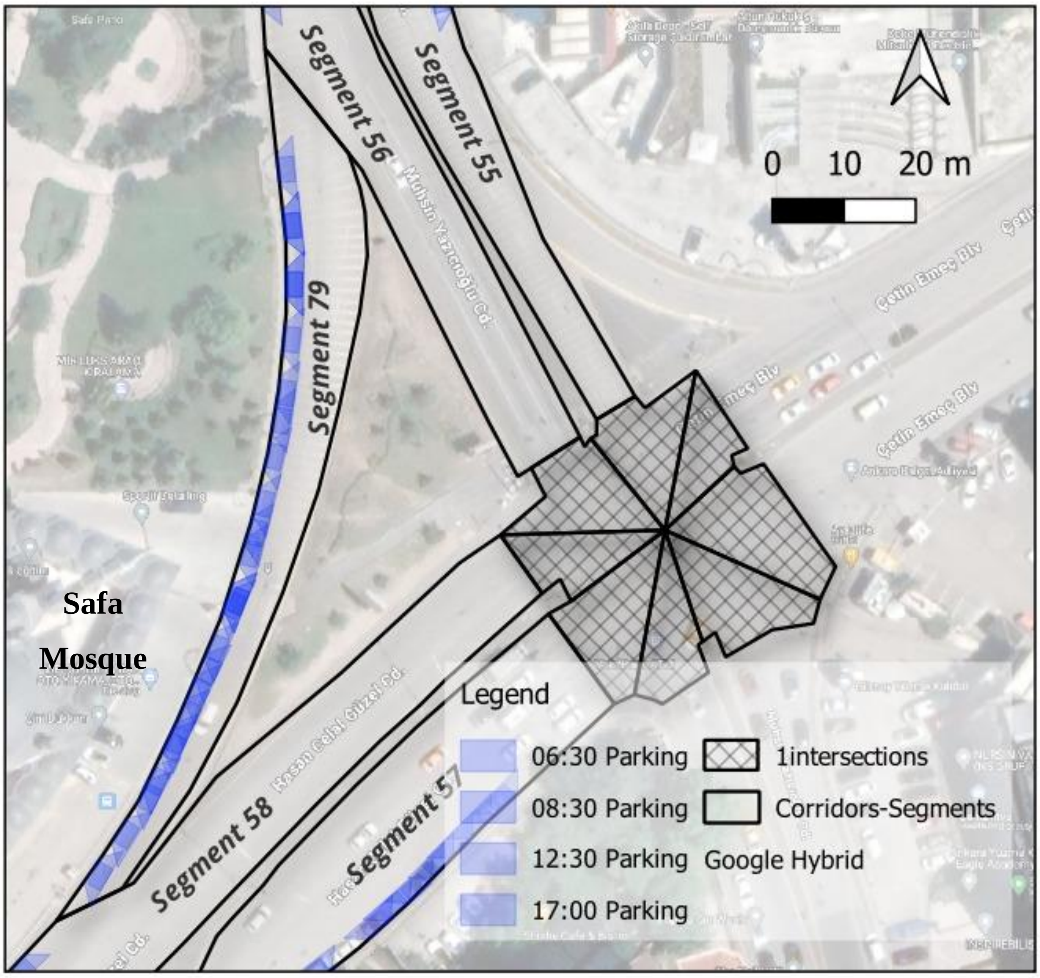


Figure 4.8 Segment 79 adjacent to Safa Mosque.

4.6.3 The METU Gate A1 Region

As shown in Figure 4.9, faces distinct parking challenges primarily due to the presence of cafes and restaurants in the neighborhood. These establishments attract significant vehicular traffic, leading to extensive roadside parking, particularly during their operating hours. Notably, the parking patterns in this area exhibit minimal activity at 06:30, indicating that the congestion is closely tied to the business hours of these commercial entities. Once the cafes and restaurants open, there is a marked increase in parking activity along Segment 2. This segment is part of an undivided and relatively narrow road, which exacerbates the potential for congestion. The narrow width of this road compared to others in the region makes it particularly susceptible to traffic jams, as the increased parking significantly reduces the effective road width available for moving vehicles.

