ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

DETERMINATION OF THE EFFECTS OF REVERSIBLE LANE OPERATION ON LANE UTILIZATION BY USING MICROSCOPIC TRAFFIC VARIABLES CASE STUDY: BOSPHORUS BRIDGE

M.Sc. THESIS

Pegah DADRAS

Department of Civil Engineering

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Thesis Advisor: Assoc.Prof. Dr. Kemal Selçuk ÖĞÜT

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

EK ŞERİT UYGULAMASININ ETKİLERİNİN MİKROSKOPİK TRAFİK DEĞİŞKENLERİ KULLANILARAK BELİRLENMESİ BOĞAZ İÇİ KÖPRÜSÜ ÖRNEĞİ

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FOREWORD

It was suprising for me to see almost empty road while we were struggling with heavy traffic of the opposite direction, when I was going to university in Tabriz. On those times, when I made some research, I saw that reversible lane operation offers a solution for this unused supply. I was so excited and remembered those days when my instructor offered me this thesis subject, so I decided to make researchs about this subject, and hope to implement this useful operation in Tabriz in the future.

I am grateful of my advisor named Assoc.Prof. Dr. Kemal Selçuk ÖĞÜT widely helped me by providing enormous information, proper guidance and support.

Thanks to my family who was with me either in good or difficult days and never neglected their financial and spiritual assistance.

Finally, thanks to all my friends who spiritually helped me and were always with me throughout writing of this theis.

September 2014

Pegah DADRAS
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ABBREVIATIONS

AASHTO	**:** American Association of State Highway and Transportaion Officials
BRT	**:** Bus Rapid Transit
DFT	**:** Department For Transportation
FHWA	**:** Federal Highway Administration
HOV	**:** High Occupancy Vehicle
HOT	**:** High Occupancy Toll
ITE	**:** The Institute of Transportation Engineers
LCC	**:** Leeds City Council
LED	**:** Light Emitting Diode
NCHRP	**:** National Cooperative Highway Research Program
RLS	**:** Reversible Lane Systm
RTMS	**:** Remote Traffic Microwave Sensor
SANDAG	**:** San Diego Association of Governments
SOV	**:** Single Occupant Vehicle
SR	**:** State Route
TRB	**:** Transportation Research Board
TTI	**:** Texas Transportation Institute
USA	**:** United State of America
VMS	**:** Variable Message Sign

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DETERMINATION OF THE EFFECTS OF REVERSIBLE LANE OPERATION ON LANE UTILIZATION BY USING MICROSCOPIC TRAFFIC VARIABLES
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SUMMARY

With dominant advances in economy, dramatic increase in the population of Istanbul and other mega cities has contributed to emerge of profound transportation issues. Constantly experienced traffic difficulties not only has resulted in tremendous pecuniary and spiritual losses for humankinds, but also it has brought about serious insufficiences in country’s economy. For this reason, in order to eliminate mentioned problems as much as possible, some studies have to be organised and implemented. In most of the cases, to rise the capacity of existing roads and solving the problem of traffic congestion, application of adding a new lane has come into question; however, these sort of applications, due to area deficiency, may require enormous investments. Because of this reason, the most proper use of existing roads’ capacity is being investigated. Thus, lane implementation methods are widely being used. Reversible lane application is one of those lane implementation methods. Reversible lane application is defined as altering the flow of vehicles to the opposite direction in one or more lanes or banquettes at specific time periods. Gaining the barely used capacity in normal flow of traffic and adding it to the opposite direction to accrue its capacity and avoiding the construction of an extra lane are the primary advantages of this method.

In Istanbul City, the Bosphorus Bridges, which connect the Asian side of Istanbul to the European side, are the motorways continuously suffering from traffic congestions. The imbalance demand in both directions at rush hours of the day, and exceeding of the capacity by high demands, cause to experiencing of mentioned traffic congestions. On the other hand, due to numerous economic and environmental reasons, costruction of additional lanes seem almost impossible. Therefore, methods which can provide the best use of existing capacity are being researched. Due to higher settlement of living apartments and houses in Asia Side and higher settlement of factories and work places in Europe Side, majority of citizens travel from Asia Side to Europe Side at the peak hours of the morning and the vice versa travelling direction at the peak hours of the evening. Therefore, demand imbalance takes place from Asia to Europe Side in the morning and from Europe to Asia Side in the evening. To eliminate this demand imbalance, by means of the aforementioned reversible lane application, which is a lane implementation method, at rush hours through borrowing a lane from the opposite direction demand imbalances in both paths can be hindered; Bosphorus Bridge is one of the passing ways in which this method was applied.

In this study, the effects and randoman of reversible lane application being applied to Bosphorus Bridge (O-1) Motorway in both directions were scrutinised carefully. In

order to scrutinise reversible lane application, a working method which uses microscopic traffic data was chosen. Thus, on the basis of the lane, time spans and speed differences among transition of vehicles were collected for three weekdays including one hour lap for each following spans: in the morning (09:00-10:00) and in the evening (20:00-21:00) as peak time periods when reversible lane application was carried out, and time periods (12:00-13:00) when reversible lane application was not carried out. These data were gained from videos recorded by motorway monitoring cameras. To notice whether the additional lane application had any impacts on the volume and speed values, data were tested statistically by using t-test.

Analysis are being performed in two groups in t-test. Investigations of additional lane are being carried out in two groups which are peak hours of morning and evening, and the time when there is not any peak in the traffic. Since the data being collected in hourly time spans are not equal in the quantity, “two-tailed t-test with different variance” was used.

In the first chapter of this thesis, a general history and definition of the analyzed topic were mentioned.

In the second chapter, terms related to the lane management were defined. Also, high-occupancy vehicle privileges, (high-occupancy vehicle lanes (HOV) and truck and bus lanes), control of participations (reversible lane, controlled working zones and express lanes and pricing (high-occupancy toll lanes (HOT) and congestion pricing) were illustrated. In the final part of this chapter, some example studies which introduce successfully applied lane managements in America, Asia and Europe were explained.

In the third chapter, terms related to reversible lane, being one type of lane management methods, related design, implementation, control and management principals were elaborated. After that, implementation of reversible lane being applied in Europe, America and Asia was illustrated. Finally, studies conducted in Istanbul which were near to ours (Fatih Sultan Mehmet Bridge, Çırağan Avenue, Kennedy Aveue and Bosphorus Bridge) were discussed.

In the forth chapter, reversible lane application, which was implemented in Bosphorus Bridge and analyzed in this study, was explained.

In final chapter, results and recommendations were presented.

First comparison, test was done for morning (09:00-10:00) and evening (20:00-21:00) rush hours at each direction, when the left lanes are operated as reversible lane and normal lane. According to the test, in segments where reversible lane applications were applied a decrease of 25-34 % in the flow rate was noticed.

Second comparison was carried out among rush hours of morning (09:00-10:00) and evening (20:00-21:00), among middle lane, when there is a reversible lane next to it and normal lane (no reversible lane next to it). In this comparison, in the middle lane, which located in the neighborhood of reversible lane, there was a fall in flow rate by 2% in the rush hours of morning (09:00-10:00), despite a 3% rise in the rush hours of evening (20:00-21:00).

Third, comparison was to the middle and left lanes out of the rush time (12:00-13:00), and at rush hours of morning (09:00-10:00) and evening (20:00-21:00), when they were operating as normal lanes or without being neighbor of any additional lanes. Considering the results, flow rate between middle lanes are almost the same, and there is not any considerable difference. This fact demonstrates that the transition of vehicles belong to the same society and have the same behavior. On the contrary, a fall of 2-3 % in the flow rate during the rush hours in left lanes was also noticed.

In second step, headway distributions were investigated. In this study normal, lognormal, gamma, gumbel ve extreme value II (evII) ditirbutions were taken into account and to check if the data fit to mentioned distributions, chi-squared test was used. According to the results of the chi-squared test, except for the data for the left lane of Asia-Europe direction in the morning (09:00-10:00) and middle lane of Asia-Europe direction in the evening (20:00-21:00) which were suitable to evII distirbution, there was no appropriate distirbution for time periods among vehicles.

EK ŞERİT UYGULAMASININ ŞERİT KULLANIMININA ETKİSİNİN MİKRİSKOPİK TRAFİK DEĞİŞKENLERİ KULLANILARAK BELİRLENMESİ BOĞAZİÇİ KÖPRÜSÜ ÖRNEĞİ

ÖZET

İstanbul'da ve diğer şehirlerde ekonominin gelişmesiyle birlikte görülen hızlı nüfus artışı ve taşıtların artışı önemli ulaştırma sorunlarının ortaya çıkmasına neden olmaktadır. Sürekli yaşanan trafik sorunları insanların hayatında maddi ve manevi kayıplara yol açmakta, ve bu da ülke ekonomisinde çeşitli olumsuzluklara neden olmaktadır, bu yüzden bu sorunları olabildiği kadar ortadan kaldırmak için bir takım çalışmalar sonucunda çeşitli düzenlemelerin yapılması gerekmektedir. Çoğu zaman var olan yollarda kapasiteyi arttırmak ve trafik sorununu çözmek için yeni şerit eklenmesi uygulamaları gündeme gelmekte, ancak bu uygulamalar alan yetersizliğinden dolayı çok yüksek maliyetler gerektirmektedir. Bu sebeple, var olan yolların kapasitesini en iyi şekilde kullanmanın ve daha fazla taşıtın geçmesini sağlanması yolları aranmakta, bu yüzden şerit yönetimi uygulamaları yapılmaktadır. Ek şerit uygulaması da şerit yönetimi türlerinden biridir. Ek şerit uygulaması, belli bir zaman aralığında bir veya daha fazla şerit veya bankette trafik akışının ters istikamete çevrilmesidir. Bunun faydası, normal akış yönündeki kullanılmayan kapasitenin ters yönde kullanılması ile bu yöndeki kapasitenin arttırılması ve ilave şerit inşasının engellenmesidir.

İstanbul'da Avrupa ve Asya yönlerini birbirlerine bağlayan Boğaz Köprüleri, bu tıkanıklıkları sürekli yaşayan karayollarındandır. Zirve saatlerde iki yöndeki talep dengesizliği ve talebin kapasiteyi aşması bu trafiğin yaşanmasına neden olmaktadır. Ancak bazı ekonomik ve çevresel nedenlerden dolayı şerit ilavesinin mümkün olmadığı görülmektedir. Bu sebeple, var olan kapasiteyi en iyi şekilde kullanmanın yolları aranmaktadır.

İstanbul şehrinde konut yerleşimi daha çok Asya yönünde, ticari ve sanayi Avrupa yönünde olduğu için, insanlar sabah zirve saatlerinde Asya yakasından Avrupa yakasına, ve akşam zirve saatlerinde Avrupa yakasından Asya yakasına yolculuk yapmaktadırlar. Bu nedenle, talep ağırlığı sabah saatlerinde Asya-Avrupa ve akşam saatlerinde Avrupa-Asya yönünde yaşanmaktadır. Bu talep dengesizliğini ortadan kaldırmak için bahsi geçen şerit yönetimi türlerinden olan ek şerit uygulaması zirve saatlerde karşı yönden ödünç alınan bir şerit ilavesiyle her iki yöndeki talep dengesizliğinin önüne geçilmeye çalışılmaktadır. Boğaziçi Köprüsü bu uygulamanın yapıldığı geçişlerin biridir.

Bu çalışmada Boğaziçi Köprüsü (O-1) karayolunda uygulanan ek şerit yönteminin her iki yöndeki trafik akımlarına olan etkileri ve verimliliği mevcut durumda incelenmiştir. Ek şerit uygulamasını incelemek amacıyla mikroscopik trafik verisinin kullanıldığı çalışma yöntemi seçilmiştir, ve bu nedenle araçlar arasındaki geçiş zaman aralıkları ve hızları şerit bazında sabah (09:00-10:00) ve akşam (20:00-21:00)

saatlerinde ek şeridin uygulandığı zirve saatlerde ve ek şeridin uygulanmadığı zamanlarda (12:00-13:00), üç gün için birer saatlik dilimler halinde ve hafta içi günlerde toplanmıştır. Bu veriler karayollarından alınan kayıtlı kamera görüntüleriyle toplanmıştır. Ek şerit uygulamasının şeritlerdeki hacim ve hız değerlerini değiştirip değiştirmediği, istatistiksel olarak t-testi kullanılarak sınanmıştır.

Bu testte incelemeler iki grup halinde ek şeridin zirve saatlerde sabah ve akşam ve zirve dışı saatlerde olmak üzere ikili grup halinde yapılmaktadır. Her saatlik dilimler halinde toplanan verilerin sayıları aynı olmadıkları için “ Farklı varyanslı iki kuyruklu t-testi” kullanılmaktadır.

Bu tezin birinci bölümünde incelemeye alınan konuyla ilgili genel bir tarihçe ve tanıtım yapılmıştır.

Ikinci bölümünde, şerit yönetimiyle ilgili terimler açıklanmıştır, ve şerit yönetimi türlerinden olan yüksek doluluklu taşıt ayrıcalığı (yüksek doluluklu taşıt şeritleri (HOV) ve ağır taşıt şeritleri), katılımların kontrolü (ek şerit, kontrollü çalışma alanları ve ekspres şeritler) ve ücretlendirme (yüksek doluluklu taşıt şeritleri (HOT) ve tıkanıklık ücretlendirilmesi) anlatılmıştır. Bölümün sonunda, Amerika, Asya ve Avrupa’da uygulanan ve başarılı olan şerit yönetimi türlerinden örnek çalışmalar anlatılmıştır.

Üçüncü bölümde, şerit yönetimi türlerinden olan ek şerit terimleri, ve bununla ilgili tasarım, uygulama, kontrol ve yönetim esasları anlatılmıştır. Sonrasında, Amerika, Asya ve Avrupa’da yapılan ek şerit uygulamaları anlatılmıştır. En son, İstanbul’da var olan ve bu çalışmaya yakın olan ek şerit uygulamalarından (Fatih Sultan Mehmet Köprüsü, Çırağan Caddesi, Kennedy Caddesi ve Boğaz içi Köprüsü) söz edilmiştir.

Dördüncü bölümde, Boğaziçi Köprüsü’nde ek şerit uygulamasının, bu tezde yapılan incelemeleri anlatılmıştır.

Son bölümde ise, yapılan çalışmanın sonuçları ve ileride yapılması gerekenler konusunda öneriler sunulmuştur.

İlk olarak bu test iki akım yönü için ayrı ayrı akşam (20:00-21:00) ve sabah (09:00-10:00) zirve saatleri arasında sol şeridin ek şerit olarak kullanılmadığı ve kullanıldığı durumlar için yapılmıştır. Yapılan teste göre, ek şeridin uygulandığı kesimlerde akımda %25-%34 azalma görülmektedir.

Ikinci karşılaştırma, zirve ssatler arasında, sabah (09:00-10:00) ve akşam (20:00-21:00), orta şeritler arasında orta şeridin yanındaki sol şeridin ek şerit olarak kullanılması ve kullanılmamsı durumları için ayrı ayrı yapılmıştır. Bu karşılaştırmada, ek şeridin komşuluğunda olması durumda, orta şeridin akımında, sabah (09:00-10:00) saatlerinde %2 azalma, ve akşam (20:00-21:00) saatlerinde %3 çoğalma görülmüştür. Dolayısıyla, ek şeridin komşuluğunda olup olmamanın zaman cinsinden aralık ve taşıt hızlarında bir farklılık oluşturduğu konusunda bir genellemeye gitmek mümkün olmamıştır.

Üçüncü olarak bu test, orta ve sol şeritler için zirve dışı (12:00-13:00) ve zirve saatler, sabah (09:00-10:00) ya da akşam (20:00-21:00) arasında şeritler normal şerit olarak kullanıldığında veya hiç bir ek şeride komşu olmadıklarında yapılmıştır. Yapılan testin sonuçlarına bakılırsa, genelde orta şeritte zirve içi ve zirve dışı saatlerde bir fark görünmediği, ancak sol şeritlerde zirve saatlerinde, akımın %2-%3 azaldığı görümektedir

İkinci adımda ise, araçlar arası zaman aralıklarının dağılımları incelenmiştir. Bu çalışmada normal, lognormal, gamma, gumbel ve ekstrem değer II (edII) dağılımlarına bakılmıştır. zaman cinsinden aralıkların bu dağılımlara uyup uymadığını incelemek için ki-kare testi kullanılmıştır. Ki-kare testinin sonuçlarına göre, araçlar arası zaman cinsinden aralıkların genelde hiç bir dağılıma uymadıklarını, ve sadece sabah 09:00-10:00), sol şerit Asya-Avrupa yönündeki verilerin ekstrem değer (edII) ve akşam 20:00-21:00), orta şerit Asya-Avrupa yönünde olan verilerin ekstrem değer (edII) dağılımına uydukları görülmüştür.

1. INTRODUCTION

It is known that with population growth and considerable advances in different fields of technology, the number of vehicles commuting in streets and roads increases dramatically. These vehicles are undoubtedly necessary for humans' daily life; however, rising the number of vehicles causes traffic congestion due to insufficient road networks. Moreover, traffic congestion leads to funding crisis, spiritual disorders and environmental cost as results of factors such as wasting of time, pollution and driver function. Construction of new roads is one of the solutions to handle these congestion; however, many factors such as high construction costs and environmental impacts prevent construction of new roads; thus, various methods of traffic management, should be implemented to manage the existing roads better.

