ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

AN ALTERNATIVE APPROACH TO ACCIDENT ANALYSIS AND PREVENTION: ROAD SAFETY AUDIT

M.Sc. THESIS

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Department of Civil Engineering

Transportation Engineering Programme

JULY 2020

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KAZA ANALİZİ VE ÖNLENMESİNE ALTERNATİF BİR YAKLAŞIM: YOL GÜVENLİK DENETİMİ

YÜKSEK LİSANS TEZİ

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Hasanburak Yücel, a M.Sc. student of İTU Graduate School of Science Engineering and Technology student ID 501171405, successfully defended the thesis entitled "AN ALTERNATIVE APPROACH TO ACCIDENT ANALYSIS AND PREVENTION: ROAD SAFETY AUDIT", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my wife and daughter,

FOREWORD

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ABBREVIATIONS

RSA	**:** Road Safety Audit
RSI	**:** Road Safety Inspection
GIS	**:** Geographic Information Systems
WHO	**:** World Health Organization
FHWA	**:** Federal Highway Administration
KDE	**:** Kernel Density Estimation
AASHTO	**:** American Association of State Highway and Transportation Officials

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AN ALTERNATIVE APPROACH TO ACCIDENT ANALYSIS AND PREVENTION: ROAD SAFETY AUDIT

SUMMARY

From past to present, traffic accidents are one of the biggest reasons that distinguish people from their families. According to the World Health Organization (WHO), approximately 1.3 million people die every year due to traffic accidents. About 2% of deaths in the world occur due to traffic accidents. In addition, traffic accidents have devastating effects on the economy. For instance, It is estimated that the financial loss and side effects that occur in traffic accidents cause an average of 500 billion dollars a year loss. As seen, traffic accidents cause serious damages all over the world.

There are many studies around the world to prevent traffic accidents. Some of these studies take precautions before the accident, while others identify the points where accidents occur frequently and develop measures. The points where accidents occur frequently are called accident hot spots. In accident hot spot identification, the points where accidents occur frequently are determined by various methods, and the necessary precautions are tried to be established by establishing a spatial relationship. In this thesis, firstly, methods of determining accident hot spots are explained. In hot spot analysis, the most accurate results are obtained with the methods in which spatial analyzes are used together with statistical methods.

One of the most common studies in the world within the scope of road safety is the Road Safety Audit. The Road Safety Audit, which was carried out for the first time in England, has been carried out in many countries for more than thirty years. Road Safety Audit basically follows the steps of auditing a road section, determining safety problems, and taking necessary measures. In the Road Safety Audit, analyzes are carried out in the field with the help of various checklists, and the problematic points are tried to be determined. The main topics in the checklists are; general topics, intersections, interchanges, alignment, and cross-section. In addition, road users and road surface issues are also evaluated. All these issues have been examined within the scope of this study. In the audit, road safety is evaluated by answering questions under these issues.

Within the scope of this thesis, the accidents that occurred in Ankara between 2016-2019 were examined with the help of the Geographical Information Systems supported by the Kernel Density method. As a result of the analysis, the Road Safety Audit was carried out for Atatürk Boulevard, where most accidents occurred. In Road Safety Audit; general issues, intersections, interchanges, alignment, cross-section, road user and road surface were inspected. As a result of the analyzes, it was determined that Atatürk Boulevard, which was built approximately 100 years ago, is the busiest region of the city and could not meet the traffic demand. In addition, the difference between the design speed and the average speed of the drivers has been found to cause safety problems. Besides, it is determined that advertisement signs are frequent because of

being the busiest region of the city and this restricts the view distance. Moreover, some deformations on the road surface have been observed to cause safety problems.

Furthermore, it has been determined that the design contains safety problems for disabled individuals and bicycle users. As a result, it was determined that Atatürk Boulevard could not meet the traffic density of today, but with the measures taken, there would be a decrease in the number of accidents.

KAZA ANALİZİ VE ÖNLENMESİNE ALTERNATİF BİR YAKLAŞIM: YOL GÜVENLİK DENETİMİ

ÖZET

Günümüzde trafik kazaları insanları sevdiklerinden ayıran en büyük nedenlerden birisidir. Dünya Sağlık Örgütü (WHO)' nün verilerine göre her yıl yaklaşık 1,3 milyon insan trafik kazaları yüzünden hayatını kaybetmektedir. Dünyada meydana gelen ölümlerin yaklaşık %2'si trafik kazaları nedeniyle olmaktadır. Bunun yanında, sakat kalan insanlar hem fiziksel hem de psikolojik olarak topluma adapte olmakta zorluk yaşamaktadır. Ayrıca, trafik kazalarının ekonomi üzerinde yıkıcı etkileri olmaktadır. Trafik kazalarında meydana gelen maddi kayıpların ve yan etkilerinin yılda ortalama 500 milyar dolar kayba neden olduğu tahmin edilmektedir. Emniyet Genel Müdürlüğüne göre trafik kazaları ülkelerin yıllık gayri safi milli hasılasında ortalama %2'lik bir kayba sebep olmaktadır. Görüldüğü üzere, trafik kazaları dünya üzerinde hem maddi hem manevi ciddi kayıplara sebep olmaktadır.

Trafik kazalarını önlemek için Dünya genelinde birçok çalışma yapılmaktadır. Bu çalışmalardan bazıları kaza öncesi önlemler alırken, bazıları kazaların sıkça gerçekleştiği noktaları tespit edip önlemler geliştirir. Kazaların sık sık meydana geldiği noktalara kaza kara noktaları denmektedir. Kaza kara noktaları belirleme çalışmaları 20 yılı aşkın süredir yürütülmektedir. Bu çalışmalarda temel olarak, kazaların sıkça gerçekleştiği noktalar çeşitli yöntemlerle belirlenir, kaza-mekân ilişkisi kurularak gerekli önlemler alınmaya çalışılır. Bu tez kapsamında öncelikle kaza kara noktaları belirleme yöntemleri açıklanmıştır.

Kaza kara nokta belirleme yöntemleri temel olarak, geleneksel yöntemler, mekânsal analizler ve istatiksel metotlar olarak üçe ayrılır. Kaza sayısı, kaza frekansı ve kaza şiddeti metotları geleneksel yöntemlerdendir. Geleneksel yöntemler temel olarak kazaların sayısını, gerçekleşme sıklığını, ölümlü veya yaralı insan sayısını göz önüne alarak hesaplamalar yapar. Fakat, mekânsal analizleri göz ardı ettiği için çok güvenilir sonuçlar vermez. Mekânsal analizler kaza konumu verileri ile yapılan analizlerdir. Kaza konumlarının proje alanına işlenebilmesiyle birlikte kazalar arasında daha doğru ilişki kurulabilir. Böylelikle, kazaların sık gerçekleştiği yerler daha güvenilir olarak elde edilir.

Bir diğer yöntem olan istatiksel metotlar, kaza kara nokta belirleme çalışmalarında en güncel yöntemlerdir. Çekirdek Yoğunluğu yöntemi, Negatif Binomial regresyon, Poisson regresyon ve Ampirik Bayes yöntemi kaza kara nokta analizlerinde en çok kullanılan istatiksel yöntemlerdir. Kara nokta analizlerinde en doğru sonuçlar mekânsal analizlerin istatiksel yöntemlerle birlikte kullanıldığı metotlarla elde edilmektedir.

Yol güvenliği kapsamında Dünya'da yapılan en yaygın çalışmalardan biri de Yol Güvenlik Denetimidir. İlk defa İngiltere'de yapılan Yol Güvenlik Denetimi, 30 yılı aşkın süredir birçok ülkede uygulanmaktadır. Yol Güvenliği Denetimi temel olarak bir yol kesiminin denetlenmesi, güvenlik sorunlarının tespit edilmesi ve gerekli önlemlerin alınması adımlarını takip eder.

Yol Güvenlik Denetimi, fizibilite aşaması, ön tasarım, ayrıntılı tasarım, açılış öncesi ve mevcut yollar olmak üzere yol projesinin farklı aşamaları için gerçekleştirilebilir. Esasen Yol Güvenlik Denetiminin yol kullanıma geçmeden yapılması tercih edilir. Bu sayede tespit edilen güvenlik sorunları hem kolaylıkla düzeltilebilir hem de düşük maliyetli olur. Fakat, mevcut yollar için de Yol Güvenlik Denetimi yapılmaktadır ve başarılı sonuçlar vermektedir.

Yol Güvenlik Denetiminin üç paydaşı vardır bunlar; müşteri ekibi, tasarım ekibi ve denetim ekibidir. Müşteri ekibi, bir yol kesimi için yol güvenlik denetimi yapılmasını talep eden taraftır. Müşteri ekibi, bunun için denetim ekibi ile anlaşır; denetim ekibi ile iletişim kurulması ve teknik yönden uygulamanın denetlemesi için ise tasarım ekibi ile çalışır. Tasarım ekibi, yol kesimi ile ilgili gerekli verileri denetim ekibi için temin eder, müşteri ekibinin beklentilerini denetim ekibine iletir. Bunun yanında, denetim ekibinin gündeme getirdiği konuları dikkate alır. Bunun yanında, denetimde bir problem olması durumunda müşteri ekibini bilgilendirir. Denetim ekibi, proje ile ilgili geçmiş bilgileri dikkatlice analiz eder ve proje alanında denetimler yapar. Denetim ekibi, müşteri ekibi ve tasarım ekibinin beklentilerini net olarak anlamalıdır. Bunun yanında, detaylıca saha analizleri yaparak güvenlik sorunlarını etraflıca analiz etmelidir. Bunun sonucunda, güvenlik sorunlarını detaylıca açıklayan, net bir şekilde anlaşılır teknik bir denetim raporunu müşteri ve tasarım ekibine sunmalıdır.

İlk defe İngiltere'de kullanılan Yol Güvenlik Denetimi, günümüzde birçok ülkede kullanılmaktadır. Özellikle Yeni Zelanda, Avustralya ve Kanada gibi ülkeler, Yol Güvenlik Denetimi alanında tecrübe kazanmış, başarılı ülkelerdir. Yol Güvenlik Denetiminde çeşitli kontrol listeleri yardımıyla sahada analizler yapılarak, sorunlu noktalar belirlenmeye çalışır. Kontrol listeleri ülkeden ülkeye ve denetim ekibinin tecrübesine göre değişmektedir. Deneyimli denetim ekipleri temel konuları içeren kontrol listelerini kullanırken, diğer denetim ekipleri daha detaylı kontrol listelerini tercih etmektedir. Kontrol listelerinde bulunan temel ana başlıklar; genel konular, kavşak, hemzemin kavşak, aliyman ve en kesit konularıdır. Bunun yanında, yol kullanıcısı, görsel tasarım ve yol yüzeyi gibi konularda denetlenmektedir. Bu çalışma kapsamında tüm bu başlıklar incelenmiştir. Denetimde bu başlıklar kapsamında sorular belirlenerek yol güvenliği denetlenir.

Bu tez kapsamında Ankara ilinde 2016-2019 yılları arasında meydana gelen kazalar Çekirdek Yoğunluğu yöntemi destekli Coğrafi Bilgi Sistemleri yardımıyla incelenmiştir. Yapılan analiz sonucunda en çok kazanın meydana geldiği Atatürk Bulvarı için Yol Güvenlik Denetimi yapılmıştır. Yol Güvenlik Denetiminde; genel konular, kavşak, hemzemin kavşak, aliyman, en kesit, yol kullanıcısı, görsel tasarım ve yol yüzeyi gibi konularda denetimler yapılmıştır.

Yapılan analizler sonucunda yaklaşık 100 yıl önce yapılmış olan Atatürk Bulvarı'nın şehrin en yoğun bölgesi olması sebebiyle trafik talebini karşılayamadığı tespit edilmiştir. Bunun yanında, tasarım hızı ile sürücülerin ortalama hızları arasındaki farkın güvenlik sorunlarına neden olduğu tespit edilmiştir. Ayrıca, şehrin en yoğun bölgesi olması sebebiyle reklam tabelaların sık olduğu bunun da görüş mesafesini kısıtladığı tespit edilmiştir.

Bunlara ek olarak, yol yüzeyindeki bazı deformasyonların güvenlik sorunlarına yol açtığı gözlemlenmiştir. Ayrıca, tasarımın engelli bireyler ve bisiklet kullanıcıları için güvenlik problemleri içerdiği tespit edilmiştir. Sonuç olarak Atatürk Bulvarı'nın günümüzdeki trafik yoğunluğunu karşılayamadığı, fakat yine de alınan tedbirlerle kaza sayılarında düşüş olacağı saptanmıştır.

1. INTRODUCTION

1.1 Motivation

Road transport is the most preferred mode of transportation in the world because of without need for any transfer. According to data from the Ministry of Environment and Urbanisation, in 2017, usage of the road at passenger transport is % 88.8, while at freight transport is % 89.2 (The Ministry of Environment and Urbanisation, 2020). Besides, popularity of road transport is increasing day by day. For instance, in 2019, according to the Turkey Statistical Institute data as of May, there are 23 million vehicles registered to traffic in Turkey (Turkish Statistical Institute, 2019a).

The most negative aspect of road transport is traffic accidents. According to the World Health Organization (WHO), approximately 2% of deaths in the world occur due to traffic accidents (World Health Organization, 2018b). Moreover, 1,35 million people died in the world in 2018 due to traffic accidents (World Health Organization, 2018a). In Turkey, in 2018 about ten thousand people lost their lives due to traffic accidents. Traffic accidents also cause serious economic losses. It causes an average of five hundred billion dollars of loss every year all around the world (Michalowska and Oglozinski, 2017). Besides, according to the General Directorate of Police, as a result of traffic accidents, there is an economic loss amount of 2% of the average annual gross national product of a country (General Directorate of Security, 2020a). Traffic accidents cause serious injuries not only financially but also spiritually. It takes years for a person who lost any of his relatives or became disabled as a result of a traffic accident to be brought back to society and to contribute to production. These people need intense rehabilitation due to the social, physical and psychological breakdown they undergo.

Traffic accidents occurring on highways can be prevented or minimized by measures to be taken. One of these precautions is the determination of the places where accidents are frequent. These areas where traffic accidents are concentrated are called accident hot spots (Elvik, 2008). By establishing a relationship about accidents that occur between accident hot spots, it can be determined that reasons of accidents. There are many different accident hot spot detection methods from past to present. The most widely used methods in recent years are Geographic Information Systems (GIS) and spatial statistics methods. With the model to be developed with Geographical Information Systems aided spatial statistical methods, we can identify accident locations, explain the cause of accidents, and take measures to prevent accidents.

Another method to prevent traffic accidents is Road Safety Audit (RSA). With the Road Safety Audit (RSA), audits can be performed for projects that are under construction, about to be completed and completed. In these evaluations, safety problems, especially traffic accidents, are determined regarding the road, and precautions are taken for these roads. Besides, permanent solutions are developed.

The purpose of this thesis study is to determine the accident hot spots with the help of Geographic Information Systems and Kernel Density Method by examining the traffic accidents that occurred in Ankara between 2016-2019. In addition, after determining the accident hot spots, the Road Safety Audit method will be applied, and improper designs will be identified in the road project, and permanent solutions will be developed to minimize accidents.

1.2 Scope of Thesis

Within the scope of this thesis, firstly traffic accidents that occurred in Ankara province between 2016-2019 have been examined. Then, accident hot spots were determined with the help of Kernel Density Method supported by Geographic Information Systems.

Afterwards, the regions with accident hot spots were examined for the 6 main subjects of Road Safety Audit. These 6 main issues are; General Issues, Intersections, Alignment and Cross sections, Interchanges, Road users and Road Surface. Due to the lack of some data during the audit, certain investigations could not be made. As a result of the examinations, after examining the problematic points along the road segment according to the Road Safety Audit criteria, solution suggestions were brought, and a Road Safety Audit report was created.

1.3 Thesis Contributions

The accident hot spot determination studies that have been carried out until this date are completed by making very shallow recommendations after determining the accident hot spot. But it is as important to find a solution as it is to identify dangerous points. As a matter of fact, accidents occur in the same regions year by year. This thesis study aims to prevent accidents by bringing solutions with the Road Safety Audit of accident points. Furthermore, demonstrating the importance of Road Safety Audit for projects carried out in the short term, it is done in the long term in Turkey for the planned project aims to promote the Road Safety Audit method.

1.4 Thesis Organization

This thesis study consists of six chapters. In the first part, the motivation of the thesis, the topics covered by the thesis and the planned contributions of the thesis are explained. In the second part, previous studies on Geographic Information Systems and Kernel Density Method are mentioned. In addition, the definition, purpose, history, checklists, stages, process and organizational structure of the Road Safety Audit are mentioned. In addition, the work done by the leading countries in the Road Safety Audit method is explained. Also mentioned is the Road Safety Inspection (RSI), which is seen as a different audit in some countries. Chapter 3 describes the method followed to identify accident hot spots. Also, in this section, Geographic Information Systems and Kernel Density Method are explained in detail. In addition, their use in accident hot spot determination studies is mentioned. In Chapter 4, the Road Safety Audit method is described in detail. The six titles of the Road Safety Audit which are Intersections, Interchanges, General Issues, Alignment and Cross sections, Road Surface and Road Users topics are explained in detail. In addition, subtitles of these 6 main titles and questions about these subtitles are included. In the 5th section, transport data, traffic characteristics and traffic accident data of Ankara province, which was chosen as the project area, were examined. Atatürk Boulevard, which was selected as a study area in section 6, was examined according to the main and subtitles explained in detail in section 4. In addition, the identified safety problems are explained. Finally, in the 7th section, the results and suggestions obtained as a result of Road Safety Audit are given.

2. ROAD SAFETY ANALYSIS

In this chapter accident analysis methods and road safety evaluation methods are explained. First of all, the studies conducted with the Geographical Information Systems used in determining the accident hot spots, which are called the hot spots where accidents are clustered, are explained. Then, studies on Kernel Density Estimation, which are frequently used in accident hot spot analysis, are included. In this section, other spatial statistical studies are also explained besides the Kernel Density Estimation. In the next section, Road Safety Evaluation methods are described at the basis of Road Safety Audit. Firstly, the definition, history, checklists, organization, stages and process of the Road Safety Audit method are explained. Afterwards, countries that worked on Road Safety Audit and experienced in this field were explained. Finally, the Road Safety Audit, which is considered to be slightly different in some countries, has been explained and its differences with the Road Safety Audit have been explained.

2.1 Traffic Accident Analysis Methods

Studies on the determination, analysis, and prevention of traffic accidents have been going on for many years. In these studies, the hot spots where accidents are frequent, are determined. Then, precautions are taken to these areas. These areas, where accidents are intense, are called accident hot spots. In the traffic accident analysis, different criteria are ascendant in urban and rural roads in determining the regions where the accident is clustered. In the urban road network, it is more complicated to identify accident hot spots, as complex parameters such as pedestrian crossings, public bus stops, shopping malls, cycling and squares come into play.

On rural roads, relatively fewer complex parameters such as, road geometry, flow characteristics, environmental factors, weather conditions and daylight are effective. For this reason, it is relatively easy to identify accident hot spots on rural roads. Usually, hot spots are determined with accident rate, accident frequency, severity index methods in rural roads in Turkey (SweRoad, 2001). However, these methods remain inefficient in determining urban accident hot spots (Anastasopoulos et al., 2012). Spatial and statistical analysis must be used at urban hot spot identification.

2.1.1 Geographic Information Systems

Geographic data that showing the place of accident, plays an important role in determining accident hot spot. By using geographical data, it can obtain information not only about the coordinates of the accidents but also about their relationship with accidents in clustered regions. Geographic Information Systems is one of the applications that analyses geographical data (Lloyd, 2010). Geographic Information Systems (GIS) is a computer-based system that combines, geographic data, people, hardware and software. Besides, GIS collects, stores, analyses, processes and offers spatial results (Aronoff, 1989). Geographic Information Systems is a very safe and comprehensive tool for determining accident hot spots with data sets, analysis tools, map sets. By using Geographical Information Systems, parameters such as accident time, number of deaths, number of injured person and accident location can be stored. In addition to this information, the causes of accidents can be analyzed.

Geographic Information Systems, which are very useful for accident analysis, have been used in hot spot identification since the 90's. Spring and Hummer (1995) combined road features and geometric designs with Geographic Information Systems, made an accident analysis for Guilford city. In their study, Kim and Levine (1996) developed a Geographic Information System for spatial analysis of traffic accidents in Honolulu, Hawaii. Spatial analysis that including points, regions, and segments, was investigated.

In their study, Affum and Taylor (1996) developed a Safety Evaluation Method for Local Area Traffic Management (SELATM). This method is a GIS-based program developed to analyze accident types according to time. In their study, Özkan and Işıldar (2001) explained the importance of GIS in order to classify accidents according to their reasons. They stated that the calculations and adjustments to be made give more consistent results in the computer-based systems.

Hirasawa and Asano (2001) made inferences about traffic accident locations and causes by transferring 10-year traffic accident data to GIS, considering road geometry, roadside objects, and weather. In their study, Karaşahin and Terzi (2003) conducted a

GIS-based analysis by examining the 3-year accident data between Isparta Antalya-Burdur roads. Erdogan et al. (2008) applied GIS-based Kernel Density Estimation to determine the locations where accidents occur at a high rate in their study.

2.1.2 Spatial Statistical Analysis

One of the most prevalent methods used in traffic accident analysis is the analyzes made using the statistical method. The usage of statistical studies in accident analysis has increased since the early 2000s. Kernel Density Estimation, Negative Binomial, Poisson regression, and Empirical Bayes methods are some of the statistical analysis methods used for accident hot spots. In this section, firstly, studies on Poisson Regression, Negative Binomial, and Empirical Bayes method will be explained, then studies on Kernel Density Estimation will be explained in detailed.

Jovanis and Chang (1986) tried to establish a relationship between the traveled road length and the possibility of an accident. In this study, they tried to find out which methods are more successful by comparing traditional accident hot spot determination methods and the Poisson Regression method. As a result of the analysis, they concluded that Poisson Regression gives better results and if the amount of road traveled increases and road is rainy, the probability of an accident increases.

Miaou (1994) tried to determine which statistical method was successful according to the length of the road section by comparing Poisson Regression and Negative Binomial method. Besides, Miaou tried to explain the relationship between the geometry of road and traffic accidents by using statistical methods.

Poch and Mannering (1996) used a Negative Binomial model-based statistical method for urban intersections. In this study, they examined the traffic accidents that occur around the intersection. In addition, they stated that the Negative Binomial method gave more accurate results than Poisson Regression due to the excess spread in traffic accident data.

Schlüter et al. (1997) revealed that the Empirical Bayes method yielded successful results as a result of examinations in 35 different regions in New Zealand. Hauer and Bamfo (1997) claimed that the most important approach for the identification of accident hot spots is the Empirical Bayes method.

Abdel-Aty and Radwan (2000) tried to determine the impact of annual average daily traffic, lane width, the classification of the road, the length of the road, the speed of the road design, the road user characteristic on accidents by using the Negative Binomial method. As a result of the studies, they found that on the roads with low lane width, female drivers were more involved in the accident. In addition, they found that male drivers often had an accident due to over speeding. In addition, they stated that young drivers were involved in accidents in the curves and on the roads with low lane width.

In their study, Jones and Jørgensen (2003) examined the applicability of the Bayes method to understand the relationship with age, gender, vehicle type, characteristics of the road segment in fatal and serious injury accidents. Cheng and Washington (2005) compared the accident rate, confidence interval, and Empirical Bayes method, and showed that the Empirical Bayes method produced significantly better results.

Lord et al. (2005) in their study, tried to determine which method will give the most accurate results according to traffic accident data. As a result of their analysis, they stated that Poisson Regression method gives more accurate results if the accident data is homogeneous and excess zero. Besides, Negative Binomial method gives more accurate results in case of excess spread. Mitra and Washington (2007) used distribution parameter and Bayes method to understand the relationship between accidents that occur at intersections.

Li et al. (2007) analyzed the 5-year traffic accident data for the city of Houston with the CBS-based Empirical Bayes method. They stated that CBS-based Empirical Bayes method was effective in predicting the probability of interrelated accidents and eliminated the instability in future safety improvements.

As a result of this comparison, they stated that the Poisson model can be used in all situations except that the average is very low, and the Negative Binomial method is weaker in accident statistics than Poisson Regression. In their study, El-Basyouny and Sayed (2009) examined the data set of 392 different segments with Empirical Bayes aided method and found that various common parameters significantly affect the frequency of accidents.

In their study, Lord and Mannering (2010) used the Empirical Bayes method to determine the frequency of accidents and achieved successful results. In their study, Daud and Ibrahim (2009) used the posterior mean and Empirical Bayes method in the examination of the frequency of accidents between the 2 locations and achieved successful results.

2.1.2.1 Kernel Density Estimation Method

One of the most used spatial statistical methods in traffic accident analysis is the Kernel Density Estimation. By using Kernel Density Estimation, the data are grouped in certain areas and the densities per group are calculated. Thus, the density of the relevant area over entire area is determined. In their study, Chainey et al. (2002) analyzed crime data in London and aimed to create hot spots places where crimes occur frequently. In this study, they used the Kernel Density Estimation. As a result of the analysis, they defined the regions that exceed certain averages as hot spots.

Erdogan et al. (2008) examined 8-year traffic accident data for Afyonkarahisar province and determined the accident hot spots with the Kernel Density Estimation. During the analysis, they tried to identify the factors affecting accidents. In addition, they used Geographic Information Systems in the study. As a result of the analysis, it presented the possibilities for accidents to occur according to the seasons and hours of the day.

Gundogdu et al. (2008) examined 10 years of accident data in Konya roads not only urban roads but also rural roads. They considered accident segments will give more accurate results instead of the accident place. Therefore, the path of those segments have divided into 1 km and analysis made with a Kernel Density Estimation.

Kuo et al. (2011) examined the 5-year traffic accident data for the College Station city. In these analyzes, they made a performance evaluation by using the Kernel Density method with Getis-Ord Gi. As a result, they made hourly and weekly analyzes. They also stated that accident data and crime data has same spatial characteristics.

2.2 Road Safety Evaluation Methods

2.2.1 Road Safety Audit

2.2.1.1 Definition and Purpose

Road Safety Audit (RSA) are official road safety evaluations for a road section or traffic project that impacts road users and is conducted by independent and competent teams. In addition, RSA is an official road safety review to evaluate the safety of an existing, planning road, and intersection (Federal Highway Administration, 2018). RSA detects potential road safety problems, reports, and offers solutions. Matters to consider when defining RSA (AUSTROADS, 2009);

- RSA is an official evaluation process.
- A planning or existing road evaluation is carried out by an independent team.
- It must be performed by teams with the necessary knowledge and experience.
- RSA deals only with road safety issues.

What is RSA not? (AUSTROADS, 2009);

- It does not evaluate a project as good or bad.
- It is not a tool to compare projects with each other.
- They are not a design criteria.
- It is not a redesign of the project.

The main purpose of RSA is to identify potential risk points for planned roads, under construction roads or existing roads and consider road safety for all road users (University of New Brunswick Transportation Group, 1999). In addition, RSA aims to minimize accident severity and risk, reduce operating costs throughout the life of the road, and raise safety awareness (Hamilton Associates, 1998). RSA seeks to answer the question of which parts of the road can pose a safety problem for which road users. In addition, it tries to answer questions that how safety problems can be reduced and eliminated (Federal Highway Administration, 2018).

2.2.1.2 History

RSA was originally developed for a railway project in England in 1989 (Trentacoste et al., 1997). The British Government commissioned officers before the railway line was opened and carried out a road safety evaluation with the help of an independent checklist. RSA has been used by many countries such as Australia, New Zealand, Denmark since the early 1990s. In 1994, the first written source titled “Road Safety Audit” was published by the Australian Transport Authority (AUSTROADS, 2002). In 1996, America cooperated with New Zealand and Australia for how to conduct a Road Safety Audit. As a result of this cooperation, they developed a road safety evaluation method that includes 13 states (Lipinski & Wilson, 2004)l.

With the RSA gaining importance in the USA, organizations such as the Asian Development Bank, the World Bank, and the United Nations have attached importance to the Road Safety Audit and allocated a budget (Asian Development Bank, 2003). In addition, Road Safety Audit has spread quickly, as it allows to view safety problems without waiting for an accident. By 2007, many European countries had published a common standard for Road Safety Audit (George et al., 2008). Today, nearly all countries use Road Safety Audit to prevent traffic accidents, and thus loss of life and property (Jones, 2013).

2.2.1.3 Checklists

One of the most important components of Road Safety Audit is checklists. The Road Safety Audit team uses checklists to identify hot spots of the relevant road segment or traffic flow. The audit team should determine the most appropriate checklists for the project before starting the audit. Checklists are means, not a purpose, in the road safety Audit project (AUSTROADS, 2009). Checklists were first used for Road Safety Audits in the UK (Trentacoste et al., 1997). The Audit team can use different checklists based on their experience in road safety Audit, experienced teams use only the main checklists (AUSTROADS, 2009). Each stage has different checklists. Figure 2.1 shows a sample section of the checklist for existing roads.

Issue	Yes	No	Comment
6.1 Road alignment and cross-section			
6.1.1 Visibility; sight distance			
Is sight distance adequate for the speed of traffic using the route?			
Is adequate sight distance provided for intersections and crossings? (for example, pedestrian, cyclist, cattle, railway)			
Is adequate sight distance provided at all private driveways and property entrances?			
6.1.2 Design speed			
Is the horizontal and vertical alignment suitable for the (85th percentile) traffic speed?			
If not: • are warning signs installed? • are advisory speed signs installed?			
Are the posted advisory speeds for curves appropriate?			
6.1.3 Speed limit/speed zoning			
Is the speed limit compatible with the function, road geometry, land use and sight distance?			
6.1.4 Overtaking			
Are safe overtaking opportunities provided?			
6.1.5 Readability by drivers			
Is the road free of elements that may cause confusion? For example: • is alignment of the roadway clearly defined? • has disused pavement (if any) been removed or treated? • have old pavement markings been removed • properly? • do tree lines follow the road alignment? • does the line of street lights or the poles follow the road alignment?			
Is the road free of misleading curves or combinations of curves?			

Figure 2.1 : A sample section from the checklist for existing roads (AUSTROADS, 2009).

Other checklists are at the design stage of project;

- Feasibility
- Preliminary design
- Detailed design
- Pre-opening

Other stages;

- Road work
- Existing roads

In addition, checklists are used during the evaluation of the project drawings, examination of the accordance of the project to the existing topography, and review of whether the related problems are solved.

2.2.1.4 Roles and Responsibilities of Participants

At the beginning of the Road Safety Audit, job descriptions and responsibilities should be clearly defined by stakeholders. How the audit process will work, and its schedule must be determined. In addition, it should be stated how to proceed in unusual conditions (night audit in winter etc.). The roles and responsibilities of participants for project-to-project road safety audit may vary (University of New Brunswick Transportation Group, 1999). For a successful Road Safety Audit, there must be good communication between the participants throughout the process (George et al., 2008).

Client: The client team usually represents an institution that starts a transport infrastructure project. The client team must approve road safety evaluation. During the project stage, client should supervise the audit team. After approving the Road Safety Audit, it should be implemented (University of New Brunswick Transportation Group, 1999). The client team should consider safety as a vital component in road designs. The client team should also inform their staff about safety (AUSTROADS, 2019). The client team should select the appropriate and experienced audit team for the project, provide the necessary information for the audit, ensure that the auditors meet their requirements, be in touch with the audit team during the audit process, and implement all the correct design changes from the audit team (Keskin, 1996).

Design Team: The design team should provide the audit team with all the information related to the project such as road drawings, traffic accidents, traffic characteristics. The design team should hold meetings with the audit team and consider the issues raised by the audit team. The design team should inform the client if there is a problem with the audit and ensure that expert opinion is received from different disciplines when necessary (AUSTROADS, 2019). In addition, design team should follow the implementation of agreed precautions. While implementing the precautions, design team should pay attention to compliance with local policies, correct implementation of the findings, and keeping the evidence records (University of New Brunswick Transportation Group, 1999).

Audit Team: The main task of the audit team is to identify the safety problems of the project by carefully examining the background information about the project and performing the audits completely (University of New Brunswick Transportation Group, 1999). Audit teams use checklists to identify problems. The audit team should fully understand the audit parameters and audit policies (Federal Highway Administration, 2018). The audit team should provide a technical and detailed report to the client team and design team, which clearly describes safety issues. The audit team should consider the feedback that the design team gives to the audit, approving or accepting the audit result is not at the discretion of the audit team.

2.2.1.5 Stages of Road Safety Audit

Road Safety Audit stages may differ according to the attribute, complexity and safety problems of the project, but are generally examined in 5 stages (Keskin, 1996; Trentacoste et al., 1997);

Feasibility: At this stage, the outlines for Road Safety Audit are determined (Trentacoste et al., 1997). Road design, solution options, the length of the road segment to be designed are determined in this process (George et al., 2008). At this stage, the changes to be made regarding the project scope and safety suggestions are low cost.

Draft Design: At this stage, features such as horizontal and vertical alignment, visibility, and intersection design calculations are inspected. Since the changes to be made after this stage will be limited, caution should be exercised in the audits to be made at this stage.

Detailed Design: At this stage, detailed audits such as guardrails, barriers, lighting, road signs, geometric design of the road are made. This stage is very important because it is the last opportunity before moving on to the implementation phase. Changes to be made after this stage are expensive and may delay the project.

Pre-opening: Before opening, audit should be done in different weather conditions and at different times of the day. All road users (bicycles, pedestrians) should be inspected.

At this stage, even if radical changes are difficult, precautions such as adding warning signs and roadside arrangement should be taken.