The undivided nature of the road further complicates traffic flow. Even with vehicles parked on the single side of the street, it is enough to obstruct movement in both directions. This situation creates a high likelihood of congestion, especially during peak times when the cafes and restaurants are busiest. The analysis underscores the need for effective parking management strategies to mitigate the impact of roadside parking and maintain smooth traffic flow in this critical area near METU Gate A1.

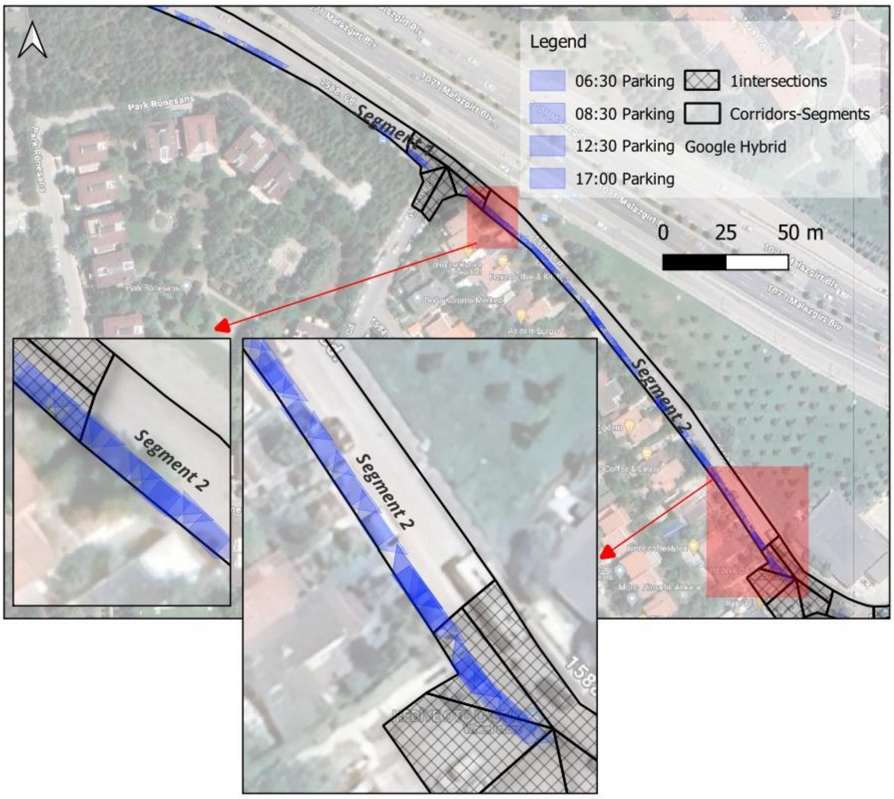


Figure 4.9 Parking in the region of METU campus gate A1

4.6.4 Areas Prone to Perpendicular Parking

Segment 33 is significantly affected by the perpendicular parking of taxis. These vehicles are present in the mornings, absent during peak hours, and return in the evenings. Their manner of parking creates a zigzag pattern that disrupts the flow of motorists passing by, adding a layer of complexity and potential hazard to this section of the road. The connection between Segments 73, 74, and 72 is another area heavily prone to perpendicular parking. The confluence of these segments creates a substantial parking hotspot, contributing to frequent traffic obstructions and requiring diligent monitoring and management to maintain smooth traffic flow. Segment 11 is particularly noteworthy due to the perpendicular parking occurring within the intersection itself. This practice not only reduces the net road width but also creates significant safety concerns, as it impedes visibility and maneuverability for vehicles navigating the intersection. Segment 47 faces perpendicular parking issues primarily due to the presence of restaurants along the road. This segment also experiences double parking, further complicating the traffic situation. There are two distinct portions of Segment 47 that are particularly prone to perpendicular parking, necessitating targeted interventions to mitigate the impact on traffic flow and safety.