Reversible lane, which is cost efficient and useful to handle congestion problems in metropolitan cities, is one of the traffic management strategies. This method is known as one of the most sophisticated operations, which manages unbalanced traffic demand among directions by allocating unused lane in opposing direction to regulate high demand of road. This effort helps to eliminate the need to construct additional lanes. It is more effective when highly unbalanced directional flows, such as those occuring during daily peak-periods of travelling time when taking place before and after large events, and during emergency evacuations.

The aim of this thesis is to determine the productivity of reversible operation on O-1 motorway in Istanbul. As it can be seen even after operating of reversible operation in peak periods of day, sometimes in each direction, traffic congestions and unbalanced traffic distributions may happen again. It can be noticed clearly, overall demand in Europe-Asia direction is undoubtedly more than Asia-Europe direction. Since transition volume in Asia-Europe direction is more in the morning and Europe-Asia direction in the afternoon, so the reversible operation is implemented in the Asia-Europe direction in the peak periods of morning and in the Europe-Asia direction in the peak periods of afternoon. However, high demands of vehicle commute in Europe-Asia direction results in traffic congestions even in the morning.

Therefore, although this operation alleviates some unfavorable effects of unbalanced traffic distribution, it also might cause some unexpected traffic jams and extended queues in the direction, which has less flow of traffic.

The purpose of this study is to search the influence of reversible lane operation on flow of vehicles in each lane through analysing the changes in the utilization and making comparisons with off-peak times when operation is not carried out.

2. MANAGED LANES

Transportation agencies are facing with the growing challenges of traffic congestion and a limited ability to expand freeway capacity due to construction costs, right-of-way constraints and environmental and social impacts. As a result, transportation officials are exploring the use of managed lanes to address mobility needs in freeway corridors, particularly where major expansion has limited feasibility.

Managed lanes provide travel options in a congested corridor through minimal capacity expansion and operational strategies that seek to manage travel demand and potentially improve transit and other forms of ridesharing (Goodin, 2005). Typically, this has been done by using lane management strategies that:

- Regulate demand.
- Separate traffic streams to reduce turbulence.
- Utilize avalible and unused capacity.

Managed lanes have been in existence for nearly 75 years and represent a family of operational strategies designed to address a wide array of transportation objectives.

2.1 Definitions of Managed Lanes

In the United States, Varios Federal and state agencies have customized managed lane definitions:

- Highway facilities where operational strategies are proactively implemented and managed in response to changing conditions (FHWA, 2008);
- Active managemnet to optimize traffic flow and vehicular throughput (Turnbull, 2003);
- A managed lane facility is one that increses freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals (Texas Transportation Institute, 2010).

- Freeway lanes that are set aside and operated using a variety of fixed and/or real-time strategies responding to local goals and objectives that move traffic more efficiently in those lanes (Louis et al, 2003).

2.2 Types of Managed Lanes

Strategies for managing lanes typically fall into one of three categories:

1. Vehicle eligibility.
2. Access control.
3. Pricing.

Agencies can use just one of these strategies for managing highways, but more complicated managed lane facilities blend more than one of these strategies. Figure 2.1 expresses types of lane management, which use as a single operation or blend more than one of these strategies.

Lane management can broadly classify into active and traditional management strategies. Active lane management is offered as a result of advancements in Intelligenet Transportation Systems and involves operations which automatically respond to changing traffic conditions in real-time. Traditional lane management includes the strategies to enhance highway throughput (Obenberger, 2004).

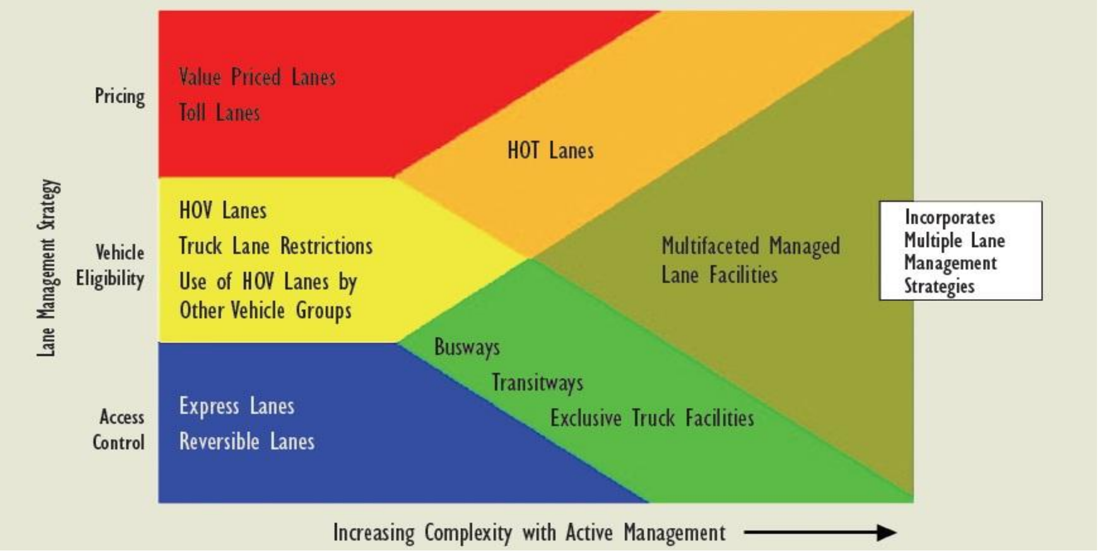

Figure 2.1 : Managed lane applications.

In Figure 2.1, HOV is high occupancy vehicles which expresses vehicles with 2 or more users in it, and HOT is high occupancy toll lanes which are designed for high occupancy vehicles and others who are willing to pay a toll to use the lane.

2.2.1 Vehicle eligibility

One of the most commonly used lane management tools for the past 40 years is restricting use based on vehicle eligibility. It can be defined by type of vehicle (buses, trucks, motorcycles or hybrids) or by the number of occupants in a passenger vehicle.

One of the goals of the vehicle eligibility restrictions is to encourage the use of transit or other high-occupancy modes (Louis et al, 2011).

The following are examples of managed lane strategies involving eligibility restrictions.

- HOV lanes

  HOV lanes provide preferential treatment for transit, vanpools, carpools. The primary goal of HOV lanes is to increase the people moving capacity of a corridor and allow for more efficient use of freeways by increasing the number of occupants per vehicles. This is accomplished for high occupancy modes to incentivize carpooling and the use of transit.

- Truck lanes

  The goals of various forms of truck lanes are to improve traffic operations and safety, and facilitate the flow of goods.

  A recent project in Houston implemented a truck restriction lane on eight-mile section of the I-10 East freeway (TTI, 2010). The study reported a 68 % reduction in crashes over a 36-week period. A truck lane on I-40 near Knoxville resulted in a substantial reduction in the percentage of trucks traveling the left lane even with minimal sign usage and enforcement (Kiattikomol, 2003).

- Bus lanes

  The HOV concept first manifested itself in the form of a bus-only freeway lane. The term busway is commonly used to refer to facilities that are reserved for exclusive use by buses. A bus-lane, more commonly located on a major arterial or roadway on separate right-of-way, is usually a component of a Bus Rapid Transit (BRT) system and as a result the terms bus-lane, busway and BRT are sometimes used synonymously.Examples of bus lanes is shown in Figure 2.2.

Figure 2.2 : Early bus-only lanes on freeways in the US.

2.2.2 Access control

It is used to limit entry to a facility based upon congestion levels or operational conditions such as an incident or maintenance needs. Demand can be managed by limiting access to fewer entry and exit points, using grade-seperated ramps or utilizing actual barriers at ramp locations to control access (Louis et al, 2003).

- Express lanes

The term "express lanes" has commonly been used for decades to refer to freeway lanes that are segregated from general-purpose traffic and are set apart by limiting access to them. Express lanes have a reduced number of entry and exit locations as compared to the general-purpose lanes.

- Reversible lanes

Reversible lanes change the directional capacity of a freeway to accommodate peak directional traffic demands. Reversible lanes on freeway have usually been implemented on roadway cross-section that includes a completely set of lanes in the center of the freeway. These are reserved in accordance with peak demands usually on a time of day basis.

- Work zone controls

A work zone is an area of a highway with construction, maintenance, or work activities; it extends from the first warning sign or stroble lights on a vehicle to the END ROAD WORK sign or the last temporary traffic control device. Traffic management in work zones is important to the safety of both workers and motorists. Work zone lanes applications can be seen in Figure 2.3.

Figure 2.3 : Work zone lanes.

2.2.3 Pricing

The pricing aspect of active management refers to the use of price controls for the purposes of controlling volumes and generating revenue on managed lanes facilities.

- Value pricing or congestion pricing

  It means the idea of charging motorists a toll for travel during the most congested times or offering a discount for traveling in the off-peak period.

- HOT lanes

  HOT lanes take advantage of available unused capacity in an HOV lane by allowing vehicles that do not meet the minimum occupancy requirement to pay a toll for access to the lanes.

2.3 Case Study Examples of Managed Lanes

- HOV and HOT lane-State Route 91 Express Lanes, Orange Country, CA, USA:

The State Route (SR) 91 Express Lanes in California were the first in the United States to vary tolls by the level of congestion on the roadway. Built within the median of 91 and opened in 1995, the four express lanes are 10 miles in length with no intermediate access. Two lanes are provided in each direction and they separated from the main lanes by plastic pylons and a painted buffer.

Toll rates are set according to the level of congestion typically experienced on the roadways, making peak periods the most expensive time to travel. Although the facility is open 24 hours per day and seven days per week and tolls are charged at all times, the operators use price to maintain free-flow speeds on the express lanes at all times.

Tolls are paid exclusively through electronic collection. Facility users must have an account and a transponder. The facility also encourages travel in HOVs. Carpools with three or more occupants (HOV3+), motorcycles, zero-emission vehicles and vehicles with disabled person license plates are free at all times, with exception of the evening peak period in the peak license, when HOVs are charged 50 percent of the posted toll. Figure 2.4 shows (SR) 91 Express lanes in Orange Conutry and the operation of manage lanes in this area (FHWA, 2008).

Figure 2.4 : State Route 91 toll express lanes.

- Reversible, HOV and HOT lane-interstate 10 and U.S. 290 QuikRide, Houston, TX, USA:

A slightly different pricing project has been implemented on Interstate 10 (I-10), also known as the Katy freeway, and U.S. 290, reffered to as the Northwest Freeway, in Houston, TX, USA. The program, which is marketed under the name QuikRide, began operating on the Katy Freeway HOV lane in January 1998 and was expanded to the Northwast Freeway HOV lane in 2000.

Both are one-lane reversible facilities separated from the main lanes with a concrete barrier. Access is allowed at intermediate locations in addition to the termini. Each lane is approximately 13 miles long. The facilities essentially operate as HOV lanes during off-peak periods and HOT lanes during peak periods, although single occupant vehicles (SOVs), are never allowed.

- Bus lane-I-10 Harbor Transitway:

An example of bus lanes is the I-10 Harbor Transitway that carries buses and HOV-2+ vehicles in the median of the freeway. There are six bus stations along the Transitway that serve many bus routes including BRT route. Although the Transitway serves all types of HOVs and will soon incorporate solo vehicle pricing, it includes several sections where bus-only lanes and separate roadways into stations for buses exist (Louis et al, 2003).

- HOV lane-I-93 Southeast Expressway-Boston, Massachusetts:

The Massachusetts highway Department operates the I-93 Southeast Expressway HOV lane, a 6-mi contraflow facility connecting Quincy and Boston. The HOV lane is based on a contraflow design, which borrows an underused off-peak direction lane and converts it to a peak-period direction HOV lane during periods of morning and afternoon congestion. The HOV lane is separated from oncoming traffic by a 6-mi flexible wall made up of movable hinged concrete barriers, which are repositioned twice each day. (NCHRP, 2004).

- HOV and HOT lanes-IH_15 San Diego, California, USA:

The FasTrak program on IH-15 in San Diego, faced with increasing congestion and limited funding, the San Diego Association of Governments (SANDAG) impelemented managed lanes, or Express lanes, in the median of IH-15. The reversible, barrier-separated lanes were previously operated as HOV lanes for buses and carpools of two or more people. However, this operating scenario resulted in excess capacity on the HOV lanes while the mainlanes of IH-15 remained heavily congested. SANDAG, working with California Department of Transportation and the FHWA, implemented a demonstration managed lanes program in 1996. The FasTrak program allows SOV to "purchase" excess capacity on the Express Lanes by paying a toll for access for motorists.

- HOV lanes, A647, Leeds, United Kingdom:

In leeds a general purpose (GP) lane in the nearside lane of the A647 has been redesignated an HOV 2^+ lane (including buses, coaches, motorcycles, pedal cycles and 2^+ vehicles, but not HGVs over 7.5Tonnes) and is in operation at peak periods only (between 07:00 to 10:00 and 16:00 to 19:00). The initiative was from Leeds City Council. The scheme is 1.5 kilometers long (in two lengths of inbound lane) on a 2 kilometers length dual carriageway. The scheme was opened in 1998. Figure 2.5 expresses the HOV operation on Leeds.

Figure 2.5 : The start of the Leeds HOV lane (Leeds City Council (LCC), 2002).

Advance signing is provided at the approach to the HOV lanes. Traffic signal control is provided at the end of the HOV lane to manage merging traffic from both lanes. The results of operation have shown a reduction in inbound journey times for buses and other high occupancy vehicles of 4 minutes in the morning peak. A reduction in the inbound journey times for the GP lane of 1.5 minutes is reported. Increases have occurred, in bus patronage and average car occupancy , from 1.35 in May 1997, to 1.43 in June 1999 and to 1.51 in 2002. There has also been a reduction in the number of accident casulations and a reported low level of violation (Department for Transportaion (DFT), 2005).

- HOV lane in Madrid, Spain:

From mid-1970 in Madrid, the number of cars on the roads has increased yet few facilities existed to deal with the extra flow. An HOV lane has been operational since 1994. The lane is divided by physical barriers and covers a distance of 40 kilometers.

The results from this scheme have been positive. The travel times were drastically reduced for the HOV lane and as a result the percentage of 2+ vehicles increased from 30% to 40% in the first year. The average vehicle occupancy increased from 1.36 to 1.47 after implementation. Also public transport use increased by 40% in the morning peak period in the first year (ILS, 2000). Due to this scheme there was an increase in commercial bus speed and service regularity, a decrease in travel time, a decrease of space use, congestion, energy consumption, pollution and accidents.

- HOV lanes in Australia:

Australia has 11 HOV lane schemes located in Brisbane, Melbourne and Sydney. The distance covered by the HOV lanes varies between inbound and outbound and, in some cases, the schemes operate inbound only into the cities. All schemes are for peak hours only with some being just for the AM peak period. The majority of schemes are for 3+ occupancy vehicles. The earliest of the schemes was impelemented in 1992.

The south east Buswaay in Brisbane, progressively opened between September 2000 and June 2001, was the result of five years planning, design, construction and community liaison. In 1996 a market survey showed that 25% of the respondents already used the bus and another 61% would consider using the South East Busway assuming there would be improvements to convenience, frequency, reliability and safety. The decision to build the Busway system was found to cost less than the do-nothing alternative and, by the year 2011, the Busway is estimated to save taxpayers about 62$ million (Australian dollars). This scheme has also increased property values by 20% within the vicinity (Transport Research Board (TRB), 2002).

Thr busway is located along one side of a 6-lane freeway and the two travel lanes are separated by a 1.6 foot barrier plus a fence. Bays are provided at the station to allow express buses to pass buses making stops.

3. REVERSIBLE LANES

The history of reversible lane systems (RLS) dates back more than 75 years and includes applications on all roadway classifications, from local city streets to freeways. Despite the long and diverse history of RLS, it is interesting to note that the practices that guide its application are not nearly as well defined or studied as many other techniques of traffic management (NCHRP, 2004). One of the earliest referenced uses of reversible roadways was in Los Angeles in 1928, with a convertible lane variant known as off-center lane movement (Dorsey, 1948). The history of reversible flow use shows that its popularity on arterial roadways in urban areas increased significantly from the 1940s to the 1960s with the widespread construction of freeways. Later uses of reversible lanes during the 1970s were associated with freeways, bridges, and tunnels both in United States and overseas, particularly in Europe and Australia. During the late 1970s and 1980s, reversible lane systems were used more extensively in conjunction with managed lane facilities such as HOV lanes in urban population centers. It is also known that reversible lane operation has been widely used for dealing with special event directional traffic scenarios, such as those associated with large sporting events, concerts, and festivals. The most recent interest in reversible lanes in the United States has been sustained since 1999, in the form of freeway contraflow for hurricane evacuation (NCHRP, 2004).

3.1 Definitions and Purpose of Reversible Lane

Reversible lane is defined as the type of roadway in which one or more lanes or lane-segment reverses its flow direction to accommodate changes in direction of peak traffic flow.

The Institue of Transportation Engineers describes the reverse laning of roadways as potentially one of the most effective methods of increasing rush-hour capacity of existing streets under the proper conditions. A reversible roadway is one, which the direction of traffic flow in one or more lanes or shoulders is reversed to the opposing direction for some periods of time (Wolshon and Lambert, 2006)

Reversible roadways most commonly are used for accommodating the directionally imbalanced traffic associated with daily commuter, in construction work zones during major events and evacuation of major metropolitan regions threatened by hurricanes.