Post-opening (Existing): Road safety Audit can be carried out after a long time after the road project is opened. Arrangements made at this stage can be costly. Audits to be carried out at this stage can be applied to certain parts of the related road segment. For example, if an accident occurs frequently on a part of the road segment as a result of accident data, it can be re-inspected for that part.

In the Figure 2.2, design opportunities that can be done for different stages of Road Safety Audit are shown according to Federal Highway Administration (Federal Highway Administration, 2018).

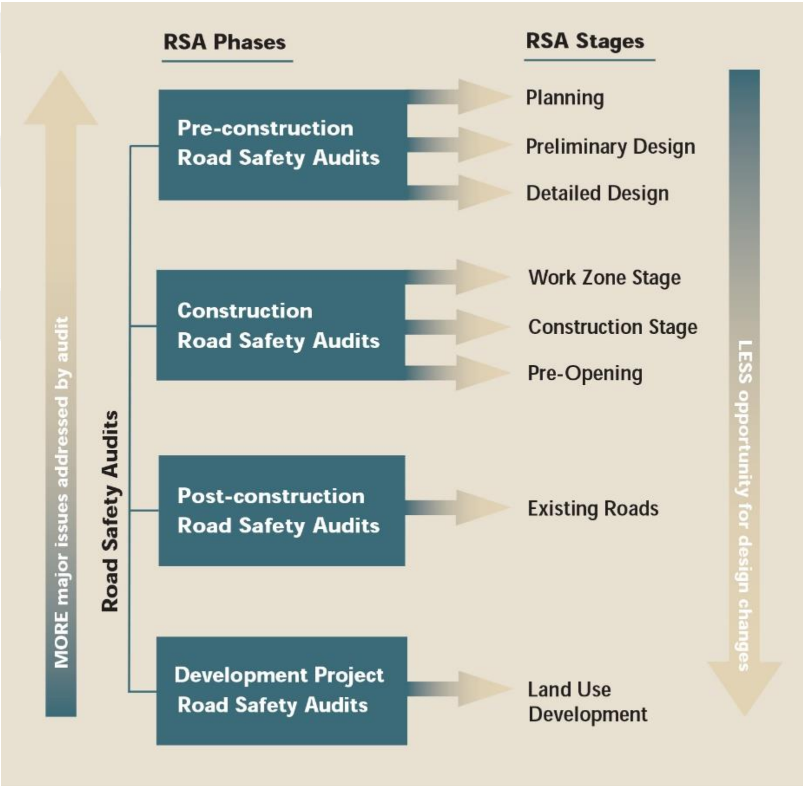


Figure 2.2 : Types of Road Safety Audits Grouped by Phase and Stage (Federal Highway Administration, 2018).

2.2.1.6 Process

Road Safety Audit operates according to a certain process. Although many countries have put clear items on the process, some are only guidance (Asian Development Bank, 2003).

Identification project to be audited: In this step, the road or project to be audited is determined. The client team should transparently explain why the project should audit.

In addition, when creating road safety audit parameters, they should clearly state their expectations from the audit team. There should be a clear answer to issues such as parameters, work schedule, audit tasks, targeted outputs, expectations from audit. In addition, the audit team should always have the opportunity to work independently. Topics included and not included in the project area should be discussed explicitly at the beginning of the project. Before the design team and the audit team start the project, they should agree on how many people will work in the project.

Determining the Audit Team: An independent, competent, interdisciplinary work team should be established to carry out the audit of the relevant project. It is the responsibility of the customer team to determine the audit team. When choosing an audit team, the most qualified team must be chosen, not the lowest cost team. In addition, the audit team leader must be selected from professionals with previous audit experience. The audit team leader should have excellent communication skills as it will ensure communication between the client team, the design team, and the audit team. The Audit team should have a road safety specialist who can understand the causes of accidents and develop effective solutions. In addition, a traffic engineer, who can analyze the traffic supply-demand relationship, is knowledgeable about the traffic flow, and knowledgeable about traffic signaling and road signs, should be on the team. In addition, the team must have a road design engineer having knowledge about the road design requirements for the relevant authority where the road is located. In addition, in the region where the accident occurred, a local person who had the opportunity to observe accidents and who has an opinion on this issue should be on the team. In addition, experts from different disciplines can be included in the study, if necessary, according to the relevant project.

Providing the background Information: The Client Team is responsible for providing project related information such as accident information, traffic counts, accident reports, technical drawings on behalf of the Audit Team. Information on field data, such as design standards used on the road, traffic counts including bicycles and pedestrians, audit information, if any, and weather conditions should be included. Information about the road, horizontal and vertical alignment design, road signs, number of lanes, lane widths should be provided.

Holding a commencement meeting: Before the project, a meeting is held between the customer team, the design team and the audit team. The purpose of the meeting is to discuss the scope of the project, to express mutual expectations, to communicate effectively, to introduce the project to the audit team and to assign responsibility to the audit team. The design team and the client team should answer the audit team's questions clearly; the project should provide relevant comprehensive data.

Examining the project data: Project data should be examined before the field trip in order to get preliminary information about the project and the road and to have a preliminary impression of safety problems. The matter to be considered here is that road sections such as intersection, interchange, if any, should be examined separately for each direction. While examining the project data, both individual and collective evaluations will add different perspectives to the project.

Field observation: It is crucial for the audit team to see the site in order to completely understand the project related problems. Observation gives the audit team the opportunity to see the problem for the road users and visualize the solution they will develop. The audit team should pay attention to the period in which the field audit will be carried out for the best observation of the safety issues in the project. For example, the problems in the project can be clearly seen during daytime control, but nighttime control also enables the audit of the adequacy of road signs and lighting. When conducting field observation, the audit team should evaluate problems not only for car drivers, but also for road use of elderly and child pedestrians, disabled drivers and cyclists. For example, a child can suddenly run towards the road. In addition, older pedestrians may respond more slowly in a sudden situation. In addition, cyclists are severely affected by the road surface and road design. For disabled drivers, issues such as visibility, road signs, road signs and lighting are very important. All members of the audit team should review the site, analyze how the road is affected for different users and different weather conditions, visually record the site and keep notes.

Writing the road Audit report: In the Road Safety Audit report, the safety problems of the project are explained in detail and based on the traffic data. In addition, if the client team requests, solutions are offered. The important matter here is the Road Safety Audit report, explains the problems related to road safety, does not evaluate the road design. There must be in the Road Safety Audit report:

- Information about the project: A report explaining the name of the road, which part of the road, which authority the road belongs to and the process of the road audit report should be written. In addition, the aims of the project, the targeted output from the audit report and any special circumstances should be explained

- Background of the project: There should be a short introduction paper including the professional backgrounds of the team members. In addition, there should be a general plan with the length of the project, with safety issues related to the project and marked on the project. All field evaluations (day, night etc.), and decisions taken at the initial and completion meetings should be specified.
- Findings and suggestions: All the safety problems identified in the project should be explained in detail, and suggestions should be included if requested by the customer.
- Official document: Official final report must be approved by the entire audit team.

Holding a Completion Meeting: In this meeting, findings and suggestions for safety problems are discussed. All participants of the project (audit team, design team, client team) should attend the meeting. In the meeting, the design team and the client team can also generate ideas for the safety problems detected.

Implementation of the audit report: At this stage, the audit report is carefully examined, and it is discussed whether the suggestions can be implemented. If not applicable, the reasons should be explained in the report. If the suggestions can be implemented, they should be implemented as soon as possible.

Evaluation of the audit report in writing: Each finding, and suggestion made by the audit team should be evaluated and documented in writing by the client team or design team. In addition, any impracticable findings or suggestions should be explained and documented in detail. The audit report can be reacted by completely accepting and developing solutions to eliminate problems, partially accepting, implementing only accepted parts, or completely rejecting the audit report. Except in cases where it is completely accepted, the reasons should be explained in writing.

Grading of safety problems: By using various tables, safety problems can be sorted according to their severity, and how to take precautions in this regard can be determined. In the first table, how often the problems repeat is determined. Besides, the severity of the problems can be evaluated. In addition, in the other table, the risk class of the safety problem can be determined. In the last table, suggestions suitable for this risk class can be determined.

Implementation of approved solutions: Approved solutions should be implemented quickly. The arrangements (time, date, visual documentation, made by whom) must be recorded.

Completion of the project: At this stage, it is aimed to transfer the experience obtained from the audit to the future audits. In the Figure 2.3 typical process of a Road Safety Audit project can be seen.

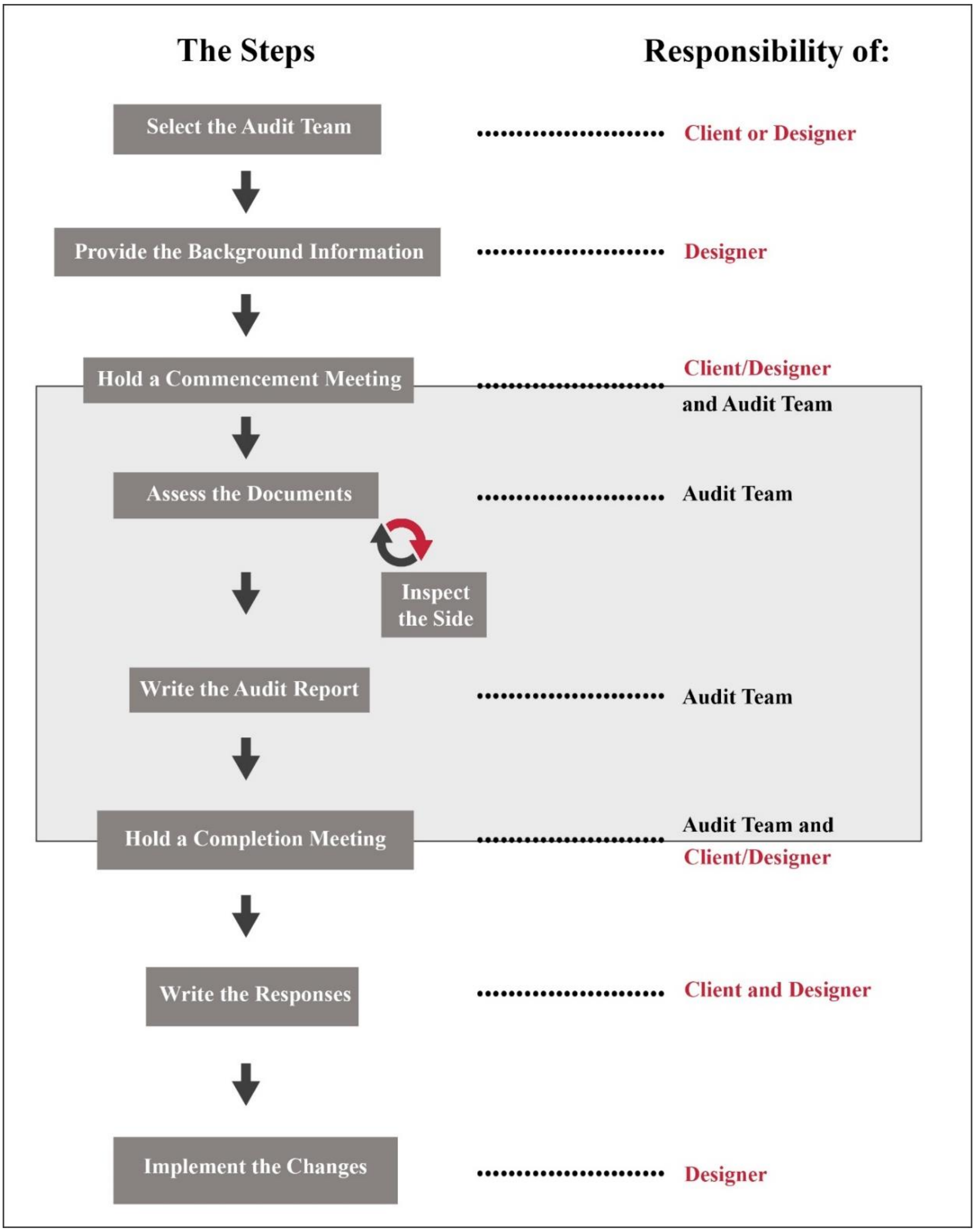


Figure 2.3 : Typical Road Safety Audit process (AUSTROADS, 2019).

2.2.2 Review of Existing Road Safety Audit Practices in Different Countries

2.2.2.1 United Kingdom

Road Safety Audit first emerged and implemented in the UK. The road evaluation developed for the railway project in United Kingdom in 1989 is the first Road Safety Audit project. In 1987, the British Government tried to develop a strategy to minimize road accidents in a 10-year period. For this reason, a law was passed in 1988, stating that safety precautions are imperative for all road constructions. As a result, two important safety procedures, Road Safety Implementation Basis and Road Safety Audit, have gained importance. In 1990, the UK Department of Transport published the first Road Safety Audit Guide. After the publication, the guide was revised in 1996. In 1991, the UK Department of Transportation made Road Safety Audit mandatory for all highways and freeways. Today, Road Safety Audits are carried out intensely in the United Kingdom.

2.2.2.2 Australia

"AUSTROADS" is called the official authority in Australia, which deals with transport issues. AUSTROADS published the Road Safety Audit Guide in 1994. This guide tries to address all the issues that need to be considered in a road safety audit project in cooperation with New Zealand. Different organizations carry out road safety audits in each region of Australia. For example, the Road Corporation of Victoria (VicRoads) strictly enforces road safety Audit. There is an obligation that Road Safety Audit must be carried out for a project that costs more than $ 5 million. In addition, Roads & Traffic Authority (RTA) in the state of New South Wales issued a road safety Audit guide in 1991. RTA oversees twenty percent of roads in all regions. In addition, it audits 20 different road projects of different sizes within the state borders every year.

2.2.2.3 United States

The United States sent a team to New Zealand and Australia in 1996 to learn about Road Safety Audit. This team included road safety experts, urban planners, transport engineers, and experts from different disciplines. As a result of these studies, it was stated in the Road Safety Audit Guide issued in 1997 that accidents can be minimized by following the principles of Road Safety Audit. By using this information, it was decided to carry out a Road Safety Audit in the United States. In 1997, Road Safety

Audits were carried out in 13 states in the United States. With these studies, road safety problems were seriously reduced. Through successful results, in 1998, FHWA initiated the Road Safety Audit incentive across the country. FHWA assists government agencies performing road safety audits.

2.2.2.4 New Zeland

Transit New Zeland (TNZ) is the official government agency responsible for the maintenance, repair and construction of the road network in New Zealand. TNZ started to work on road safety with the institution it established in 1989. TNZ, which studies the road safety studies in United Kingdom and Australia, started to work in this direction and gave importance to RSA. As a result of these developments, TNZ published his own Road Safety Audit guide in 1993. According to this guide, Road Safety Audit guide should be used in all projects whose construction cost exceeds 5 million dollars. Since 2004, Road Safety Audit has been required for a new road project loan.

2.2.2.5 Canada

Canada is one of the first countries that implemented Road Safety Audit. In 1997, the first Road Safety Audit was conducted for Vancouver. Since then, many local states have started implementing Road Safety Audit with the support of the Insurance Corporation of British Columbia. With these developments, Minister of Transport of Canada has issued its own Road Safety Audit Guide. Studies on Road Safety Audit in different states of Canada:

- British Columbia: The Insurance Corporation of British Columbia encouraged many municipalities to conduct Road Safety Audits. "Road Safety Audit and Design Reviews" by Hamilton Associates in 1998 is one of the important publications made with this fund.
- Alberta: Road Safety Audit was used in the city of Calgary in 1998 in the province of Alberta. During these studies, the city university was also included in the project and it was aimed to create an infrastructure for future projects.
- Ontario: After the state of Ontario analyzed the prosperous results of the Road Safety Audit, they attached importance to work RSA and published a guideline called the Highway Performance Assessment in 1999.

2.2.2.6 Turkey

In 2001, with the aid of the World Bank, the first Road Safety Audit work have been taken in Turkey. This project, which is carried out under the consultancy of the Swedish National Road Consulting (SweRoad) company, is a 10-year project and aims to establish the road safety basis at short date. Besides, it aims to reduce the amount of death and injury in traffic accidents by at least 40% in the long run. With these developments, the Road Traffic Safety Handbook was prepared in 2007. In this book, information about the determination of accident hot spots and suggestions is given. In addition, it has been tried to determine the standards that should be followed in order to have safer roads.

2.2.3 Road Safety Inspection

Road Safety Inspection is the evaluation of the road according to safety criteria to eliminate the risks of accidents in a road network. Road Safety Inspection are assessment methods that perform the same function as Road Safety Audit. Some countries such as USA and Australia accept the RSI and RSA the same, while some European countries such as France and Austria accept the two separately. The only difference here is that RSA is made for roads planned in the future, while RSI is made for existing roads.

3. METHODOLOGY FOR HOT SPOT ANALYSIS

3.1 Geographic Information Systems

Geographic Information Systems collect the location data, store, regulate, which is a set of systems analyses and the results are revealing. Since the end of the 1990s, transportation, military, medical and many other disciplines such as telecommunications used GIS. Geographic Information Systems is a system that can process geographic data with its software, convert detailed data sets to maps and analyze them (Yomralıoğlu, 2000). Geographical Information Systems are advantageous compared to other systems, with the ability to collect data, display, store, query and analyze together.

Geographic Information Systems data can be grouped into 2 categories. Firstly, the data in the first category are point, line, and area data which are graphic data. Second, data in the other category are verbal. The data in this category include the properties of the graphic data. Geographic Information Systems has 5 components which are; data, hardware, software, methods, and people (Dereli, 2016). Analysis of data from components in Geographic Information Systems is a very difficult process, because the data is very complex and tough data. Another component, hardware tools that are generally a computer. With hardware tools, data can be stored, analyzed, and the results can be obtained. In addition, with the aid of software, data can be processed and the accuracy of the analyzes can be checked. The methods chosen when using Geographic Information Systems are very important for the success of the analysis (Dereli and Erdogan, 2017). Finally, analysis is made on the needs of people, people with knowledge should work in GIS for successful results.

3.2 Kernel Density Estimation Method

Kernel Density Estimation (KDE) produces a continuous spatial point density on a 2-dimensional surface. Kernel Density Estimation method is one of the most frequently used methods for determining accident hot spots. In this method, accidents are emphasized according to their proximity to each other, and dense regions are thus determined by accident hot spots. The Kernel density estimation method was developed in the late 1950s to determine histogram density. The Kernel Density Estimation method is a widely used method because it can analyze density without the need for prior knowledge (Polat and Ozden, 2006). The Kernel density Estimation is used between two points or along the straight plane. Kernel Density Estimation is an accident intensity falling into a circle with a certain radius and a function expressed due to the increase and decrease of this density. Accordingly, the values that are dense at the center of the circle decrease as they move away from the center of the circle. In Kernel density estimation, it shows regions like raster with low and high probability of accident (Prasannakumara et al., 2011). The determined domains hovered over the regions in the study area and density values are found in the relevant region (Figure 3.1). In the Kernel Density Estimation method, the density decreases with excessive extremes in the center. In addition, the sample density surface obtained by analyzing different accidents with the Kernel Density Estimation is shown in the Figure 3.2.

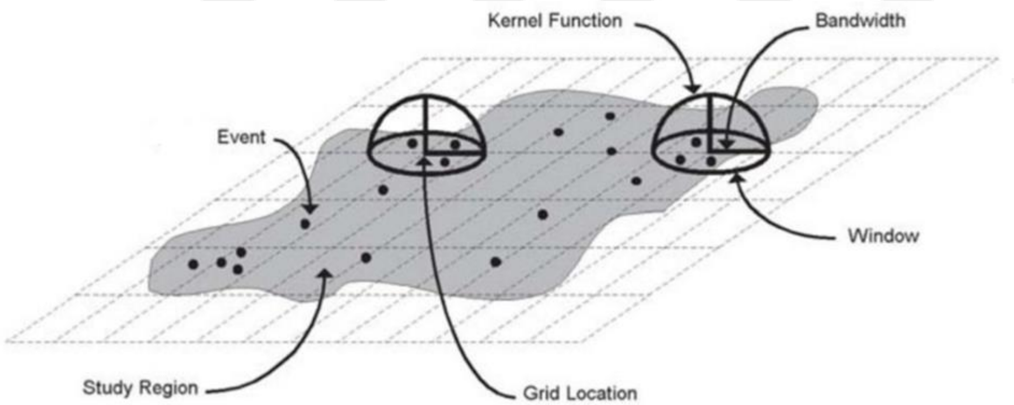


Figure 3.1 : Basic principles of KDE (Cromley and McLafferty, 2011)

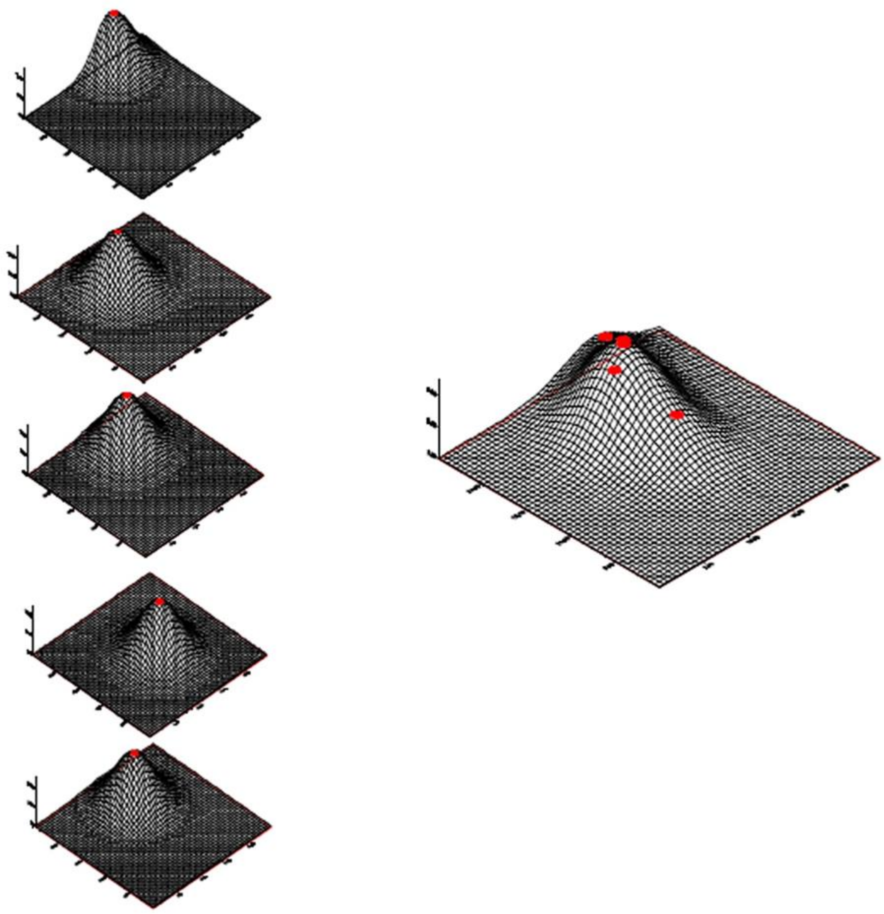


Figure 3.2 : Density surface obtained by five different accidents (Levine, 2005)

The Kernel Density Estimation method allows us to model the event in a plane. It also shows spatial clusters. With the Kernel Density Estimation method, we can analyze accidents by determining their severity according to whether they are fatal, injured, or not (Kaygisiz et al., 2012). The Kernel Density Estimation method has different functions; normal, uniform, quartic, triangular, and negative exponential are the most frequent ones. The most general formula of the Kernel Density Estimation Method in a 2D plane as seen in Equation 3.1 (Levine, 2005):

$$f(x, y) = \frac{1}{nh^2} \sum_{i=1}^{n} k \left(\frac{d_i}{h}\right) \tag{3.1}$$

In this formula, n refers to the density value of accidents, while h refers to the bandwidth. Besides, k is the weight value of the point, the distance from the point (x,y) to point i.

3.2.1 Normal Distribution

It is the most used function in the Kernel Density Estimation method. As seen in Equation 3.2, formula of Normal Distribution:

$$g\ (j) = \sum_{i=1}^{N}[\ KW_i\ I_i \frac{1}{h^2 2\pi} e^{-\frac{d^2 ij}{2h^2}}\ ] \tag{3.2}$$

In this formula, g(j) indicates the density of the cells, while d_{ij} is the distance between the location of the accident and the corresponding point. In addition, h is the standard deviation of the normal distribution, i.e. bandwidth. Besides, while W_i is the weight at that point, K is constant. Besides, I_i is the density of the relevant point. This function can be applied anywhere in the region as it can be applied to an infinite length area. Figure 3.3 shows the density estimation created by 5 different accident points with normal function.

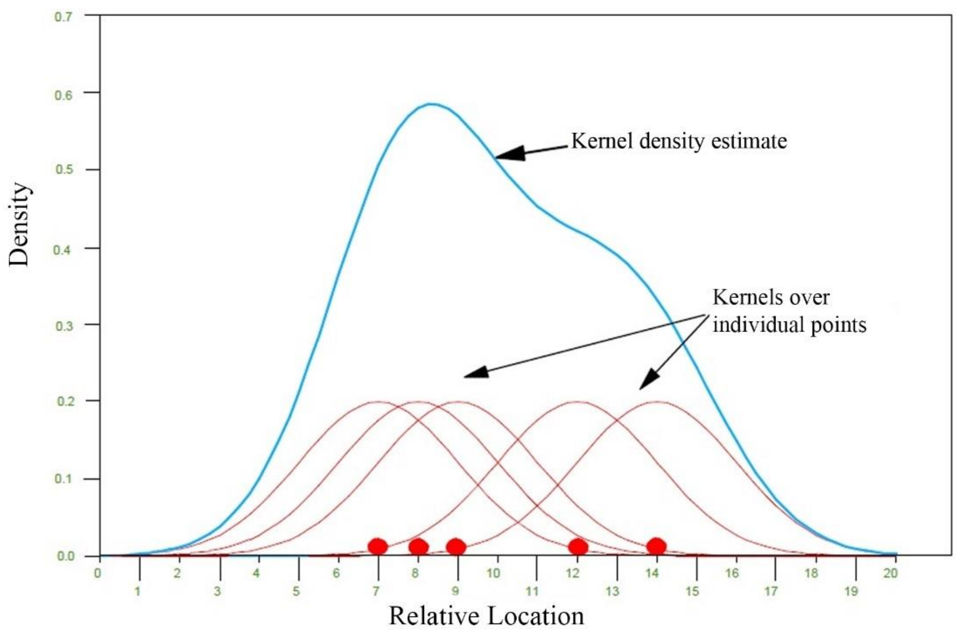


Figure 3.3 : Summing of Normal Kernel Functions for five points

3.2.2 Uniform Distribution

Uniform distribution gives equal weight to all accident points within a certain area. As shown in Equation 3.3, formula of Uniform Distribution:

$$g\ (j) = \sum_{i=1}^{N} W_i\, I_i K \qquad (3.3)$$

In this formula, g(j) shows the density of the cells. Besides, while W_i is the weight at that point, K is constant. Besides, I_i is the density of the relevant point.

3.2.3 Quartic Distribution

The quartic function is applied to a limited area around each event point defined by the radius. It gradually decreases until the bandwidth is reached. As seen in Equation 3.4, formula of Quartic Distribution:

$$g\ (j) = \sum_{i=1}^{M_j} [\ K W_i I_i \frac{3}{h^2 2\pi} (1 - \frac{d^2 ij}{h^2})^2] \qquad (3.4)$$

In this formula, g(j) shows the density of the cells, while d_{ij} is the distance between the location of the accident and the corresponding point. In addition, h is the standard deviation of the normal distribution, i.e. bandwidth. Besides, while W_i is the weight at that point, K is constant. Figure 3.4 shows the density estimation created by 5 different accident points with the quartic function.

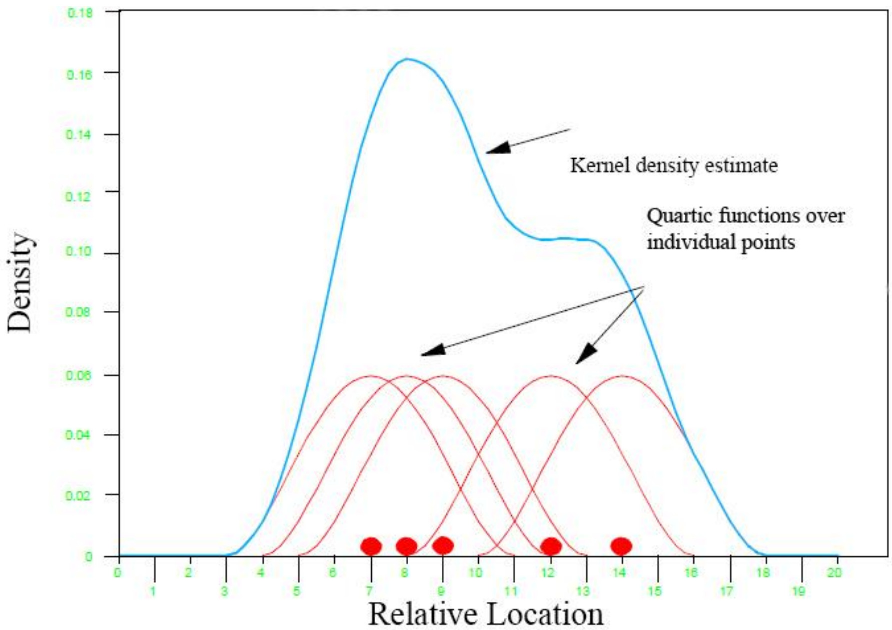


Figure 3.4 : Summing of Quartic Kernel Functions for five points

3.2.4 Triangular Distribution

The triangular (or conical) distribution has a limited radius and is therefore applied to a limited area around each event point. It decreases faster compared to the quartic function. As seen in Equation 3.5, Formula of Triangular Distribution:

$$g\ (j) = \sum_{i=1}^{N}[W_i\, I_i \left(K - \frac{K}{h}\right) d_{ij}] \tag{3.5}$$

In this formula, g(j) shows the density of the cells, while d_{ij} is the distance between the location of the accident and the corresponding point. In addition, h is the standard deviation of the normal distribution, i.e. bandwidth. Besides, while W_i is the weight at that point, K is constant.

3.2.5 Negative Exponential Distribution

The negative exponential distribution decreases very quickly with the distance to the constrained radius. As shown in Equation 3.6, formula of Negative Exponential Distribution:

$$g\ (j) = \sum_{i=1}^{N} W_i\, I_i K e^{A d_{ij}} \tag{3.6}$$

In this formula, g(j) indicates the density of the cells, while d_{ij} is the distance between the location of the accident and the corresponding point. Besides, while h is the standard deviation of the normal distribution, that is the bandwidth, A is the exponential value. Besides, while W_i is the weight at that point, K is constant. The relationship of normal, uniform, quartic, triangular, and negative exponential between distance and density is shown in the Figure 3.5.

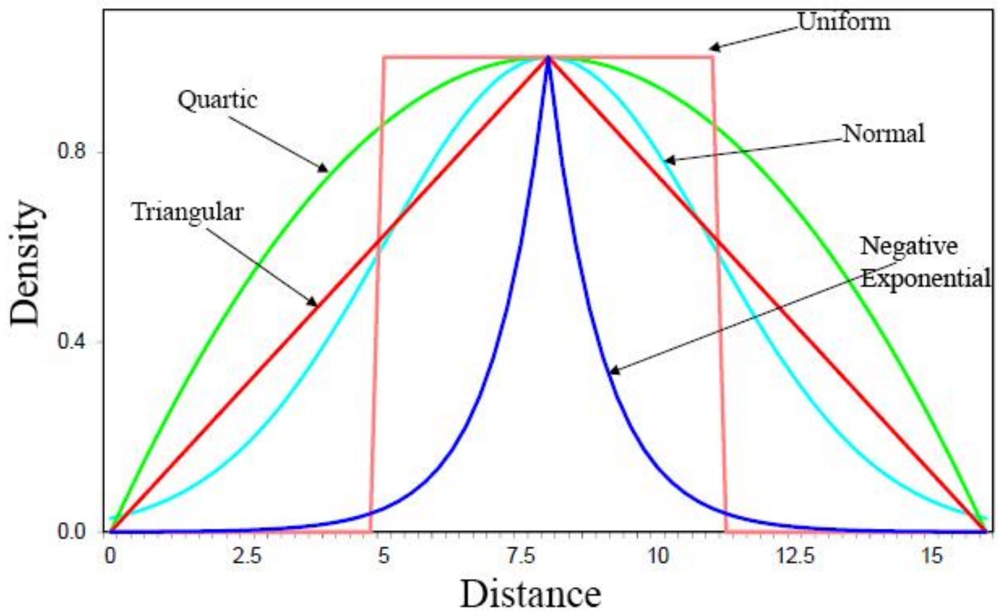


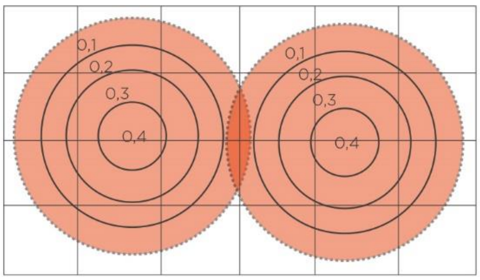
Figure 3.5 : The relationship of normal, quartic, triangular, uniform, negative exponential distributions (Levine, 2005)

3.3 Identification of Hot Spots Using GIS

Accident analysis is the whole process of detecting, documenting, analyzing accidents, and preventing possible accidents in the future by drawing conclusions (Stringfellow et al., 2010). Hot spot is the occurrence of accidents and crime in a region more than once and repeatedly (Clarke & Eck, 2005). Identifying these regions is important for the efficiency of the measures to be taken (Erdogan et al., 2008). Hot spots are generally determined in 3 different ways, traditional methods (number of accidents, accident rate, accident severity, etc.), spatial analysis (geographic information systems, etc.), and statistical methods (Kernel Density Estimation, Empirical Bayes, Poisson Regression, Negative Binomial, etc.). Traditional methods generally focus on only one criterion such as time, space, and damage. But accidents are complex events in which multiple variables come into play, the examinations made only considering the time or place are incomplete and inaccurate. In addition, the use of more than one method in hot point analysis will enable the analysis to be performed by considering different criteria, and thus more accurate results will be obtained. For this reason, GIS supported Kernel Density Estimation was used in accident hot spot analysis.