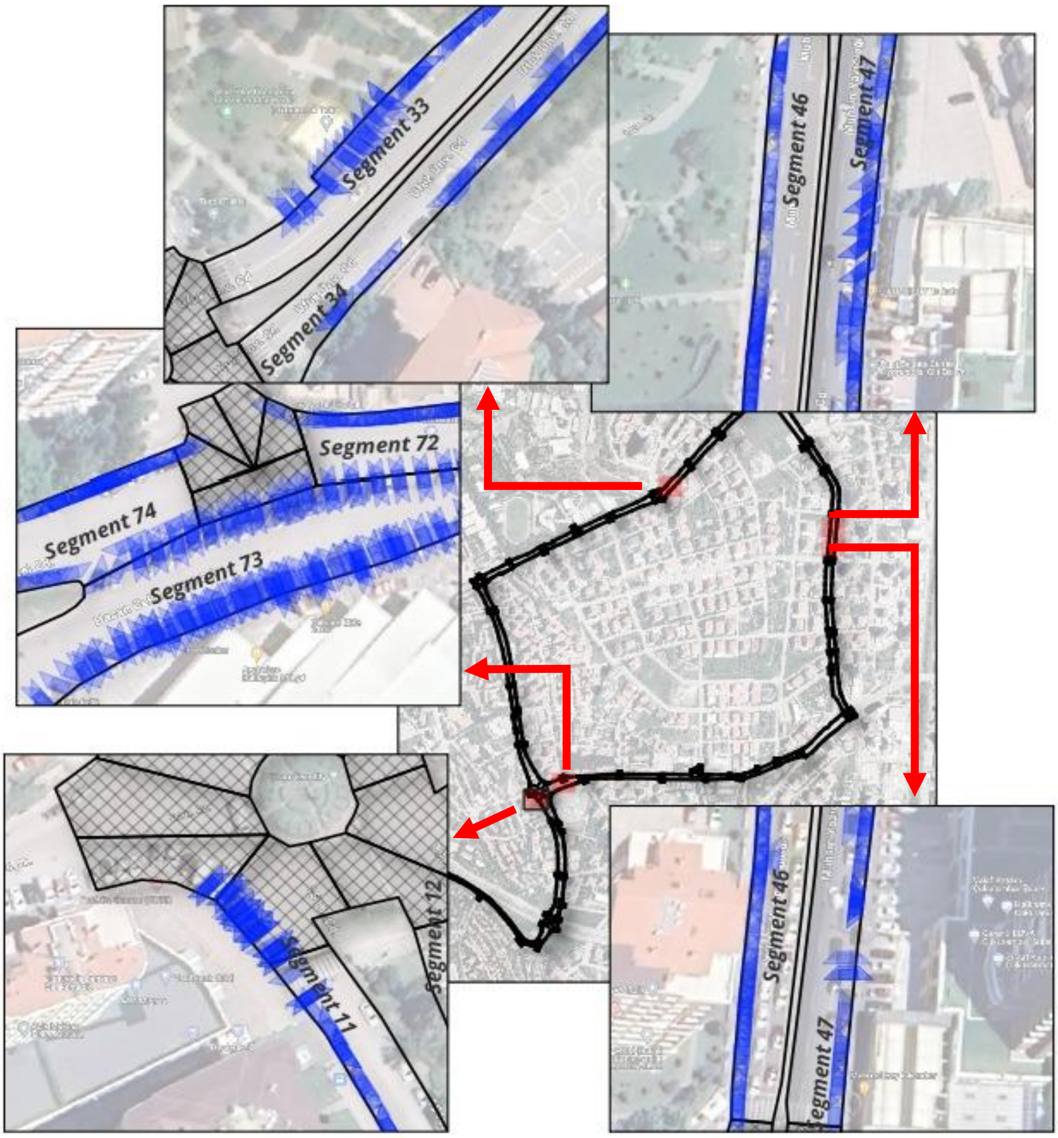


Figure 4.10 Areas prone to perpendicular parking.