Reversible roadways can be categorized into similar groups based on their purpose and the type of roadway on which they are used such as (Wolshon and Lambert, 2006):

- Peak period traffic management;
- Event traffic management;
- Construction zone traffic management;
- Emergency traffic management.

The most important factor that, influence the overall plan of a reversible roadway is its volume characteristics. Many other factors influence the planning and design of a reversible lane system, which are:

- The cost and the level of complexity and sophistication of traffic control;
- The functional type of roadway on which it is used;
- The purpose and/or intended goals for which it is used; and
- The agency responsible for the planning, design, implementation and management;

Reversible lanes have two kinds of properties: spatial and temporal.

The key spatial elements of a reversible roadway segment include the geometric features such as its overall length, number of lanes and the configuration and length of the inbound and outbound transition.

Lahthrop (1972) generalized the configuration of reversible roadway segments within the context of five zones; illustrated and numbered in Figure 3.1. Zone 1 is regarded as the approach zone. In this zone, drivers need to be informed that a reversible roadway is ahead. Information given to drivers should include how many and which lanes are open and available to them. Zone 2 is the decision zone whereby drivers must move into or out of the reversible lanes. That area is often regarded as the most potentially hazardous, because merging and weaving movements are occurring and the number of lanes is changing; therefore, it needs to be carefully designed. In Zone 3, drivers continue in the normal and reversible lanes. Typically, various traffic control devices are used to remind drivers about which lanes are open for use in each direction. Adequate control in Zone 3 is critical, because opposing traffic may exist in an adjacent lane, increasing the risk of head-on collisions. The transition from the reverse flow lanes back to the normal lanes occurs in Zone 4 must be properly designed, because converging maneuvers will be taking place within that area. In Zone 5, traffic departs the reversible section and continues in normal flow patterns.

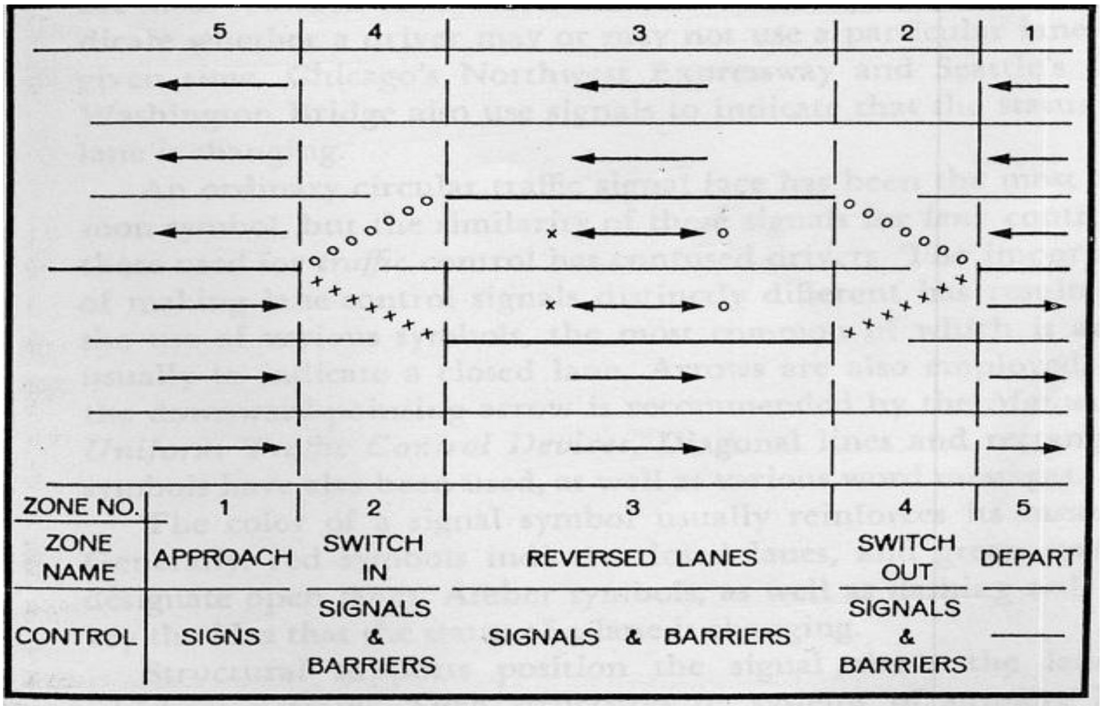

Figure 3.1 : General configuration of reversible lane facilities (Lahthrop 1972).

From an operational standpoint, the most critical areas of reversible segments are the transition zones. For reversible lanes to be effective, the capacity of the transition section must be accommodate the increased volume, or else the reversible affort is naught. Several reversible lane segments have been discontinued because the capacity of the downstream terminus was less than that of the reversible segment.

The result was a slow buildup of congestion within the segment that diminished or eliminated the anticipated benefit from the additional lane.

The primary components of RLS include the frequency and duration of a particular configuration and the time required to transition traffic from one direction to another.

As with spatial characteristics, temporal characteristicsof reversible roadways can be viewed according to the time taken to effect a transition from one direction to another and the duration for which they are in use (NCHRP, 2004).

3.2 Principals of Implementing Reversible Lanes

The basic principals for implementing reversible lanes are planning, design and control.

3.2.1 Planning

The traditional transportation planning process uses a developed set of principals to analyze, evaluate, and select appropriate projects to meet the needs of a location. In addition to describing the costs and benefits of a proposed improvement to the transportation system, planning processes can be used to identify the impact on the development of communities, in terms of problems that need to be addressed by facility or operational starategy. Followed by the development of goals that would be achieved with its implementation. With this knowledge in hand, alternative designs and strategies are generated and then evaluated to assess how each of them achieves the established goals and delivers the highest comparative benefit at an acceptable level of cost.

3.2.2 Control and management

It means the signs used to control and guide traffic on such roadways, most of these signs are locally and they are not uniform from one location to another. The range of control schemes vary widely in terms of their costs, level of sophistication and creativity (Wolshon and Lambert, 2006).

The complexity of these systems apeared to be based primarily on the regularity of their use, characteristics of volume and speed associated with the particular roadway.

3.2.3 Design

The design of reversible roadways varied from one location to another. The vast majority of reversible operations took place on roadways that were not originally planned or designed for bidirectional use. Most applications were incorporated into conventionally designed roadways that were later reconfigured for permanent or periodic flow conversions using various permanent or temporary design and control features. The primary exceptions to this case were applications on freeways, and in particular freeway HOV and transit reversible lanes, where transition termini and lane seperations were planned, designed, and constructed specifically for the purpose of reversible lane systems. The most widely accepted highway design manual in USA, A policy on Geometric Designof Highways and Streets (AASHTO 2004) commonly known as ”The Green Book”, does discuss the principals of reverse flow lanes, for examples (AASHTO) suggests that reversible lanes on arterial roadways should be designed as a normal travel lane. The lack of published information about design of reversible roadways led transportation agencies to develop their own design guidelines covered areas such as guardrails, crash attenuators, roadway cross-section width, and termination zone design (NCHRP, 2004).

3.3 Case Study Examples of Reversible Roadways

3.3.1 Reversible operations in USA

- The Rock creek Parkway and Canal Road:

The other reversible segments were utilized on arterial roadways. The Rock creek Parkway and Canal Road are arterial routes with very few intermediate access points. At about two to three miles in length, both of these segments are relatively short and operate on one-way in basis from 7:00 to 9:00 and a one-way out basis from 16:00 to 18:00 movements into and out of the segments are controlled at signalized intersections with assistance from D.C. Park Police.

- I-95 Suburban D.C./Va:

An area where reversible lanes have been both popular and successful is the Washington, D.C., metropolitan area. The first is Interstate 95 (I-95) in suburban Virginia. On this freeway, two lanes between the directional lanes are dedicated for inbound transit and HOV in the morning, then outbound in the afternoon. Traffic can enter and depart the reversible lanes at several points along the 18 mile section. Access is controlled by gated ramp crossovers between the reversible and directional freeway lanes and by signal controlled reversible ramps between the reversible freeway lanes and grade seperated arterial roadways. Figure 3.2 shows reversible freeway ramp termini.

Figure 3.2 : Reversible freeway ramp termini (I-95 Suburban D.C./Va.).

3.3.2 Reversible operation in China

This operation is implemented on urban erterial roadways in a typical urban commuter situation in China. This reversible operation is on a north-south urban arterial roadway with regularly spaced signalized intersection. The north-south urban arterial roadway consists of six travel lanes on the section including two center lanes which are reversible but are not physically seperated. Each northbound or southbound approach at signalized intersection is widened to add one right-turn lane. Vehicles are allowed to make left turns at signalized intersection.

During off-peak periods, the north-south urban arterial roadway operates as a bidirectional facility, with three travel lanes in each direction on the section. As the right reversible lane is called ”number 1 lane”, and the lane to the left of the ”number 1 lane” is ”number 2 lane”, the number 1 lane is operated northbound and the number 2 lane is operated southbound during off-peak periods. At signalized intersections, three travel lanes in each direction are converted into four lanes, including one left-turn lane and one right-turn lane. During the morning peak-period travel time, the predominant travel direction is southbound. For lanes including two reversible lanes are operated southbound and two lanes northbound on the section. During the evening peak-period travel time, the predominant travel direction is northbound. Four lanes including two reversible lanes are operated northbound and two lanes southbound on the section.

Changeable lane-use signals are installed above each reversible lane. There are four overhead changeable lane-use signals on each section of the north-south urban arterial roadway (Li et all, 2013).

3.3.3 Reversible operation in Hungary

- Stage common of M1-M7 in Budapest, Hungary:

One of the large traffic of Budapest happens on common part of the M1 and M7 motorways. Directed to pest of this traffic can be conduct to Eger Road. This route is two lanes, but the exit ramp from the motorway is only one lane and the modification of this to duple lanes would not demand for large investment. During the peak period hours the users of exit ramp would have priority opposite to traffic of Eger Road. During non-peak hours the present formation would remain, consequently, the change would be signalled by LEDs. Figure 3.3 shows the practical changing-direct or bending- lane on the mentioned road-section (Bede, 2008).

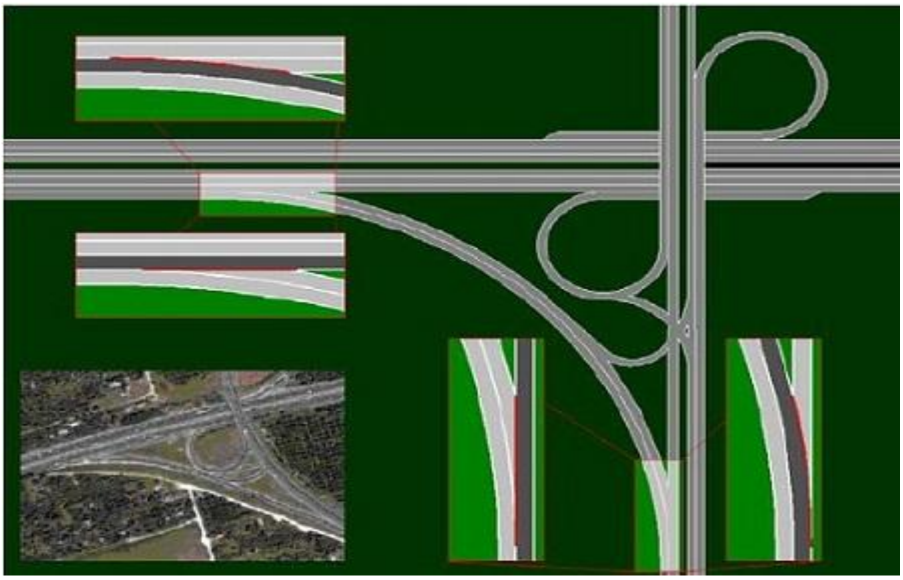

Figure 3.3 : Junction of Stage common of M1-M7 and Eger Road.

3.3.4 Reversible operations in Istanbul

In Istanbul there are four different locations where reversible lanes are implemented. They are:

1. Reversible lane on Çırağan Street,
2. Reversible operation on Fatih Sultan Mehmet Bridge,
3. Reversible operation on Boshphorus Bridge,
4. Reversible operation on Kennedy Street,

- Reversible lane on Çırağan Street:

One of reversible operations in Istanbul was implemented between Beşiktaş and Ortaköy. The operation was carried out along Çırağan Street and started in the end of Beşiktaş Street. The length of the street in which the operation was implemented is about 1.5 kilometers. The Çırağan Street have approximately 3 lanes which operate as two-directional street; however, unbalanced traffic distributions in peak periods of day cause to operate reversible operation in this street in order to manage the unbalanced demand more influentially. The middle lane in this street has been used as reversible lane which works between 07:00-10:00 in Ortaköy-Beşiktaş direction, and between 17:00-20:00 in Beşiktaş-Ortaköy direction. Additionally, in off-peak hours, the street operates as one lane each direction and middle lane is used for overtake by both direction traffic. Information about reversible lane was mounted at the beginings and along street where reversible operation was applied. Figures 3.4 and 3.5 are express the reversible operation on Çırağan Street.

Figure 3.4 : Time table of reversible operation on Çırağan Street.

Figure 3.5 : Information signs along reversible segment on Çırağan Street.

The green sign expresses the lane which can be used by vehicles in the related direction and the red sign expresses the lane which is not allowed to the vehicles coming from the front side, and the yellow sign expresses the time when lane does not operate as reversible operation and both directions can use the lane.

- Reversible operation on Fatih Sultan Mehmet Bridge:

Another reversible operation in Istanbul is on Fatih Sultan Mehmet Bridge. This Bridge is the second roadway connection between Asian and European side, but there are unbalanced traffic distributions and it results in congestions during peak periods of day. So reversible operation is implemented to handle this problem. Each side of this Bridge consist of 4 lanes which the most left lanes of each side operates as reversible operation to control demand. Reversible lane is operated in Asian-European direction between 6:40-11:00 hours in the morning and between 16:20-21:00 hours for Asian direction.

This operation is implemented in peak periods of day and in off-peak hours, the most left lane of each side operate as regular lane. Reversible operation starts in Toll Plazas and ends in about 300 meters far from Kavacık Interchange in the evening and vice versa, it starts in about 300 meters far from Kavacık Bridge and it ends in Toll Plazas in the morning. The length of operation is about 4.5 kilometers. Figure 3.6 express the operation which being operated.

Reversible lane operation for the Fatih Sultan Mehmet (FSM) Bridge causes bottlenecks along the road and long vehicular queues in the direction from which a lane was borrowed. This consequence deserves to question the effectiveness of reversible lane operation. The reversible lane operation as one of the lane management types has been investigated by referring to the application on the FSM Bridge (O-2 Freeway). established a simulation model of the study stretch using TSIS/CORSIM package is established and is calibrated the model with actual field data. The effects of contraflow lane operation on traffic flows in the two directions were examined by comparing the current operation with various scenarios of reversible lane operation. Simulation results show that significant improvements in total travel time (15,17% reduction) and average speed (15,83% increase) could be obtained without reversible lane operation. Some minor improvements were also achieved by shifting lane operation timing backward and forward (Aydın,2008).

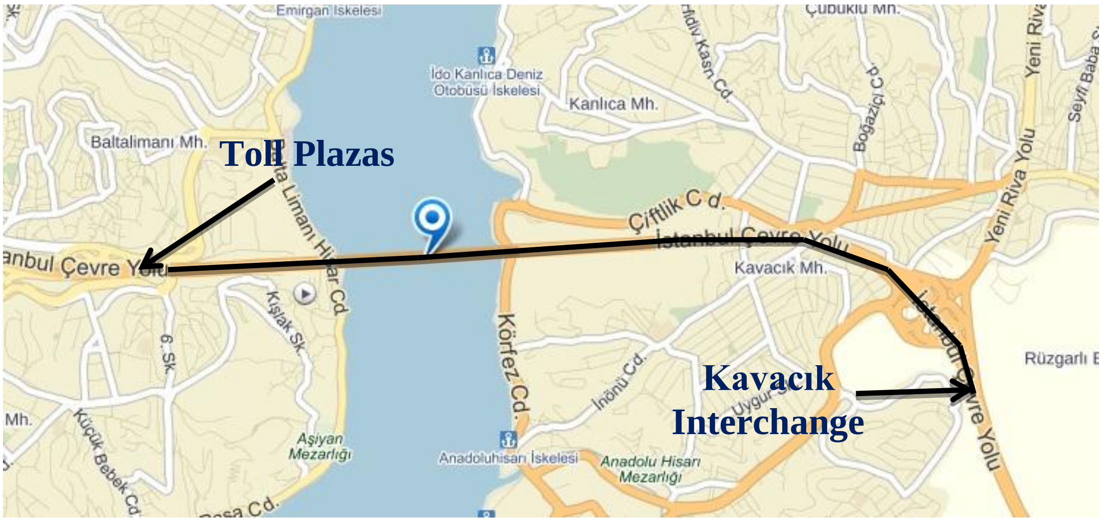

Figure 3.6 : Reversible lane operation on Fatih Sultan Mehmet Bridge.

- Reversible operation on Bosphorus Bridge:

The next reversible operation which exists in Istanbul is on Bosphorus Bridge which connects Asian-European sides to each other. Each side of this roadway have 3 lanes which the most left lane of each side operates as reversible lane in peak periods of day. The reversible operation length is about 2.5 kilometers which is about Toll Plazas to Beşiktaş exit. Reversible operation works as the borrowing of the most left lane of each side for the opposite side to balance demand and capacity between sides. Reversible lane operates in Asia-Europe Side between 7:00-11:00 hours in the morning and in Europe-Asia Side between 16:00-21:00 hours. The rest of times each lanes operates as regularly lane.