Accident data can be easily analyzed in Geographic Information Systems after it is received from the relevant administration. All numerical information about the accident can be stored at the GIS base. In addition, more detailed analyzes can be made about the region like the socio-cultural situation of the region, as a result of the the accidents analysis. While making studies on Geographic Information Systems, density analysis can be made with various field definitions. In this study, in order to make a detailed result, an analysis was made with a 500-meter bandwidth length.

In addition, the sensitivity and accuracy of the analyzes to be made in the Geographic Information System can be increased by Kernel Density Estimation. The main purpose of the Kernel Density Estimation is to determine where the accident hot spots are. For this reason, the density value determined with the help of the KDE formula is also the region where there are accident hot spots. After entering the accident data in the relevant region into the GIS system, analyzes are made with the bandwidth determined for KDE, and accident hot points are obtained. In the Kernel Density Estimation, the density of accidents is higher at the center, the density decreases as we go out of the circle. In addition, if different circles intersect with each other, the density at this point is equal to the sum of the densities of the circles. In the Figure 3.6, the density of an area with 2 different accident areas is shown with the help of the grid system.



0.0	0.1	0.1	0.0	0.1	0.0
0.1	0.3	0.2	0.2	0.3	0.1
0.1	0.4	0.2	0.2	0.4	0.1
0.0	0.1	0.0	0.1	0.1	0.0

Figure 3.6 : Densities calculated by KDE method and its display in grid system

If the bandwidth is chosen as large in the Kernel Density Estimation, more accident points are included in the identification but the raw results are obtained like Figure 3.8; ıf the bandwidth is chosen small, the results will be obtained in which fewer boilers are analyzed in more detail such as Figure 3.7. In this study, the 500 meters was chosen as the bandwidth.

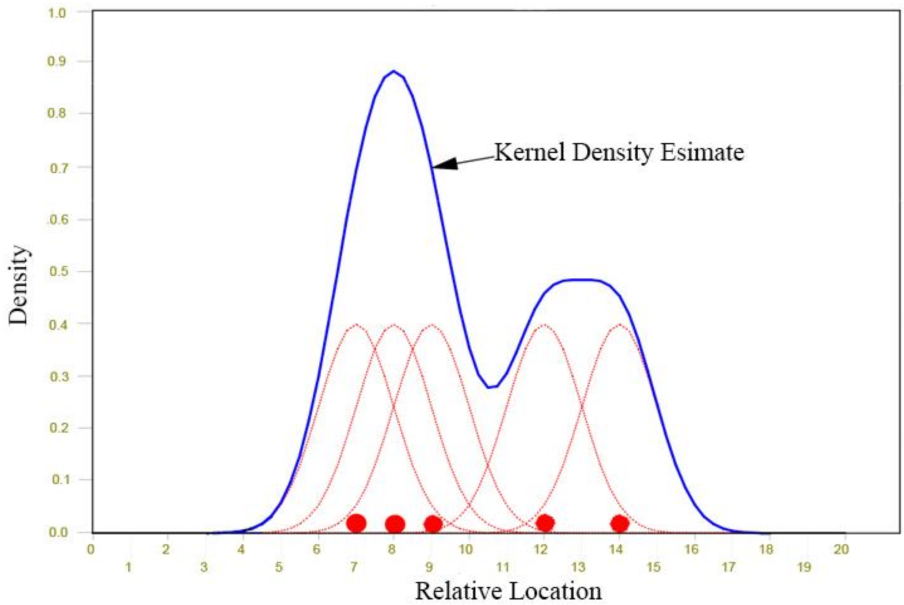


Figure 3.7 : Narrower Bandwidth

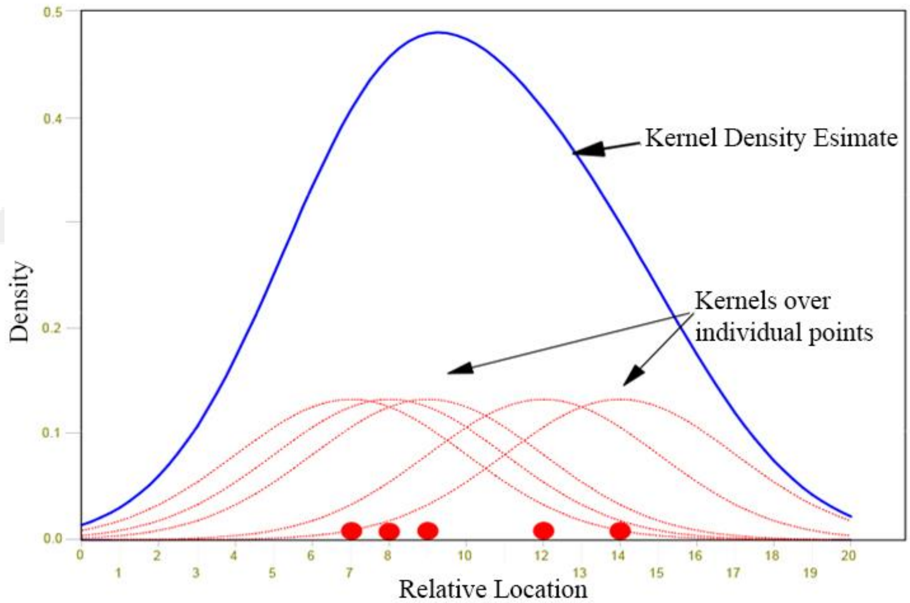


Figure 3.8 : Wider Bandwidth

4. ROAD SAFETY AUDIT

In this section, Road Safety Audit's General Safety, Alignment and Cross Section, Intersectıons, Interchanges, Road Surface and Road User ıssues will be explained.

4.1 General

Within the scope of General Issues, sub-titles such as Traffic Safety, Landscape, Temporary work, Headlight Glare, and Accident Database will be examined. In addition, road safety will be evaluated by asking questions about subtitles.

4.1.1 Traffic Safety

Existence of obstructions at clear zone

The clean zone is unobstructed areas outside the road segment, which is necessary to prevent the vehicle from hitting any obstacles if it loses control of the road. As shown in Figure 4.1, shoulders, bicycle way, and auxiliary lanes are also considered clean areas.

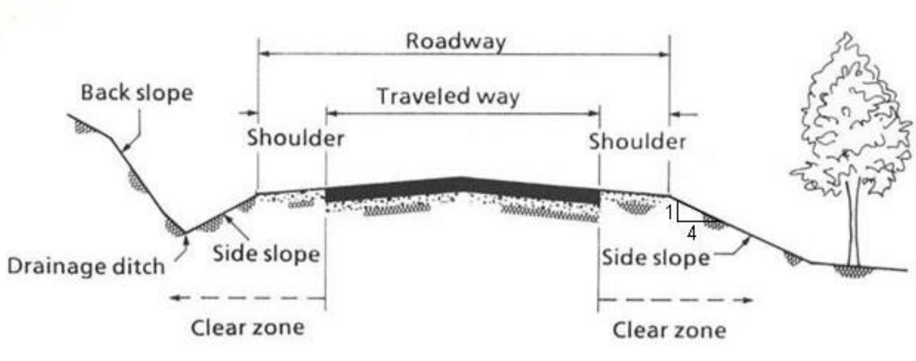


Figure 4.1 : Clear zone illustration

Parameters such as daily average annual traffic, design speed, road grade are activated in the selection of the clean zone. Figure 4.2 shows the minimum clean zone distances that should be based on the traffic characteristics and design of the relevant road segment. However, it is very difficult to achieve the recommended minimum values as there are a large number of signals, signs, lighting luminaries, pavement furniture in urban arterials (American Association of State Highway and Transportation Officials, 2018). Therefore, instead of providing the required clear zone values, roadside obstacles can be lifted, or positioned in sections such as pedestrian paths and bicycle paths.

Design Speed (Km/h)	Design AADT +	Fill Slopes			Cut Slopes		
		6:1 or Flatter	5:1 to 4:1	3:1	3:1	5:1 to 4:1	6:1 or Flatter
60 or less with barrier curb***	All	0.5	0.5	0.5	0.5	0.5	0.5
60 or Less	Under 750	2.0 – 3.0	2.0 – 3.0	**	2.0 – 3.0	2.0 – 3.0	2.0 – 3.0
	750 – 1500	3.0 – 3.5	3.5 – 4.5	**	3.0 – 3.5	3.0 – 3.5	3.0 – 3.5
	1500 – 6000	3.5 – 4.5	4.5 – 5.0	**	3.5 – 4.5	3.5 – 4.5	3.5 – 4.5
	Over 6000	4.5 – 5.0	4.5 – 5.0	**	4.5 – 5.0	4.5 – 5.0	4.5 – 5.0
70 –80	Under 750	3.0 – 3.5	3.5 – 4.5	**	2.5 – 3.0	2.5 – 3.0	3.0 – 3.5
	750 – 1500	4.5 – 5.0	5.0 – 6.0	**	3.0 – 3.5	3.5 – 4.5	4.5 – 5.0
	1500 – 6000	5.0 – 5.5	6.0 – 8.0	**	3.5 – 4.5	4.5 – 5.0	5.0 – 5.5
	Over 6000	6.0 – 6.5	7.5 – 8.5	**	4.5 – 5.0	5.5 – 6.0	6.0 – 6.5
90	Under 750	3.5 – 4.5	4.5 – 5.5	**	2.5 – 3.0	3.0 – 3.5	3.0 - 3.5
	750 – 1500	5.0 – 5.5	6.0 – 7.5	**	3.0 – 3.5	4.5 – 5.0	5.0 – 5.5
	1500 – 6000	6.0 – 6.5	7.5 – 9.0	**	4.5 – 5.0	5.0 – 5.5	6.0 – 6.5
	Over 6000	6.5 – 7.5	8.0 – 10.0 *	**	5.0 – 5.5	6.0 – 6.5	6.5 – 7.5
100	Under 750	5.0 – 5.5	6.0 – 7.5	**	3.0 – 3.5	3.5 – 4.5	4.5 – 5.0
	750 – 1500	6.0 – 7.5	8.0 – 10.0 *	**	3.5 – 4.5	5.0 – 5.5	6.0 – 6.5
	1500 – 6000	8.0 – 9.0	10.0 – 12.0 *	**	4.5 – 5.5	5.5 – 6.5	7.5 – 8.0
	Over 6000	9.0 – 10.0 *	11.0 – 13.5 *	**	6.0 – 6.5	7.5 – 8.0	8.0 – 8.5
110	Under 750	5.5 - 6.0	6.0 – 8.0	**	3.0 – 3.5	4.5 – 5.0	4.5 – 4.9
	750 – 1500	7.5 – 8.0	8.5 – 11.0 *	**	3.5 – 5.0	5.5 – 6.0	6.0 – 6.5
	1500 – 6000	8.5 – 10.0 *	10.0 – 13.0 *	**	5.0 – 6.0	6.5 – 7.5	8.0 – 8.5
	Over 6000	9.0 – 10.5 *	11.0 – 14.0 *	**	6.5 – 7.5	8.0 – 9.0	8.5 – 9.0
120 or More	750 – 1500 +	8.0 – 9.0	9.0 – 12.0	**	3.5 – 5.0	6.0 – 6.5	7.0 – 7.5
	1500 – 6000 +	9.0 – 10.0	10.0 – 14.0	**	5.5 – 6.5	7.0 – 8.0	8.0 – 9.0
	Over 6000 +	10.0 – 11.0 *	11.0 – 15.0	**	7.0 – 8.0	8.5 – 9.5	9.0 – 10.0

Figure 4.2 : Required clear zone values

Are there any risks for crossing over the medians?

Medians are zones that help traffic safety, separating opposite lanes on divided roads. Medians are usually used for roads that have four or more lanes. Median width is identified as the span between the edges of the way in opposing directions bearing left shoulders. A typical median design is shown in the figure 4.3.

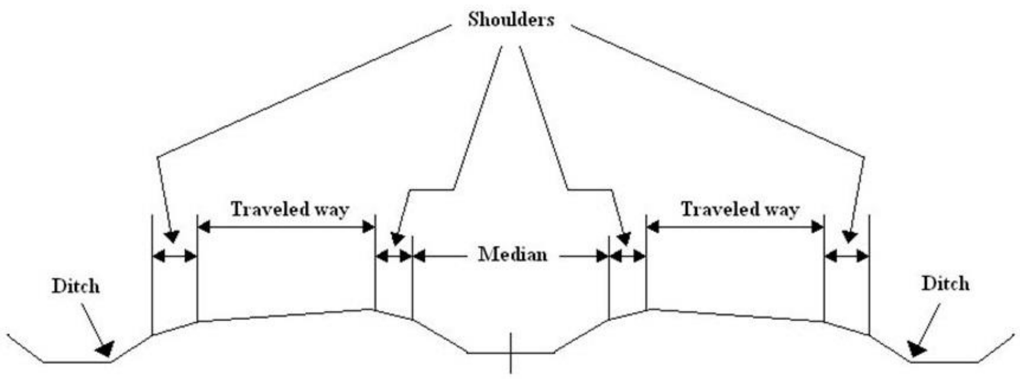


Figure 4.3 : Typical median design

The median design varies according to road design and traffic volume. In addition, the median is generally not used on roads with low volume and low design speed. However, using a median of at least 1.2 meters wide helps seriously reduce accident severity (American Association of State Highway and Transportation Officials, 2018). On high volume roads with high design speed, the median width should be designed as high as possible. However, due to economic reasons and the location of the road segment concerned, medians of the desired width may not be designed. In addition, FHWA observed that even though the median width was wide enough, the vehicles crossing the opposite lane caused serious damage. As a result, FHWA conducted studies on median barriers. A chart was designed by AASHTO for the median barrier design according to the road volume and median width is shown in Figure 4.4.

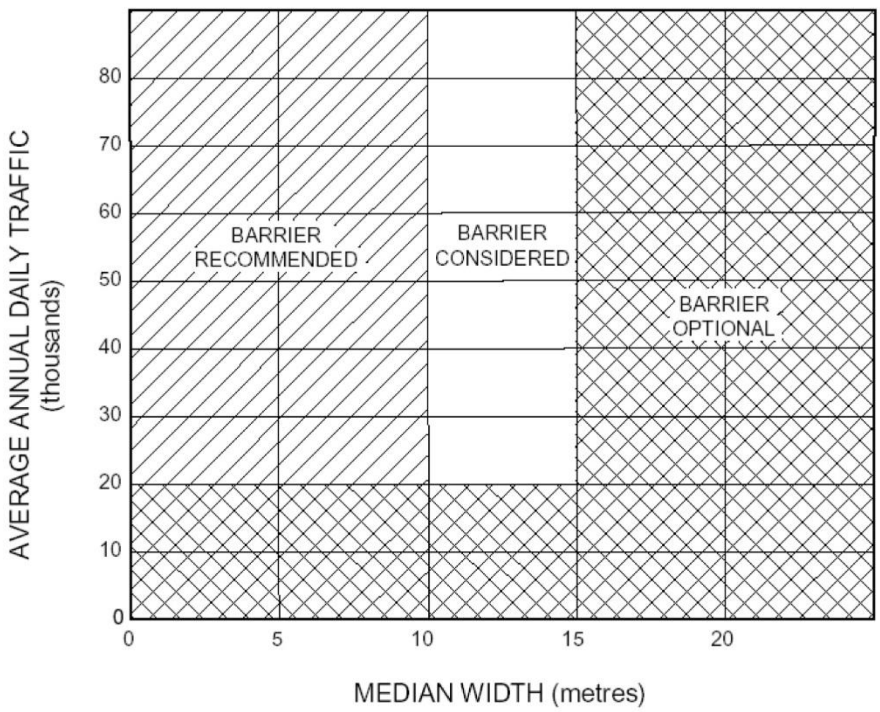


Figure 4.4 : AASHTO Roadside Design Guide

4.1.2 Landscape

Accordance of landscape with road guidelines

Landscape provides road aesthetics, lowers costs, and increases awareness of road users. However, landscape studies contribute to preventing potential fights in traffic by reducing the anger of drivers. In addition, landscape works should be done properly in road guidelines. Because, the misdirection between the road and landscape during driving in traffic distracts the driver, as a result, endangers safety. Landscape works should be done by considering the safety of the road on which it is built.

Possibility of inadequate sight distance due to future plant growth

Landscape elements can be efficient in accidents by obstructing their view distances due to their location and dimensions. Therefore, while landscaping in the road design there must be paid to attention sight distance, traffic signs, signals, dimension of landscaping, locations at interchanges, and intersections. Hence, landscape design and maintenance should be done carefully and frequently. In addition, landscape maintenance is relatively rare, especially on intercity roads. Thus, sight distances can be restricted and traffic safety may be compromised as a result of plant growth over time. As a result, plants should be checked periodically.

4.1.3 Temporary Work

Is there any temporary work on the road segment? If so, adequately signed?

One of the reasons for traffic accidents is temporary work on the road. During the studies carried out, the warning signs may not have been used adequately, they have been placed in the wrong place or the wrong signs have been used. Therefore, the driver may be distracted and traffic safety may be compromised. Thus, road works should be as clear and understandable as the driver can understand the required stopping sight distance or passing sight distance. Besides, necessary precautions must be taken for the safety of workers working in road works.

4.1.4 Headlight Glare

Are there any annoying headlight glare at night?

According to researches, more accidents occur at night than daytime due to limited sight distance. This finding shows the importance of adequate lighting on the road segment. Lighting is important for both rural and urban areas. However, with the more frequent usage of roads by pedestrians and cyclists in urban areas, the importance of lighting increases for urban areas. However, other vehicles' headlights or opposite lanes' luminaries can cause headlight glare for the driver. This situation, especially in urban areas, seriously threatens traffic safety. For reducing headlight glare, luminaires must be at least 9 meters in height. However, it is desirable to position the luminaires at a height of 10-15 meters (American Association of State Highway and Transportation Officials, 2018).

4.1.5 Accident Database

Availability of accident reports

It is desired that the Road Safety Evaluation be done at the stages before the road usage. Nevertheless, it also should be made to existing roads. The traffic accident data in the related road segment shows us the road safety problem and the importance of its evaluation.

Relationship of accidents at the same location

Another advantage of traffic accident data is the relationship that can be established between locations where accidents clustered. Accident clusters that occur at intersection, alignment, or interchanges indicate a design fault in that part of the road design. Thus, instead of general analysis, the problem can be detected with a more detailed and faster inspection and the solution can be developed.

4.2 Alignment and Cross Section

Within the scope of Alignment and Cross Section, classification, speed, cross-sectional elements, alignments, sight distance, readability of elements will be examined. Within the scope of these topics, subtopics will be created and related titles will be explained in detail.

4.2.1 Classification

Is the selection of classification according to the traffic volume appropriate?

The classification of the road is very important in any examination of the road. With the classification of the road, many information like road design features, safety precautions, and traffic volume can be obtained. There are many kinds of classifications according to numbering, administration, and design features. The functional classification, shown in the figure 4.5, is based on traffic characteristics. In the functional classification of the road, the classification is made based on whether the road is in urban or rural areas. Later, roads are classified as arterial , collector, or local based on their traffic volume and design. Arterial roads have high mobility low accessibility while local roads have low mobility high accessibility.

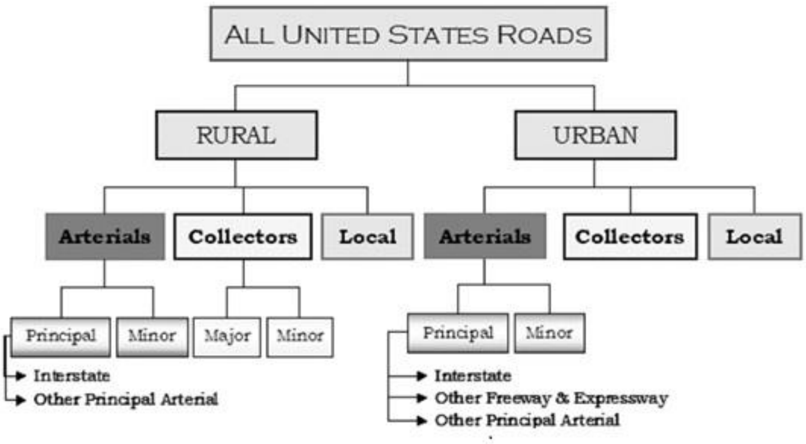


Figure 4.5 : FHWA functional classification (Federal Highway Administration, 2013)

Can the project be expanded for an unforeseen increase in traffic volume?

While designing roads, it should be taken into consideration whether it will meet the needs not only today but also in the future. Factors such as migration from rural areas to the city, increase usage of vehicles, also road requirement. Especially in metropolitan cities, new roads are needed with the increasing population density and number of vehicles. Therefore, the design should be done by considering the future population and the number of vehicles in existing road designs.

4.2.2 Speed

Obedience of posted speed limit

The General Directorate of Highways determines the speed limit with the Ministry of Interior approval in Turkey. Exceeding the speed limit creates safety problems. According to the World Health Organization, one percent increase in speed limit means four percent increase in the risk of fatal accidents. The speed limits determined by the General Directorate of Highways are shown in Table 4.1.

Table 4.1 : Speed limits according to vehicles (General Directorate of Highways, 2018)

Vehicle Type	Urban	Rural		State Highways
		Dual carriageways	Divided Highways	
Passenger Car	50	90	110	120
Medium Commercial Vehicle	50	80	85	95
Bus	50	80	90	100
Truck	50	80	85	90

4.2.3 Cross Section Elements

Can be made expansion in dimensions for the future?

In situations where congestion is experienced in traffic, the accident rate increases. Thus, the widening in the cross-section of the road where the traffic volume is dense will relieve the traffic. In addition, it will provide significant savings since there is no need for new road projects. However, the segment where the project is located must be suitable for expansion.

4.2.3.1 Drainage

Does the roadway have adequate drainage?

One of the important factors for traffic safety is drainage. If the proper drainage is not done, the water in the ground may freeze in the winter and damage the road pavement. In addition, if there are materials such as clay in the road layer, the road surface may be adversely affected by contact with water. In addition, accumulation of water, especially in interchanges, may cause the driver to lose control of the steering wheel, resulting in traffic accidents. This condition called ponding is definitely undesirable in drainage designs. In every arterial road design, there should be a sufficient drainage system for safe discharge of water. If a parking lane or shoulder is designed, the entire lane can be covered with a drainage system. If there is not enough drainage system and the road surface is covered with water, the probability of hydroplaning of vehicles moving with a speed of 70 km / h and above is much higher than that of low-speed vehicles (American Association of State Highway and Transportation Officials, 2018). In addition, there must be extra inlets at right-curves to prevent ponding.

4.2.3.2 Lane Width

Appropriate of lane width for road design?

Lane width affects comfort, traffic flow characteristics, and safety features. Besides, it also affects the Level of Service (LOS). According to AASHTO, the lane width in urban arterials should be between 3 meters and 3.6 meters as seen in Table 4.2. In addition, 3.6 meters is the desired width for safety and high mobility. Generally, lane width is chosen 3 meters for rural roads, while 3.5 meters for the main roads in Turkey.

Table 4.2 : Lane widths according to road functions (American Association of State Highway and Transportation Officials, 2018)

Type of Roadway	Rural		Urban	
	US (feet)	Metric (meters)	US (feet)	Metric (meters)
Freeway	12	3.6	12	3.6
Ramps (1-lane)	12-30	3.6-9.2	12-30	3.6-9.2
Arterial	11-12	3.3-3.6	10-12	3.0-3.6
Collector	10-12	3.0-3.6	10-12	3.0-3.6
Local	9-12	2.7-3.6	9-12	2.7-3.6

4.2.3.3 Shoulders

Adequacy of shoulder width for all road users

Shoulder length should be minimum 0.6 meters in urban arterials as seen in Table 4.3. In addition, roads that can be used by heavy tonnage trucks, the minimum shoulder width should be 1.2 meters. Although, for those roads, 3.6 meters shoulder width is desired design, that may result in security problems due to because of usage of shoulders as an additional lane (American Association of State Highway and Transportation Officials, 2018). Besides, the minimum design shoulder width should be 1.2 meters in case of bicycle usage.

Table 4.3 : Shoulder widths according to road functions (American Association of State Highway and Transportation Officials, 2018)

Type of Roadway	Rural		Urban	
	US (feet)	Metric (meters)	US (feet)	Metric (meters)
Freeway	4–12	1.2–3.6	4–12	1.2–3.6
Ramps (1–lane)	1–10	0.3–3.0	1–10	0.3–3.0
Arterial	2–8	0.6–2.4	2–8	0.6–2.4
Collector	2–8	0.6–2.4	2–8	0.6–2.4
Local	2–8	0.6–2.4	–	–

4.2.3.4 Pavement Widening

Adequacy of pavement width for off-tracking characteristics

Off-tracking is the situation that the rear wheels of heavy tonnage vehicles do not follow the front wheels on the horizontal curve or when turning. Off-tracking depends on parameters such as superelevation, speed, and friction force. However, basically it depends on the type of vehicle and the radius of the curve. While designing, it must be considered that the largest vehicles that will use related road. In addition, if the vehicle size increases and the radius of the curve decreases, the required widening increases. Parameters used in calculation of width; track width of the design car, U; the width of rear overhang, F A; the width allowance for driving on curves is Z. Figure 4.6 shows some of the parameters used in the calculation.

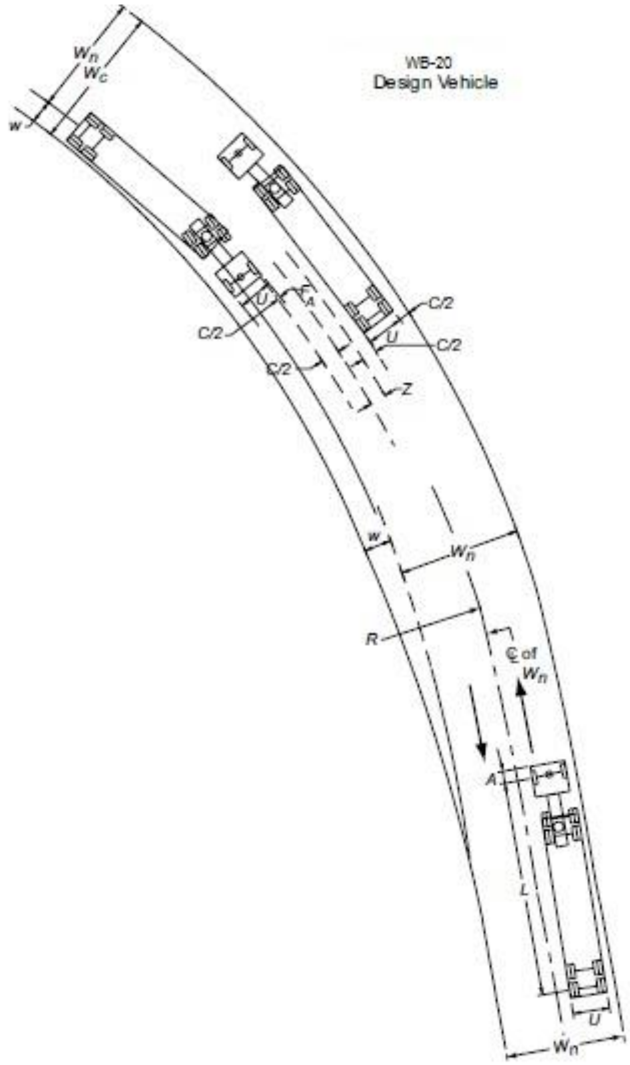


Figure 4.6 : Widening components for WB-20 (American Association of State Highway and Transportation Officials, 2018)

U is calculated as follows as seen in Equation 4.1:

$$U = u + R - \sqrt{R^2 - \sum {L_i}^2} \qquad (4.1)$$

U : Track width on curve in meters

u : Track width on tangent in meters

R : Radius of curve or turn in meters

L_i : Wheelbase of design vehicle between consecutive axles in meters

The width of front overhang (FA) and the width of rear overhang, (FB) can be seen in the figure 4.7.

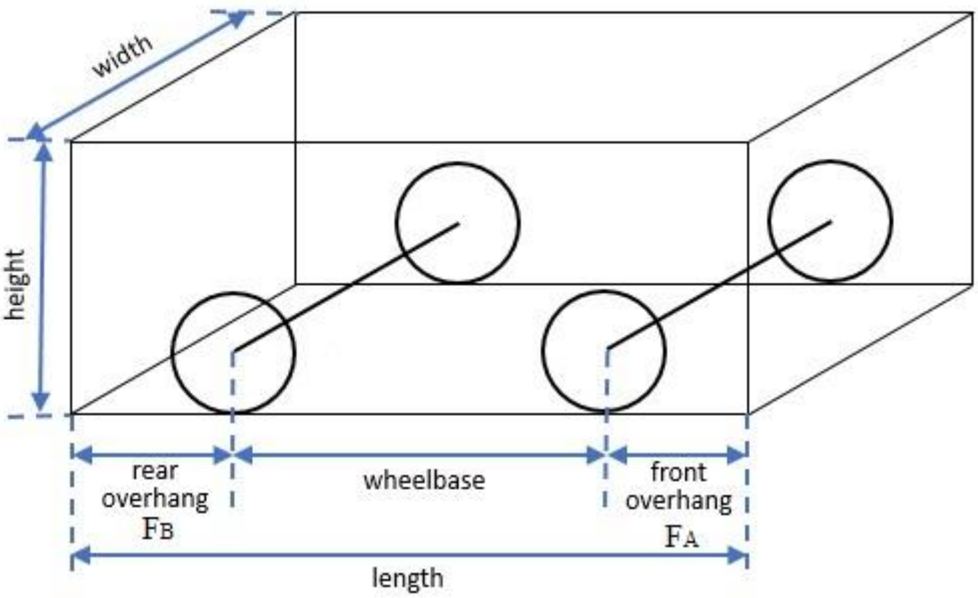


Figure 4.7 : FA and FB

As seen in Equation 4.2, F_A is calculated by the following formula:

$$F_A = \sqrt{R^2 + A(2L + A)} - R \qquad (4.2)$$

F_A : width of front overhang in meters

R : radius of curve in meters

A : front overhang of inner-lane vehicle in meters

L : wheelbase of single unit tractor in meters

As shown in Equation 4.3, Z is a parameter that is taken into consideration when entering the curve:

$$Z = 0.1\left(\frac{v}{\sqrt{R}}\right) \qquad (4.3)$$

Z : extra width allowance in meters

v : design speed of the roadway

R : radius of curve

In addition, W_c is calculated by the formula as seen in Equation 4.4:

$$W_c = N\,(U + C) + (N-1)\,F_A + Z \qquad (4.4)$$

W_c : width of traveled way on curve in meters

N : number of lanes

U : track width of design vehicle in meters

C : lateral clearance in meters

F_A : width of front overhang of inner-lane vehicle in meters

Z : extra width allowance in meters in meters

4.2.4 Alignments

4.2.4.1 Horizontal

Requirement of transition curve between tangent and curve.

Transition curve increases driving comfort by gradually increasing or decreasing the lateral slope while entering curves. However, AASHTO recommends to maximum curve radius to prevent safety vulnerability due to overconfidence to transition curve. Therefore, AASHTO improved a chart for the determination of curve radius depending according to different design speeds in order to eliminate transition curve requirement. Figure 4.8 shows the chart developed for different design speeds.

Metric	
Design speed (km/h)	Maximum radius (m)
20	24
30	54
40	95
50	148
60	213
70	290
80	379
90	480
100	592
110	716
120	852
130	1000

Figure 4.8 : Maximum Radius according to design speed (American Association of State Highway and Transportation Officials, 2018)

4.2.4.2 Vertical

Existence of extreme grades in adverse weather conditions.

Grades can have a positive or negative impact on road design. In areas with heavy rainfall, drainage can be facilitated by high grades. Grades can be 2.5% in places with heavy rainfall. However, if there is no heavy rainfall, the grade should be limited to 2% (American Association of State Highway and Transportation Officials, 2018). On the other hand, high grades can pose security problems, especially for heavy tonnage vehicles. However, it is recommended that the grade value should not be less than 0.5%.

4.2.5 Sight Distance

Sufficiency of sight distance at horizontal alignments.

One of the most important safety elements in horizontal alignment is the sight distance. In horizontal alignment, if there is an obstacle obstructing the view, removing only that obstacle is generally not an efficient solution. In such a case, it is necessary to make an adjustment in the design because there are many variables that affect the designs in alignments and cross-sections. In horizontal alignments, the sight distance is measured along the centerline of the inner lane. Factors affecting horizontal sight distance design are shown in the Figure 4.9.