CHAPTER 5

CONCLUSION

5.1 Key Findings and Implications

This study aimed to analyze the impact of roadside parking (especially the unregulated, illegal and hazardous ones) and its variability over time and space on the urban traffic network and management via simple and flexible GIS-based tool. The evaluation of roadside parking in a study area in the 100. Yıl neighborhood of Ankara, Turkey, shows that net road width after roadside parking can vary significantly which also affects the operational capacity of the road capacity, which can fluctuate within a day or among different days. This variation is primarily influenced by parking behaviors, especially when double parking becomes more prevalent. These findings underscore the need for dynamic traffic management strategies that can adapt to changing road conditions. Along corridors with dual carriage function (serving both directions) but limited capacity (such as 2-lane undivided roads), parking can severely reduce capacity and cause directional capacity loss, blocking the traffic flow. While parking on both sides of the divided roads can reduce the road capacity, the remaining road width may allow enough capacity to serve the demand, if the road geometry had enough physical width (such as 3 lanes); however, this still may cause safety problems to motorized traffic due to parking maneuvers from both sides. Furthermore, if parking is not officially allowed but unofficially observed like this, illegal parking behavior is indirectly reinforced causing more hazardous situations in other places, where parking on both sides of the streets can block the traffic flows, such as ramps or channelized sections at the intersections.

Safety and congestion are concepts which are also connected to each other. The research highlights how reduced road width due to parking, particularly double parking, increases the risk of accidents and traffic congestion. This situation not only affects traffic flow but also raises significant safety concerns, emphasizing the urgent need for effective parking management solutions.

Inadequate parking management is a problem to solve. The current parking management strategies in Ankara are insufficient. This inadequacy is most evident during the peak hours, suggesting that current policies and enforcement are not effectively deterring problematic parking behaviors. Additionally, in several locations, the NRW was reduced to less than the width of a single car, indicating critical areas where stricter parking fines and regulations should be implemented to prevent such occurrences. At bottleneck sections, the current traffic signalization may be contributing to congestion and should be reevaluated to improve traffic flow. These areas, in particular, could benefit from adjusted signal timings or additional traffic control measures to reduce the congestion.

Implementing these solutions would likely lead to dramatic improvements. The study demonstrates a significant impact by showing that problems can be swiftly identified and that practical recommendations can be formulated within a single day using methods of this study. This responsiveness is crucial for urban planning and could contribute substantially to enhancing overall traffic management and safety. If these measures are applied effectively, the positive changes in traffic flow and road safety could be observed shortly after implementation, showcasing the study's practical benefits in addressing urban traffic issues.

5.2 Recommendations for Decision Makers

Need for increased parking enforcement is obvious. However, before enforcement, it is necessary to clearly define and designate the parking permits and restrictions in urban road networks, thus, there is a clear need for clear parking regulations. The roadside parking regulations. Road corridors should be classified according to allowed parking permits such as i) parking on one-side (designating which side is allowed), ii) parking on both sides, and iii) no-parking zones. Roadside parking capacity should be designated by road marking and lines clearly designating the start and end of parking permit limits: these zones can be further divided into parking spaces as defined in the standards or simply left undivided to accommodate various sizes of vehicles. Continuous monitoring is the key for adaptation. Utilizing GIS for regularly monitoring parking patterns and road capacity is crucial. This ongoing assessment can inform traffic management decisions, allowing for more responsive and effective strategies to cope with the dynamic nature of road usage and parking behaviors. By the iteration of investigation, traffic authorities can adopt to changing variables of illegal parking.

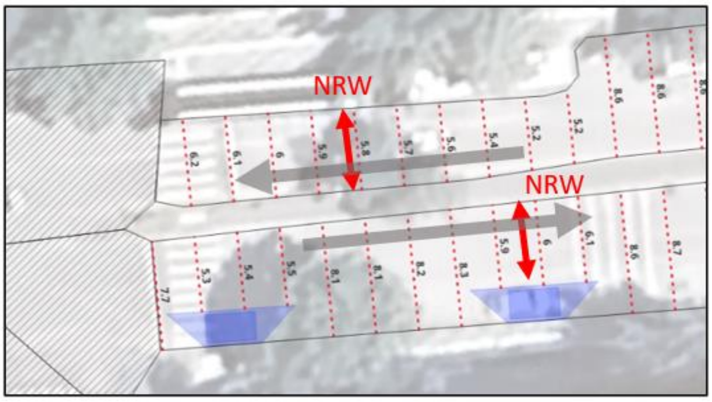
As a second stage, parking enforcement should be continuously performed (2-3 times a day) and at severe parking demand periods (such as school start and end times, marketplace days, etc.) where traffic flow is guaranteed. This requires a authorized parking enforcement personnel provided by the municipalities, as handled in many developed countries as police and gendarmerie do not have enough manpower to monitor and enforce all the urban road network. Even smart parking enforcement systems can be utilized at very critical and highly demanded corridors. But, for better results, enforcement should be coupled with public awareness campaigns to educate drivers about the impact of their parking choices. By education indirect solutions may also come to life like mass-transportation choice to single person vehicle usage.