A study which is done in Istanbul is to determine the level of capacity usage at the approaching roads in the Asian side to the Istanbul Bosphorus Bridge; and also is to bring out some features of traffic stream and current operating regulations into the open. In this study data are obtained through traffic counts. Data are collected in the morning peak hours when reversible operation is working for Asia-europe direction. The results are imported from cumulative vehicle graphs. 1563 vehicles transit from fourth (reversible) lane in an hourly period, however at least 2000 vehicles transit from the rest of those three lanes in an hourly period. Bottlenecks cause to decrease in level of capacity usage. To improve these decreases, some operations like making traffic counts in bottlenecks and finding where these bottlenecks are placed, have to be done for improve these unexpected decreses in capacities (Şahin, 2001).

Another study is done for making improvements in queues and flow rates of roadways which are connecting to O-1 Motorway in both Asia-europe and Europe-Asia Side (Şahin, 2004).

- Reversible operation on Kennedy Street:

The other reversible lane operation is operated on Kennedy Street between Yenikapı and Bakırköy. The length of operation is about 8 kilometers. As it is represented in Figure 3.7 and 3.8, the operation is started in Yenikapı intersection and ended at the beginning of Rauf Orbay Street. The street has about 6 lanes, in which 2 right lanes in each directions operate as general-purpose lanes, and the left 2 lanes in the middle of street operate as reversible lanes in certain time periods of a day. The reversible lanes were separated from general-purpose lanes by guard rails.

Figure 3.7 : Beginning of reversible operation in Yenikapı.

Figure 3.8 : Beginning of reversible operation in Bakırköy.

The operation works between 06:00-13:00 in Bakırköy-Yenikapı direction, and between 13:00-23:00 in Yenikapı-Bakırköy direction, and the reversible lanes are close to traffic between 23:00-06:00. Figure 3.9 expresses the time table guiding drivers at the beginning of operation.

Figure 3.9 : Times table of reversible operation on Kennedy Street.

4. CASE STUDY

4.1 Description of Area

In Istanbul, Bosphorus strait seperates Asia and Europe Sides from each other. Bridges are designed to connect these two sides, two Bosphorus Bridges are connecting the Europe and Asia Sides, and they are the only roadways between these two continents. The directional traffic demands during peak hours are not equal to each other because of the location of residential and commercial, industrial areas, so reversible operation is one of the methods to balance capacity supply by borrowing additional lane from opposing direction. In general, it operates in peak times of day.

The field where reversible lane implemented on Bosphorus Bridge, starts at Toll Plazas on Asian side and it ends in Beşiktaş exit on European side. The length of operation is about 2.5 kilometers. The method works by the means of borrowing the most left lane of European-Asian side in the morning and Asian-European side in the afternoon to respond the demand of opposite direction. Since the motorway is operated as 2×3 system, then when the reversible lane is being operated, it gets 4 lanes to work in the direction where reversible lane is applied, and supplies 2 lanes for opposite direction. Figures 4.1 and 4.2 express the length and location of reversible operation, which is obtained from Google-Earth.

The reversible lane effects can be determined by using microscopic or macroscopic variables. In macroscopic perspective, data are gathered in certain sections, and analyses are done in a “flow” concept. Macroscopic variables are volume, speed and density. The second method is to determine the changes by the means of microscopic view, where variables are headway, spacing, vehicle speed, that deals with “vehicle speed”. In this thesis, microscopic data are used to analyze the effects of reversible operation. Headways and speeds of vehicles for each lane have been examined separately in the analysis.

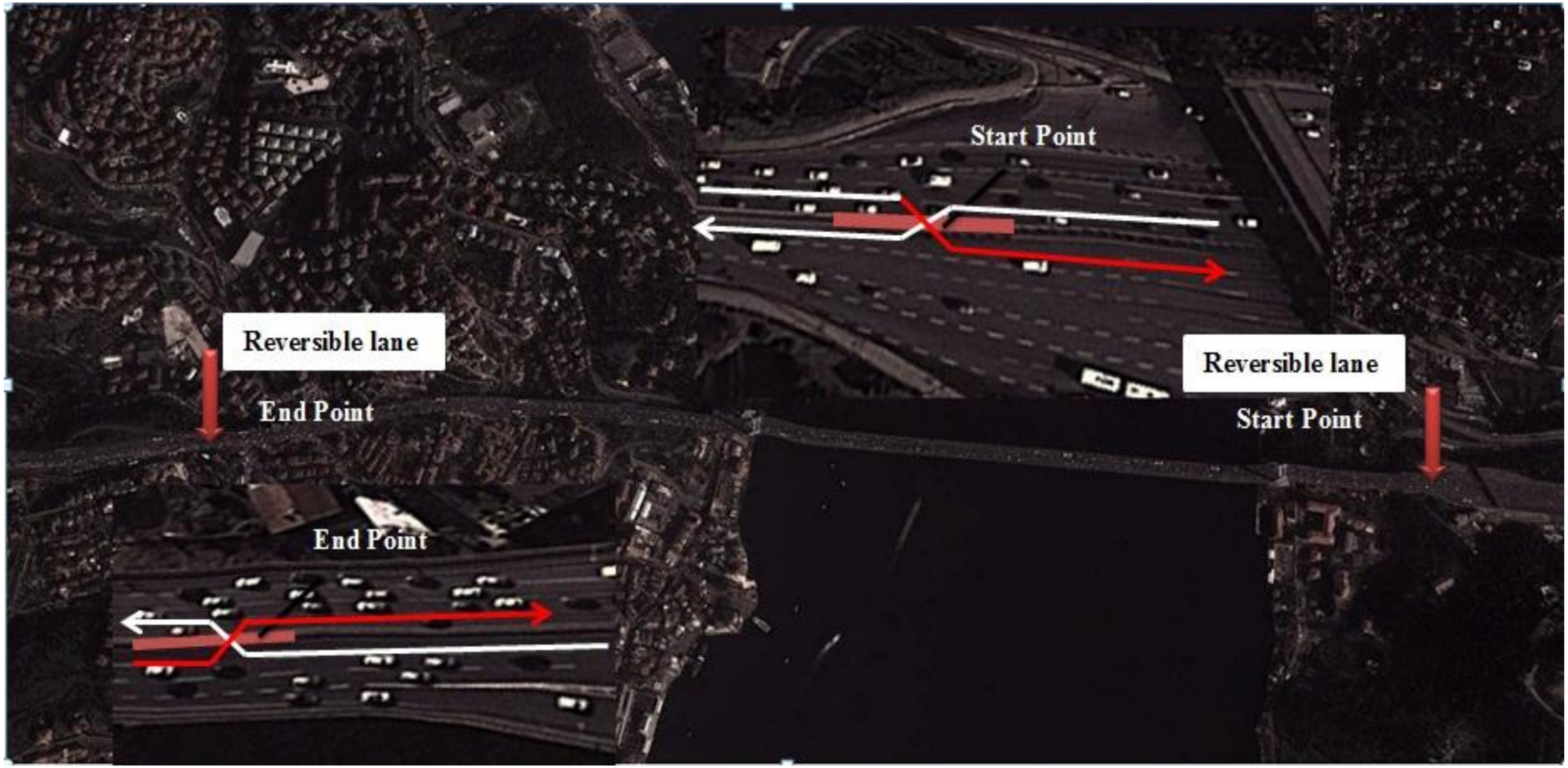

Figure 4.1 : Section of reversible operation.

Figure 4.2 : Reversible operation on Bosphorus Bridge.

4.2 Microscopic Study

The aim of this investigation is to scrutinise the changes in headways and speeds in each lane when the reversible operation is implemented. Hence, the aim is to explore the behavior of vehicles while passing through each lane in reversal time periods, and responding the crucial question of whether they face major changes in comparison with none-reversible time spans or not. Changes have been explored in 2 points of view, which are headways and speeds of vehicles passing each lane in different time periods. As a result, it is necessary to gather recorded data of different time periods of each day while the reversal operation is being implemented and as the traffic runs in a normal lane. Secondly, headway distribution analyses of vehicles in lanes in peak periods of day while reversal operation is being carried out and off-peak times as normal traffic system is being operated in lanes are done. Thus, it will be useful to use these results in modeling of reversible operations in order to improve its productivity.

4.3 Description of Gathering Data

Once reversible lane is operated in left lanes of each direction, it is not possible to get effects of operation at all in the rightmost lane, so the research has been done on the rest of lanes in each side. To gather data from vehicles and total traffic in operation time, camera records, which are installed in different points of motorway, are used. Actually, these cameras are mounted throughout the motorway for controlling of crashes and traffic conditions. For implementing of the researchs, records of the camera, which is mounted on the bridge tower in Asian side, are used. Figure 4.3 shows the camera, which is used for data gathering.

Data are used to clarify the effects of reversible operation, so it is extremely necessary to get information of reversal and none-reversal time periods. Since the operation gets to work between 7:00-11:00 in the Asia-Europe direction in the morning and between 16:00-21:00 in the Europe-Asia direction in the afternoon, for making comparisons between reversible operation and normal operating condition, data are gathered in 3 periods of each day which are between 09:00-10:00, 12:00-13:00 and 20:00-21:00 on 21-22 and 25 of December, 2013. It is important to pay

Figure 4.3 : Location of camera for gathering data.

attention to weather conditions to be the same because of occuring unexpected changes at the directional roadway capacity and vehicle running speeds. Moreover, as the traffic flow patterns on weekend and weekdays are not the same, the research was carried out only on weekdays for gathering consistent results. Headways of vehicles and the speeds of vehicles in each lane are collected. As it was explained before, the left lanes which reversible operation was implemented to, and the middle lanes in the neighborhood of reversible lane are assumed to be the most basic lanes affected by reversal operation. Thus, for 3 days that each day splited into 3 parts, the data used for examination were in 36 parts. Since the test is done to analyze the changes in time periods which reversible operation got to work in opposite side and the time when the lanes operated like normal traffic sructure, the information of headways and speeds in 3 days and in each section gathered together, so data was prepared in 12 parts which are given in Table 4.1. Figures 4.4, 4.5 and 4.6 express direction of lanes and times when they are operated.

Table 4.1 : The positions of lanes where data collected.

Time	Asia-Europe		Europe-Asia	
	Lanes		Lanes	
09:00-10:00	Middle	Left	Reversible	Middle
12:00-13:00	Middle	Left	Left	Middle
20:00-21:00	Middle	Reversible	Left	Middle

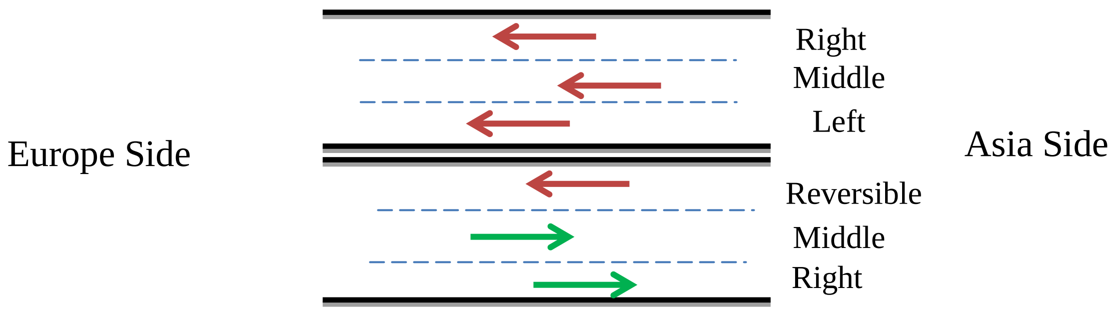

Figure 4.4 : Lane directions between 09:00-10:00, morning peak hours.

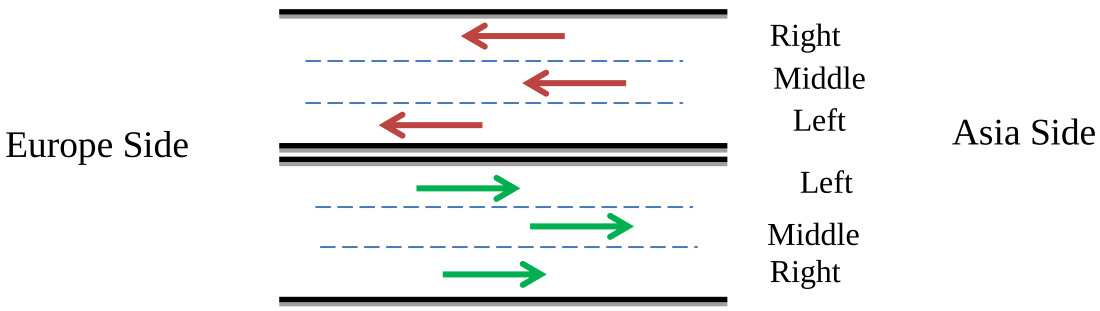

Figure 4.5 : Lane directions between 12:00-13:00, off-peak hours.

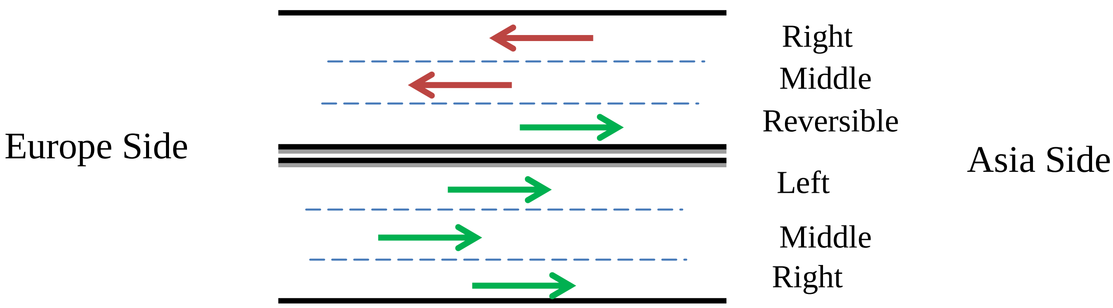

Figure 4.6 : Lane directions between 20:00-21:00,evening peak hours.

4.3.1 Headway

The method of gathering headway information in each lane is done by using stopewatch. At first, base line is defined in the lane, and then with the move of first vehicle, the time is started when the bumper of this vehicle meets the base line and with move of each vehicle on base line, time is saved in stopwatch. By gathering data in each time periods, it is paid attention to get the headways of vehicles when flow was almost near the capacity, which means that when the vehicles stopped or were moving with quit low speed, are eliminated from the survey. It can be said that the headway data were collecting at level of service E during peak hours (09:00-10:00

and 20:00-21:00) and at higher level of service during mid-day (12:00-13:00). Table 4.2 expresses average flow rates, averages, variances and other statistics of headway data, which are gathered for each lane and histograms of headways are given in Appendix A.

4.3.2 Speed

Another data being used to conduct analyzes are vehicle speed. The same camera records have been used to gather the speed data of vehicles passing by each lane in reversal and none reversal time spans. Stopwatch method was used to gather speed level of vehicles, similarly. 2 base lines were chosen to record time laps in which vehicles pass each 2 lines, so the transition time for each vehicle between these 2 base lines were saved in stopwatch. The distance between 2 lines is selected as 21 meters.

In this method 2 time values, when the bumper of vehicle meets the first line, and the buffer of the same vehicle meets the second base line are recorded. Therefore, the difference of these two time values, which is travel time, is divided to 21 meters in order to obtain vehicle speed. This method has been done for 3 days in 3 different time periods which have been mentioned in section 4.3. By gathering speed data. A sampling is applied by gathering vehicle speeds. Only the speeds of 5 vehicles have been recorded every minute, so the speed of 900 vehicles have been obtained for each lane. To get accurate and trustworthy results from this research similar to headway measurments, the speed data of time periods in which the demand is more than the capacity of the lane have been eliminated from the data. Table 4.3 expresses average flow speeds, average speed and variances of data, which are gathered for each lanes.

4.4 Data Analyze

As expressed in Table 4.1 data was collected in 3 hours for each lane, composed of middle lanes of each side and the left lane, which is operated as reversible lane in Asian-European direction between 20:00-21:00 and in European-Asian direction between 09:00-10:00 and as normal lanes between 12:00-13:00. To determine the effect of reversible operation, at each lane in different time periods, t-test two-sample with unequal variances is used.

Table 4.2 : Headway parameters of each lane in different times.

Time	Flow direction	Lane	Number of observed data	Average flow rates (Veh/h)	Headway (Second)		
					Average	Variance	Skewness
09:00-10:00	Asia-Europe	Middle	3630	1945	1.85	0.52	1.58
		Left	4062	1967	1.83	0.61	1.93
		Reversible	2985	1389	2.59	2.16	2.32
	Europe-Asia	Middle	4439	2000	1.80	0.88	1.92
12:00-13:00	Asia-Europe	Middle	3373	1945	1.85	0.59	1.80
		Left	3420	2011	1.79	0.47	1.67
	Europe-Asia	Left	3475	1855	1.94	1.35	2.13
		Middle	4694	1956	1.84	1.25	2.27
20:00-21:00	Asia-Europe	Middle	3330	1875	1.92	0.51	1.53
	Europe-Asia	Reversible	1637	1281	2.81	3.58	2.73
		Left	4685	1791	2.01	0.97	1.79
		Middle	4350	1956	1.84	0.72	1.87

Table 4.3 : Speed parameters of each lane in different times.