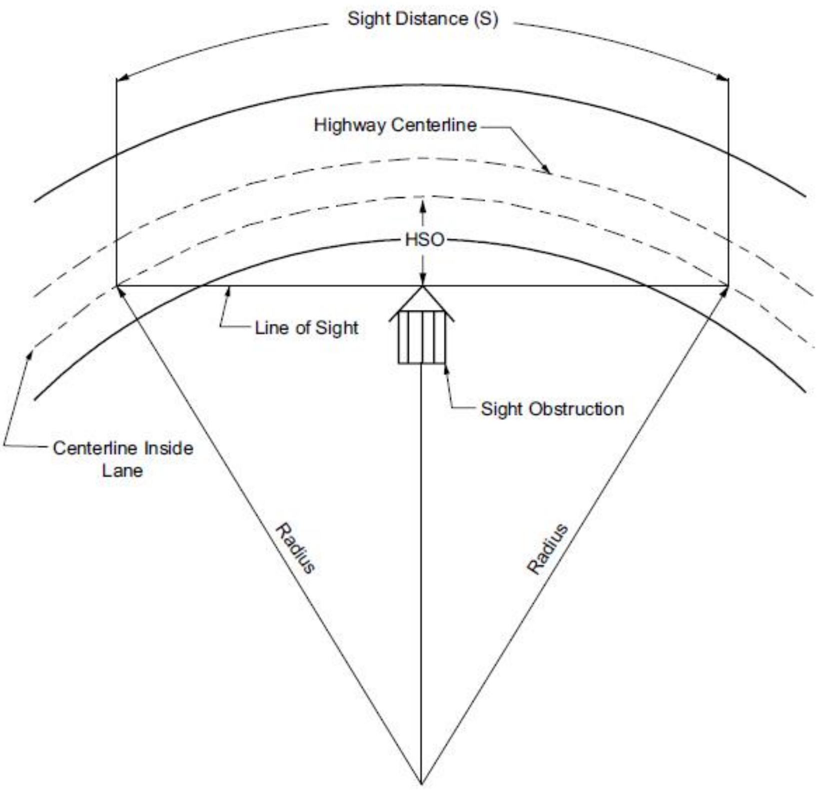


Figure 4.9 : Components for Determining Horizontal Sight Distance (American Association of State Highway and Transportation Officials, 2018)

The horizontal sightline offset value is very important in designing sufficient stopping sight distance. As seen in Equation 4.5, horizontal sightline offset is calculated with the following formula:

$$HSO = R\left[1 - \cos\left(\frac{28.65\,S}{R}\right)\right] \tag{4.5}$$

HSO: Horizontal sight line offset

S: Sight distance

R: Radius of curve

Depending on radius and speed, horizontal sightline offset can be calculated following the chart as shown in Figure 4.10.

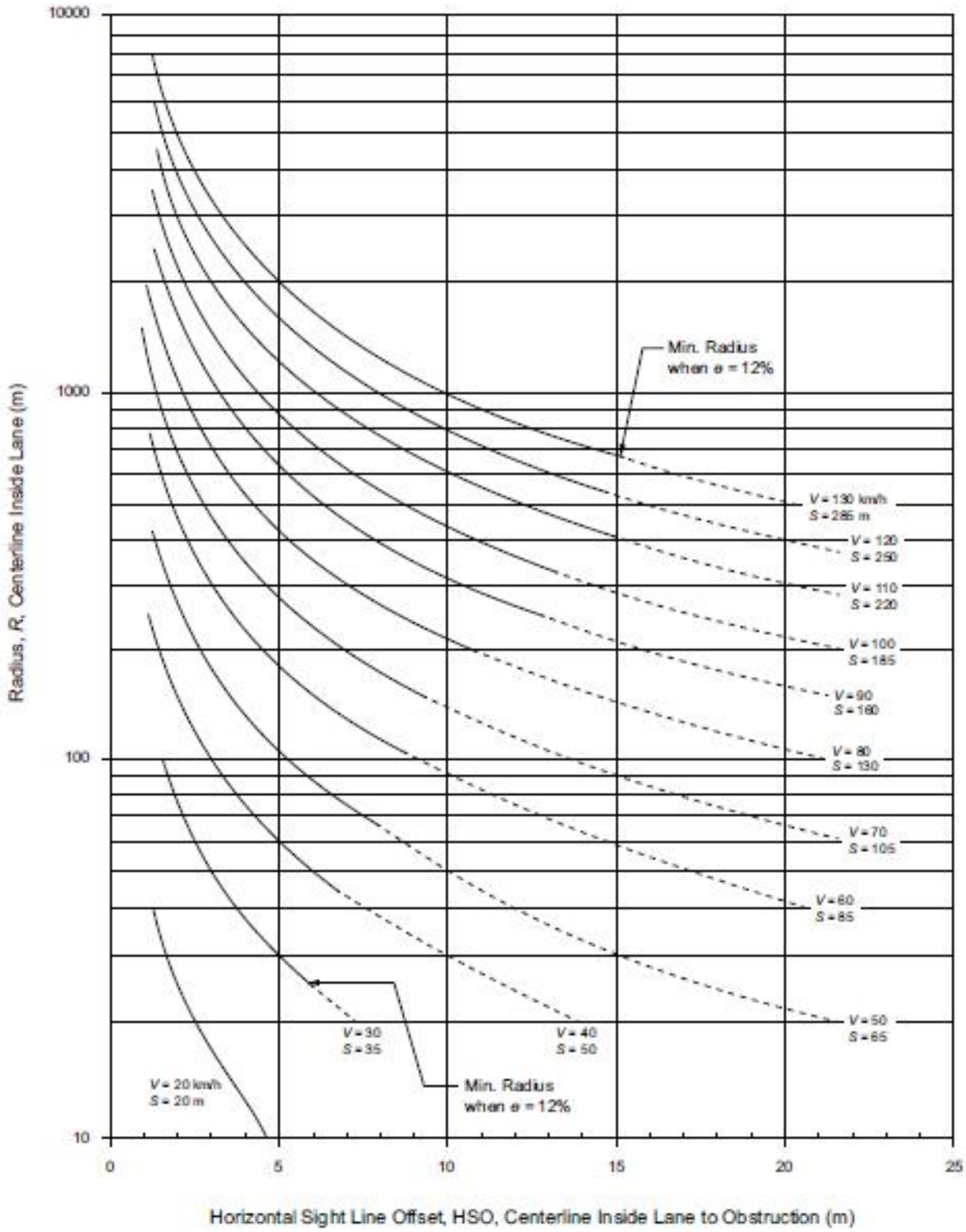


Figure 4.10 : Horizontal Sightline Offset (HSO) to Provide Stopping Sight Distance (American Association of State Highway and Transportation Officials, 2018)

For example, in a horizontal curve with a design speed of 80 km / h and a radius of 350 meters, the Horizontal Sightline Offset length will be about 6 meters.

4.2.6 Readability of road elements

Existence of old pavement markings.

Road users encounter many road elements while driving such as advertisement signs, traffic signs, bicycle users, and pedestrians in urban arterials. Old lane lines can cause the driver to lose their lane. In addition, it may cause safety problems in situations where abrupt decisions are required. Thus, road signs should be clearly understood by road users.

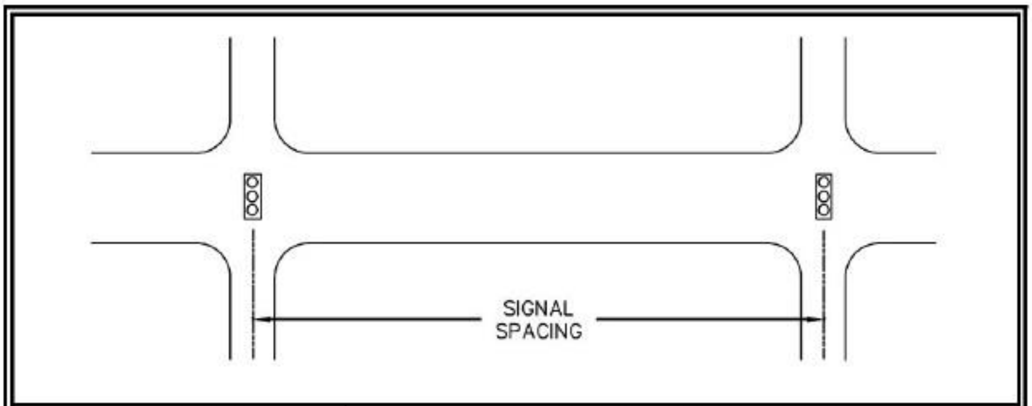
4.3 Intersection

Issues such as location, sight distance, auxiliary lanes, markings, signs, signals, pedestrians, bicyclists will be examined within the scope of the intersection. Within the scope of these topics, subtopics will be created and related titles will be explained in detail.

4.3.1 Location

Spacing between intersections.

Intersections should be positioned appropriately so that there is no traffic congestion. The appropriate design for this is when the traffic is in the green wave, that is, when the vehicles are not stuck on red lights. It is relatively easy to provide the green wave situation in one-way traffic flow, so the distance between the intersections is insignificant. However, in the 2-way traffic flow, if the distance between the two intersections is equal to the distance between the average vehicle speed and the total duration of the yellow and red lights that can be passed without stopping, the green wave traffic can also be provided. The minimum distance between the two signalized intersections is shown in the Figure 4.11.



ROADWAY TYPE	MINIMUM SIGNAL SPACING, Ft
RURAL	1320
URBAN	1000

Figure 4.11 : Minimum spacing between signalized intersection (American Association of State Highway and Transportation Officials, 2018)

Is intersection appropriate for all vehicle movements?

Especially, heavy tonnage vehicles struggle in intersections points. Therefore, ıntersection should be designed for vehicles with the lowest maneuverability permitted to use the road. The width of the roads depends on the type of vehicle using the road, the radius of the curve, and the design speed. While making our design checks, we will make calculations according to the type of vehicle that can face the most negative result. Thus, we will choose the vehicle type WB-20 interstate semi-trailer. Figure 4.12 shows the dimensions of the WB-20 vehicle type.

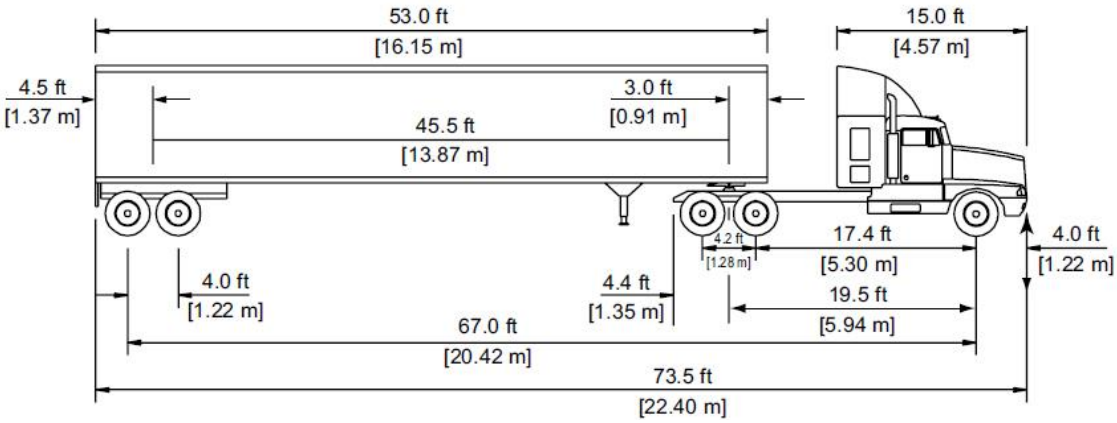


Figure 4.12 : WB-20 vehicle dimensions (American Association of State Highway and Transportation Officials, 2018)

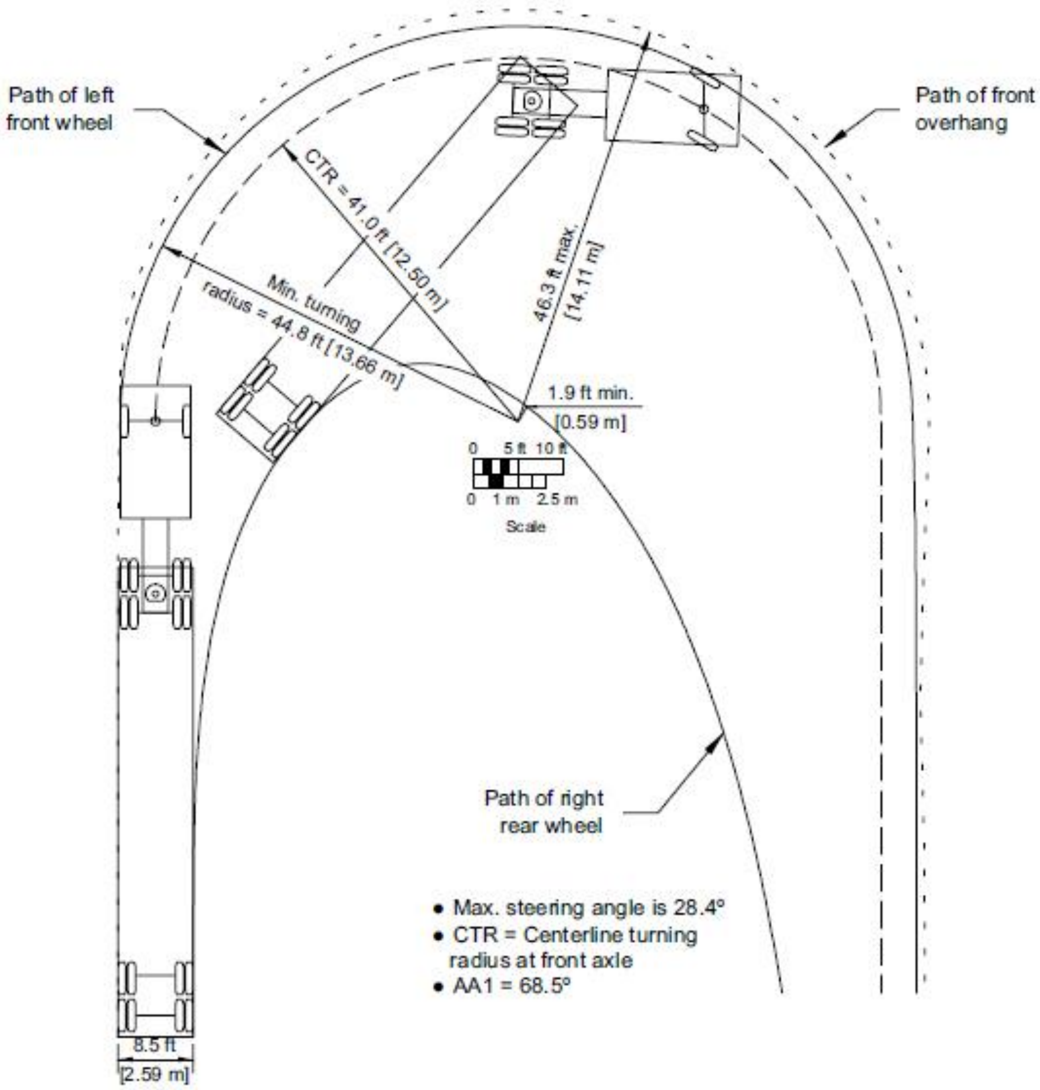


Figure 4.13 : WB-20 returning route (American Association of State Highway and Transportation Officials, 2018)

As seen above, the WB-20 interstate semi-trailer needs a minimum radius of 13.66 meters to turn. Furthermore, pavement width that the truck occupies during the turn is called swept width is also an important criterion in the design. The greater the distance between the kingpin and the axles means the larger the swept width. Figure 4.14 shows swept widths of different radii for the WB-20 vehicle type.

Metric																				
Radius on Inner Edge of Pavement, *R* (m)	P	SU-9	SU-12	BUS-12	BUS-14	CITY-BUS	S-BUS-11	S-BUS-12	A-BUS-11	WB-12	WB-19	WB-20	WB-20D	WB-28D	WB-30T	WB-33D	MH	P/T	P/B	MH/B
15	4.0	5.5	6.3	6.6	7.2	6.5	5.7	5.5	6.7	7.0	13.5	—	8.8	—	11.6	—	5.5	5.7	5.4	6.5
25	3.9	5.0	5.4	5.7	5.9	5.6	5.1	5.0	5.7	5.8	8.5	9.5	6.8	9.6	7.9	12.0	5.0	5.1	4.9	5.5
30	3.8	4.9	5.2	5.4	5.7	5.4	5.0	4.9	5.5	5.5	7.8	8.5	6.3	8.6	7.3	10.3	4.9	5.0	4.8	5.3
50	3.7	4.6	4.8	5.0	5.2	5.0	4.7	4.6	5.0	5.0	6.3	6.7	5.5	6.8	6.1	7.7	4.6	4.7	4.6	4.9
75	3.7	4.5	4.6	4.8	4.9	4.8	4.5	4.5	4.8	4.7	5.7	5.9	5.1	6.0	5.5	6.6	4.5	4.5	4.5	4.7
100	3.7	4.4	4.5	4.7	4.8	4.7	4.5	4.4	4.7	4.6	5.3	5.5	5.0	5.6	5.2	6.0	4.4	4.5	4.4	4.5
125	3.7	4.4	4.5	4.6	4.7	4.6	4.4	4.4	4.6	4.5	5.2	5.3	4.8	5.3	5.0	5.7	4.4	4.4	4.4	4.5
150	3.7	4.4	4.4	4.6	4.6	4.6	4.4	4.4	4.6	4.5	5.0	5.2	4.8	5.2	4.9	5.5	4.4	4.4	4.4	4.4
Tangent	3.6	4.2	4.2	4.4	4.4	4.4	4.2	4.2	4.4	4.2	4.4	4.4	4.4	4.4	4.4	4.4	4.2	4.2	4.2	4.2

Figure 4.14 : Swept width values for different radii (American Association of State Highway and Transportation Officials, 2018)

Is the location of intersections safe according to alignments?

In order to have sufficient stopping sight distance during the approach to the intersection, a road should be designed that the road user can easily notice. For an easily noticeable road design, the intersection should not be approached with a more than 6% approach angle. On roads with design speeds of 80 km / h and above, this value should be at most 3%. In addition, intersections should not be located along the horizontal curve of intersecting roads. Furthermore, another safety precaution is approach designs. The approach design means to place small radius curves that follow each other at points close to the intersection. With the aid of approach design, road users that approaching the intersections can be warned and the speed of the vehicles can be reduced. Figure 4.15 shows a sample approach design. The approach design gives more effective results when used in intersection with speed limit signs and recommended speed signs.

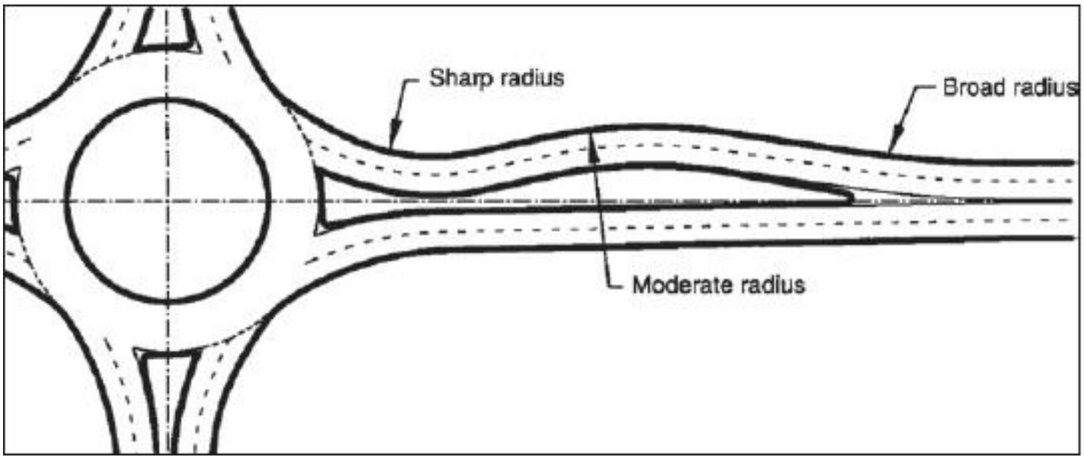


Figure 4.15 : Sample approach design (American Association of State Highway and Transportation Officials, 2018)

4.3.2 Sight Distance

Is there sufficient visibility of intersections?

Intersections which are the cluster points of roads from different directions, are always suspect accident points. However, with sufficient sight distance, traffic signs, and appropriate road design, these accidents can be minimized. In addition, if a design that will provide sufficient stopping sight distance, the driver will notice the intersection, thereby preventing potential hazards. For intersection design, the stopping sight distance should be observed in the entire road network, including the roads that connect the intersection. Furthermore, while designing horizontal and vertical alignment around an intersection as much as possible straight and perpendicular angles must be preferred. A road user approaching the intersection should be faced with well-designed horizontal alignments that enable them to comprehend the entire intersection design, including pedestrians, vehicles, and traffic signs. Hence, as much as possible flat design at vertical alignment while steep design at horizontal alignment must be preferred. For intersection design, the angle must be a maximum of 6% however, at high-speed designs, this must be less than or equal to 3% (American Association of State Highway and Transportation Officials, 2018).

Are there any obstacles in terms of the view of intersections?

Road users that will use the intersection, must be warned in order to have a sufficient stopping sight distance. Therefore, there should be no obstacle to the road user to realize the intersection. Any obstacles that will prevent the view of the road user should be removed from the road, such as buildings, trees, vehicles, plants, walls. In order for an object in view angle to be called an obstacle, features such as its dimension and location should be taken into consideration. In addition, this evaluation should be made for both horizontal and vertical alignment. It's accepted that both the driver's perspective and obstacles are 1.8 meters above the road surface (American Association of State Highway and Transportation Officials, 2018). If the driver's perspective is considered during design, drivers can easily notice each other.

Is there sufficient sight distance for all road users?

All road users must have sufficient sight distance to avoid accidents at intersections. At this distance, the road user should be able to reduce his speed or stop. Although parameters such as the angle of approach to the intersection are efficient in the view of the distance at the intersection, in this study, obstacles that may affect the sight distance will be examined. İncluding traffic signs at the intersection point, any obstacle should not be limit the sight distance of the road user.

The areas required for the road user not to be adversely affected by obstacles and having sufficient sight distance are called the clear sight triangle. The design of the sight triangle depends on the road design speed and the type of traffic control. There are 2 different sight triangle designs, the approach sight triangle, and the departure sight triangle. The approach sight triangle is used in vehicle designs that have not yet entered the intersection point, while the departure sight triangle is used in the calculations of vehicles that are about to enter or cross the intersection. In the approach sight triangle, there should be triangular areas for the four corners of the intersection that will not obstruct the visibility of the road user. The edges of these triangles along the road should be long enough to allow the time for drivers to slow down or stop at the intersection. Figure 4.16 shows typical sight triangular areas for vehicles approaching the intersection from left or right.

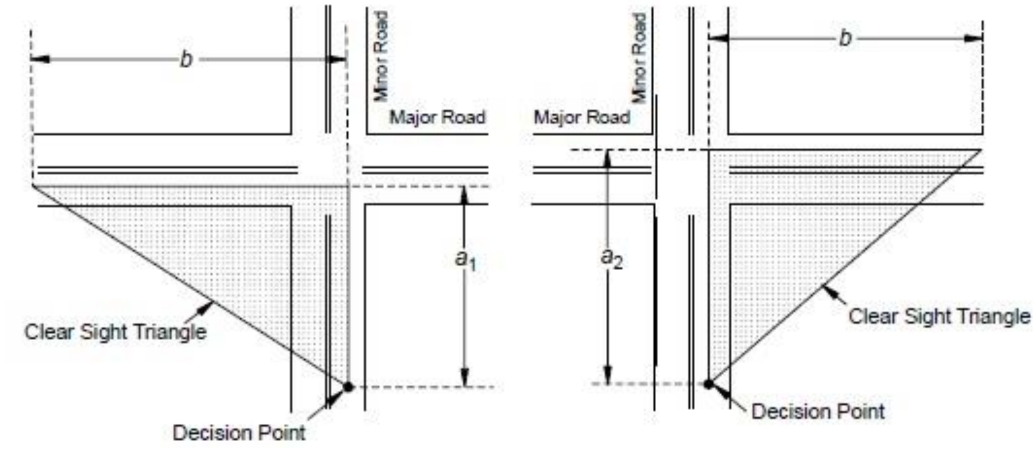


Figure 4.16 : Approach sight triangle (American Association of State Highway and Transportation Officials, 2018)

The vertex of the sight triangle is the minimum distance required for the driver coming from the minor road to stop if he sees another vehicle at the intersection. As seen in the figure, a_1 is the distance from the decision point to the axis of the major road while a_2 is the sum of the length of a_1 and the width of the lane. In addition, b denotes the leg length of the sight triangle. With the aid of the sight triangle, the vehicle with the right-of-way and the vehicle without the right-of-way can notice each other, so accidents can be prevented. The departure sight triangle provides requirement sight distance to the road user that coming from the minor road, so as to enter or leave the intersection. Figure 4.17 shows the sight triangles of a vehicle that is about to cross the intersection from the minor road. The departure sight triangle must be designed for the four different corners of the intersection.

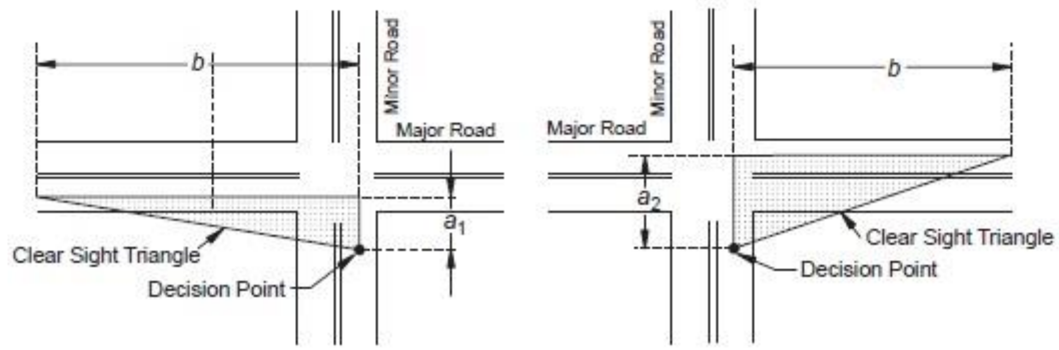


Figure 4.17 : Departure sight triangle (American Association of State Highway and Transportation Officials, 2018)

As seen in the figure, a_1 and a_2 denotes the same concepts as in the sight triangle. In addition, a_1 and a_2 may vary from project to project depending on the design of the stop line. By using the sight triangle, a vehicle from the major road can see a vehicle standing at the intersection coming from the minor road and take safety precautions.

4.3.3 Auxiliary Lanes

Are auxiliary lanes of appropriate length?

Auxiliary lanes are additional lanes that are usually located before the intersection, allowing drivers to join the traffic safely, enter, and leave the intersection safely. It is often used in designs with a right or left turn. By using the auxiliary lanes, the road capacity can be increased and the number of accidents can be reduced. Furthermore, an auxiliary lane should be preferred after turning right to accelerate and easily maneuver.

Figure 4.18 shows a sample of auxiliary lane design and components designed for left-turning.

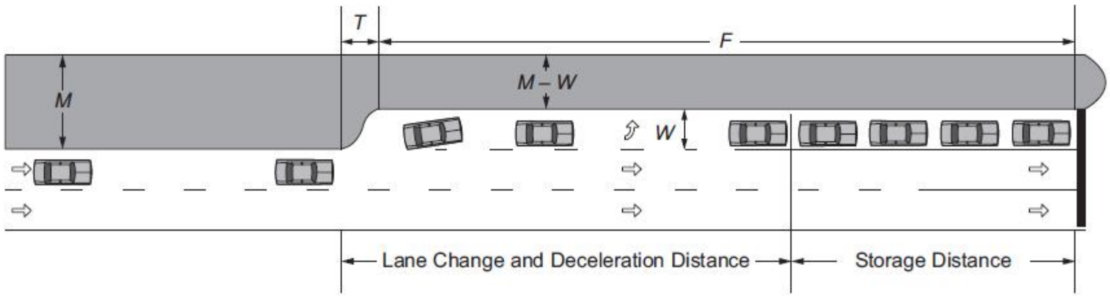


Figure 4.18 : Sample Left-Turn Auxiliary Lanes (American Association of State Highway and Transportation Officials, 2018)

In this design;

F: Total auxiliary lane length,

M: Median width,

T: Taper length,

W: Left turn auxiliary lanes width.

Auxiliary lanes should be at least 3 meters wide in urban arterials. In rural areas, this value should be at least 1.8 meters. Auxiliary lanes should be 0.6 to 1.2 meters at certain road segments that used by heavy tonnage vehicles and vehicles with off-tracking movement.

4.3.4 Markings

Are pavement markings obviously visible?

Pavement markings are another important issue that need to be considered in the design of intersections. Because, there are multiple route choices, many road users, and intersection elements so, pavement marking must contribute at easy route selection for road users. Well-designed road signs reduce the number of accidents, ensure efficient use of the road. Figure 4.19 shows a design with an appropriate pavement marking.

Figure 4.19 : Sample appropriate pavement marking

4.3.5 Signs

Are readability of signs adequate?

Signs on the road should be designed in such a way that the driver understands until he interacts with the next sign. Thus, parameters such as writings on the sign, distances between signs, size of signs are important.

Are there any missing, redundant, or broken signs?

For safe design, guidelines at the intersection should not mislead the drivers. Hence, missing, broken, or redundant road signs should not be in the design.

Are stop signs located in the appropriate places?

Positioning the stop signs in the wrong place in the intersection leads to congestion. This is undesirable in terms of safety and traffic flow. In addition, misplacement of yield signs can lead to serious security weaknesses. Therefore, it is important to position these marks correctly.

4.3.6 Signals

Are signals visible?

Signals on the road should be designed so that the driver can detect each other. Thus, it is important to positioning the signal. Besides, there should be no obstacle that preventing the signal's visibility.

Are the number of signals sufficient?

Drivers must completely comprehend what needs to be done for safe traffic. Therefore, they must comprehend traffic signals. Hence, a sufficient number of traffic signals should be located in the intersections.

Do traffic signals on the adjacent road affect the road user?

The driver must have a fully understanding of the traffic signals. Additionally, ıt should be able to easily understand which traffic signal appeals to it. Hence, whichever route the traffic signal appeals to the road user, it should have the position and angle that it can easily be understood by related road users.

4.3.7 Warnings

Are there any detectable warnings for people with disabilities?

There is a multiple route vehicle circulation at the intersection point. Therefore, it is necessary to put detectable warnings on the road surface especially for individuals with disabilities. These detectable warnings must be placed on walking surfaces and can be easily detected by vehicles such as walking sticks. This surface as shown in the Figure 4.20, warns persons with disabilities for the existence of vehicle road.

Figure 4.20 : Sample warning for people with disabilities

4.3.8 Pedestrians, bicyclists

Are intersections designed pedestrians friendly?

According to studies, 50 percent of the demand for transport is met by walking in underdeveloped countries while this rate is 10% from in developing countries. Therefore, pedestrians should be considered in intersection designs. Pavement width should be sufficient for pedestrians to travel safely. In the Table 4.4, the required pavement width as per person for different types of pedestrians using the intersection and the parameters affecting them in the intersection design are mentioned.

Table 4.4 : Required sidewalk width for different road users (Federal Highway Administration, 2006)

User and Characteristic		Dimension	Affected Intersection Features
Pedestrian		0.5 meter	Sidewalk width, crosswalk width
Wheelchair	Minimum Width	0.75 meter	Sidewalk width, crosswalk width, ramp landing areas
	Operating Width	0.90 meter	
Person pushing stroller		1.70 meter	Median island width at crosswalk
Skaters		1.80 meter	Sidewalk width

Is there a safe driving environment for bicyclists?

Another road users that must be considered during intersection design are bicyclists. For bicyclists, attention should be paid to the following design features at the intersections; bike lanes should be designed, left and right turn bike lanes should be designed, bike lanes should have a width of at least 2 meters (Federal Highway Administration, 2006). In addition, if it is not possible to provide a safe driving opportunity for bicyclists in intersection designs, an additional road should be designed.

4.4 Interchange

Subjects such as location, sight distance, shoulders, markings, signs, ramps, pedestrians, bicyclists will be examined within the scope of the issue of interchange. Within the scope of these topics, subtopics will be created, and related titles will be explained in detail.

4.4.1 Location

Are spacing between interchanges and ramp in the network is sufficient?

In road design, the distance between interchanges and ramps is an important parameter in the safety of the design. The distance of ramps depends on the type of interchanges and the ramp locations. Due to the high traffic flow, it is difficult to obtain the appropriate range of values in urban areas. The range of arterial interchanges depends on the type of interchange, traffic volume, and lane design. The interchange interval is generally considered to be at least 1.5 km for urban areas and at least 3 km for rural areas. In urban areas, if a minimum of 1.5 km cannot be obtained, grade-separated ramps and collector-distributor should be used to better design. The range of interchanges is determined as in the Figure 4.21.

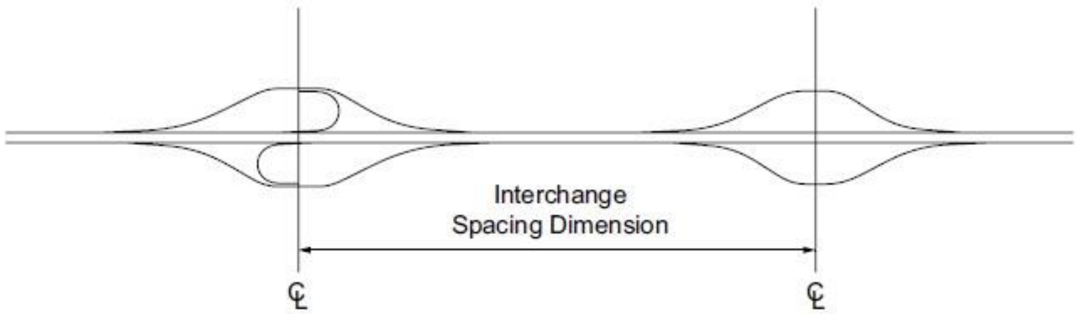


Figure 4.21 : Spacing between interchanges (American Association of State Highway and Transportation Officials, 2018)

4.4.2 Sight Distance

Is there adequate stopping sight distance?