Alternative parking solutions are very convenient strategies. Developing additional parking spaces or structures, particularly in high-demand areas and during critical times, could alleviate some of the pressure on road capacity. These solutions should be planned in a way that integrates seamlessly with the existing urban infrastructure.

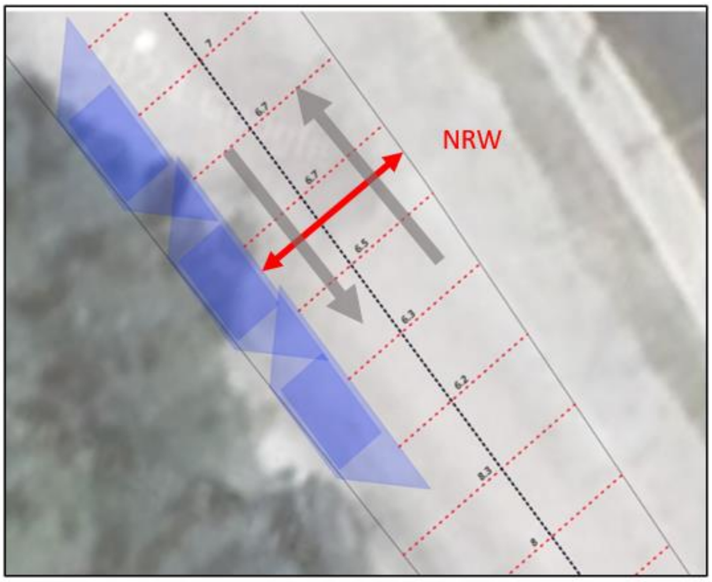
5.3 Enhancements (Future Research Directions)

Need for Estimation of Directional NRW on Undivided Roads

In this thesis, the calculation of NRW for divided roads is defined as shown in Figure 5.1a. For undivided roads, the definition is depicted in Figure 5.1b. Unlike divided roads, undivided roads lack physical separation, allowing vehicles to trespass into opposite lanes. This characteristic necessitates calculating NRW using the entire road capacity, thus capturing the real situation on such roads.



(a)



(b)

Figure 5.1 NRW on divided and un-divided roads

However, to correctly understand the NRW of individual directions, a new concept should be established. This involves using an imaginary centerline on undivided roads for calculation, introducing the concept of "Directional Net Road Width" (DNRW). (Figure 5.2) This approach can be particularly helpful in understanding capacity shortages due to illegal parking on undivided roads more accurately on the directional basis. Even though vehicles may utilize the entire road capacity, the concept of directional net road width should be investigated and analyzed separately. By using DNRW, more precise understanding of the impact of illegal parking on each direction's capacity can be gained, ultimately leading to more effective traffic management strategies.