Time	Flow direction	Lane	Number of observed data	Average flow speed (Km/h)	Speed		
					Average (Km/h)	Variance	Skewness
09:00-10:00	Asia-Europe	Middle	577	39.94	41.53	63.47	0.13
		Left	589	43.46	46.16	115.71	0.12
		Reversible	585	48.25	50.39	96.02	-0.15
	Europe-Asia	Middle	591	53.87	54.57	38.39	0.17
12:00-13:00	Asia-Europe	Middle	866	39.92	42.79	144.98	1.08
		Left	876	41.32	44.58	171.90	1.12
	Europe-Asia	Left	908	56.23	63.89	162.39	-1.07
		Middle	844	55.83	57.19	82.26	0.69
20:00-21:00	Asia-Europe	Middle	744	34.46	36.29	75.23	1.12
	Europe-Asia	Reversible	810	54.67	56.12	80.78	0.27
		Left	896	45.57	47	272.09	23.80
		Middle	892	30.05	38.79	28.68	0.28

This test is used to determine the effect of reversible operation on the selected motorway. The two-sample t-test analysis tools test for equality of the population means that underlie each sample. The three tools employ different assumptions: that the population variances are equal, that the population variances are not equal, and that the two samples represent before-treatment and after-treatment observations on the same subjects. For all three tools below, a t-Statistic value, t, is computed and shown as "t Stat" in the output tables. Depending on the data, this value, t, can be negative or nonnegative. "P(T <= t) two-tail" gives the probability that a value of the t-Statistic would be observed that is larger in absolute value than t. "P Critical two-tail" gives the cutoff value, so that the probability of an observed t-Statistic larger in absolute value than "P Critical two-tail" is Alpha. t- test two-sample assuming unequal variance analysis tool performs a two-sample student's t-Test. This t-Test form assumes that the two data sets came from distributions with unequal variances. It is referred to as a heteroscedastic t-Test. As with the preceding equal variances case, it can be used this to determine whether the two samples are likely to have come from distributions with equal population means. This test can be used when there are distinct subjects in the two samples.

As it is expressed in formula 4.1 average flow rates of vehicles for the hourly periods are calculated by average headways of vehicles passing the lane.

$$q = \text{——} \qquad \textbf{(4.1)}$$

Table 4.4 expresses the results of t-test. As it has been expressed in Tables 4.3, comparisons were done between each pair of lane in different time periods of day. In this analyze two tail t-test is used. Furthermore, in this test, variables, which are headways are defined in 2 ranges, and level of significance is defined for analyzing which is 5% for these comparisons. Critical value, which are obtained for 5% level of significance for two-tail t-test is 1.96. in this table when the left lane of Asia-Europe carriageway direction is operated as reversible lane it means that the flow direction is from Europe to Asia. Similarly, when there is no reversible lane application for this lane, the flow direction is the same with carriage way direction.

In the middle lanes for both directions, when there is no reversible lanes next to them, the comparison of peak hours and off peak hours headways showed that they are coming from the same population.

However, in the left lanes for both directions, the comparison when none of the left lanes in each directions operates as reversible lanes at peak hours and left lanes of off-peak hours showed that they are not coming from the same population.

The next comparison between left lanes of both directions, when the left lanes at peak hours operates as reversible lanes and the other left lanes operates in its normal direction at peak hours or at off-peak hours showed that they are not coming from the same population too.

At the end, the comparison between middle lanes in both directions, when one of them is in the neighborhood of reversible lane and the other which is not in the neighborhood of reversible lane showed that, they are not coming from the same population too.

The same t-test-two-sample assuming unequal variances was used for leading analyzes between each pairs of data which were collected in 3 different time periods for each lanes. As it was expressed before, the aim is to distinguish different behaviors of vehicles while the most left lane operates as reversible lane and the time spans in which related lanes operate as normal lane. This test is carried out for headways of vehicles passing each lane, and our aim is to anlyze these relations from another perspective; therefore, data of speed are collected for making comparisons.

As it was already explained, middle and left lanes of each side were used for testing, and as the aim was to determine the changes which reversible operation causes on the behavior of vehicles, it is significant to choose time periods when the reversible operation was being operated and the time ones when was not. The reversible operation was implemented in the most left lane of each side, then the most right lanes were not utilized for conducting analyzes as they could not be affected by reversible operation.

In these comparisons the same method, which is named two-tailed, was used. Like methods which were used in headways, speed variables were defined in 2 ranges for speed data in each lane for 3 time periods: while the reversible operation works for Asian-European side in the morning, for Europe-Asia direction in the evening and the time in which no reversible operation did not operate. Each of these periods were scrutinised precisely one by one. In this part level of significance is defined as the same one being defined for headways. Thus, t Critical for 0.05 level of significance was calculated about 1.960 in two-tail method, which means as the boundries, that t Statical from the test is in the ranges of ± 1.96, it shows that the pairs of data which are used in this comparison express same characteristics and vice versa.

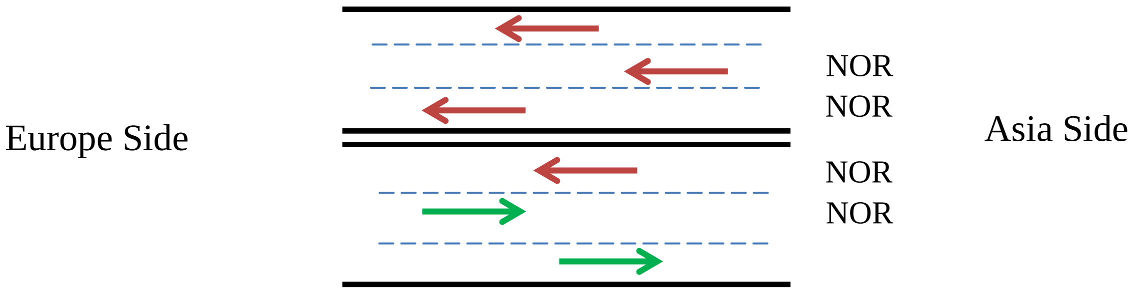

Figure 4.7: Lane directions between 09:00-10:00, morning peak hours.

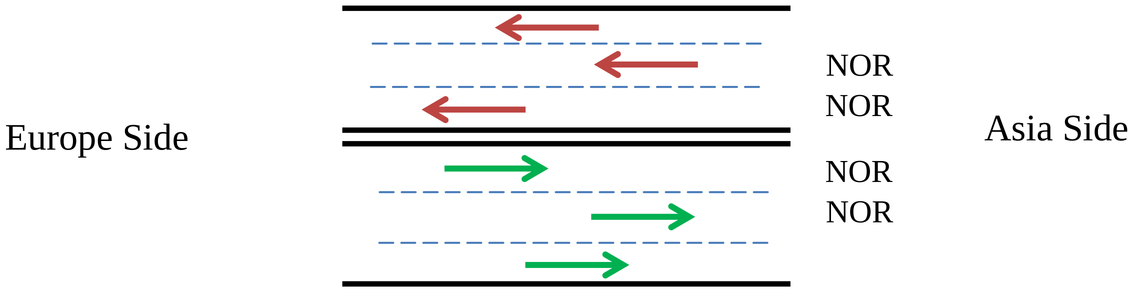

Figure 4.8: Lane directions between 12:00-13:00, off-peak hours.

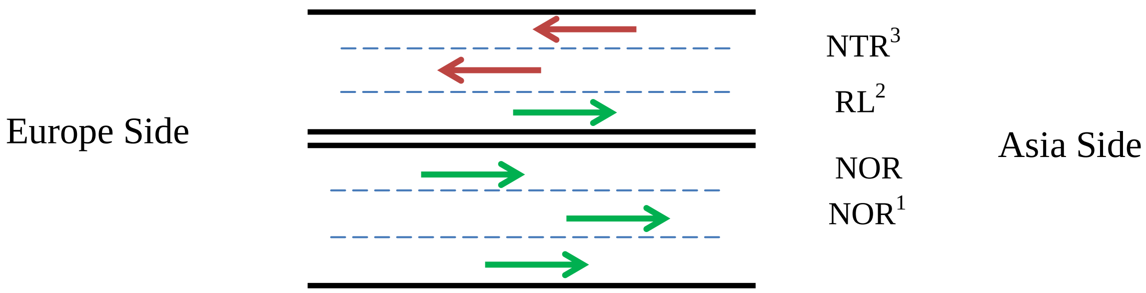

Figure 4.9: Lane directions between 20:00-21:00, evening peak hours.

---

1. NOR: O Reversible Lane or Not Neighbor to Reversible Lane, 2. RL: Reversible Lane,
3. NTR: Neighbor To Reversible Lane

Table 4.4 : t-test results of headway.

Carriage-way direction	Lane	Operation type	Time	t Stat	$t_{0.05/2}$	Degree of freedom
Asia-Europe	Left	NOR NOR	09:00-10:00 12:00-13:00	2.78	1.96	7467
		NOR RL	09:00-10:00 20:00-21:00	-20.16	1.96	1867
		NOR RL	12:00-13:00 20:00-21:00	-21.20	1.96	1846
	Middle	NOR NOR	09:00-10:00 12:00-13:00	0.33	1.96	6883
		NOR NTR	09:00-10:00 20:00-21:00	-3.64	1.96	6923
		NOR NTR	12:00-13:00 20:00-21:00	3.80	1.96	6677
Europe-Asia	Left	RL NOR	09:00-10:00 12:00-13:00	19.48	1.96	5660
		RL NOR	09:00-10:00 20:00-21:00	18.82	1.96	4703
		NOR NOR	12:00-13:00 20:00-21:00	3.09	1.96	6746
	Middle	NTR NOR	09:00-10:00 12:00-13:00	-2.01	1.96	9008
		NTR NOR	09:00-10:00 20:00-21:00	-1.97	1.96	8729
		NOR NOR	12:00-13:00 20:00-21:00	0.29	1.96	8710

.

As it can be understood from overall view of roadway, middle lanes between 9:00-10:00 (no reversible operation in neighborhood) and 12:00-13:00 (no reversible operation) hours operate as normal lane, and there is no reversible operation in their neighborhood; so they seem to show the same characteristics. This can be cleatly understood from the results of t-test because the amount of t-Statical, which is about 1.75, is in the ranges of ±1.96, so these pairs of data have the same characteristics in their hourly time period. The same results were not obtained for pairs of data between 9:00-10:00, 20:00-21:00 and 12:00-13:00, 20:00-21:00 hours since the middle lane between 20:00-21:00 hours is in the neighborhood of reversible operation being implemented for vehicles tarnsitting from European-Asian side. Also, results obtained from t-test, which are about 12.19 for pairs between 12:00-13:00, 20:00-21:00 and 11.38 for 9:00-10:00, 20:00-21:00 hours, expressed the fact that comparison results are the same with the thoughts considering the idea that vehicles passing the lane have different characteristics in these 2 pairs of time.

Next comparisons were carried out between left lanes of Asian-European side in 3 time periods. As the left lanes operate as normal lanes between 9:00-10:00, 12:00-13:00 hours, and there is no reversible operation on their neighborhood, it was supposed that these pairs of data will illustrate the same characteristics as always. In contrast, obtained results from test have the amount of 2.53; moreover, this statical amount is not in the areas of critical value of t-test and it is more than ±1.96, so it means that data in these time periods, when the commuter vehicles are in left lane of Asian-European side, do not have the same behavior. The same situation exists for vehicles commutting in left lane of European-Asian side between 12:00-13:00 and 20:00-21:00 hours, because, although the lane in these time periods operates as normal lane and there is no reversible operation which may effect transition of vehicles; on the contrary, the results of statical value of t-test which is approximately 24.32 expressed different characteristics existing among vehicles passing related lanes in mentioned time periods.

Rest of the analyzes were done between paıirs of data incuding the left lanes of Asian-European side between 12:00-13:00, 20:00-21:00 hours and 9:00-10:00, 20:00-21:00 hours; hence, when the most left lane between 20:00-21:00 hours operates as reversible lane, analyzes between each pairs of data demonstrate that statical value of T-test for pairs between 9:00-10:00, 20:00-21:00 and 12:00-13:00, 20:00-21:00 are about -18.30 and 21.22. Furthermore, as these two results are out of ranges of critical value of t-test, so it expresses that implementing of reversible operation between 20:00-21:00 hours causes vehicles to show different behaviors from vehicles commutting in lanes with normal operation.

The other group of tests were carried out between the most left lane of European-Asian side, and as it is known this lane operates as reversible lane in the morning, so it is clearly noticable as the left lane in this side operates as reversible lane between 9:00-10:00 hours. doing analyzes between speed data, being collected for 9:00-10:00, 20:00-21:00 and 9:00-10:00, 12:00-13:00 expresses the same results between reversible operation and normal operation of left lanes in the opposite side. Even the statical-t amounts being calculated from t-test for pairs of time between 9:00-10:00, 20:00-21:00 and 9:00-10:00, 12:00-13:00 express different behavior of vehicles while passing reversible lane.

The last analyzes were implemented with in the speed data of vehicles commuting in European-Asian Side which were collected between 9:00-10:00, 12:00-13:00 (no reversible) and 20:00-21:00 (no reversible lane) hours. As the left lanes of European-Asian Side operate as reversible lane between 9:00-10:00, so the middle lane, being in its neighborhood, is effected by reversal operation, and the amounts of test, which are 6.47 and -51.09, show different characteristics of vehicles in middle lanes of pairs of time between 9:00-10:00, 12:00-13:00 and 9:00-10:00, 20:00-21:00 hours.

At the end, comparison between middle lane at 12:00-13:00 (off-peak), 20:00-21:00 (no reversible lane) in Europe-Asia direction released the amount of -50.65 for static value, which is also out of level of significance critical-t. For 0.05 of critical-t, level of significance was calculated ±1.96. This means that while these pairs of time for vehicle transitions express different behavior, as it is shown, both of the data in each time period operate as normal lane and lack of reversible operation effects their transition in their neighborhood.

Table 4.5 : t-test results of speed.

Carriage-way direction	Lane	Operation type	Time	t Stat	$t_{0.05/2}$	Degree of freedom
Asia-Europe	Left	NOR NOR	09:00-10:00 12:00-13:00	2.53	1.96	1406
		NOR RL	09:00-10:00 20:00-21:00	-18.30	1.96	1126
		NOR RL	12:00-13:00 20:00-21:00	21.22	1.96	1556
	Middle	NOR NOR	09:00-10:00 12:00-13:00	1.75	1.96	1438
		NOR NTR	09:00-10:00 20:00-21:00	11.38	1.96	1282
		NOR NTR	12:00-13:00 20:00-21:00	12.19	1.96	1584
Europe-Asia	Left	RL NOR	09:00-10:00 12:00-13:00	23.04	1.96	1445
		RL NOR	09:00-10:00 20:00-21:00	4.96	1.96	1467
		NOR NOR	12:00-13:00 20:00-21:00	24.32	1.96	1683
	Middle	NTR NOR	09:00-10:00 12:00-13:00	6.47	1.96	1432
		NTR NOR	09:00-10:00 20:00-21:00	-51.09	1.96	1352
		NOR NOR	12:00-13:00 20:00-21:00	-50.65	1.96	1134

4.5 Distribution Analysis of Headways

In this section, the distributions of headways are determined for each lane, during reversible and non-reversible operation periods. In this analysis, headways, which have been collected for each lane in 3 parts of day, are utilized for making progress. Tables 4.6 and 4.7 express distributions functions and their parameters which have been used to analyze data.

The method for scrutinizing the conformity of data for all distributions has been applied by chi-squared test. Chi-squared test can be used to search whether observed frequency distribution differs from a theoretical distribution or not. In this test, a normalized sum of squared observed and theoretical frequencies have been calculated, and for determination of degree of freedom, the number of frequencies have been reduced by the number of parameters of the fitted distribution. For the test of Normal, Lognormal and Gamma distributions, classes with equal probability is used. However in Gumbel and Extreme value type II (evII) distributions, classes with equal range (interval) have been utilized.

Table 4.6 : Distributions and their required parameters.

Distribution	Parameters		
Normal	Average	Standart.Deviation	-
Lognormal	Average	Standart.Deviation	-
Gamma	Average	Standart.Deviation	Skewness
Gumbel	Average	Standart.Deviation	Skewness
Extreme value	Average	Standart.Deviation	Skewness

The number of classes have been calculated by the amount of data in each section, which can be followed in this formula:

$$M = 3.3 \times \log(N) + 1 \quad \textbf{(4.2)}$$

Table 4.7: Function of distributions and their required parameters.