The stopping sight distance should be strictly sought throughout the design and connections of the interchanges. Horizontal curves should have a clear sight distance that is purged from obstacles. For vertical curves, the necessary visibility must be provided in the crest. Besides, road lighting should be sufficient for adequate visibility. Furthermore, at accident hot spots, it is expected to have a decision sight distance, but a stopping sight distance is compulsory. Additionally, for a safety design, ramp terminals should not approach at angles greater than 6%. In addition, this value should not exceed 3% in high-speed road designs.

Is there adequate sight distance provided in advance of each exit?

At the exit ramp of interchanges, decision sight distance is always desired design. However, even if the decision sight distance cannot be obtained, the stopping sight distance must be absolutely obtained. In cases where the decision sight distance cannot be obtained, a lack of assessment is made. If the deficiency is less than 16 km/h, it is considered low risk. In addition, if there is a difference of more than 16 km/h, it is considered as high risk and requires some precautions to be taken (American Association of State Highway and Transportation Officials, 2018). For instance, the interchange design may be revised, or the exit ramp can be redesigned.

4.4.3 Shoulder

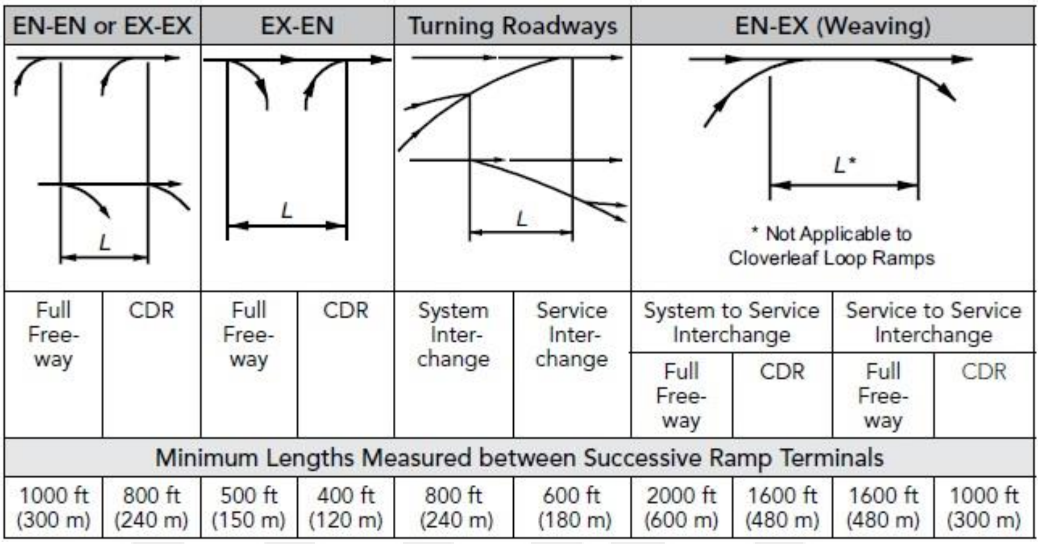
Is shoulder width sufficient?

The length of the shoulder must be 0.6 to 1.2 meters for the left-side shoulder at urban arterials. Besides, for the right-side shoulder, it should be 2.4 to 3.0 m meters (American Association of State Highway and Transportation Officials, 2018). Additionally, if necessary, these values can be used in the opposite direction.

4.4.4 Ramps

Is there adequate distance between the entrance and exit terminals?

In order to ensure road safety and driving comfort, there must be sufficient distance between consecutive terminals. Figure 4.22 shows the minimum distances that should be between consecutive terminals for different types of interchanges.



EN-EN or EX-EX		EX-EN		Turning Roadways		EN-EX (Weaving)			
Full Free-way	CDR	Full Free-way	CDR	System Inter-change	Service Inter-change	System to Service Interchange		Service to Service Interchange	
						Full Free-way	CDR	Full Free-way	CDR
Minimum Lengths Measured between Successive Ramp Terminals									
1000 ft (300 m)	800 ft (240 m)	500 ft (150 m)	400 ft (120 m)	800 ft (240 m)	600 ft (180 m)	2000 ft (600 m)	1600 ft (480 m)	1600 ft (480 m)	1000 ft (300 m)

Figure 4.22 : Recommended Minimum Ramp Terminal Spacing (American Association of State Highway and Transportation Officials, 2018)

4.4.4.1 Exit Terminals

Is sufficient length for deceleration at exit ramps?

In an appropriate interchange design, an additional lane should be added in order not to reduce the number of lanes, and it should be ensured to exit the intersection safely with the required speed reduction in turns. The length of the additional lane is usually designed as 450 meters. In addition, as shown in Figure 4.23, the horizontal curve connected at the exit from the interchange should have a radius of at least 300 meters.

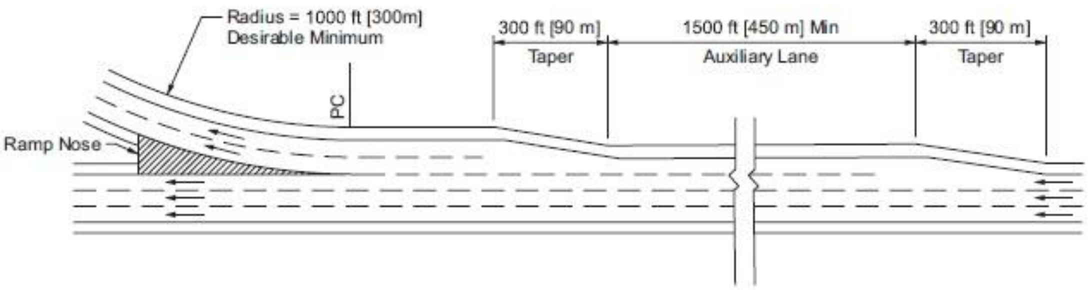


Figure 4.23 : Two-lane Exit Terminal design (American Association of State Highway and Transportation Officials, 2018)

Is adequate sight provided at exit terminals?

At the exit terminals, the stopping sight distance must be absolutely met. Besides, it is desirable that the road user entering or leaving the exit terminal should be provided with decision sight distance in order to they can better understand the road and choose the direction they want to go without any safety problem. The stopping sight distance values are shown in Figures 4.24.

Metric				
Design Speed (km/h)	Brake Reaction Distance (m)	Braking Distance on Level (m)	Stopping Sight Distance	
			Calculated (m)	Design (m)
20	13.9	4.6	18.5	20
30	20.9	10.3	31.2	35
40	27.8	18.4	46.2	50
50	34.8	28.7	63.5	65
60	41.7	41.3	83.0	85
70	48.7	56.2	104.9	105
80	55.6	73.4	129.0	130
90	62.6	92.9	155.5	160
100	69.5	114.7	184.2	185
110	76.5	138.8	215.3	220
120	83.4	165.2	248.6	250
130	90.4	193.8	284.2	285
140	97.3	224.8	322.1	325

Figure 4.24 : Stopping sight distance according to speed (American Association of State Highway and Transportation Officials, 2018)

In addition, decision sight distance values are given in Figure 4.25.

Metric					
Design Speed (km/h)	Decision Sight Distance (m)				
	Avoidance Maneuver				
	A	B	C	D	E
50	70	155	145	170	195
60	95	195	170	205	235
70	115	235	200	235	275
80	140	280	230	270	315
90	170	325	270	315	360
100	200	370	315	355	400
110	235	420	330	380	430
120	265	470	360	415	470
130	305	525	390	450	510
140	340	580	420	490	555

Figure 4.25 : Decision sight distance according to speed and location (American Association of State Highway and Transportation Officials, 2018)

In the related figure;

A: Stop on the road in a rural area

B: Stop on road in an urban area

C : Speed / path / direction change on rural road

D: Speed/path/direction change on suburban road or street

E: Speed/path/direction change on the urban, urban core, or rural town road or street

4.4.4.2 Entrance Terminals

Is adequate length for acceleration at entrance ramps provided?

In order to reach sufficient speed while connecting to the interchange, the entrance ramps must be of adequate length. In addition, the grade and slope of the ramp affect acceleration. Acceleration lane values recommended for safe and comfortable travel are shown in Figure 4.26.

Metric									
Acceleration Lane Length, L_a (m) for Design Speed of Controlling Feature on Ramp, V' (km/h)									
Highway		Stop Condition	20	30	40	50	60	70	80
Design Speed, V (km/h)	Merge Speed, V_a (km/h)	Average Running Speed (i.e., Initial Speed) at Controlling Feature on Ramp, V'_a (km/h)							
		0	20	28	35	42	51	63	70
50	37	60	50	30	—	—	—	—	—
60	45	95	80	65	45	—	—	—	—
70	53	150	130	110	90	65	—	—	—
80	60	200	180	165	145	115	65	—	—
90	67	260	245	225	205	175	125	35	—
100	74	345	325	305	285	255	205	110	40
110	81	430	410	390	370	340	290	200	125
120	88	545	530	515	490	460	410	325	245
130	92	610	580	550	530	520	500	375	300

Figure 4.26 : Decision Minimum Acceleration Lane Lengths for Entrance Terminals (American Association of State Highway and Transportation Officials, 2018)

V = design speed of highway

V_a = merge speed

V'= design speed of controlling feature on ramp

V'_a = average running speed (ie ., Initial speed) at controlling feature on ramp

L_a = acceleration lane length

4.4.5 Signs

Are signs at interchanges appropriate?

All signs, signals should be plain and easily understandable to ensure safe driving at interchanges. Road signs and signals should be used effectively to prevent road users from being confused at interchanges. Furthermore, it must be considered that there is no confusion on the road user due to the usage of smart transportation systems. In addition, the design features that wanted to be explained should be explained in the shortest way.

4.4.6 Pedestrians, bicyclists

Is the design of interchanges appropriate for pedestrians and bicyclists?

Sidewalk and bike paths should be considered during the design of the interchange. Especially, vehicles that enter the ramp terminal speedy pose a risk to pedestrians and bicyclists. Besides, on roads that pedestrians and bicyclists can use, sewage treatment should be avoided at the interchange of the ramp. In some cases, a grade-separated freeway can be designed for pedestrians and bicyclists at a different location in the interchanges.

4.5 Road Surface

4.5.1 Skid Resistance

Are there skid indications on the road?

Skidding is one of the major causes of traffic accidents. Road users are not the only reason for accidents caused by skidding. The road surface should provide adequate slip resistance that can tolerate braking movement and sudden maneuvers to a certain standard. Besides, road geometry is also effective at skidding. Whence, slip resistance should be considered in road designs. In addition, pavement types and textures also affect skidding. Besides, wet surfaces also increase the possibility of skidding. The causes of skidding at the wet surface are rutting, polishing, bleeding and dirty pavements. Furthermore, oil, dust, and organic matter on the road surface also increase the possibility of skidding. The most commonly used method to prevent skidding on bituminous surfaces is the usage of the polish-resistant coarse aggregate coating.

4.5.2 Pavement Defects

Are there any defections on the pavement?

Road users are not the only reason for traffic accidents. Factors such as road design, road surface, and weather conditions also trigger the accident. A cracking, blistering, collapse and corrugation on the road surface will cause the driver to lose steering control, resulting in accidents.

4.5.3 Ponding

Risk of ponding on the pavement

Accumulation of water at the pavement or on the shoulder is called ponding. The accumulation of water in wheel paths and ruts poses a danger to all road users. Especially, motorcyclists and bicyclists are affected by ponding. Furthermore, ponding at intersections leads to higher stopping sight distance. A road with ponding may cause the road user to be unable to recognize the road and deviate from the road if there is any defect in the road surface. Besides, the road user who sees ponding may want to change lanes with sudden maneuvers, as a result, may endanger the traffic. In addition, ponding on the edge of the pavement may cause deterioration. Additionally, ponding can rut stabilized soil that supports the pavement edge.

4.6 Road Users

4.6.1 Public Transport

Is road design appropriate for public transport?

One of the important issues that must be considered in urban arterial is public transport. Public transport is a desired transportation choice for high flow traffic as it takes up less space in terms of per passenger. However, urban arterials need to pay attention to urban transport design. For example, when a bus stops at a station, it affects not only its own lane but also all lanes. Public transport stations, the design of stations, design of turnouts, reservation of public transport lanes are the factors that must be considered in the urban arterial design. The first of these factors, bus stations, is designed according to the intersection points and transfer points of bus routes. In addition, it should be designed in places where pedestrians and cyclists can easily reach. Bus stops are usually designed near the intersection. Thus, pedestrians can cross the way as soon as they get off the bus. Moreover, midblock locations are also preferred if the distances between intersections are too long. As shown in Figure 4.27, bus stations can be designed at the near (approach) or far (departure) side of intersections.

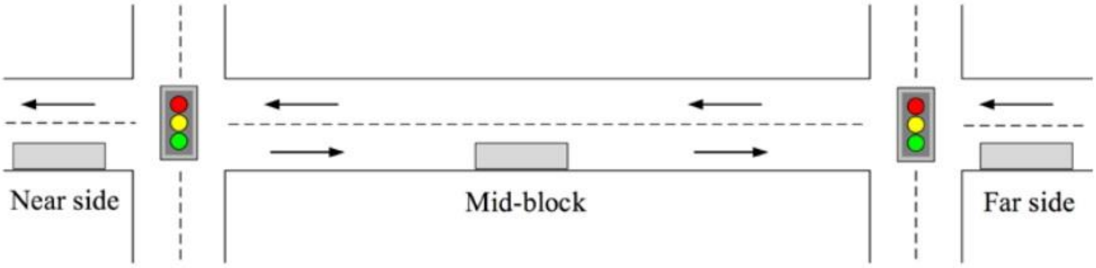


Figure 4.27 : Near side, Far side, Mid-block bus stop desigs (Wang et al., 2016)

Furthermore, far side designs are generally preferred. However, since each bus station may have its own design features, a design suitable for the location should be preferred.

Far side bus stops contribute to high traffic flow by facilitating the movement of buses that will turn from the arterial (especially those who will make a right turn). Besides, a reduction in the number of accidents involving pedestrians was observed on the far side bus station designs. Additionally, a road user approaching an intersection in the far side design can easily detect vehicles that coming from the right. In the near side design, the sight distance can be restricted. Moreover, if it is a signalized intersection, road users may not be able to see traffic signs. Besides, on the near side designs, the return of vehicles becomes difficult if there is a bus at the station. In addition, a vehicle making a turn in near side designs cannot use the deceleration lane. However, the vehicle that will take a turn in far side designs can easily do this. Midblock bus stops have advantages over near side bus stops with vehicle storage ve turning without congestion. Furthermore, if traffic volume is high, crosswalk design must be done at midblock bus stop designs. In this design, signal control should be preferred. Midblock signals disturb drivers, so they should only be used in locations where use is absolutely required.

For a bus turning left, the bus stop before an intersection, must be located at a sufficient distance to the intersection. Otherwise, the bus that must quickly cross to the left lane for the turning will endanger traffic. Besides, a stop should be preferred near the intersection after turning. The negative effect of public buses on high flow traffic can be decreased by designing a separate lane for public buses. These lanes that apart from the private vehicle lanes and will be used by public buses during passenger pick up or drop off are called bus turnouts as shown in Figure 4.28.

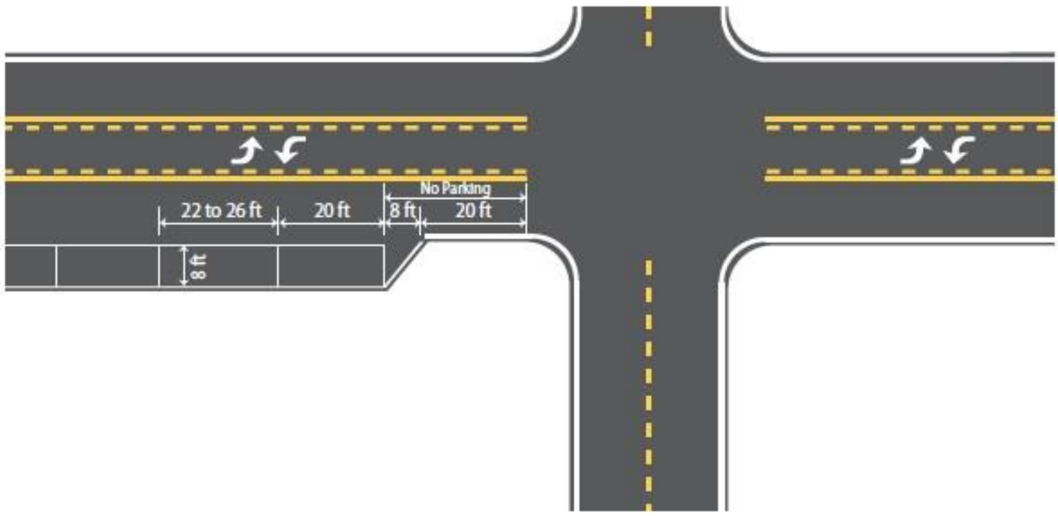


Figure 4.28 : Sample bus turnout design (Knapp et al., 2014)

However, bus turnouts should be designed in such a way that bus drivers can easily rejoin traffic. In some road segments, a lane can be designed that can only be used for public transportation, this lane is called reserved bus lanes. Figure 4.29 shows a reserved bus lane application for peak hours.

Figure 4.29 : Sample reserved bus lane (American Association of State Highway and Transportation Officials, 2018)

However, the efficiency of this design is limited due to there are some congestion problems for other vehicles on the right turns. In addition, public transport design for high flow traffic in urban arterial depends on the design characteristics and traffic flow characteristics of the related road segment. These designs cannot always be successful, a trial must be made on the road segment before application.

4.6.2 Cyclists, Pedestrians

Is there a safe driving environment for bicyclists?

Another road user that must be taken into account during the road segment design is the bicyclists. For cyclists, attention should be paid to the following design features at the throughout road; bike lanes should be designed, left and right turn bike lanes should be designed, bike lanes should have a width of at least 2 meters (Federal Highway Administration, 2006). Besides, if it is not possible to provide a safe driving opportunity for bicycle riders in design, a separate road should be designed.

Are people with disabilities taken into account in road design?

Some road users may have difficulties throughout the road segment. One of these users is people with disabilities. There must be braille brick sign at the pathway for people with disabilities as shown in Figure 4.30.

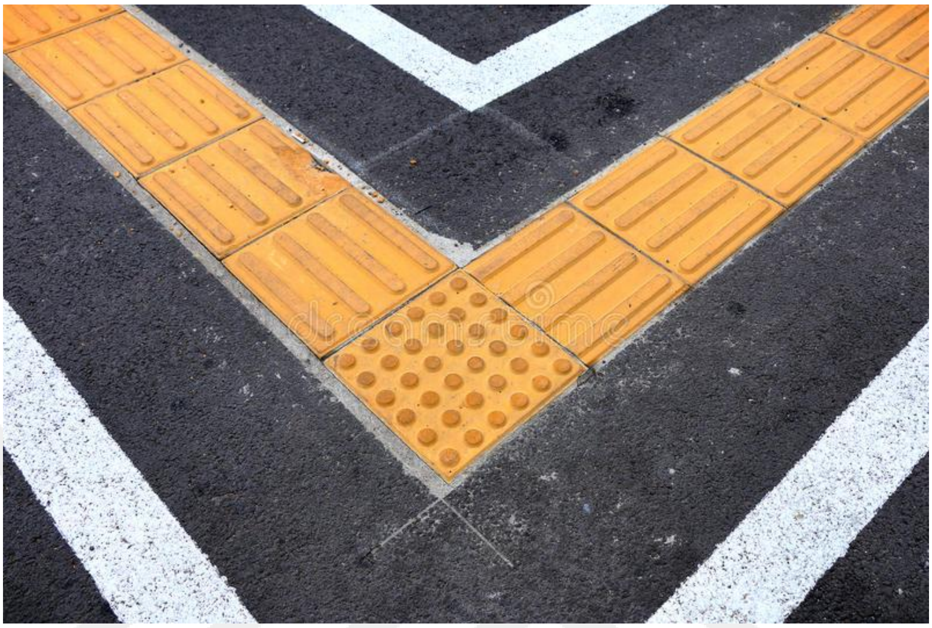


Figure 4.30 : Sample braille brick sign

The maintenance of these signs must be carried out periodically. Furthermore, people with disabilities should also be considered in pedestrian signs at crossing points. Moreover, people with disabilities should also be considered in all road elements like the design of metro stations along the road and the design of pedestrian overpasses. Therefore, elevators can be preferred at these points.

5. STUDY AREA: ANKARA

5.1 Ankara

Ankara that selected as study area, is Turkey's capital and second most populous city. According Turkish Statistical Institute (TUIK), Ankara's total population is 5,639,076 people, including provinces and districts (Turkish Statistical Institute, 2019). There are 25 districts of Ankara, which are; Altındağ, Ayaş, Bala, Beypazarı, Çamlıdere, Çankaya, Çubuk, Elmadağ, Güdül, Haymana, Kalecik, Kızılcahamam, Nallıhan, Polatlı, Şereflikoçhisar, Yenimahalle, Gölbaşı, Keçiören, Mamak, Sincan, Kazan, Akyurt, Etimesgut, Evren and Pursaklar. The the total surface area of Ankara which is majority in Central Anatolia Region, is 25632 km^2 (General Directorate of Mapping, 2014). In addition, neighboring provinces of Ankara are Bolu, Çankırı, Kırıkkale, Kırşehir, Aksaray, Konya and Eskişehir. Ankara is the intersection point of Konya highway, Istanbul Highway, Kırıkkale highway, Eskişehir highway, therefore it acts as a node point for transportation. Figure 5.1 shows the location map of Turkey in Ankara.

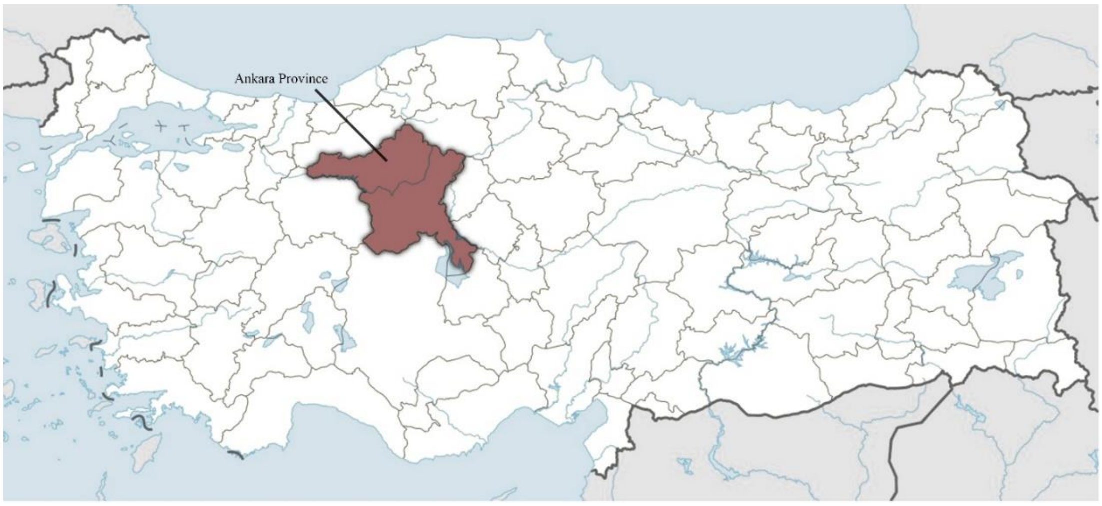


Figure 5.1 : Ankara's position on the Turkey

Ankara, which has been the capital since 1923, has developed rapidly from this date and has become Turkey's largest second city at the gross domestic product (Turkish Statistical Institute, 2018). Because of being the capital, many people work in the public sector in Ankara. The population of people working in the service industry makes up 70% of the entire population. In addition, 25% of the population lives in the industrial sector, while others live in agriculture (Ankara Development Agency, 2017). The literacy rate in Ankara is 97%. Figure 5.2 shows Ankara's population by years.

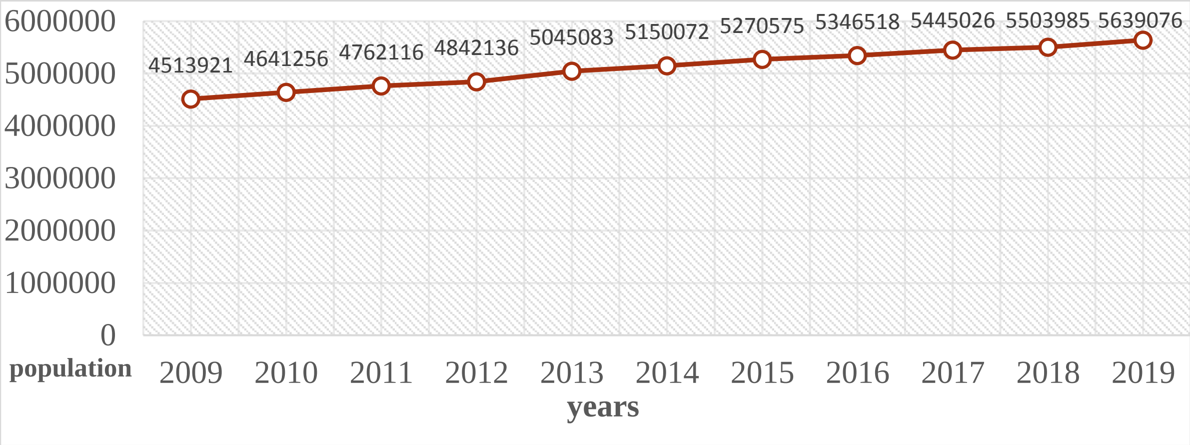


Figure 5.2 : Population of Ankara by years

In addition, with 20 universities in the city, approximately 30% of the population consists of students (Ankara Metropolitan Municipality, 2000). In Ankara, 60% of the total surface area is used as an agricultural area. The most produced products are wheat, barley, and sugar beet. 9% of Turkey's wheat production is carried out in Ankara (Ankara Development Agency, 2017). Ovine breeding is more preferred in Ankara. Because of the lack of pasture, cattle breeding is not suitable for Ankara. In addition, Ankara's symbol brand Angora goat breeding is widely seen and its breeding is supported by local and national institutions (Ankara Development Agency, 2017). Besides, winter and spa tourism is preferred in Ankara. There are famous towns such as Kızılcahamam and Haymana. However, the rate of foreign tourists visiting Ankara remains still low. Only 2 percent of tourists coming to Turkey to visit Ankara (Ankara Development Agency, 2017).

5.2 Transportation Statistics

Ankara has a wide intercity and international transportation network. Due to the geographic location of Ankara which can be considered as the center of Turkey's, it is a node point for highway and railway network. Ankara has an improved road network. As shown in the Figure 5.3, Ankara has a total road network of 1832 km (General Directorate of Highways, 2019b).

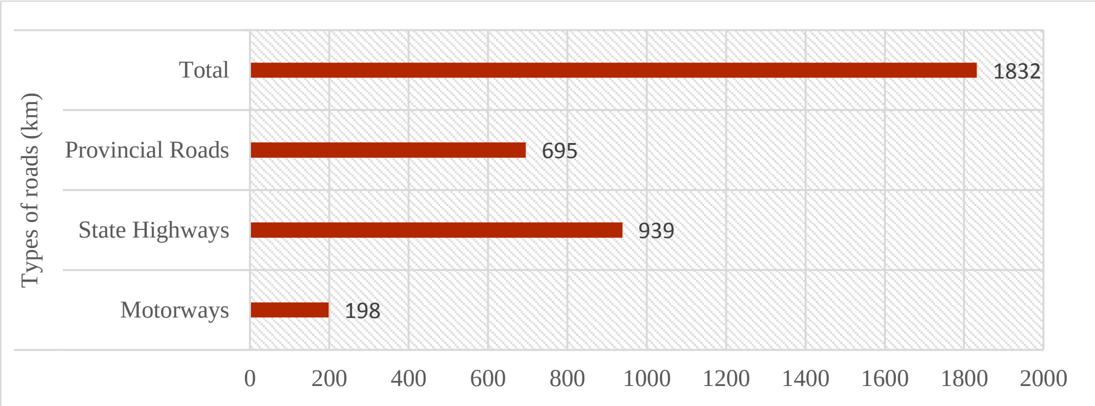


Figure 5.3 : Road network in Ankara

Owing to the O-20 beltway, transportation to other cities can be provided for the city without traffic congestion. In addition, the O-4 highway is Ankara's connection to Istanbul. In addition, the D200 road connects Bursa and Eskişehir to Ankara, while the D750 road connects Adana to Ankara (General Directorate of Highways, 2019a). The Figure 5.4 shows Ankara's intercity road network.

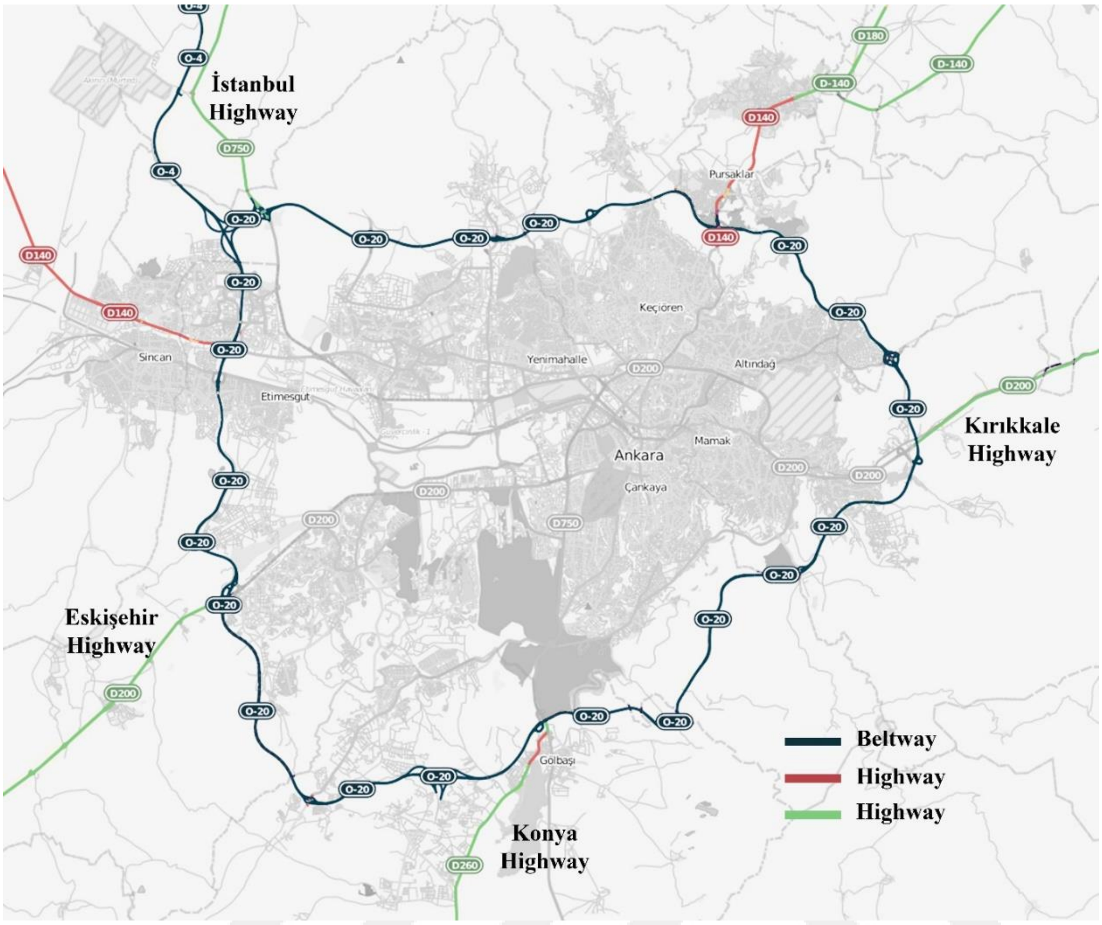


Figure 5.4 : Ankara's intercity road network

Through planned high-speed railways and existing railway network, Ankara has an advanced railway network. In the target included in the development plan of the Ministry of Transport and Infrastructure, Ankara has been accepted as the center for new high-speed railway projects. Currently, Izmir and Sivas lines are planned to be added to the Ankara high-speed railway network, which has a high-speed rail service to Istanbul, Konya, and Eskişehir. Esenboğa Airport, which is one of the national and international transportation opportunities of Ankara, continues its development day by day. Domestic and international flights can be made directly to 100 different destinations from Esenboğa Airport, which is used by 14 million passengers per year (Ankara Development Agency, 2017). However, Ankara still makes few flights especially on international flights compared to other big cities.

Ankara serves in public transportation with municipal and private-public buses, light rail (Ankaray), metro, suburban (Başkentray), and cable car. In Ankara public transportation network, public transportation is mostly done by bus. There is a metro network of 56 km, 4 different lines in Ankara. 9 million passengers are transported on these four metro lines per month. In addition, a light rail system called Ankaray provides public transportation services to important points of the city, such as the bus station. Approximately 3.5 million passengers are transported monthly in Ankaray. With the suburban system called Başkentray, transportation is carried out mostly to districts far from the city center. Figure 5.5 shows public transportation statistics in Ankara for January and February 2020.