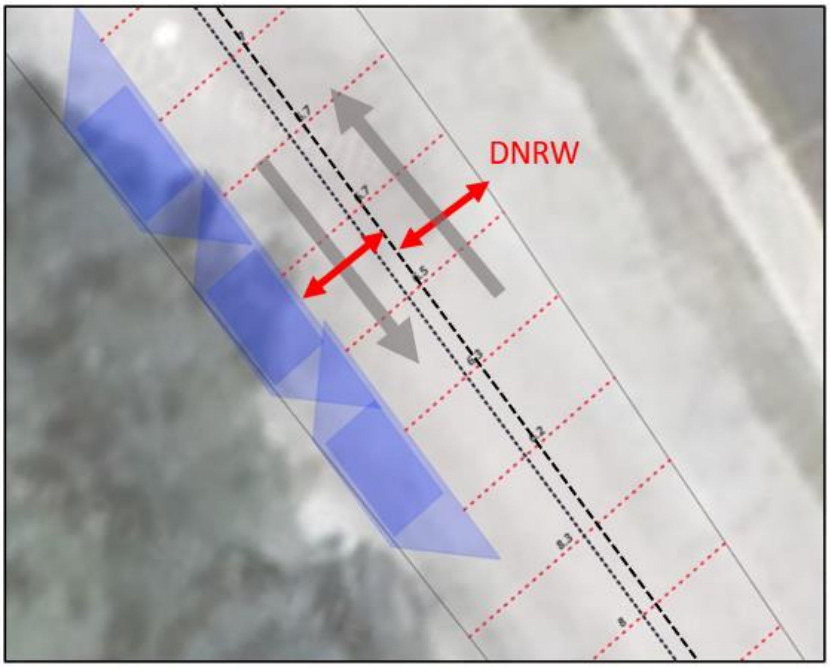


Figure 5.2 Directional Net Road Width (DNRW)

Evaluation of Parking at Intersections

Although this study did not specifically focus on this aspect, GIS analyses revealed that parking also occurs within intersections. It was observed that out of a total of 377 vehicles parked along the road, 23 were parked inside intersections. (Figure 5.3)

This finding suggests that if the research is further developed, a separate investigation into parking within intersections is warranted.

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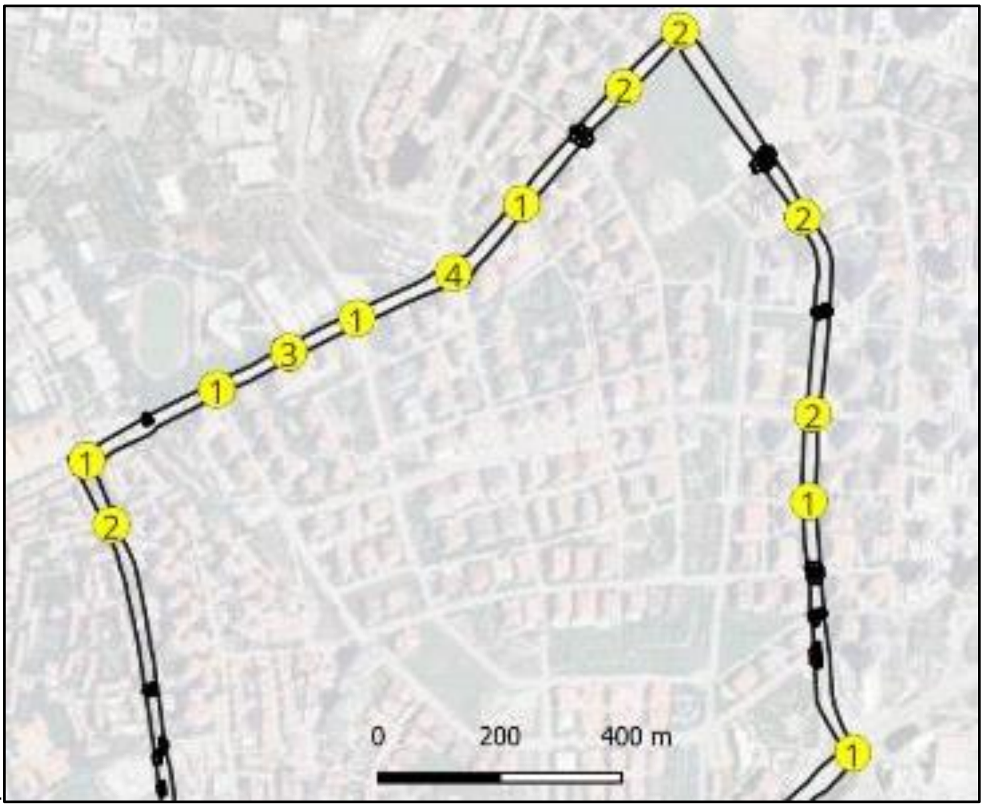

Figure 5.3 Parking Quantities Inside Intersections

Mapping of Parking Hazardous to Non-Motorized Transportation

An essential direction for future research involves the mapping of illegal parking that poses significant hazards to non-motorized transportation. This research should focus on the detection and analysis of illegal parking in critical areas such as pedestrian crossings, bus stops, and school crossings, which are particularly vulnerable to the dangers posed by unauthorized parking. Detecting illegal parking at pedestrian crossings is high in importance. (Figure 5.4) Vehicles parked too close to or directly on pedestrian crossings obstruct the view for both drivers and pedestrians, thereby significantly increasing the risk of accidents. Such obstructions compel pedestrians to maneuver around parked cars, often stepping into the path of oncoming traffic. This scenario is particularly perilous for children, the elderly, and individuals with disabilities.