Distribution Model	Probability Density Function	Parameters	Mean	Variance
Normal	$\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$	μ, σ : Continuous Parameters	μ	σ^2
Lognormal	$\frac{1}{x\sqrt{2\pi}\sigma'} e^{-\frac{1}{2}\left[\frac{\ln x-\mu'}{\sigma'}\right]^2}$	μ, σ : Continuous Parameters	μ	σ^2
Gamma	$\frac{x^{\alpha-1} e^{-x/\beta}}{\Gamma(\alpha)\,\beta^{\alpha}}$	α : Cont. Shape Parameter β : Continuous Scale Parameter	$\alpha\,\beta$	$\alpha\,\beta^2$
Gumbel	$\frac{1}{\beta} e^{-(z+e^{-z})}$ Where $z = \frac{x-\mu}{\beta}$	μ : Continuous Parameter β : Continuous Scale Parameter	$\mu + \beta\gamma$	$\frac{\pi^2}{6}\beta^2$
Extreme value	$f(x) = \frac{\alpha}{\beta}\left(\frac{\beta}{x-\gamma}\right)^{\alpha+1}$	α : Cont. Shape Parameter S : Continuous Scale Parameter m : Continuous Location Parameter	$\begin{cases} m + s\Gamma\left(1-\frac{1}{\alpha}\right) & \text{for } \alpha > 1 \\ \infty & \text{otherwise} \end{cases}$	$\begin{cases} s^2\left(\Gamma\left(1-\frac{2}{\alpha}\right) - \left(\Gamma\left(1-\frac{1}{\alpha}\right)\right)^2\right) & \text{for } \alpha > 2 \\ \infty & \text{otherwise} \end{cases}$

The graphs of probability density function of each distribution are given in Figures 4.10, 4.11, 4.12, 4.13 and 4.14.

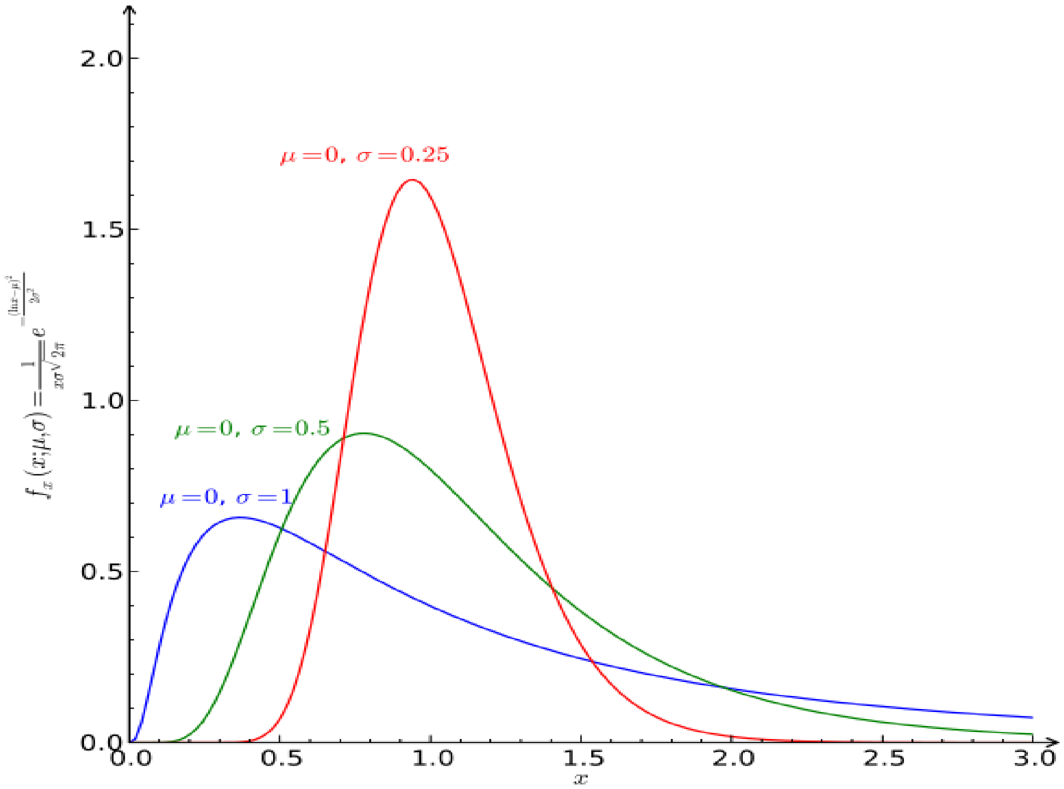

Figure 4.10 : Graph of probability density function for Lognormal distribution.

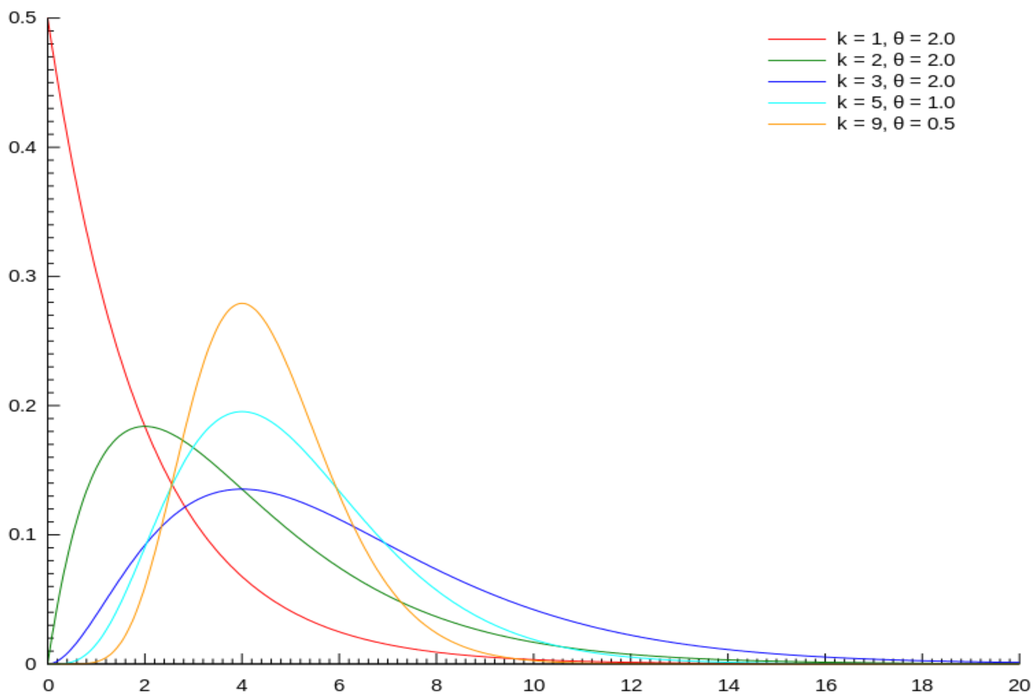

Figure 4.11 : Graph of probability density function for Gamma distribution.

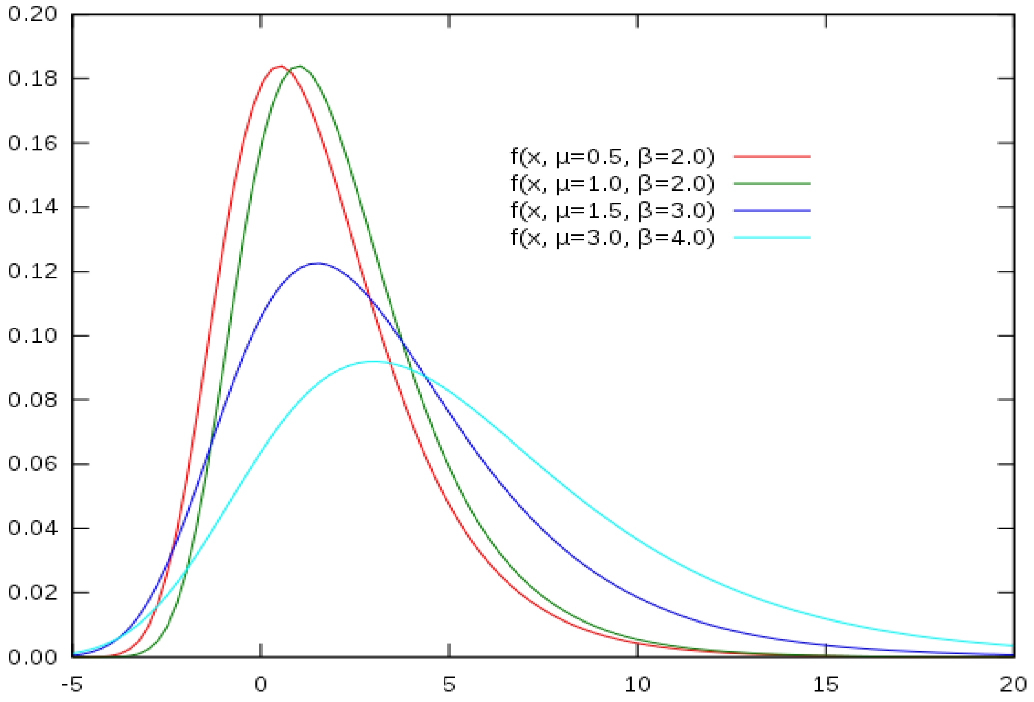

Figure 4.12 : Graph of probability density function for Gumbel distribution.

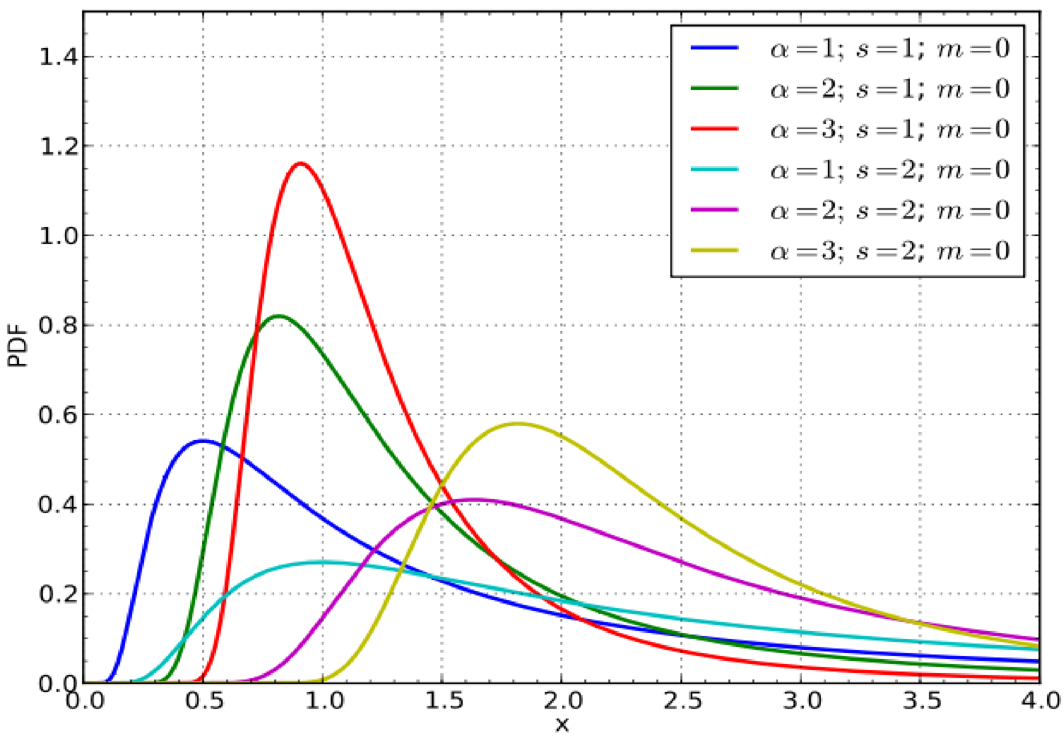

Figure 4.13 : Graph of probability density function for Extreme value distribution.

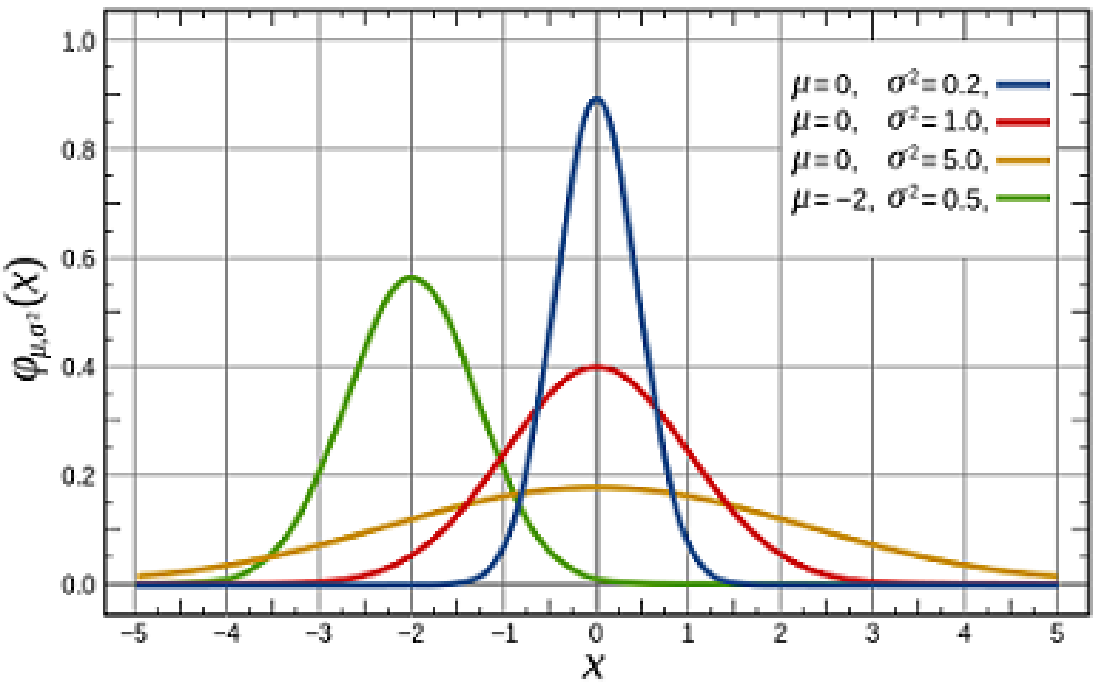

Figure 4.14 : Graph of probability density function for Normal distribution.

Tables 4.8 to 4.10 clarify the test of distributions for each lane and the attained results.

In all of the tests, except for the left lane in the Asia-Europe direction between 20:00-21:00 operating as reversible lane, the number of classes have been obtained was 13 whereas the number of classes for related lane was 12. Since equal probability have been used for Normal, Lognormal and Gamma distributions, theoretical probability obtained for each class was 0.08.

As it can be noticed, the parameters used for Normal distribution are average and variance. Hence, for the 10 degrees of freedom and 5% level of significance, the critical value of chi-squared is obtained as 18.31, which is lower than a normalized sum of squared deviations between observed and theoretical frequencies. As a result, it can be said that headways are not fitted to the normal distribution.

Lognormal distribution has the same degrees of freedom and the parameters used are variance and average, so as the results are expressed, headways are not fitted to lognormal distribution, either. In Gumbel, Gamma and EvII, 3 parameters have been used, so degrees of freedom is calculated as 9, and for 5% level of significance, the critical value of 16.92 has been obtained. Moreover, a normalized sum of squared deviations of observed and theoretical frequencies is more than Critical value, so the headways in lanes are not fitted to the Gamma, Gumbel and EvII distributions.

As it was mentioned before, the number of classes in testing distributions in left lane of Asia-Europe direction between 20:00-21:00 is 12, so degrees of freedom for normal and lognormal distribution was obtained as about 9, and in 5% level of significance, the critical value of 16.92 was accomplished. The same situation has been seen for gamma, gumbel and evII, which with 8 degree of freedom and 5% level of significance, the critical value of 15.51 was gained. As it is observed, the sum of squared deviations of observed and theoretical frequencies are more than Critical value, so data in left lane of Asia-Europe direction are not fitted to any of the distributions.

Table 4.8 : Results of χ^2 test to determine the distribution of headway in the morning (09:00-10:00).

Time	Flow direction	Lane	Normal			Lognormal			Gamma			Gumbel			EvII		
			df	χ^2		df	χ^2		df	χ^2		df	χ^2		df	χ^2	
				Critic	Stat		Critic	Stat		Critic	Stat		Critic	Stat		Critic	Stat
09:00-10:00	Asia-Europe	Middle	10	18.30	631	10	18.30	76	9	16.90	6967	9	16.90	99	9	16.90	55
		Left	10	18.30	794	10	18.30	53	9	16.90	9038	9	16.90	314	9	16.90	8
		Reversible	10	18.30	1251	10	18.30	109	9	16.90	4658	9	16.90	405	9	16.90	82
	Asia-Europe	Middle	10	18.30	1417	10	18.30	113	9	16.90	103	9	16.90	405	9	16.90	411

Table 4.9 : Results of χ^2 test to determine the distribution of headway in the afternoon (12:00-13:00).

Time	Flow direction	Lane	Normal			Lognormal			Gamma			Gumbel			EvII		
			df	χ^2		df	`χ^2		df	χ^2		df	χ^2		df	χ^2	
				Critic	Stat		Critic	Stat		Critic	Stat		Critic	Stat		Critic	Stat
12:00-13:00	Asia-Europe	Middle	10	18.30	622	10	18.30	40	9	16.90	7057	9	16.90	110	9	16.90	177
		Left	10	18.30	526	10	18.30	35	9	16.90	7900	9	16.90	100	9	16.90	217
	Europe-Asia	Middle	10	18.30	1791	10	18.30	86	9	16.90	5913	9	16.90	711	9	16.90	158
		Left	10	18.30	1340	10	18.30	63	9	16.90	3476	9	16.90	460	9	16.90	136

Table 4.10 : Results of χ^2 test to determine the distribution of headway in the afternoon (20:00-21:00).