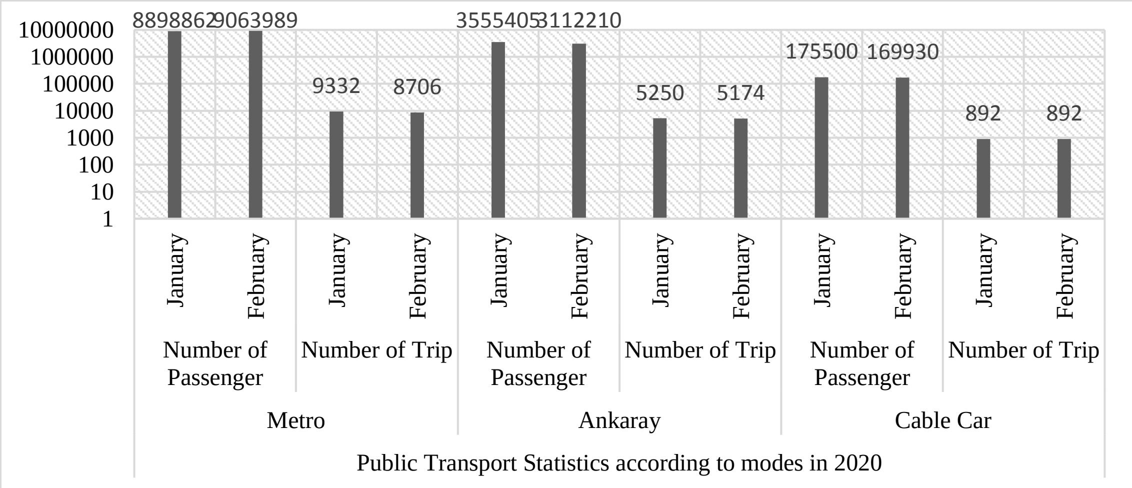


Figure 5.5 : Public Transport Statistics according to 2020 (Ankara Metropolitan Municipality, 2020)

An average of 42 thousand passengers per day is carried by Başkentray, which is usually used by people or students who come to the city center. In addition, the cable car is another public transportation vehicle frequently used by people living in the high altitude Şentepe region in Ankara. An average of 180 thousand passengers is transported every month by cable car. Ankara's most preferred public transport is municipal buses and private-public buses. Approximately 20 million passengers are transported every month with these buses serving many points of the city (Ankara Metropolitan Municipality, 2018).

5.3 Road Safety

According to the data of the World Health Organization, approximately 1.5 million people die every year due to traffic accidents. In addition, countries spend 3% of their gross domestic product in traffic accidents. In Turkey, about 8 thousand people lose their lives every year. As seen, traffic accidents cause great losses both in spiritual and financial terms. At the Table 5.1, accidents that occurred between the years of 2002-2018 in Turkey, and their spiritual and financial damages are shown.

According to the Turkish Statistical Institute data, through 3.8 people/car ratio, Ankara has the highest per capita rate of car ownership. This situation declares the importance of traffic safety studies in Ankara. Figure 5.6 shows vehicle ownership in Ankara according to vehicle types.

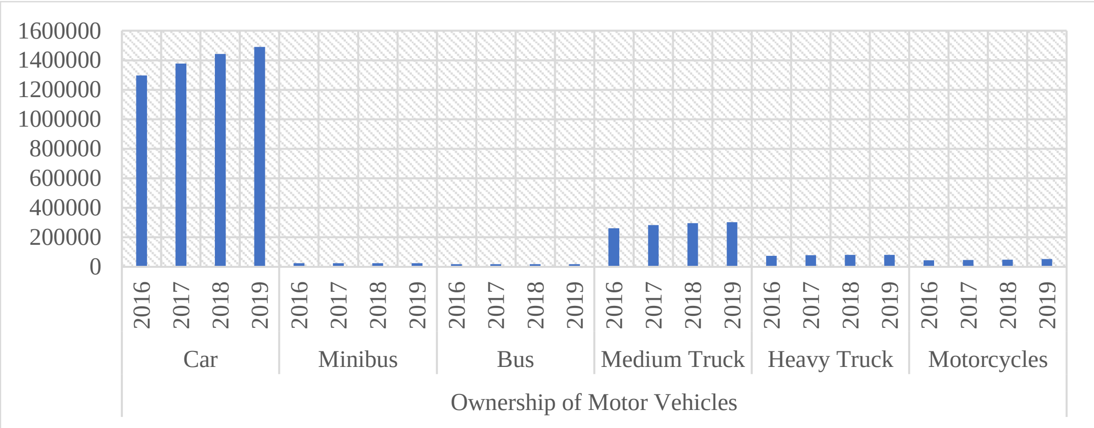


Figure 5.6 : Vehicle ownership by vehicle types in Ankara

According to the Turkish Statistical Institute, Ankara is the second city where the most death accidents happened in 2018. This shows that serious measures should be taken regarding traffic safety.

Year	Total number of accidents	Accidents involving material loss only	Accidents involving death and personal injury	Killed persons			Number of persons injured
				Total	At accident scene	Accident follow-up	
2002	439 777	374 029	65 748	4 093	4 093	-	116 412
2003	455 637	388 606	67 031	3 946	3 946	-	118 214
2004	537 352	460 344	77 008	4 427	4 427	-	136 437
2005	620 789	533 516	87 273	4 505	4 505	-	154 086
2006	728 755	632 627	96 128	4 633	4 633	-	169 080
2007	825 561	718 567	106 994	5 007	5 007	-	189 057
2008	950 120	845 908	104 212	4 236	4 236	-	184 468
2009	1 053 346	942 225	111 121	4 324	4 324	-	201 380
2010	1 106 201	989 397	116 804	4 045	4 045	-	211 496
2011	1 228 928	1 097 083	131 845	3 835	3 835	-	238 074
2012	1 296 634	1 143 082	153 552	3 750	3 750	-	268 079
2013	1 207 354	1 046 048	161 306	3 685	3 685	-	274 829
2014	1 199 010	1 030 498	168 512	3 524	3 524	-	285 059
2015	1 313 359	1 130 348	183 011	7 530	3 831	3 699	304 421
2016	1 182 491	997 363	185 128	7 300	3 493	3 807	303 812
2017	1 202 716	1 020 047	182 669	7 427	3 534	3 893	300 383
2018	1 229 364	1 042 832	186 532	6 675	3 368	3 307	307 071

Table 5.1 : Between 2012 and 2018 occurring in Turkey financially, spiritually damaged traffic accidents (General Directorate of Security, 2018)

Although Ankara is the most second populous city in Turkey, Ankara's population density is ten times lower than İstanbul. Therefore, private vehicles are frequently preferred in transportation demand. This increases the accident rate, especially in the city center. As seen in the Figure 5.7, except for 2019, traffic accidents in Ankara have increased year by year.

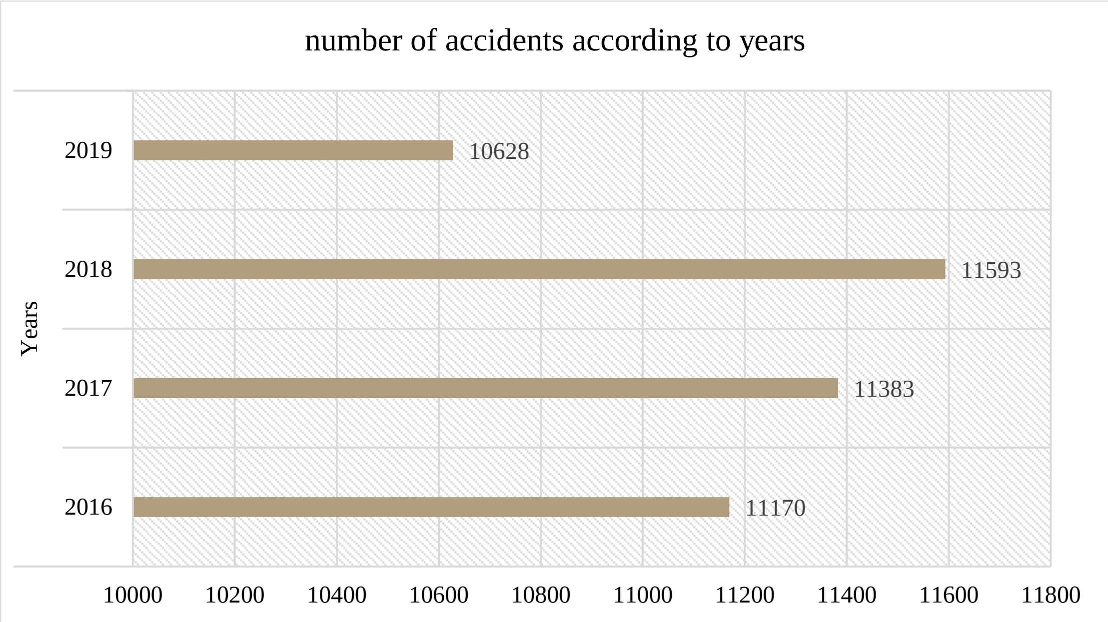


Figure 5.7 : Number of accidents by years in Ankara (General Directorate of Security, 2020b)

When the accident data is examined in the Figure 5.9, it is observed that accidents intensify especially in Çankaya, Altındağ, Etimesgut, Keçiören, and Yenimahalle districts. Traffic accidents that occur are causing great spiritual and financial damages in Ankara. As shown in the Figure 5.8, 505 people died in the city of Ankara between 2016 and 2019. According to the data of Anadolu Agency, Ankara was the city where the most mortal accident happened in 2018. All these data show the importance of road safety studies in Ankara.

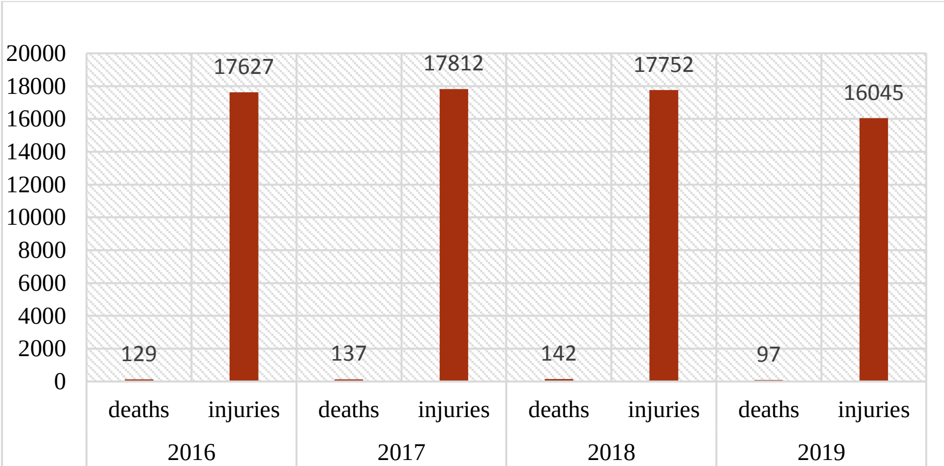


Figure 5.8 : Number of fatal,injured accidents that occurred between the years 2016 and 2019 in Ankara

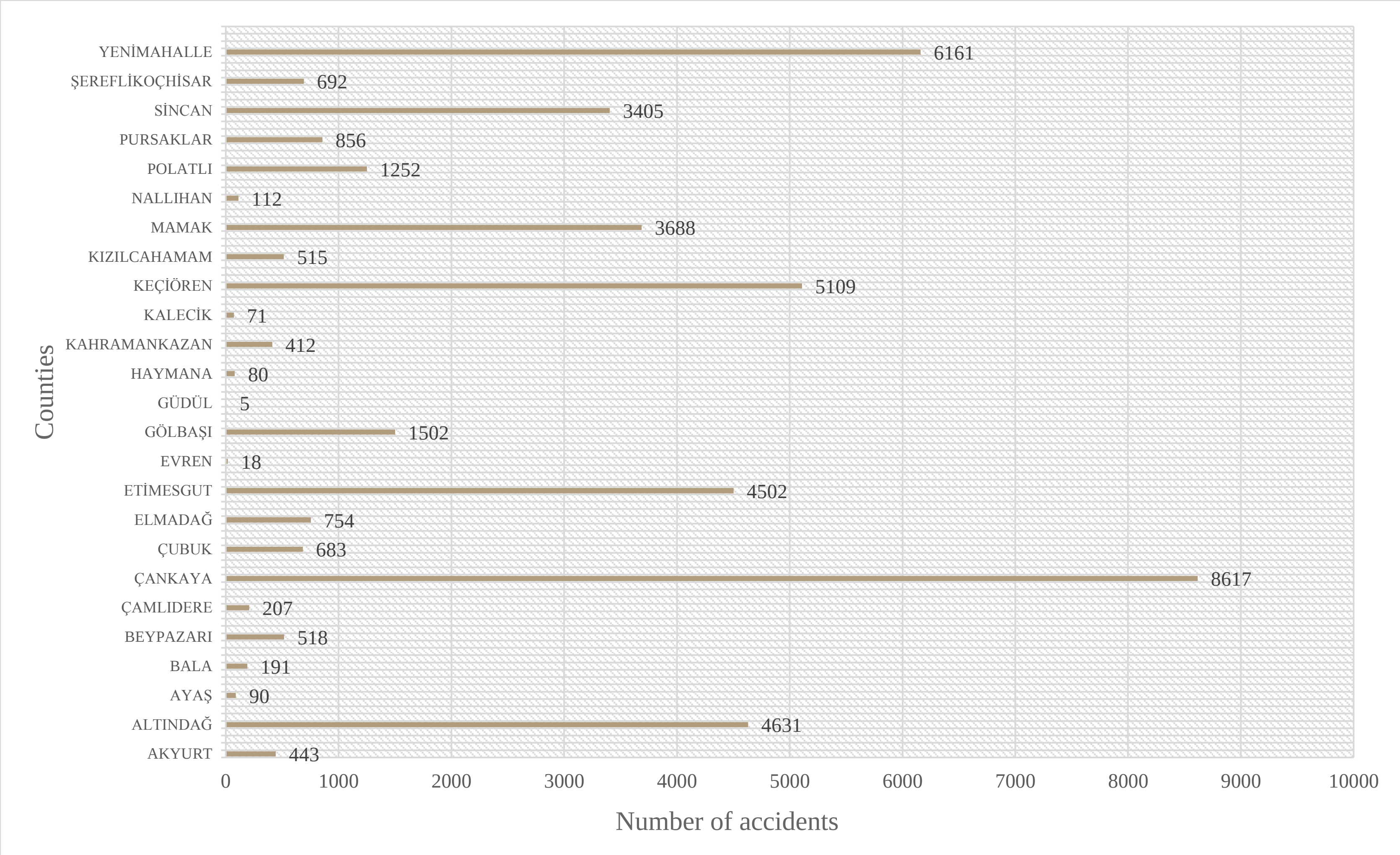


Figure 5.9 : Number of accidents by counties in Ankara (General Directorate of Security, 2020b)

6. CASE STUDY: ATATÜRK BOULEVARD

6.1 Hot Spot İdentification

Within the scope of the thesis, traffic accidents between 2016 and 2019 in Ankara were examined. The total number of accidents recorded between these years is 44771. Besides, 69236 people were injured in these accidents, 505 people died. The locations of the accident data received from the General Directorate of Security were transferred to the Geographic Information Systems. Afterward, accident hot spot analysis was performed with Kernel Density Estimation aided Geographic Information Systems. As a result of the analyzes, the regions where accidents occur most frequently in Ankara are shown as in Figure 6.1.

Figure 6.1 : Ankara hot spot analysis

As seen, the regions where the accidents are most clustered are the Sincan High-Speed Train Station and the Çankaya district Atatürk Boulevard. Furthermore, it is seen that Atatürk Boulevard is a more clustered region. Therefore, Atatürk Boulevard was chosen as the study area. Figure 6.2 shows a detailed accident analysis of Atatürk Boulevard.

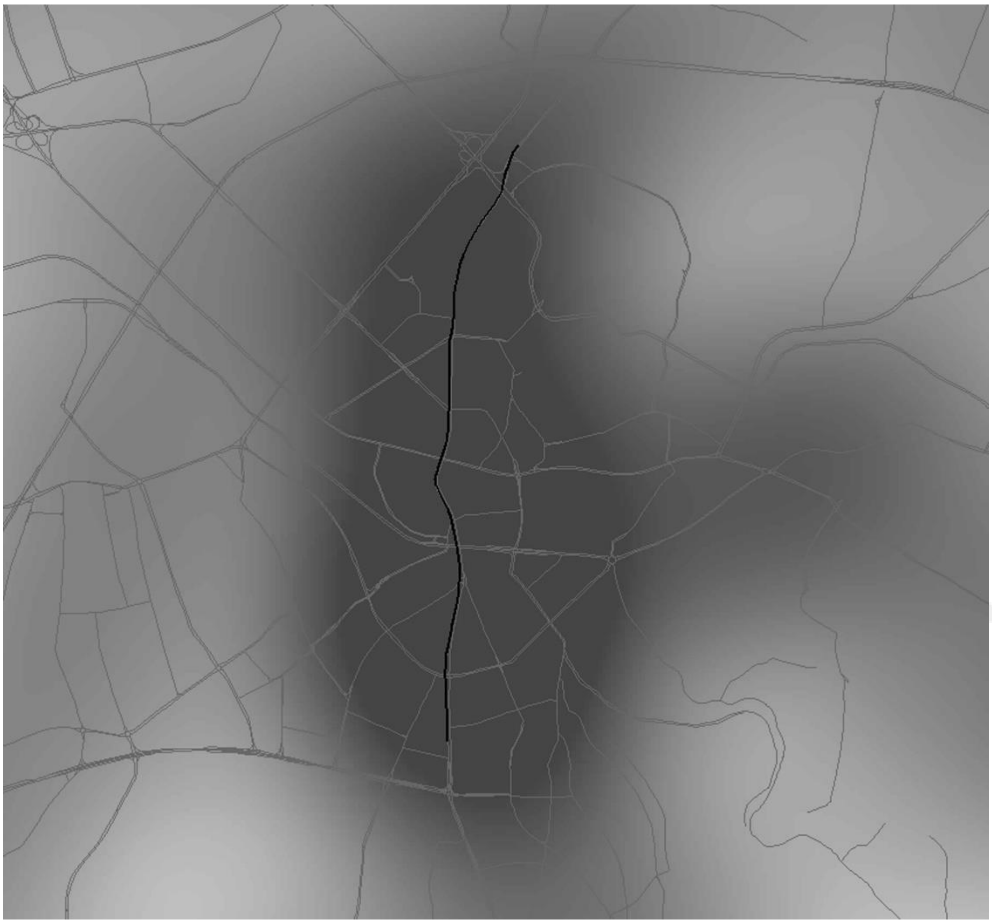


Figure 6.2 : Atatürk Boulevard hot spot analysis

6.2 Atatürk Boulevard

Ataturk Boulevard, which was chosen as the project area, was designed by Hermann Jansen in 1932 within the master plans, also known as the Jansen Plan. The boulevard is about 5.6 kilometers length. In addition, it has 6 lanes and is about 30 meters wide. An average of 60 thousand vehicles passes through this boulevard, which can be considered as the busiest boulevard in Ankara. According to the General Directorate of Highways, the speed limit of Atatürk Boulevard is 50 km/hour. Moreover, this boulevard, which can be considered as the Central Business District, is used extensively by public transport and pedestrians. This boulevard, which was planned about 100 years ago, cannot meet the traffic demand as it is the busiest and most popular area of the city over time. The population of Ankara, which was 540 thousand in 1935, has increased to 5.5 million today. In addition, vehicle ownership has increased above the population growth rate. The figure shows a photograph of Atatürk Boulevard, taken in the 1930s. Due to the increasing population and vehicle volume, Atatürk Boulevard cannot provide sufficient traffic supply in today's conditions. Therefore, hundreds of accidents occur on the boulevard every year. These accidents can be fatal, injured, or cause material damage. Thus, Atatürk Boulevard was chosen as the study area. Atatürk Boulevard is an urban principal arterial based on vehicle volume and design features. Furthermore, RSA will be done not for the entire Atatürk Boulevard, but for the parts with the most traffic accidents. In this context, Atatürk Boulevard is divided into 11 sections which are Akay Interchange, Alignment between Akay Interchange and Kızılay Square, Kızılay Square, Alignment between Kızılay Square and Sıhhıye Interchange, Sıhhıye Interchange, Alignment between Sıhhıye Interchange and Talatpaşa Boulevard, Talatpaşa Boulevard, Alignment between Talatpaşa Boulevard and Opera Square, Opera Square, Aliment Square and Ulus Square, Ulus Square. Figure 6.3 shows these 11 parts.

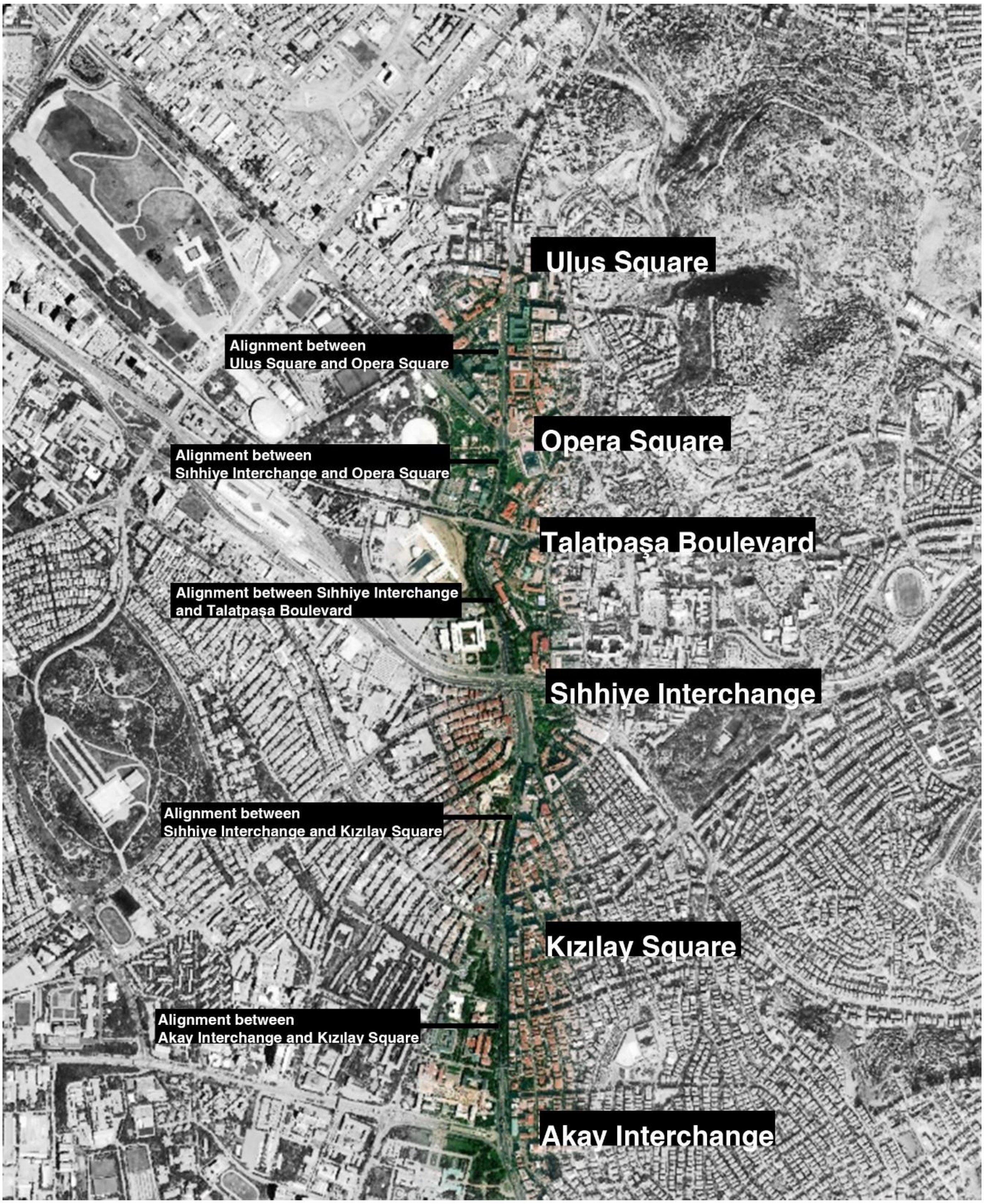


Figure 6.3 : Sections of Atatürk Boulevard

Road Safety Audit field inspections were made for different hours of the day, different hours of traffic, such as morning-evening peak hours, midday, and night hours. During the field investigations, detailed observations were made, notes were taken and photographs were taken. In addition, interviews were made with traffic police and permanent residents (taxi drivers, store workers, etc.) in the area.

6.3 Road Safety Audit of Atatürk Boulevard

In this thesis, the road safety evaluation of Atatürk Boulevard will be made. Hence, the checklist will be determined first. After the checklists are determined, questions about the title will be asked. There are many checklists used by public or private institutions. In addition, the checklists used can vary depending on the characteristics of the project. As part of this thesis, Road Safety Audit checklists prepared by the Federal Highway Administration (FHWA), AUSTROADS, University of New Brunswick Transportation Group, and The Chartered Institution of Highways & Transportation were examined and tried to create unique, most appropriate checklists. Moreover, due to lack of data, some titles determined in checklists will not be examined.

6.3.1 General

6.3.1.1 Traffic Safety

Existence of obstructions at clear zone

As we mentioned before, the area required for the vehicle to stop without hitting any obstacles is called clear zone if the vehicle loses control of the road. Shoulders, bicycle way, and auxiliary lanes are also considered clear zones. As mentioned before, the design speed of Atatürk Boulevard is 50 km/hour and the average number of vehicles per day is 60 thousand. Therefore, the desirable clear zone width is between 4.5 meters and 5 meters as shown in Figure 6.4.

Design Speed (Km/h)	Design AADT +	Fill Slopes			Cut Slopes		
		6:1 or Flatter	5:1 to 4:1	3:1	3:1	5:1 to 4:1	6:1 or Flatter
60 or less with barrier curb***	All	0.5	0.5	0.5	0.5	0.5	0.5
60 or Less	Under 750	2.0 – 3.0	2.0 – 3.0	**	2.0 – 3.0	2.0 – 3.0	2.0 – 3.0
	750 – 1500	3.0 – 3.5	3.5 – 4.5	**	3.0 – 3.5	3.0 – 3.5	3.0 – 3.5
	1500 – 6000	3.5 – 4.5	4.5 – 5.0	**	3.5 – 4.5	3.5 – 4.5	3.5 – 4.5
	Over 6000	4.5 – 5.0	4.5 – 5.0	**	4.5 – 5.0	4.5 – 5.0	4.5 – 5.0
70 –80	Under 750	3.0 – 3.5	3.5 – 4.5	**	2.5 – 3.0	2.5 – 3.0	3.0 – 3.5
	750 – 1500	4.5 – 5.0	5.0 – 6.0	**	3.0 – 3.5	3.5 – 4.5	4.5 – 5.0
	1500 – 6000	5.0 – 5.5	6.0 – 8.0	**	3.5 – 4.5	4.5 – 5.0	5.0 – 5.5
	Over 6000	6.0 – 6.5	7.5 – 8.5	**	4.5 – 5.0	5.5 – 6.0	6.0 – 6.5
90	Under 750	3.5 – 4.5	4.5 – 5.5	**	2.5 – 3.0	3.0 – 3.5	3.0 - 3.5
	750 – 1500	5.0 – 5.5	6.0 – 7.5	**	3.0 – 3.5	4.5 – 5.0	5.0 – 5.5
	1500 – 6000	6.0 – 6.5	7.5 – 9.0	**	4.5 – 5.0	5.0 – 5.5	6.0 – 6.5
	Over 6000	6.5 – 7.5	8.0 – 10.0 *	**	5.0 – 5.5	6.0 – 6.5	6.5 – 7.5
100	Under 750	5.0 – 5.5	6.0 – 7.5	**	3.0 – 3.5	3.5 – 4.5	4.5 – 5.0
	750 – 1500	6.0 – 7.5	8.0 – 10.0 *	**	3.5 – 4.5	5.0 – 5.5	6.0 – 6.5
	1500 – 6000	8.0 – 9.0	10.0 – 12.0 *	**	4.5 – 5.5	5.5 – 6.5	7.5 – 8.0
	Over 6000	9.0 – 10.0 *	11.0 – 13.5 *	**	6.0 – 6.5	7.5 – 8.0	8.0 – 8.5
110	Under 750	5.5 - 6.0	6.0 – 8.0	**	3.0 – 3.5	4.5 – 5.0	4.5 – 4.9
	750 – 1500	7.5 – 8.0	8.5 – 11.0 *	**	3.5 – 5.0	5.5 – 6.0	6.0 – 6.5
	1500 – 6000	8.5 – 10.0 *	10.0 – 13.0 *	**	5.0 – 6.0	6.5 – 7.5	8.0 – 8.5
	Over 6000	9.0 – 10.5 *	11.0 – 14.0 *	**	6.5 – 7.5	8.0 – 9.0	8.5 – 9.0
120 or More	750 – 1500 +	8.0 – 9.0	9.0 – 12.0	**	3.5 – 5.0	6.0 – 6.5	7.0 – 7.5
	1500 – 6000 +	9.0 – 10.0	10.0 – 14.0	**	5.5 – 6.5	7.0 – 8.0	8.0 – 9.0
	Over 6000 +	10.0 – 11.0 *	11.0 – 15.0	**	7.0 – 8.0	8.5 – 9.5	9.0 – 10.0

Figure 6.4 : Desirable clear zone width

However, as there are lots of traffic signs, signals, luminaries, billboards, and landscapes on the road segment, meet this length is very difficult in urban arterials. In our study area, the clear zone length varies between 1 meter and 2 meters throughout the road segment as shown in Figure 6.5.

Figure 6.5 : Sample clear zone in Atatürk Boulevard

However as shown in Figure 6.7, in some parts along the road segment, the clear zone length is also less than 1 meter. In these parts, especially the trees and luminaries on the roads threaten traffic safety as shown in Figure 6.6. In such cases, the obstacle in the clear zone can be covered with a safe material or road users must be warned against these obstacles.

Figure 6.6 : Undesirable clear zone design

Figure 6.7 : Undesirable clear zone

Are there any risks for crossing over the medians?

On high volume roads with high design speed, wider medians should be preferred. According to the chart developed for the desirable median width by AASHTO, it is recommended that the median width of Atatürk Boulevard, which has 60 thousand AADT, is 10 meters as shown in Figure 6.8.

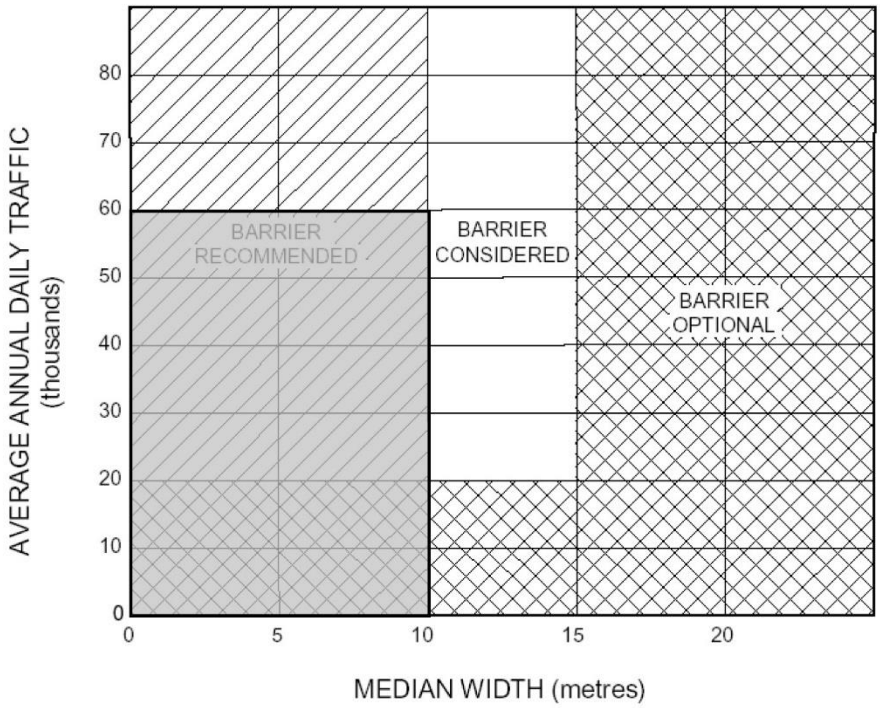


Figure 6.8 : Recommended median width

Figure 6.9 and Figure 6.10 shows different types of median designs were used in the project.

Figure 6.9 : Sample median design in Atatürk Boulevard

Figure 6.10 : Sample median in Atatürk Boulevard

However, the median width is generally designed as 3 meters throughout the project. In addition, the median height is usually designed between 1.5 meters and 2 meters. This median design largely prevents crossing over median accidents. However, some median designs along the road segment remain poor in preventing accidents. First of all, the median made of glass material in the figure may be poor in preventing accidents due to both the median width and the type of material as shown in Figure 6.11.

Figure 6.11 : Median that made of glass material

In addition, the median design with the intermittent structure in the Figure 6.12, endangers the traffic by allowing pedestrians to cross the street.

Figure 6.12 : median design with the intermittent structure

It has been observed that this median design endangered traffic safety both as a result of field observation and interviews with traffic police.

6.3.1.2 Landscape

Accordance of landscape with road guidelines

Since the road segment is in the most central region of the city, the road landscape is suitable for road guidelines throughout the project. But in some turns like in Figure 6.13, there are plants that can obstruct the driver's sight distance. Furthermore, there are plants at several points to reduce the visibility of traffic signs as shown in Figure 6.14.