Bus stops is also crucial for ensuring the efficiency and safety of public transportation. Illegally parked vehicles at bus stops hinder buses from pulling in properly, causing delays and forcing passengers to board or alight in the middle of the road. This not only disrupts the flow of traffic but also places passengers at a higher risk of accidents, especially during peak hours. The detection of illegal parking around school crossings is vital. School zones are high-traffic areas, particularly during the start and end of the school day. Vehicles parked illegally in these areas endanger young students who may not be fully aware of traffic rules and are at greater risk of being involved in accidents. Illegal parking in these zones also causes significant traffic congestion, creating hazardous conditions for schoolchildren and their caregivers. In addition to these examples, other areas of concern include parking in bike lanes, near emergency exits, and in front of fire hydrants. Each of these situations presents unique challenges and dangers, necessitating comprehensive mapping and detection efforts to address them effectively. Future research should focus on developing advanced GIS-based tools and methodologies to identify and map these hazardous parking behaviors.

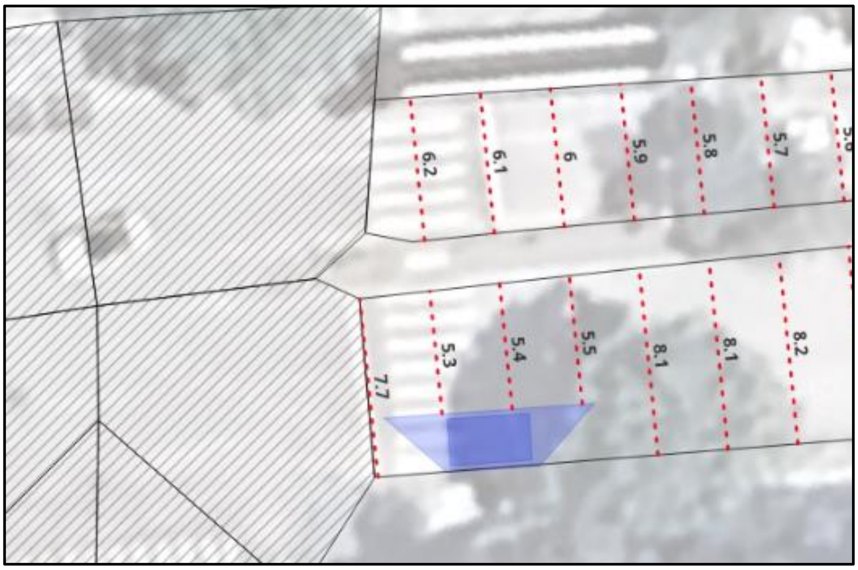

Figure 5.4 Parking on pedestrian crossings

Artificial Intelligence and Complete Automation of the Proposed Methodology

The innovative methodology presented in this thesis is also open to further advancements. Until now, this study has enabled semi-automated data collection and processing. The next step is to fully automate the process. This could be achieved through a portable device equipped with a camera(s), a mini-computer (such as a Raspberry Pi), and a GSM card. Arduino based hardware – software hybrids can be effectively deployed. This technological enhancement offers the possibility of mounting the device in various vehicles that are frequently at the center of traffic issues, such as police cars or ambulances. The device would use its camera in conjunction with real-time GPS coordinates and incorporate an automatic car-detection algorithm to pinpoint the location of parking violations. An internal GIS software would process the data, and an integrated email system could then send tables and color-graded thematic maps directly to users. As AI technology continues to advance rapidly, there is potential for integrating this concept into all vehicles, enabling nationwide detection of parking violations and the automated updating of electronic parking signs. This approach not only enhances the efficiency of traffic management but also aligns with contemporary trends in smart transportation solutions.

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