Time	Flow direction	Lane	Normal			Lognormal			Gamma			Gumbel			EvII		
			df	χ^2		df	χ^2		df	χ^2		df	χ^2		df	χ^2	
				Critic	Stat		Critic	Stat		Critic	Stat		Critic	Stat		Critic	Stat
20:00-21:00	Asia-Europe	Middle	10	18.30	474	10	18.30	53	9	16.90	7321	9	16.90	67	9	16.90	16.89
	Europe-Asia	Reversible	9	16.90	937	9	16.90	109	8	15.51	2657	8	15.51	548	8	15.51	118
		Left	10	18.30	1094	10	18.30	77	9	16.90	5388	9	16.90	207	9	16.90	45
		Middle	10	18.30	997	10	18.30	74	9	16.90	7053	9	16.90	203	9	16.90	35

5. CONCLUSIONS AND RECOMMENDATIONS

In this study reversible lane operation, which is one of the lane management types and operated on Bosphorus Bridge O-1 Motorway was analyze. In this analysis, the effects of reversible lane operation was investigated. To analyze the effects of reversible operation, t-test assuming two tail unequal variances method was used. This test was done for headway and speed data of vehicles which use the O-1 Motorway on Bosphorus Bridge section.

Initially, the comparisons of headways and speed were carried out separately for the left lanes of each direction in the peak hours of morning (09:00-10:00), and evening (20:00-21:00), while one of them was operating as reversible lane, and the other one was operating as regular lane in its normal direction. The test results expressed the fact that these two pairs of lanes have different behavior and are not from the same population while testing headway and speed data separately, and the flow rates of reversible lanes have about 25%-34% decreases in comparison with normal operated left lanes.

Secondly, the comparison for the middle lanes of each direction in the peak hours of morning (09:00-10:00), and evening (20:00-21:00), when there was a reversible lane next to it (neighbor to one of them) and when there was no reversible lanes next to it (which means the left lanes were operating as a normal left lanes) were done, and test results expressed that these two pairs were not from the same population and it was expressed 2% increases in flow rate of middle lane which was in neighborhood of reversible lane in the morning (09:00-10:00) peak times, in comparison with middle lane which was no reversible lane next to it in the evening (20:00-21:00) peak times. Furthermore, it has been expressed 3% decreases in flow rates of middle lane which is in neighborhood of reversible lane in the evening (20:00-21:00) peak times. The same results were reached for the speed data, also the mentioned middle lanes data were from different population.

At the end, the comparisons were done for middle and left lanes during off-peak (12:00-13:00) and peak hours in the morning (09:00-10:00) or evening (20:00-

21:00). At these comparison none of these lanes are being operated as a reversible or neighbor to reversible lanes. In this comparison only the middle lanes expressed the same behavior and their flow rates are the same, and the left lanes have about 2%-3% decreases in flow rates. The results which are obtained from t-tests of speed data were expressed that the only middle lanes in Asia-Europe direction between 09:00-10:00 (no reversible lane in neighborhood) and 12:00-13:00 (off-peak) hours expressed the same behavior and there were from the same population and other t-test pairs had different behavior from each other.

The last study which was done for distributions of headways expressed that, headways do not match for none of the analyzed statistical distributions and the only headways between 12:00-13:00 hours in middle lane and 09:00-10:00 hours in left lane of Asia-Europe side match to evII distribution.

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APPENDICES

APPENDIX A: Histogram of Headways

APPENDIX A

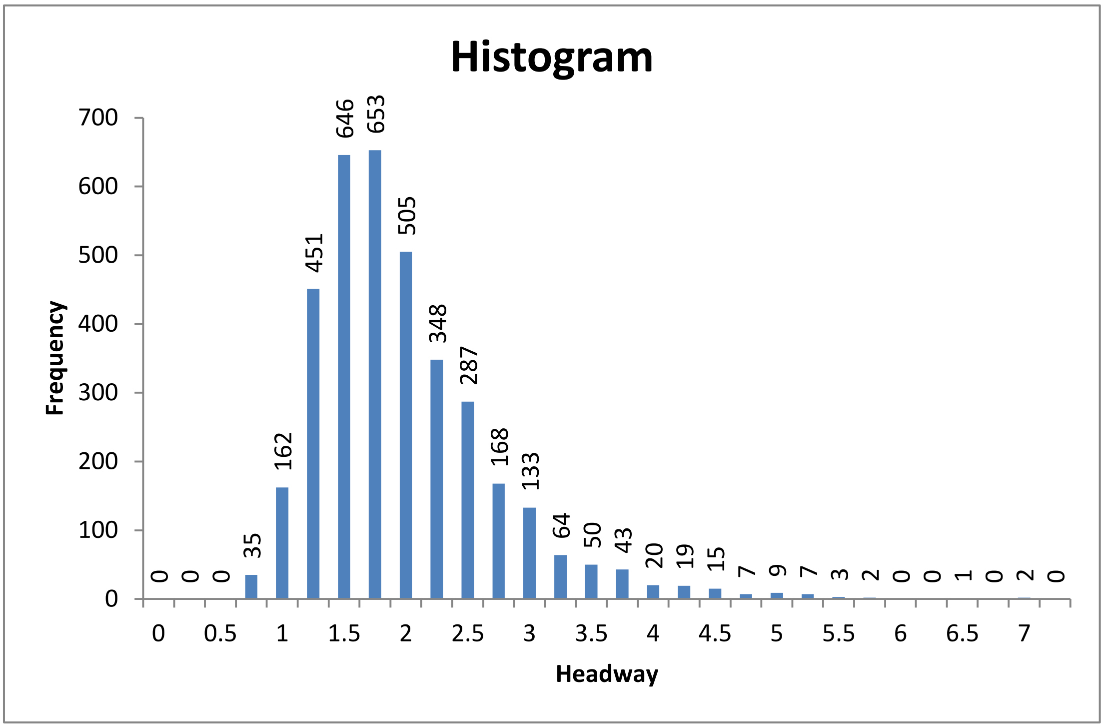

Figure A.1 : Middle lane of Asia-Europe direction between (09:00-10:00)

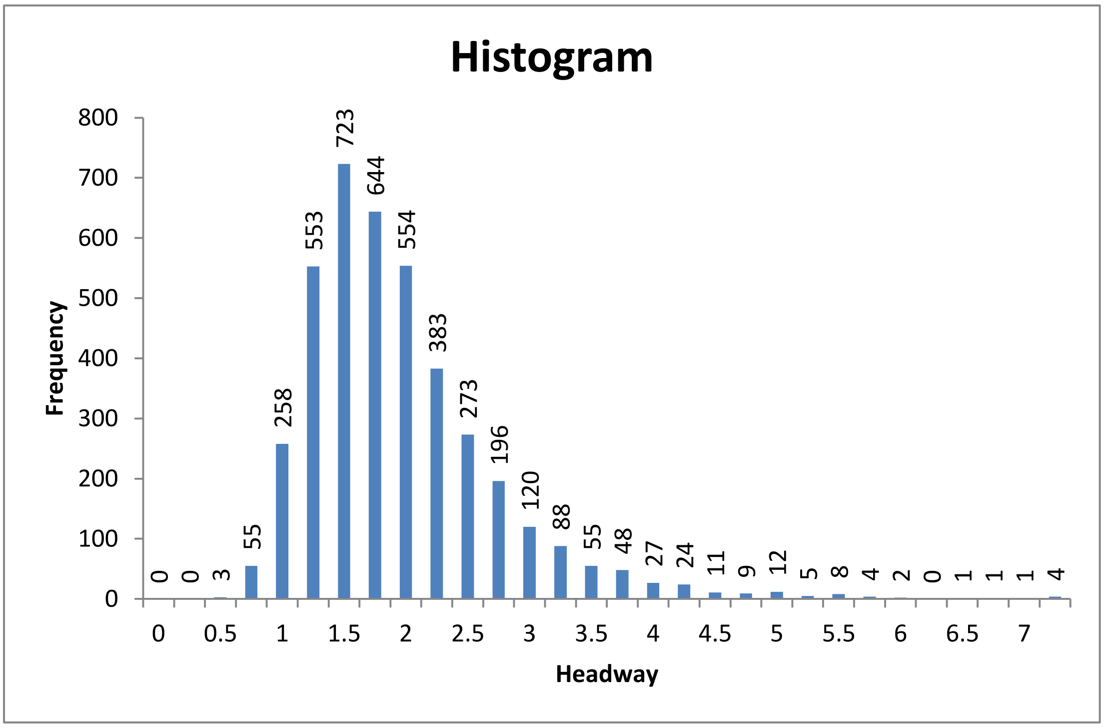

Figure A.2 : Left lane of Asia-Europe direction between (09:00-10:00)

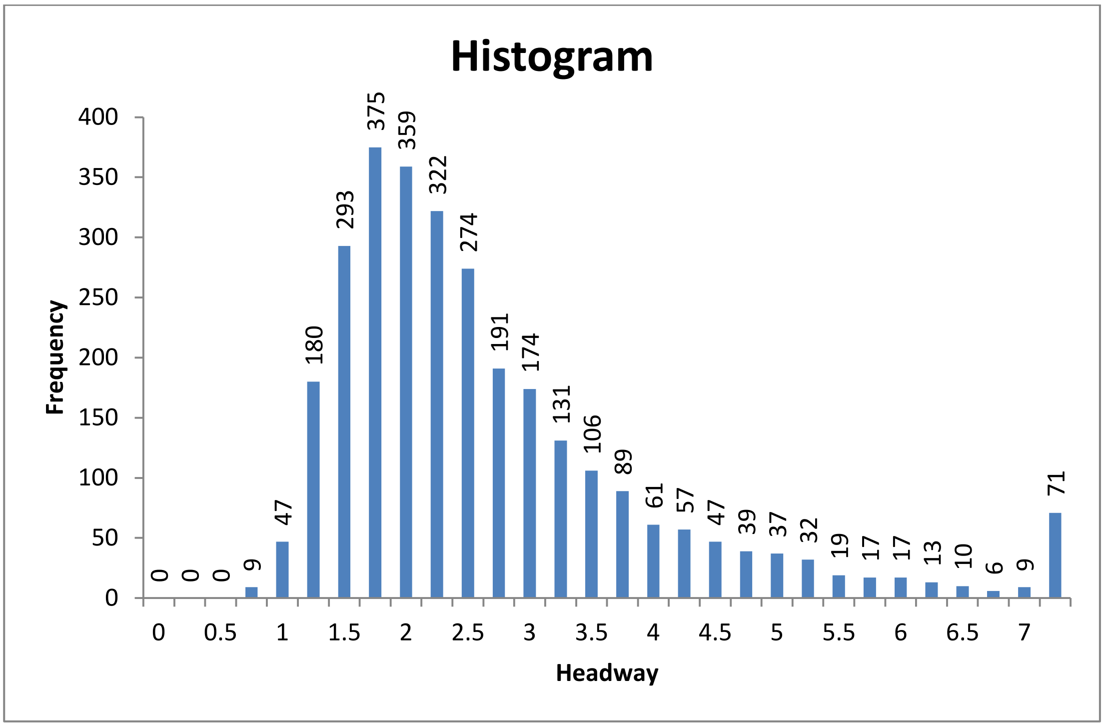

Figure A.3 : Reversible lane of Europe-Asia direction between (09:00-10:00).

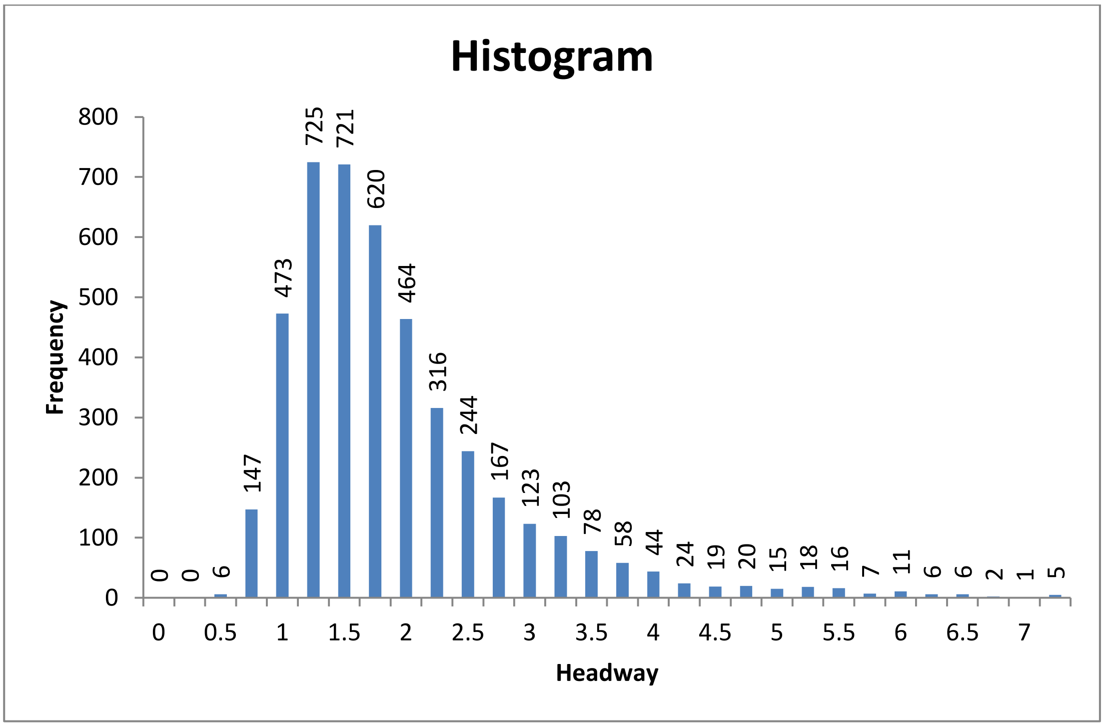

Figure A.4 : Middle lane of Europe-Asia direction between (09:00-10:00).

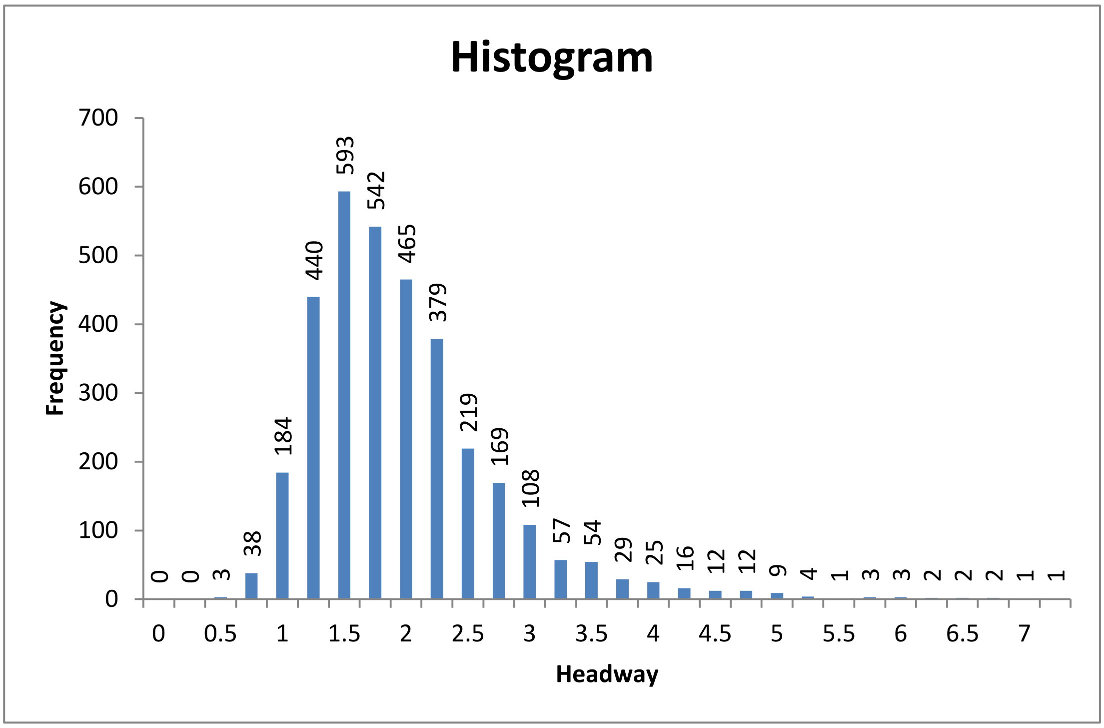

Figure A.5 : Middle lane of Asia-Europe direction between (12:00-13:00).