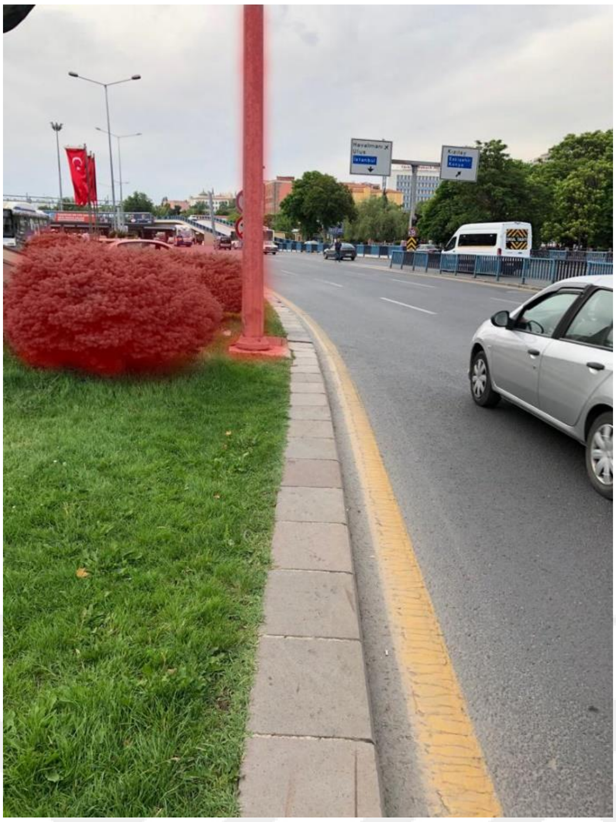


Figure 6.13 : Undesirable landscape for road guidelines

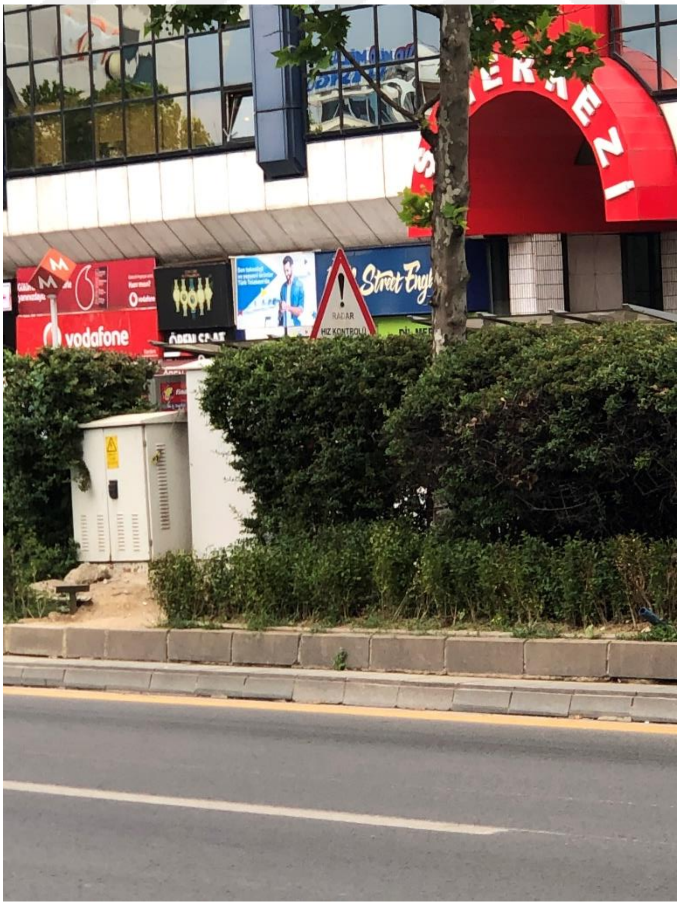


Figure 6.14 : Obstructed traffic signs due to plants

Possibility of inadequate sight distance due to future plant growth

Due to the central location of the road segment, since landscape maintenance is carried out regularly, there is no possibility of limited sight distance due to future plant growth.

6.3.1.3 Temporary Work

There is no road work along the road segment. However, Figure 6.15 shows temporary work is being carried out in the pathway. Although maintenance work is not too dangerous for pedestrians, just pulling a strip remains a poor warning.

Figure 6.15 : Temporary work on pathway

6.3.1.4 Headlight Glare

Since the project is divided way, oncoming vehicles mostly do not cause a headlight glare effect. Besides, there are lighting sources in the project such as road lighting, pathway lighting, and billboard. The road and pathway luminaries as shown in the Figure 6.16 and Figure 6.17 are measured according to the standards.

The luminaries that brighten the road segment are 12 meters in height. In addition, the luminaries in the pathway are 5 meters in height. Both luminaries meet standards.

Figure 6.16 : Sample pathway luminaries on Atatürk Boulevard

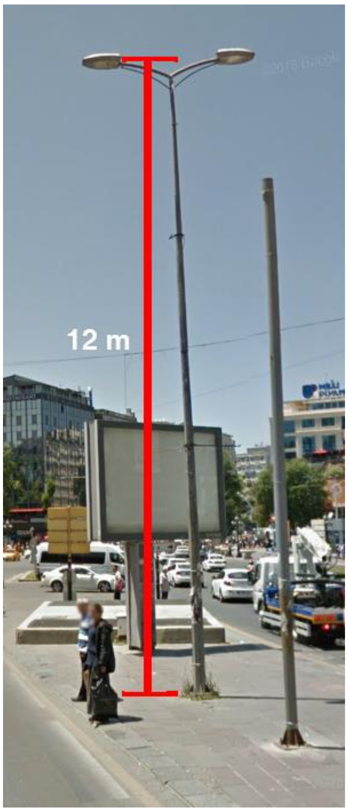


Figure 6.17 : Sample road luminaries on Atatürk Boulevard

However, some billboards in Kızılay Square such as in Figure 6.18, can have a headlight glare effect.

Figure 6.18 : A billboard that may cause headlight glare in Kızılay Square

6.3.1.5 Accident Database

Availability of accident reports

After the accident occurred, traffic police arrive upon the scene and make the documentation of the accident. In this report, features such as accident coordinates, hour, day, year, road pavement features, speed limit, number of casualties, number of injured, type of road, and weather are reported. Accidents were reported in Atatürk Boulevard and stored in the General Directorate of Security data warehouse.

Relationship of accidents at the same location

Hot spot identification, which is one of the main titles within the scope of the thesis, establishes a relationship between accident points clustered to each other. After hot spot identification for Ankara province, hot spots were identified in Atatürk Boulevard, where the most accidents occurred. Accident locations that obtained as a result of the analysis:

<u>Akay Interchange:</u>

The accidents that at the Akay Interchange generally occurred at the superposition of Atatürk Boulevard and Esat Street, due to there is no auxiliary lane in design as shown in Figure 6.19. In addition, Figure 6.20 shows that the sight distance of the drivers who will join Atatürk Boulevard from Esat Street are restricted due to the metro entrance.

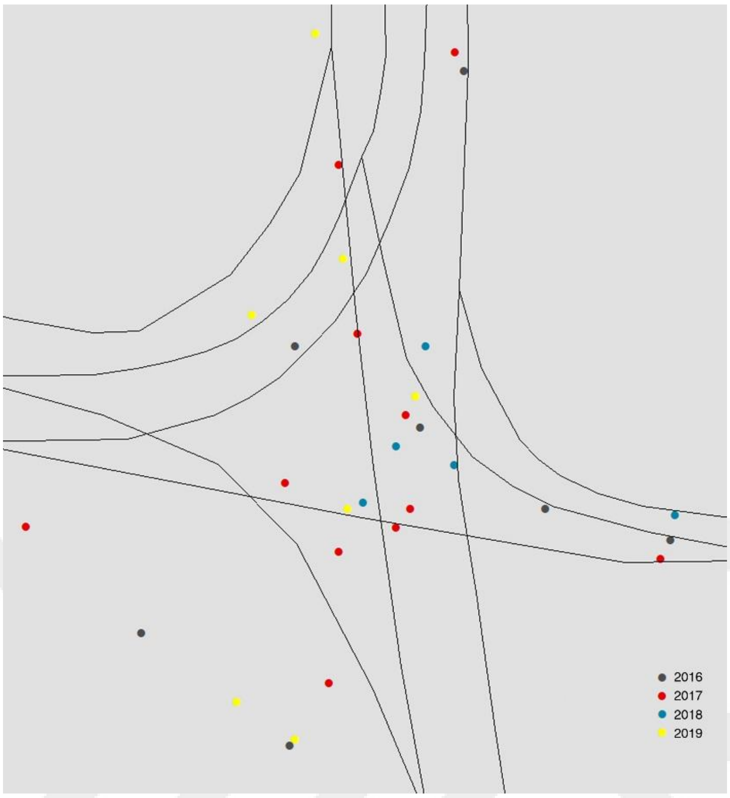


Figure 6.19 : Accidents that occurred between 2016 and 2019 at the Akay Interchange

Figure 6.20 : Restricted sight distance due to metro entrance

<u>Alignment between Akay Interchange and Kızılay Square</u>

Many accidents have occurred during the alignment between Akay Interchange and Kızılay Square. However, as shown in Figure 6.21, especially in intersection turning locations, it was observed that an accident occurred due to the restricted sight distance. Also, it was observed that the confusion between public transport and private vehicle traffic caused lots of accidents.

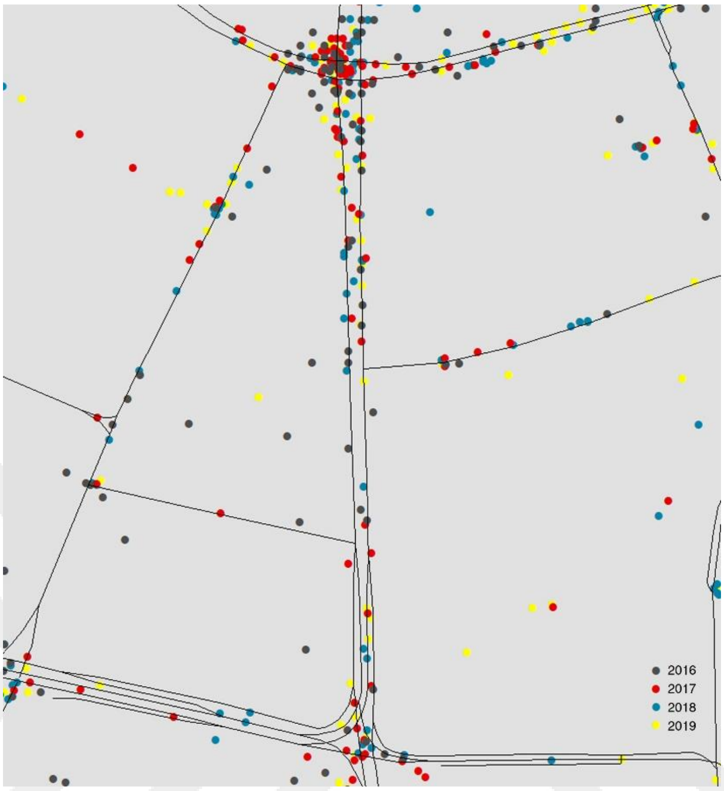


Figure 6.21 : Accidents that occurred between 2016 and 2019 at the alignment between Akay Interchange and Kızılay Square

<u>Kızılay Square</u>

Kızılay square is the clustered point where most accidents occur in the study area. Although there are many reasons for the accidents, it has been observed that restricted sight distance and pedestrian based accidents occur, especially when turning from Ataturk Boulevard to Gazi Mustafa Kemal Boulevard. In addition, due to a lack of readability of traffic signs, some drivers violate turning restrictions and cause accidents as shown in Figure 6.22.

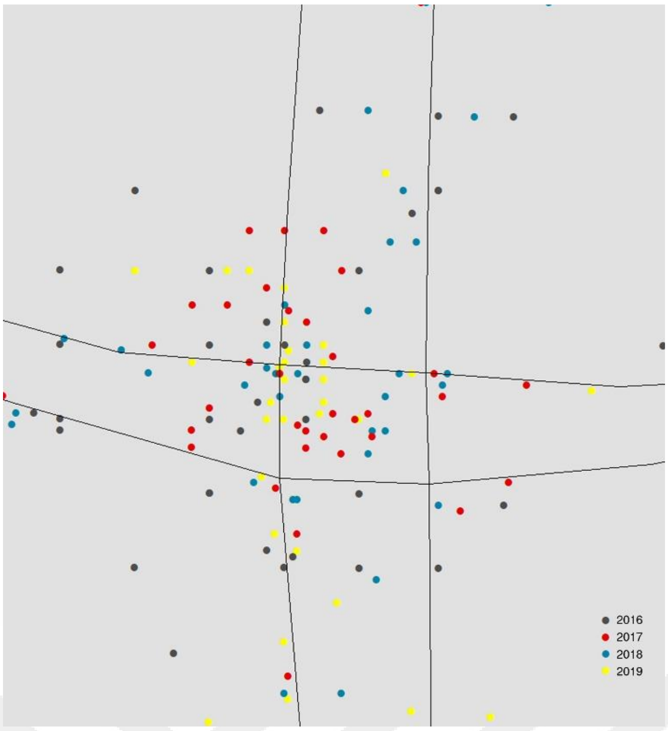


Figure 6.22 : Accidents that occurred between 2016 and 2019 at the Kızılay Square

Alignment between Kızılay Square and Sıhhıye Interchange

As seen in the Figure 6.23, lots of accidents occurred throughout the alignment. The main reasons for these accidents are the confusion between public transport and private vehicle traffic and the absence of auxiliary lane designs.

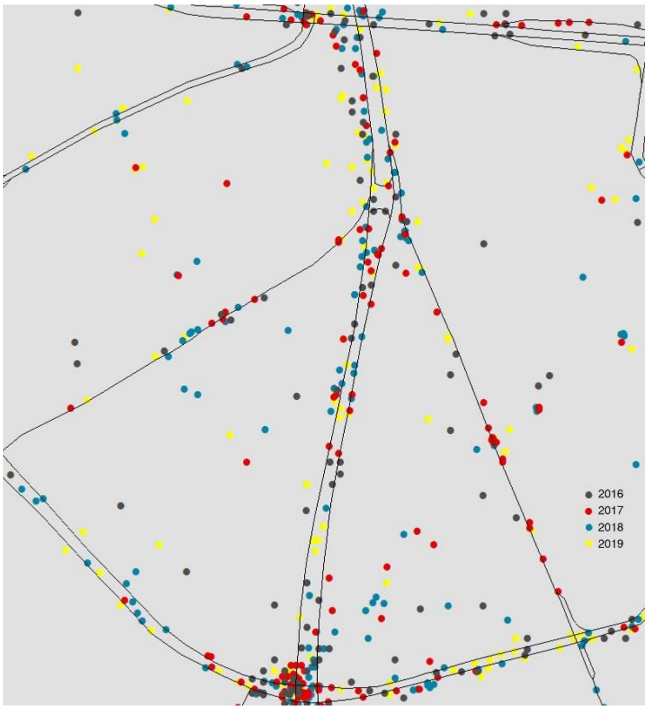


Figure 6.23 : Accidents that occurred between 2016 and 2019 at the alignment between Kızılay Square and Sıhhıye Interchange

Sıhhıye Interchange

The main reason for the accidents occurring in Sıhhıye Interchange is the confusion between public transport and private vehicles as seen in Figure 6.24.

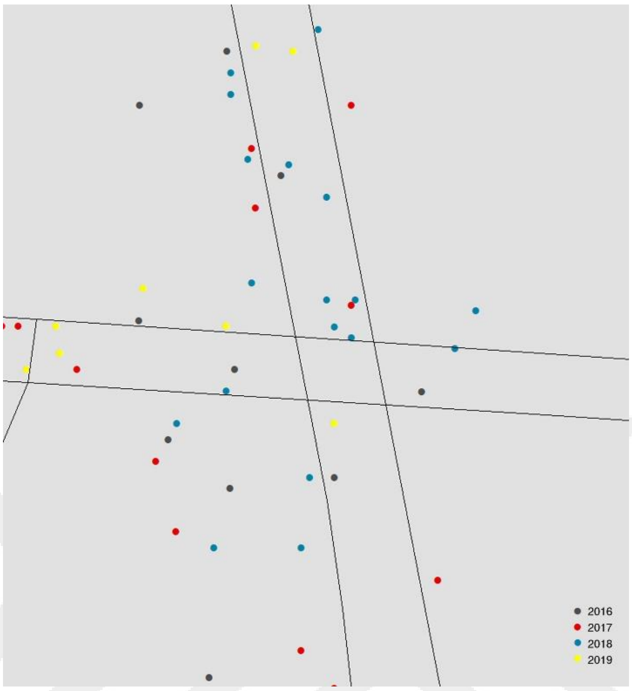


Figure 6.24 : Accidents that occurred between 2016 and 2019 at the Sıhhıye Interchange

Alignment between Sıhhıye Interchange and Talatpaşa Boulevard

Many accidents occurred on Talatpaşa Boulevard with Sıhhıye Interchange. However, it is seen that there is clusterization in the near section of Sıhhıye Interchange. As seen in Figure 6.25, the main reason for this is that the entrance ramp design is inappropriate and the congestion between public transport and private vehicle.

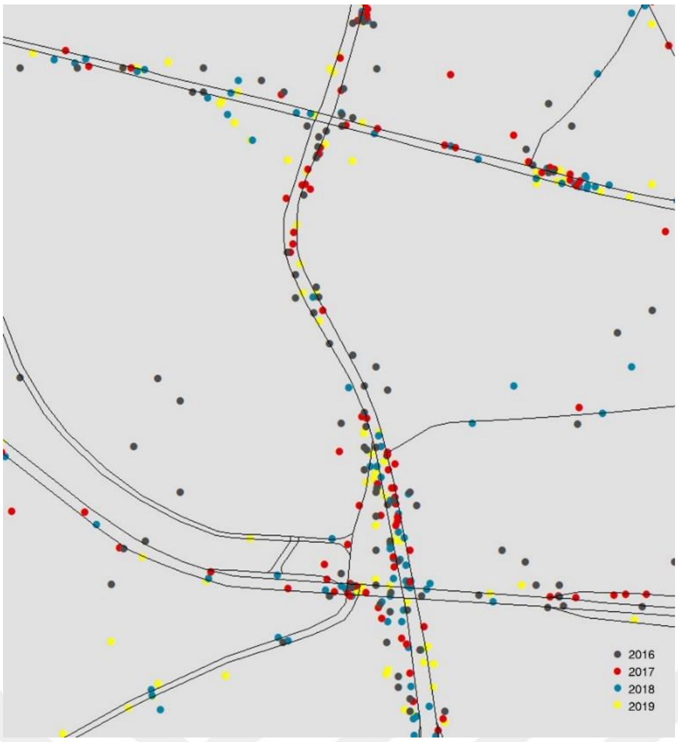


Figure 6.25 : Accidents that occurred between 2016 and 2019 at the alignment between Sıhhıye Interchange and Talatpaşa Boulevard

Talatpaşa Boulevard

One of the main reasons for accidents that occur on Talatpaşa Boulevard is restricted sight distance as seen in Figure 6.26.

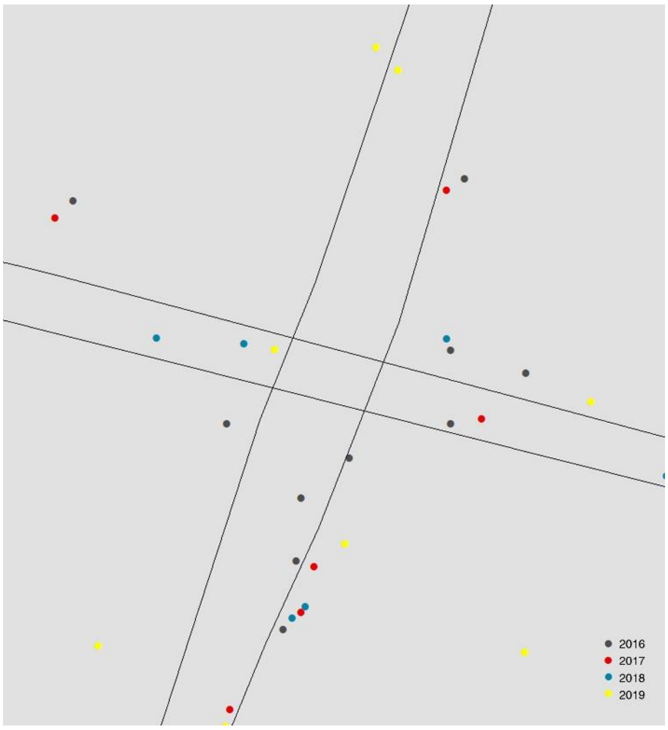


Figure 6.26 : Accidents that occurred between 2016 and 2019 at the Talatpaşa Boulevard

Alignment between Talatpaşa Boulevard and Opera Square

Figure 6.27 shows that the main causes of accidents between Talatpaşa Boulevard and Opera Square are public transport congestion and pedestrians.

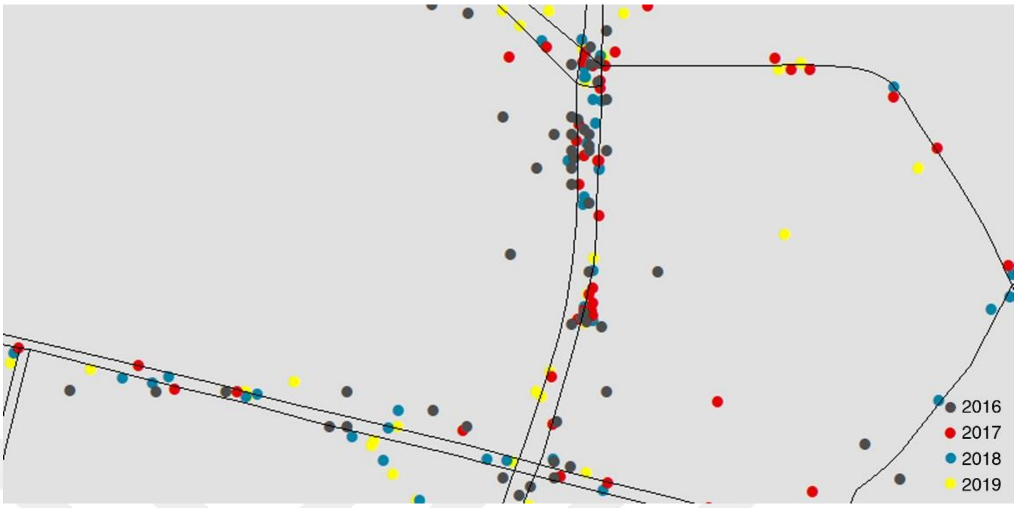


Figure 6.27 : Accidents that occurred between 2016 and 2019 at the alignment between Talatpaşa Boulevard and Opera Square

Opera Square

Figure 6.28 shows that the main reason for the accidents occurring in Opera Square is that there is no roundabout design in the intersection.

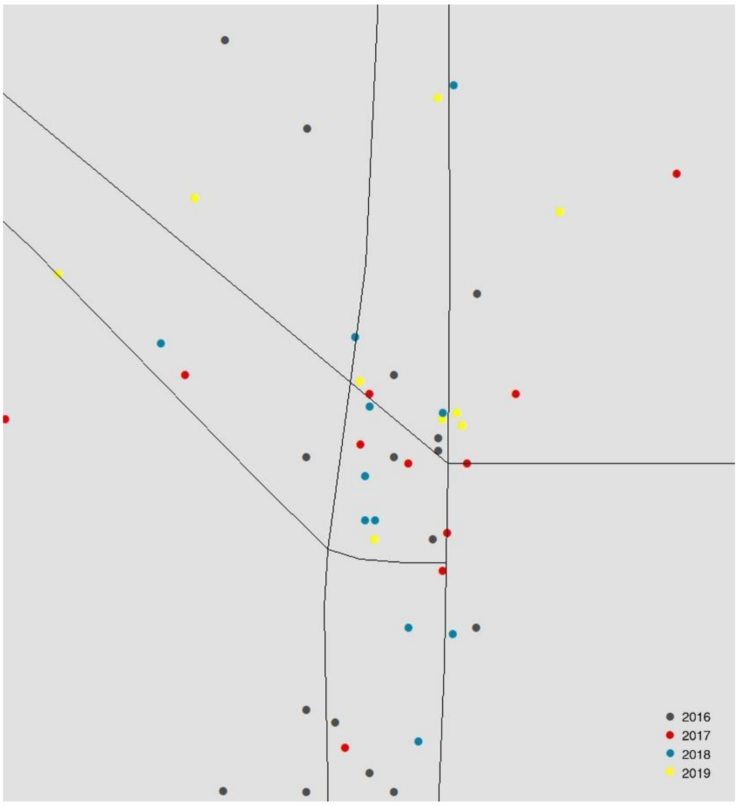


Figure 6.28 : Accidents that occurred between 2016 and 2019 at the Opera Square

As seen in the Figure 6.29, vehicles that want to change direction cause congestion because there is no roundabout design in the intersection. Therefore, vehicles that suddenly maneuvering endanger traffic.

Figure 6.29 : Congestion at Opera Square

Alignment between Opera Square and Ulus Square

The main causes of accidents between Opera Square and Ulus Square are public transport congestion and pedestrians as seen in Figure 6.30.

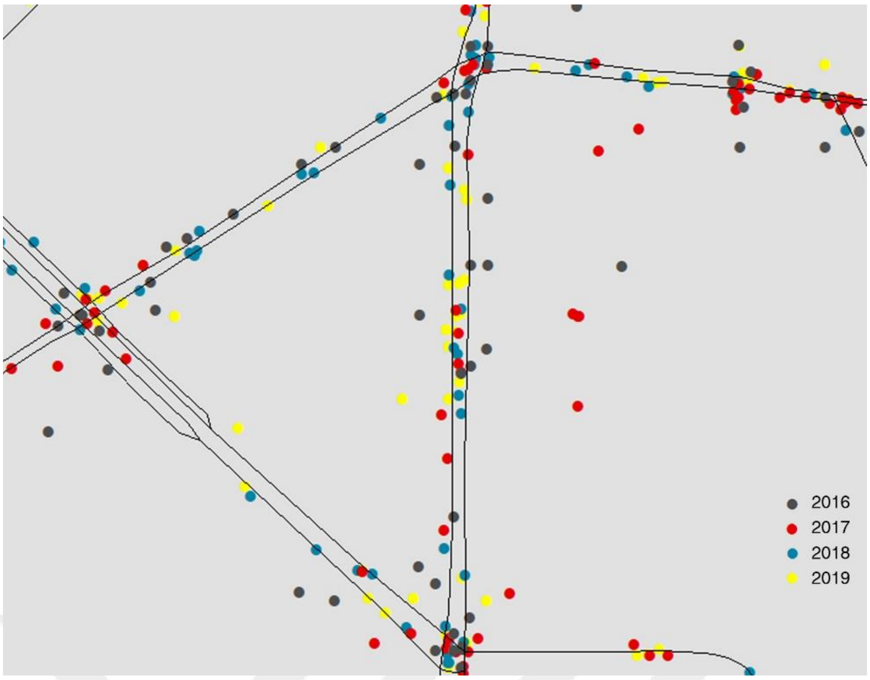


Figure 6.30 : Accidents that occurred between 2016 and 2019 at the alignment between Opera Square and Ulus Square

Ulus Square

One of the main reasons for accidents in Ulus square is that the intersection design cannot provide adequate traffic supply as shown in Figure 6.31.

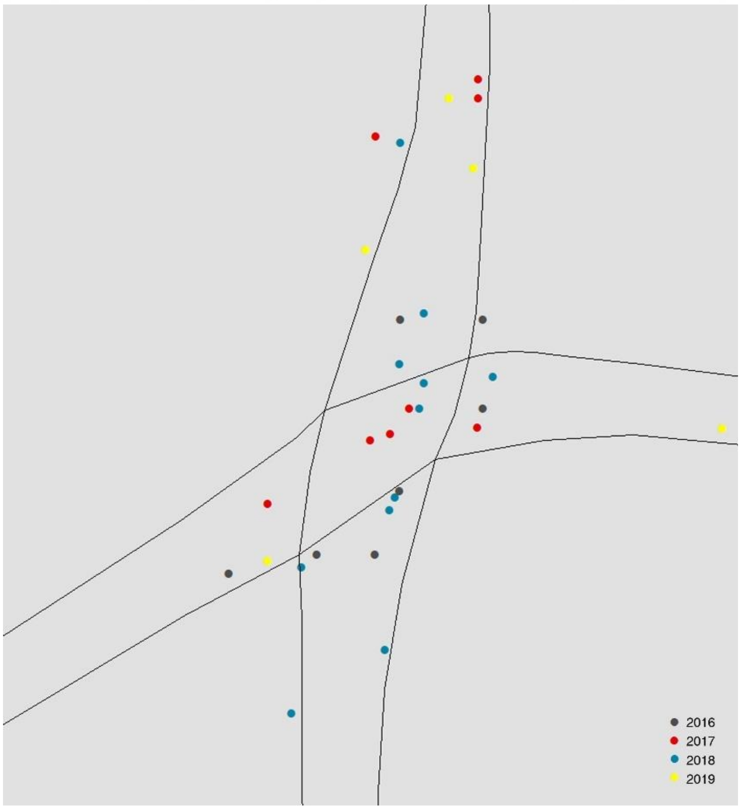


Figure 6.31 : Accidents that occurred between 2016 and 2019 at the Ulus Square

6.3.2 Alignment and Cross Section

6.3.2.1 Classification

Is the selection of classification according to the traffic volume appropriate?

According to Ankara Metropolitan Municipality data, an average of 60 thousand vehicles passes through Atatürk Boulevard per day. Atatürk Boulevard that designed nearly 100 years ago cannot meet the traffic demand. Atatürk Boulevard, which is in the urban principal arterial category today, is not compatible with the traffic volume in terms of design features.

Can the project be expanded for an unforeseen increase in traffic volume?

As we mentioned before, this road segment, built in the first years of the Republic of Turkey, cannot provide sufficient traffic supply nowadays. However, with the multi-storey road system, private vehicle traffic or public transportation network can be lowered underground and traffic can be relieved. Ankara Metropolitan Municipality plans to implement such a solution for Ulus Square.

6.3.2.2 Speed

Obedience of posted speed limit

One of the main problems that risk traffic safety on Atatürk Boulevard is the obedience of posted speed limit. As we mentioned before, the speed limit set by the General Directorate of Highways in the city center is 50 kilometers/hour. However, speed limits are not being complied except for morning and evening peak hours. As a result of the interviews with traffic police, it was learned that green wave application was performed except peak hours. As a result of this application, the vehicles can move at an average speed of 65 km/hour. In this region where pedestrians are very busy, this average speed creates serious problems in terms of traffic safety. Besides, another point to note is that a traffic sign that indicates the speed limit was found at only one point throughout the boulevard as seen in Figure 6.32. This is undesirable in terms of awareness of both drivers and other road users.

Figure 6.32 : Speed limit in Atatürk Boulevard

6.3.2.3 Cross Sectional Elements

Can be made expansion in dimensions for the future?

As seen in the Figure 6.33, it is impossible to make an expansion in Atatürk Boulevard that the city's busiest region. Therefore, expansion is not possible in the future.

Figure 6.33 : Building density of Atatürk Boulevard

Does the roadway have adequate drainage?

Drainage designs on the road are shown in Figure 6.34, throughout the road segment. Ponding occurs due to inadequate infrastructure design especially in the days when there is excessive rainfall.

Figure 6.34 : Sample drainage design in Atatürk Boulevard

In addition, as a result of hydroplaning, the vehicles are lost their control, therefore traffic is endangered. Figure 6.35 shows ponding in the region as a result of excessive rainfall.

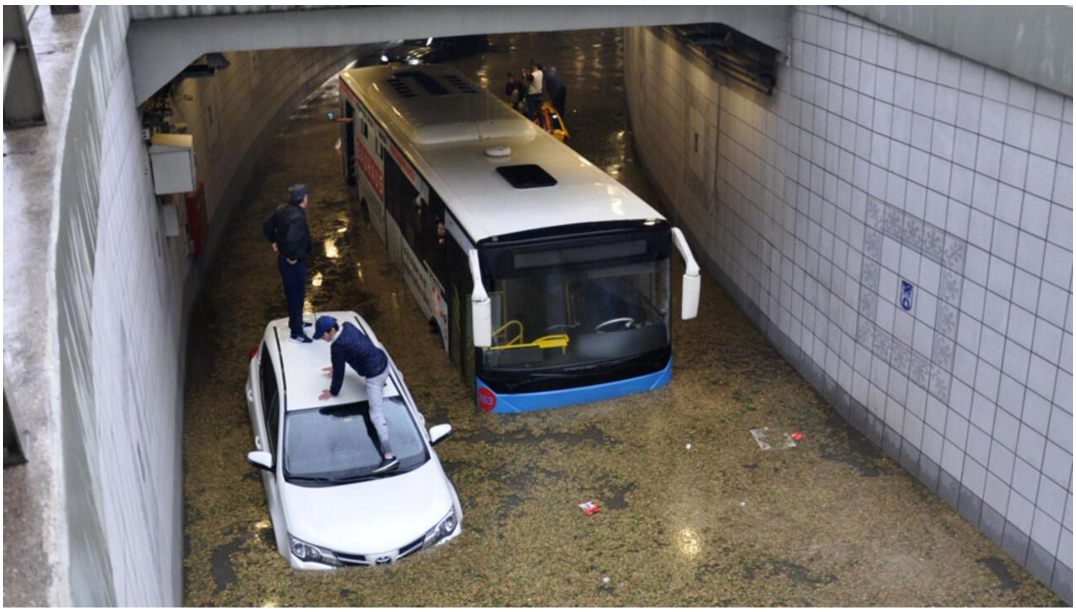


Figure 6.35 : Ponding in Atatürk Boulevard

Appropriate of lane width for road design.