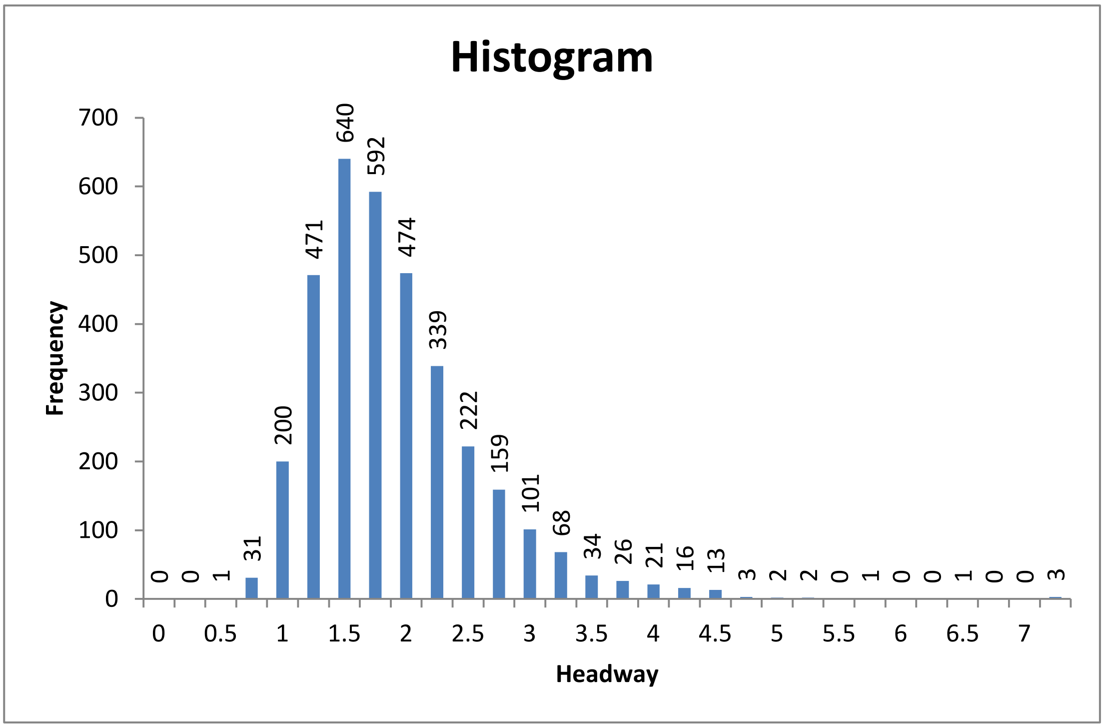

Figure A.6 : Left lane of Asia-Europe direction between (12:00-13:00).

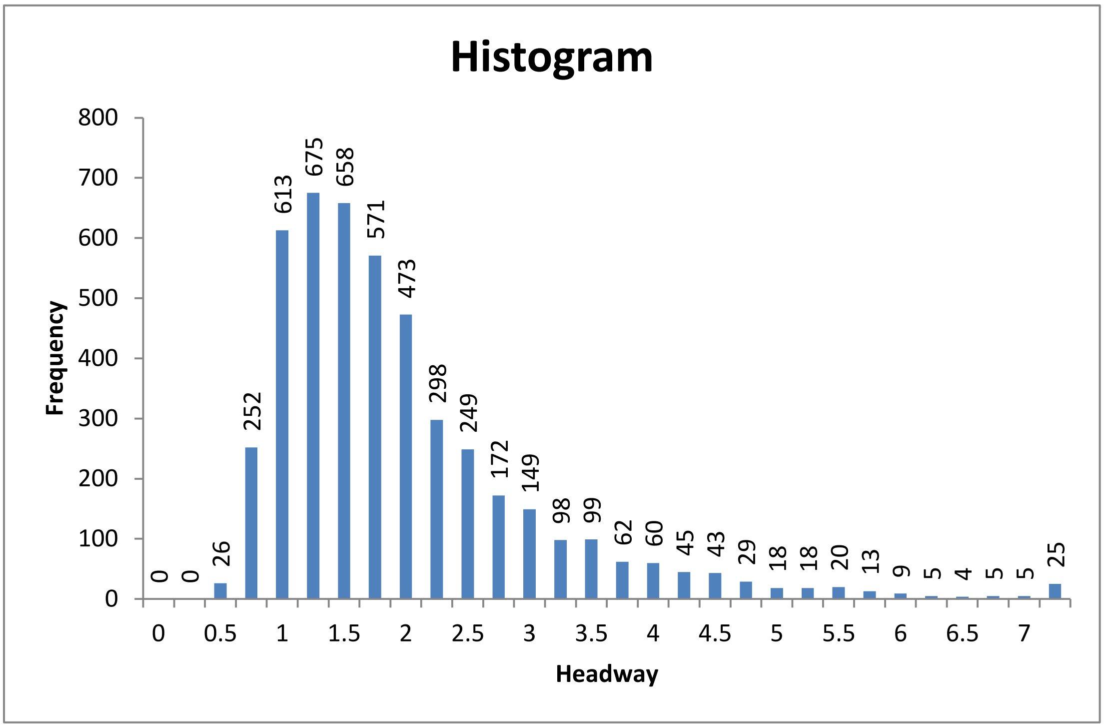

Figure A.7: Middle lane of Europe- Asia direction between (12:00-13:00).

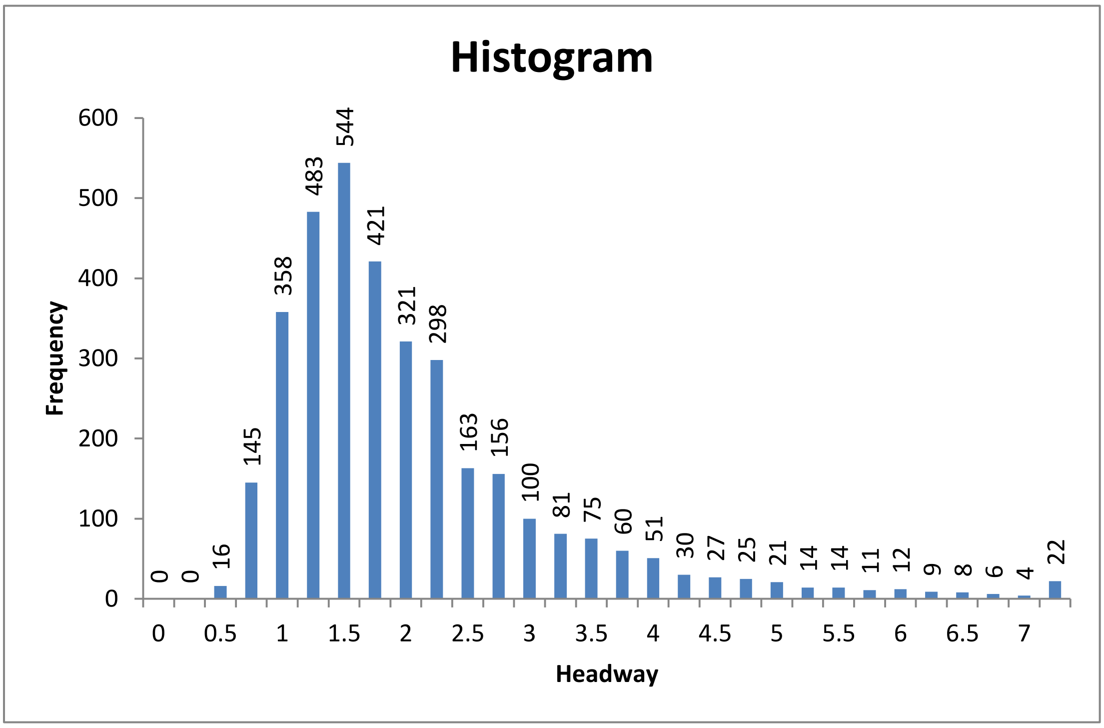

Figure A.8 : Left lane of Europe- Asia direction between (12:00-13:00).

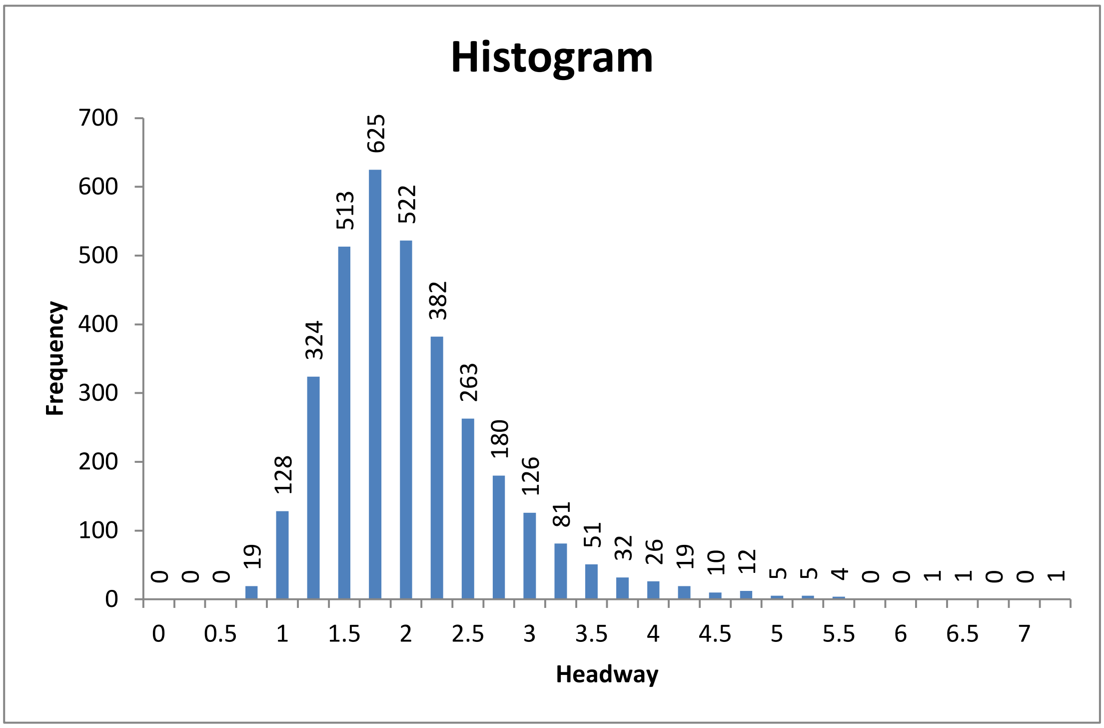

Figure A.9 : Middle lane of Asia-Europe direction between (20:00-21:00).

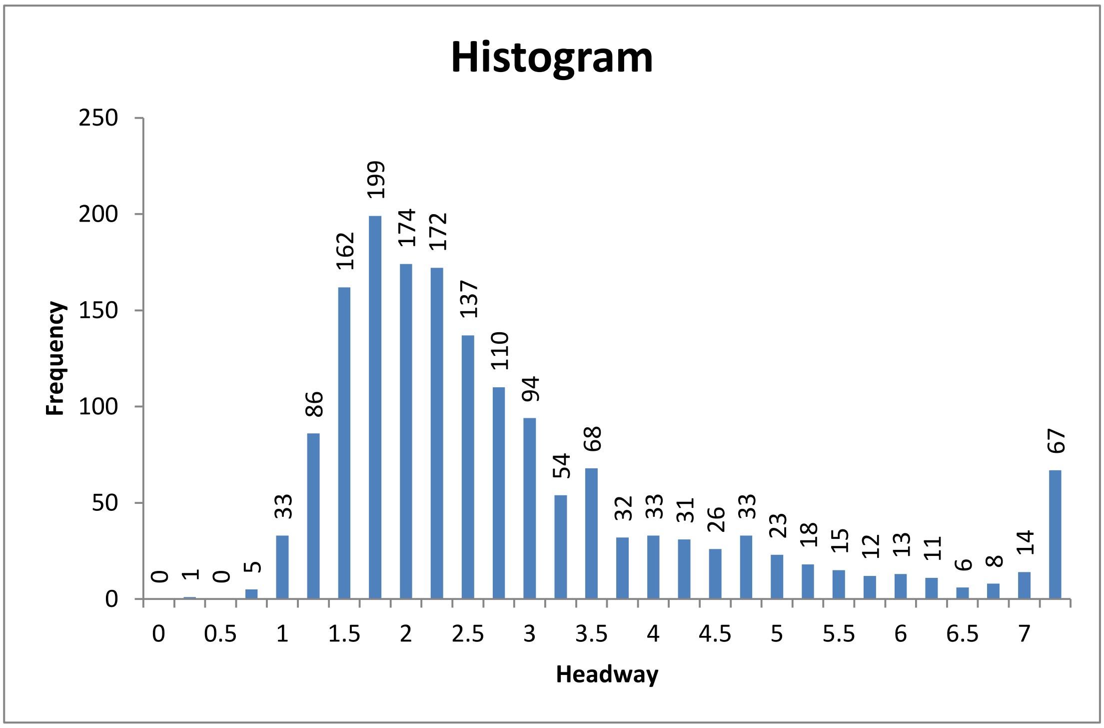

Figure A.10 : Reversible lane of Asia-Europe direction between (20:00-21:00)

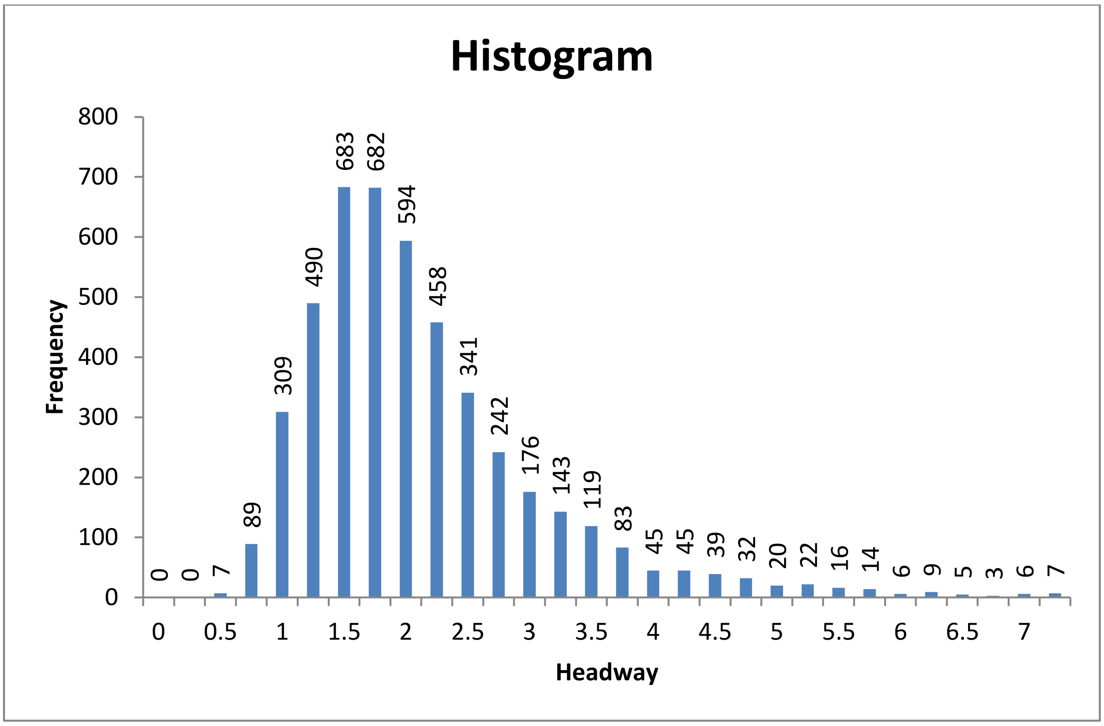

Figure A.11 : Left lane of Europe- Asia direction between (20:00-21:00).

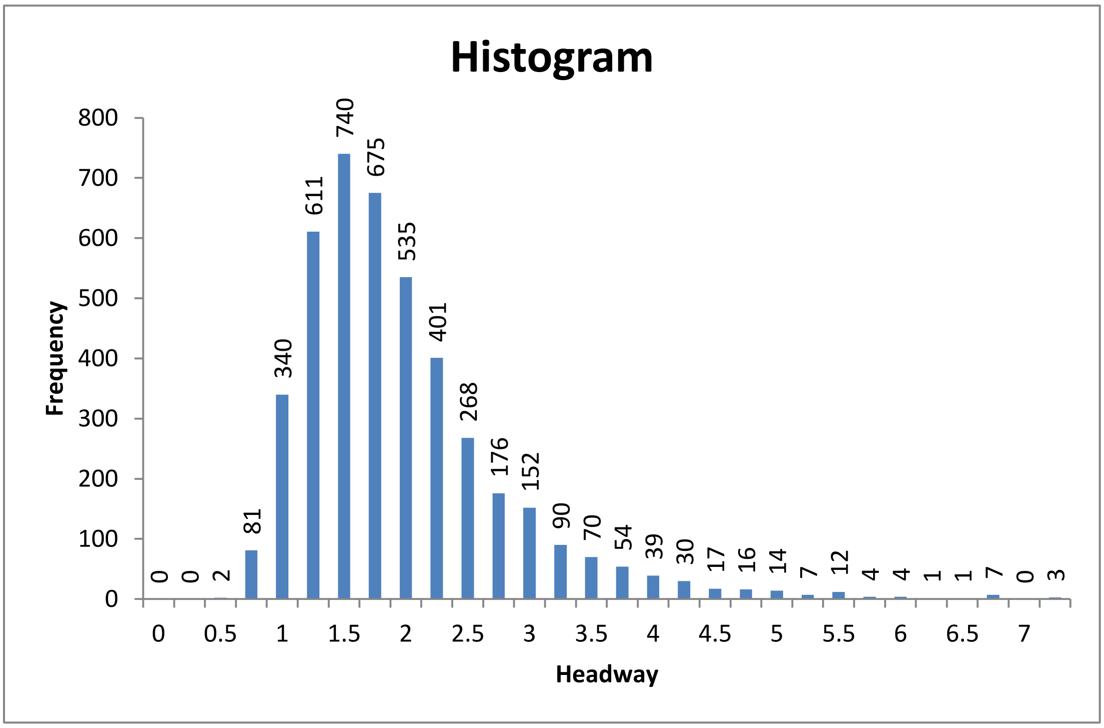

Figure A.12: Middle lane of Europe- Asia direction between (20:00-21:00).

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