Road lane width affects driving comfort, traffic flow characteristics and traffic safety. Hence, the lane width should be sufficient length. The lane width must be between 3-3.6 meters in urban principal arterials according to AASHTO. The lane width is 3.5 meters along Atatürk Boulevard and it is within the desired value range as seen in Figure 6.36.

Figure 6.36 : Lane width in Atatürk Boulevard

Adequacy of shoulder width for all road users

According to FHWA, the minimum shoulder width in urban arterials should be 0.6 meters. Minimum shoulder width is provided in most of the road segment. Moreover, the minimum shoulder width should be 1.2 meters, considering that cyclists can also use the road. However, as seen in Figure 6.37, this value cannot be achieved in most parts of the road, so it can be said that the road segment is not suitable for cyclists.

Figure 6.37 : Shoulder width in Atatürk Boulevard

6.3.2.4 Readability of Road Elements

Existence of old pavement markings

Atatürk Boulevard has pavement markings that are regularly maintained by the relevant administration. Road segment pavement markings can be easily understood and comply with the guidelines as shown in Figure 6.38.

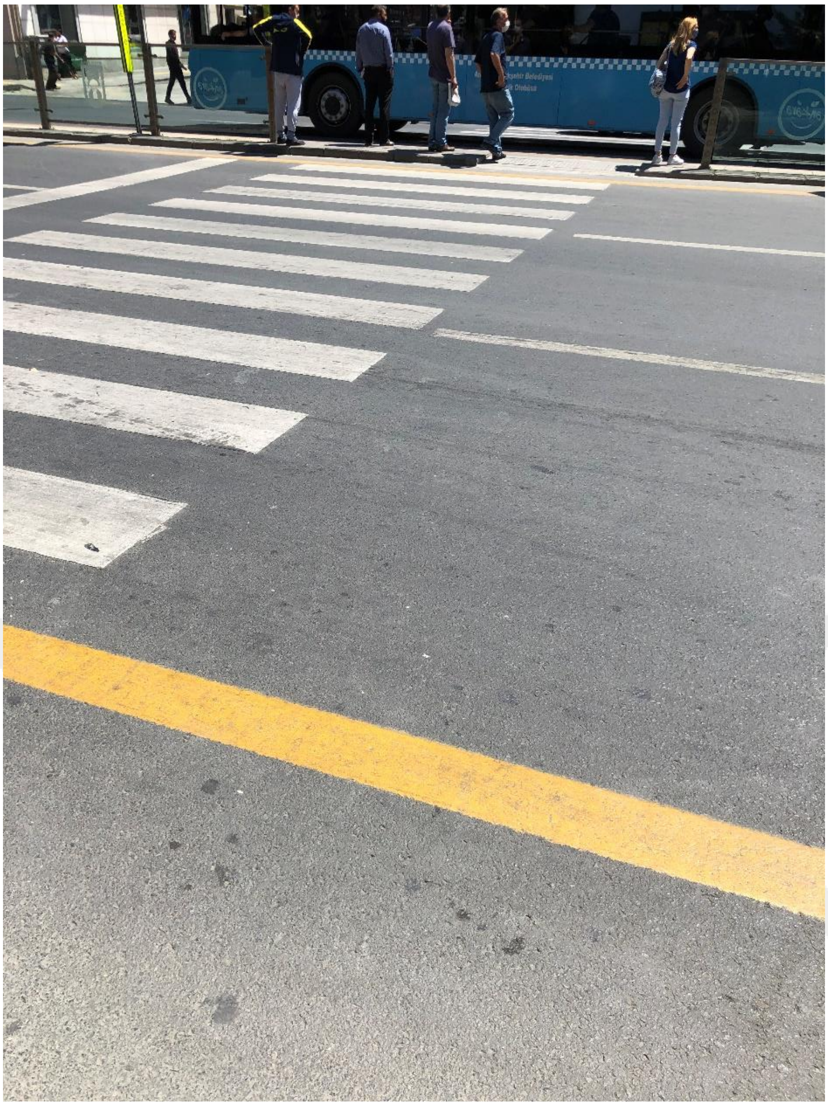


Figure 6.38 : Sample pavement marking in Atatürk Boulevard

6.3.3 Intersections

6.3.3.1 Location

Spacing between intersections

Intersections must be positioned appropriately so that there is no traffic congestion. The most appropriate solution for congestion is green wave design. However, it is difficult to always meet the green wave design. Nevertheless, minimum distances between intersections can help to reduce traffic congestion. According to AAHSTO, the minimum distance in signalized urban intersections should be 300 meters. There are 3 intersections throughout the study area. As seen in the Figure 6.39, the distance between these intersections provides the minimum distance condition.

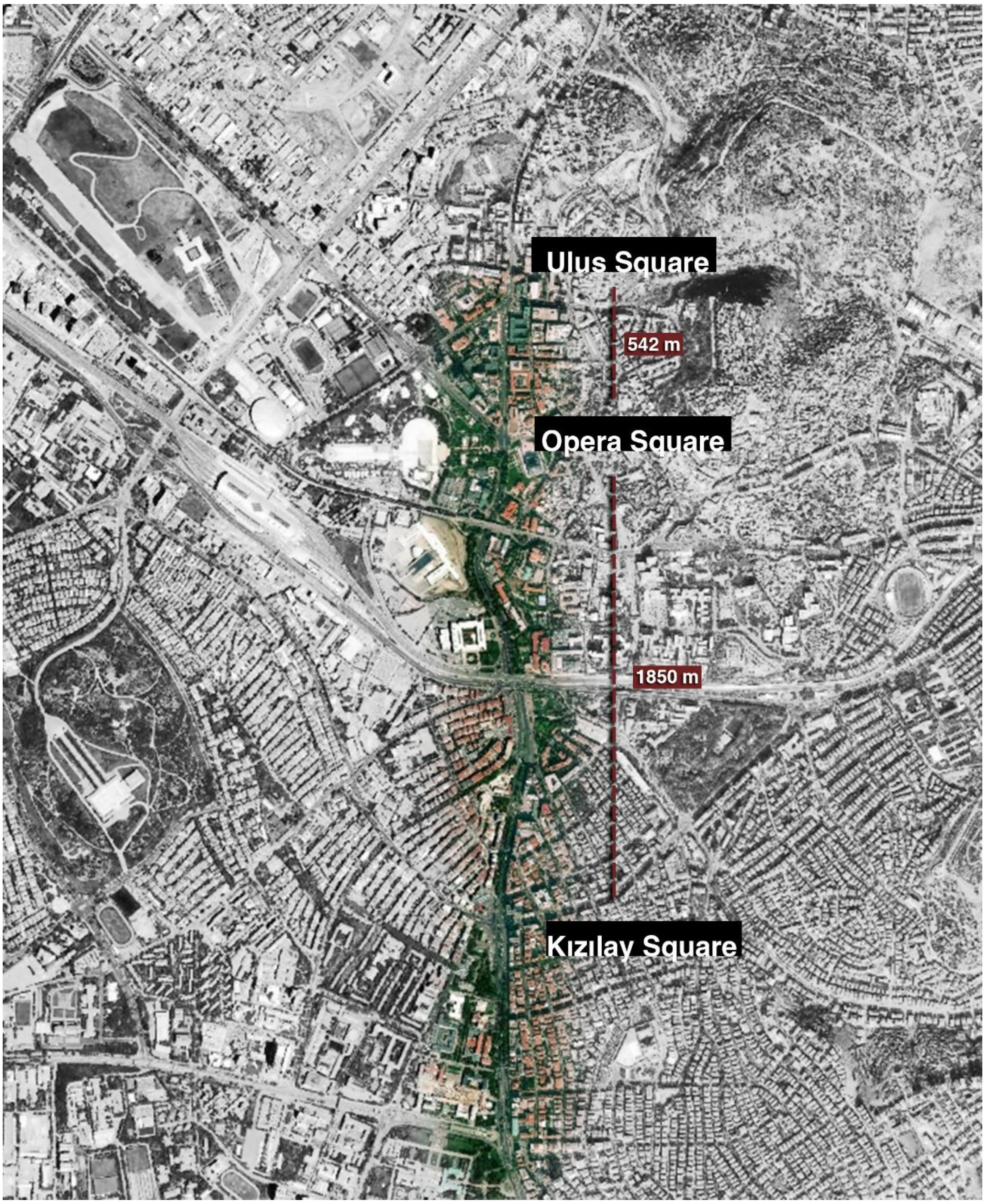


Figure 6.39 : Spacing between intersections at Atatürk Boulevard

6.3.3.2 Visibility, Sight Distance

Are there any obstacles in terms of the view of intersections?

Ataturk Boulevard is a road segment that is not only used by road users but also by pedestrians. Therefore, public bus stops, shops, billboards are found on the boulevard. Hence, there are obstacles around the intersection that could limit visibility. As seen in the Figure 6.40, these obstacles are factors that make it difficult for both the driver entering the intersection and the driver in the intersection to detect each other.

Figure 6.40 : Sample billboard that obstruct sight distance

6.3.3.3 Auxiliary Lanes

Are auxiliary lanes of appropriate length?

Auxiliary lanes allow vehicles to safely enter and leave traffic. In urban arterials, the minimum auxiliary lane must be at least 3 meters wide. Besides, the desired auxiliary lane length is 360 meters. Auxiliary lane is located at 3 different points throughout Atatürk Boulevard. As shown in Figure 6.41, Figure 6.42, and Figure 6.43, these auxiliary lanes have the desired width but have not the length. This causes problems in safely approach or departure to traffic. Moreover, auxiliary lanes are used as parking lanes in some locations. This poses an important problem for traffic safety. Furthermore auxiliary lane, which was closed to traffic for security purposes, was used outside its purpose.

Figure 6.41 : The auxiliary lane that closed due to safety issues at Akay Interchange

Figure 6.42 : The auxiliary lane that used as a parking lane at Talatpaşa Boulevard

Figure 6.43 : The auxiliary lane at Sıhhıye Interchange

6.3.3.4 Markings

Are pavement markings obviously visible?

Pavement markings are well-maintained throughout Atatürk Boulevard. Similarly, pavement markings are well-designed in intersection approaches. However, especially in Kızılay Square and Opera Square, there may be confusion due to turning restrictions. Thus, guiding pavement markings must be preferred at these points.

6.3.3.5 Signs

Is the readability of signs adequate?

Some signs in the road segment are indistinguishable in decision sight distance. The driver that determines his/her direction too late can make sudden maneuvers and cause accidents. As seen in Figure 6.44, a sign that may be difficult to distinguish is seen in Kızılay Square.

Figure 6.44 : Sample indistinguishable sign in Kızılay Intersection

Furthermore, as shown in Figure 6.45, the visibility of the signs behind bus stops or plants at a few points is limited.

Figure 6.45 : A sign obstructed by bus stop

Are there any missing, redundant, or broken signs?

There are not any missing, redundant, or broken signs along the road segment. Signs are appropriate to safe design, except for the dimensions of the signs.

Are stop signs located to appropriate place?

Positioning the stop signs in the wrong place in the intersection designs leads to congestion. This is undesirable in terms of safety and traffic flow. Stop signs are positioned correctly along the road segment.

6.3.3.6 Signals

Are signals visible?

For safe traffic in intersections, the driver must be able to clearly understand traffic signals. In addition, the visibility of the signals becomes more important due to the density of traffic components in the central business district areas. Throughout the Ataturk Boulevard, the signals are visible enough and have a design that can be easily distinguished by the driver as seen in Figure 6.46.

Figure 6.46 : Sample signal in Atatürk Boulevard

6.3.3.7 Warnings

Are there any detectable warnings for people with disabilities?

All road users should be considered throughout the road segment for safe traffic. One of these users are persons with disabilities. Warnings should be placed on the road surface and pathway surface and must easily detectable for persons with disabilities. However, one of the main problems along Atatürk Boulevard is that the boulevard is not a disabled-friendly design. As shown in Figure 6.47 and Figure 6.48, the warnings at the intersection crossing points are dismantled, neglected, or show the wrong directions. This makes it difficult for a person with disabilities to travel alone, also endanger traffic safety.

Figure 6.47 : A warning with the wrong guidance

Figure 6.48 : A dismantled warning in Atatürk Boulevard

6.3.3.8 Pedestrians

Are intersections designed pedestrians friendly?

There is a safe design for pedestrians in intersections. With the aid of traffic signals and traffic police, pedestrians can easily cross intersections. However, pedestrian based traffic accidents occur frequently in intersections. As a result of the interviews with traffic police, there are lots of sudden brake accidents during turnings, due to pedestrians suddenly take out the road. Also, a significant part of the accidents stems from pedestrians suddenly take out the road in Kızılay Square, based on interviews with traffic police.

6.3.4 Interchanges

6.3.4.1 Location

Are spacing between interchanges in the road network is sufficient?

The distance between interchanges in road design is an important criterion in terms of traffic safety. Due to the high traffic volume, it is difficult to meet the appropriate distance value in urban arterials. There are 3 interchanges throughout the study area as seen in Figure 6.49. The desired distance between them is at least 1.5 kilometers. The distance between Akay Interchange and Sıhhıye Interchange is 1720 which is the desired length. However, the distance between Sıhhıye Interchange and Talatpaşa Interchange is 620 meters and it is below the desired value.

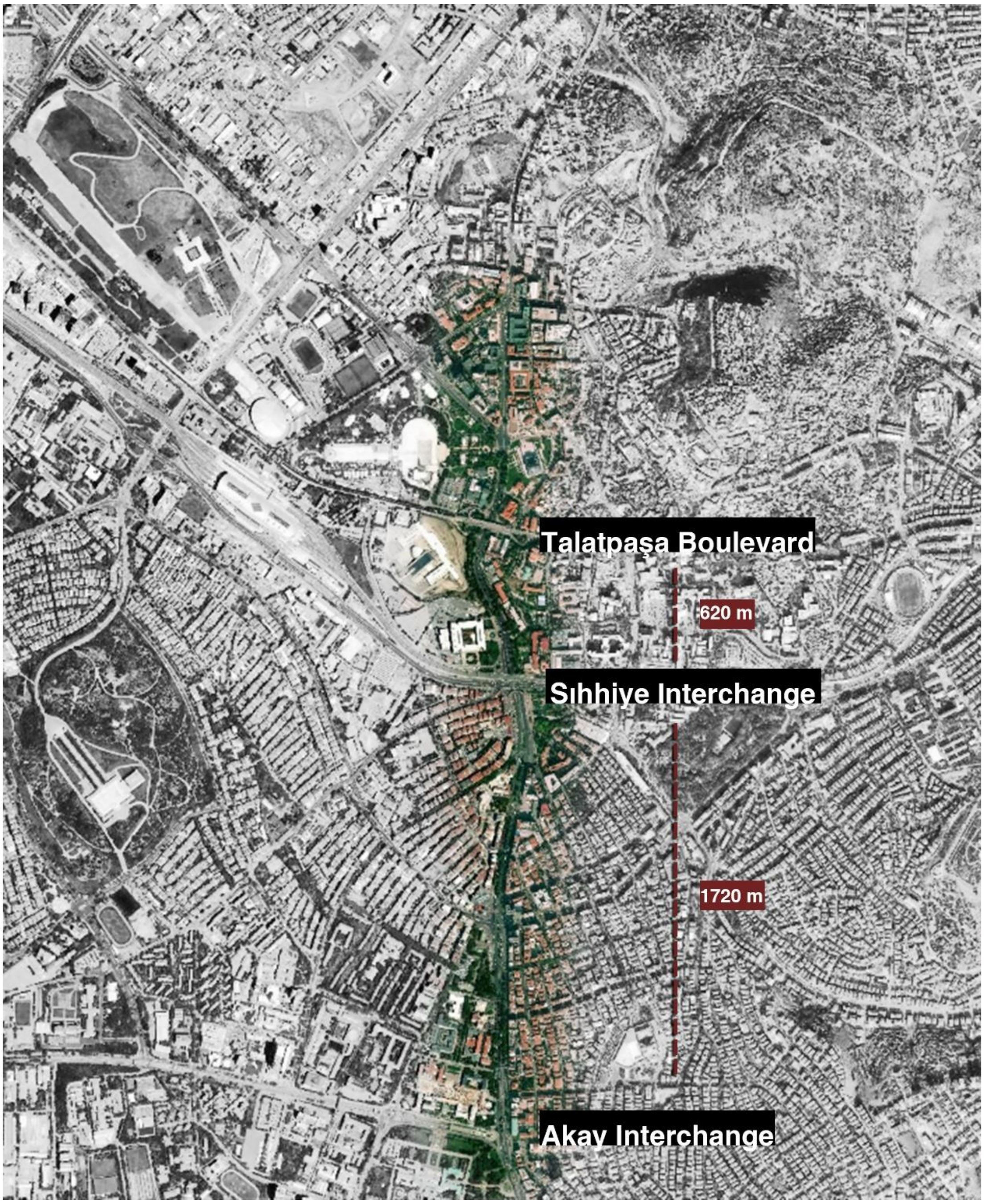


Figure 6.49 : Spacing between interchanges at Atatürk Boulevard

6.3.4.2 Shoulders

Is shoulder width sufficient?

Throughout the road segment, shoulder width in interchanges has values ranging from 0.5 to 1 meter. Although this is not a desired value, it is an expected situation for urban arterials.

6.3.4.3 Ramps

Is there adequate distance between entrance and exit terminals?

There should be sufficient distance between consecutive terminals to ensure road safety and driving comfort. The project has three interchanges. The first of these, Akay Interchange, is an EX-EN type interchanged. The distance between the exit ramp and the entrance ramp is approximately 120 meters and is at the desired value. Sıhhıye Interchange is an EX-EN (weaving) type interchange. The distance between the exit ramp and the entrance ramp is approximately 50 meters and is below the desired value. Talatpaşa Boulevard is an EX-EN type interchange. The distance between the exit ramp and the entrance ramp is approximately 40 meters and is below the desired value.

6.3.4.4 Signing

Are signs at interchanges appropriate?

All signs, boards, signals should be plain and easily understandable to ensure safe driving at intersections. Road signs and signals should be used effectively to prevent road users from being indecisive at intersections. Signs are well-maintained throughout the project, but due to their dimensions, they do not allow road users to decide within a decision sight distance. Drivers, especially in the decision-making phase, risk traffic with sudden maneuvers due to perceiving the signs late. Thus, accidents occur especially in Akay Interchange as seen in Figure 6.50.

Figure 6.50 : Signs at Akay Interchange

6.3.4.5 Pedestrians, bicyclists

Are the design of interchanges appropriate for pedestrians and bicyclists?

Atatürk Boulevard is appropriate for pedestrian usage in all three interchanges in the road segment. It has adequate pathway width. However, the lane is not suitable for bicyclists, and the pathway is also inappropriate for bicycle use as it is rough.

6.3.5 Road Surface

6.3.5.1 Skid Resistance

Are there skid indications on the road?

Skidding occurs on the road if there is no slip resistance that tolerates braking movement and sudden maneuvers of road users. Skidding is one of the major reasons for traffic accidents. In the observations made throughout Atatürk Boulevard, no skidding was observed on the road.

6.3.5.2 Pavement Defects

Are there any defections on the pavement?

Cracking, blistering, collapse, and corrugation occurring on the road surface causes the driver to lose steering control and traffic accidents. As a result of the observations made along the boulevard, there was no defect to cause loss of steering control on the road. However, there are defections to reduce driving comfort on the road. In addition, defects on the road may cause road users to make sudden maneuvers and traffic accidents when they see the defect.

6.3.5.3 Ponding

Risk of ponding on the pavement

As a result of the observations, holes that could form ponding in the road pavement were not observed. However, it has been determined that there may be ponding especially on the shoulder. Moreover, as a result of the researches, it was determined that severe ponding occurred in the region in the past. The reason for this ponding is the lack of road infrastructure as well as the hole in the pavement.

6.3.6 Road Users

6.3.6.1 Public Transport

Is road design appropriate for public transport?

As we mentioned before, we stated that there were 60 thousand vehicles passing on Atatürk Boulevard daily. There are 45 bus stops along Atatürk Boulevard as seen in Figure 6.51. At these stops, people can travel all over Ankara with different lines. This public transport network is over congested for boulevard considering the average number of vehicles per day. Some stops on the boulevard are located clustered to each other. Each bus stop at certain stops. Therefore, buses trying to approach and depart the different stops cause extra congestion. Furthermore, when the locations of bus stops are examined, near-side designs are also seen. Near side designs can be seen in Kızılay Square, Opera Square, and Ulus Square. As a result of the observations made in the study area, it is seen that the attempts of the public buses to cross from the far right lane to the left lane seriously endanger the traffic. Besides, vehicles that try to turn right, faces problems at near side designs.

6.3.6.2 Cyclists, Pedestrians

Is there a safe driving environment for bicyclists?

Unfortunately, there is no safe driving environment for the bicyclist along the way.

Are people with disabilities taken into account in road design?

For people with disabilities, the pathway must have braille brick. These braille bricks should be maintained at regular intervals. Unfortunately, the braille bricks throughout the way is irregular and neglected.

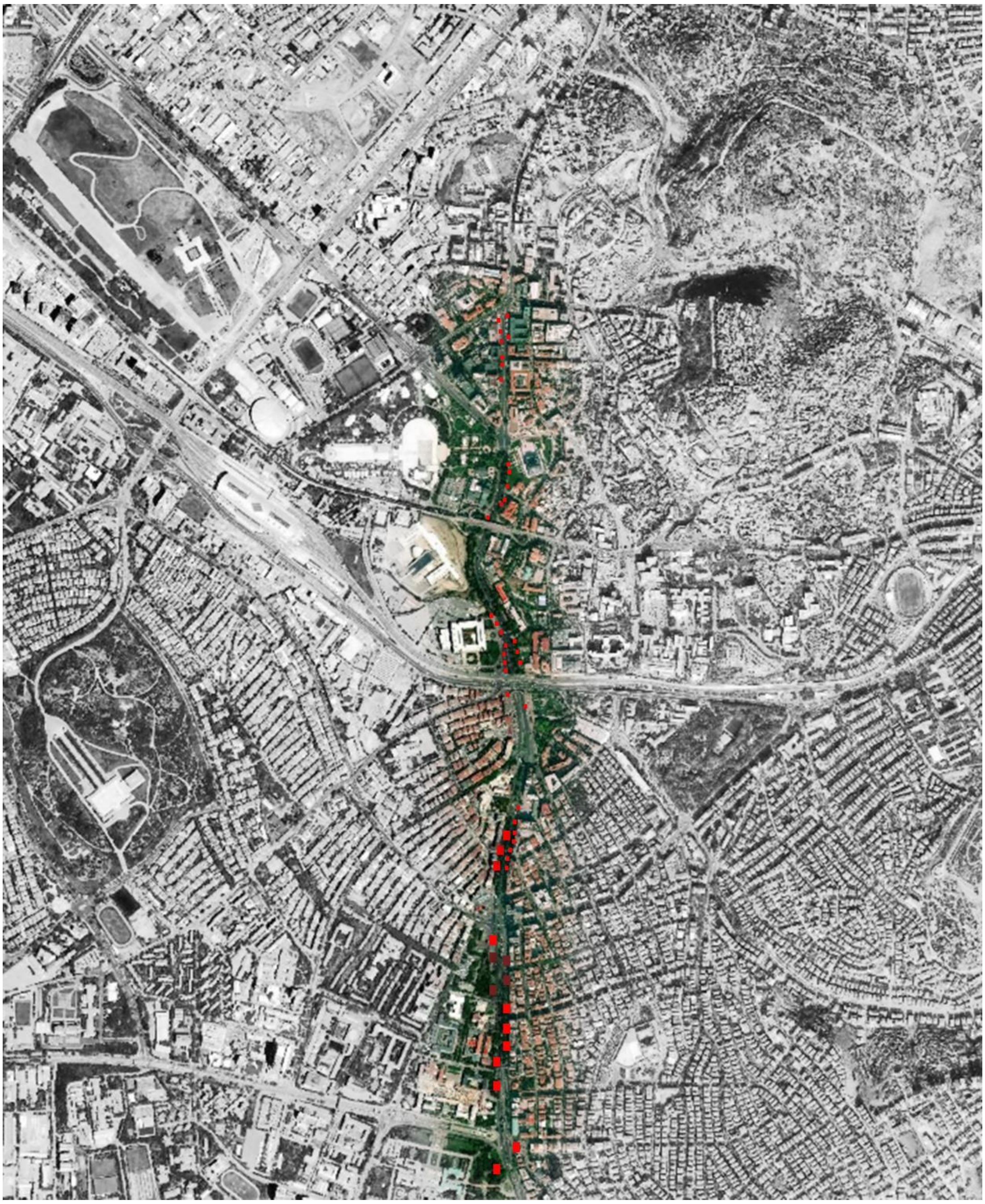


Figure 6.51 : Bus stops at Atatürk Boulevard

7. CONCLUSION

Within scope of the thesis, traffic accidents that occurred between 2016 and 2019 in Ankara were examined. The locations of the accident data that occurred between these years were taken from the General Directorate of Security and transferred to the Geographic Information Systems. Afterwards, accident hot spot analysis was performed with Kernel Density Estimation aided Geographic Information Systems. As a result of the analyzes, the regions where accidents occur most frequently were determined in Ankara. These areas, called accident hot spots, are around the Sincan High Speed Train Station and Atatürk Boulevard for Ankara. As a result of the analyzes, Atatürk Boulevard, which is determined as the busiest region, was chosen as the study area. Then, Road Safety Audit application was carried out for Atatürk Boulevard. Within the scope of Road Safety Audit, examinations were made on 6 basic subjects. These issues are;

General, Alignment and Cross Section, Intersection, Interchange, Road Surface, and Road Users. Ataürk Boulevard was inspected for morning and evening traffic peak hours, daytime weekdays and daytime weekends for inspection. The observations made were noted and reported. Furthermore, interviews were made with the residents and traffic police of the region. Findings obtained as a result of interviews and observations were analyzed. Findings obtained as a result of these analyzes are explained below as summary:

General

The clear zone width along Ataturk Boulevard is generally much below the desirable value. However, this is a frequently observed situation in urban arterials. Because in urban arterials, elements such as landscape, billboard, and luminaries are frequently found in pathways. However, at some points, roadside elements that violate the clear zone are dangerous for traffic. These obstacles, such as a tree or luminaries, can lead to dangerous consequences in the event of a possible out of the way. These roadside elements can be moved or covered with safe materials. Moreover, four different types of median designs were used on Atatürk Boulevard. The median width is generally 3 meters, and the height varies between 1.5-2 meters. This is an adequate size to prevent crossing over accidents. However, the glass median barrier used in a section of the boulevard may break due to a violent vehicle crash, and crossing over accidents may occur. Although the boulevard is closed to commercial vehicles, large vehicles can use the boulevard with some permissions. Therefore, the possibility of the mentioned crossing over is always possible. In addition, the intermittent median designs used in some parts of the boulevard threaten traffic safety by using pedestrians as a crossing point. As a result of interviews with traffic police, pedestrians who use these points as a crossing point should be injured and involved in fatal accidents. Due to the fact that Atatürk Boulevard is in the most central location of the city, landscape maintenance is carried out regularly. It complies with landscape road guidelines. However, plants at some points can obstruct the driver's sight distance. Besides, some plants reduce the visibility of traffic signs. Since the study area is regularly inspected in the city center and by the Ankara Metropolitan Municipality, a sight distance restriction is not expected in the future due to plant growth. Furthermore, there is no temporary work throughout the way. However, a study has been observed on the pathway. Surrounding this work with only one strip remains a weak warning. Throughout the Ataturk Boulevard, headlight glare from luminaries or vehicles coming from opposite directions was not observed. However, at some points, such as the Kızılay Square, billboards with bright lights and constantly changing colors can be observed to disturb drivers. Atatürk Boulevard is the location where most accidents occurred in Ankara. When the accidents are examined by years, there is a similarity between them. Accident data are reported by traffic police at the accident scene according to their features and stored in the archives of the General Directorate of Security.

Alignment and Cross Sections

Atatürk Boulevard is a boulevard that designed in the 1930s. The boulevard, designed with 6 lanes according to the traffic volume of that day, becomes a boulevard used by an average of 60 thousand vehicles daily nowadays. Hence, it cannot supply sufficient traffic volume. In addition, due to the fact that there are business centers and shopping centers around it, an expansion on the boulevard is not possible. One of the biggest traffic safety problems of Atatürk Boulevard is the obedience of posted speed limit. 50

km/hour, which is the speed limit set in the city center by the General Directorate of Highways, is not complied with by drivers. According to Ankara Metropolitan Municipality data, the average speed along the boulevard is 65 km/hour. This is a serious safety problem for this boulevard, which is frequently used by pedestrians. Drainage design was found to be insufficient in some locations along the boulevard. Especially in the shoulder parts and interchange parts, ponding that causing hydroplaning occurs frequently, to cause drivers to lose steering control. Moreover, the lane width required by AASHTO for urban arterials is between 3 and 3.6 meters. The lane width is 3.5 meters along Atatürk Boulevard and it is in the desired range. Besides, the minimum shoulder width of 0.6 meters that must be in urban arterials according to FHWA was met throughout the boulevard. However, the 1.2 meters required for cyclists cannot be provided. Additionally, Pavement markings along Atatürk Boulevard are in desired visibility and well maintained.

Intersections

Intersections should be done intermittently to ensure green wave design in traffic. AASHTO has determined this range as 300 meters. Intersections on the boulevard meet this condition. Atatürk Boulevard is used extensively not only by vehicle drivers but also by pedestrians. There are also many roadside elements such as billboards, plants, signs, and signals along the way. Thus, the road user who will use the intersection must have adequate sight distance. However, there are some obstructs such as billboards, plants, and parking vehicles that restrict sight distance at turnings. Auxiliary lanes that allow vehicles to enter and leave traffic safely must be of a certain length. This value determined by AASHTO is 360 meters. Throughout the boulevard, auxiliary lanes are inadequate length. In addition, some auxiliary lanes have been used outside of their purpose such as parking lanes or for safety reasons. Pavement markings on intersections are regular and well-maintained. However, the restriction of turning in Kızılay Square and Opera Square seriously threaten traffic. Guidance pavement markings should be used for these points. Due to the density of road elements, drivers sometimes cannot detect signs. This causes sudden maneuvers in near areas at the turnings. Therefore, bigger signs that easily readable should be preferred in intersections. Furthermore, there are no missing, redundant and broken signs that were detected throughout Atatürk Boulevard. In addition, stop signs are positioned correctly along the road segment. Signals throughout the road segment are sufficiently visible and understandable. One of the most common traffic safety problems along Atatürk Boulevard is that it is not a disabled-friendly design. The warnings and directions made on the pathway and road surface along the road segment are irregular and misdirected. Besides, there is a safe crossing for pedestrians at the intersection points. Pedestrians can cross the street safely with the aid of both pedestrian crossings and traffic police in intersections. However, traffic accidents occur due to suddenly crossing pedestrians to the road. As a result of the interviews with the traffic police, it was stated that the main reason for the accidents, especially in Kızılay Square, were the pedestrians who suddenly cross the road.

Interchanges

The distance between interchanges is an important criterion for both traffic safety and green wave traffic. The distance requested by AASHTO between the interchanges is specified as 1500 meters. The distance between Akay Interchange and Sıhhıye Interchange is 1720 meters and is at the desired value. However, the distance between Sıhhıye Interchange and Talatapaşa Interchange is 620 meters and is below the desired value. Moreover, in interchanges, shoulder width is between 0.5 meters and 1 meter and is below the desirable value, but this is a situation encountered for urban arterials. Moreover, in order to ensure road safety and driving comfort, there must be a certain distance between the exit ramp and the entrance ramp.

While Akay Interchange meets this condition, Sıhhıye Interchange and Talatpaşa Interchange do not meet this distance. Besides, there should be acceleration for the entrance ramp in certain lengths and deceleration for the exit ramp. However, these lengths are below the desired values along Atatürk Boulevard. Throughout the Ataturk Boulevard, the signs are well maintained at interchanges. However, at some points, there is a difficulty in perceiving due to their dimensions. Besides, there is an appropriate interchange design in the usage of pedestrians. However, since it is not a bicycle way and the pathway is not suitable for bicycle use, it can be called the design is not appropriate for bicycle usage.

Road surface

There is no skid indications were observed on the road throughout Atatürk Boulevard. This also stems from maintaining the road at certain periods. In addition, there are no defections on pavement that cause the driver to lose control of the steering wheel.

However, defections were observed at some points along the boulevard. These defections can cause the driver to suddenly maneuver and cause an accident. Moreover, there are holes along the boulevard that may cause ponding on the shoulder parts. Whereas, there are no holes on the road pavement that can cause ponding. However, due to the lack of infrastructure of Atatürk Boulevard, pondings frequently occur in the road segment in heavy rains.

Road Users

The main traffic safety problem of Atatürk Boulevard is public transportation. Atatürk Boulevard is a 6-lane road designed 100 years ago, serves 60 thousand vehicles, and 47 bus stops daily nowadays. Therefore, Atatürk Boulevard's failure to provide this traffic supply is the main cause of safety problems. Although some of the bus stops on the boulevard are close to each other, they are designed for different bus lines. This means buses trying to approach the station at multiple points. When buses approach or leave the station, serious safety problems occur during traffic participation. In addition, near-side designs seen in Kızılay Square, Ulus Square, and Opera Squares restrict the sight distances of vehicles that will turn right at intersections. In addition, the braille brick designs for people with disabilities along the boulevard were dismantled and misdirected.

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