DEVELOPING LINK CAPACITY FUNCTIONS AT URBAN ARTERIALS

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ABSTRACT

DEVELOPING LINK CAPACITY FUNCTIONS AT URBAN ARTERIALS

Link capacity functions are the relationships among the main variables of the vehicular traffic flow at any links. Moreover, developing link capacity function is a task that is related to traffic engineering, yet it is too difficult to find a unique link capacity function belonging to all links in cities. Therefore, this thesis does aim to develop link capacity functions peculiar to the selected divided and undivided links in downtown city İzmir. The main process of developing the link capacity functions depends upon the fastidious site selection, data collection and data analyses techniques. Especially, the main vehicular traffic variables such as flow rate, capacity, speed, travel time data describe the links capacity function. After the data collection process, the data manipulation and their analyses lead to build mathematical model about the link capacity functions. When considering the steps of this thesis, first of all, this thesis reviews the literature and formulates the problem statement and the research objective. Secondly, it conducts the task that consists of the site selection and data collection. In the following parts, this thesis study manipulates and analyzes the obtained data. Then, it performs the linear and non-linear model building by utilizing different functions called V/C ratio & dummy variable, BPR (Bureau of Public Roads) function and Overgaard function for the selected link groups in İzmir. Ultimately, this thesis study compares the model results and manifests the best link capacity function model.

ÖZET

KENTSEL ARTERLERDE LİNK KAPASİTE FONKSİYONLARININ GELİŞTİRİLMESİ

Link kapasite fonksiyonları, araçsal trafik akımının temel değişkenleri arasındaki ilişkilerdir. Ayrıca, link kapasite fonksiyonlarının geliştirilmesi süreci trafik mühendisliğinin çalışma konusu olmaktadır. Fakat bütün şehirlerdeki linklere özgü tek bir link kapasite fonksiyonundan bahsetmek çok zordur. Bu nedenle, bu tez çalışması, İzmir şehrinin içinden seçilmiş olan bölünmüş ve bölünmemiş linkler için link kapasite fonksiyonu geliştirmeyi amaçlar. Link kapasite fonksiyonlarının geliştirilmesi titizce bir çalışmayla temel olarak bir alan seçimi ve linklerin belirlenmesi, veri toplanması ve bu verilerin analizi sürecine dayanmaktadır. Özellikle araçsal trafik akımının değişkenlerinden olan akım oranı, kapasite, seyahat hızı ve süresi link kapasite fonksiyonlarını tarif etmektedir. Link kapasite fonksiyonlarının geliştirilmesi sürecinde, veri toplanmasının bitmesinden sonra veri manipülasyonu ve veri analizi matematiksel modeller oluşturulmasına olanak sağlar. Bu tez çalışmasının temel adımları dikkate alındığında, ilk olarak literatür araştırması yapılmış olup, problemin tarifi ve araştırma hedefi belirlenmiştir. İkinci sırada ise, bu çalışma için alan seçimi, link seçimi ve veri toplama aşaması tariflenmiştir. Daha sonraki adımlarda ise toplanan verinin manipülasyonu ve analizi yapılarak İzmir şehrinden seçilmiş link grupları için lineer ve lineer olmayan matematiksel modeller oluşturulmuştur. Bu modeller oluşturulurken V/C oranı & dummy değişken, BPR (Kamu Yolları Bürosu) ve Overgaard fonksiyonlarından yararlanılmıştır. Bu çalışma, model sonuçlarının kıyaslanması ve en uygun model denkleminin ifade edilmesiyle tamamlanmaktadır.

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CHAPTER 1

INTRODUCTION

This chapter describes a background concerning the link capacity functions and discusses the problem statement and the research objective of this thesis. Furthermore, the last part of this chapter explains the organization of this thesis.

1.1. Background

This thesis study focuses on the relationships between the fundamental variables of the traffic flow. Particularly, these relationships are described as the functions among travel speed, traffic flow and travel time. In this context, Branston (1976) defines these relationships as "the functions used to relate travel speed or its reciprocal, travel time per unit distance, and flow of traffic on networks are often termed link capacity functions" (Branston, 1976, pp.223)

Travel speed, travel time and traffic flow relate to each other at the traffic stream. It is obvious that the travel time increases, while travel speed decreases, or any increase in traffic flow leads to the rise in travel time. These relationships, then, shape the link capacity functions on the roadways. Furthermore, the term of the link capacity function can be identified by different names. In literature, the link capacity function is sometimes called as the link performance function or the capacity restraint function or the congestion function or the link cost function or the capacity function (Suh, Park, & Kim, 1990). This thesis study calls it as the link capacity function.

The link capacity function is significant for the traffic assignment process in travel demand modeling. Building an accurate link capacity function necessitates many meticulous observations and data analyses. Moreover, if the well established link capacity function is performed, it is feasible to model the driver's route choice behavior, which is depend on travel time spent at the traffic stream (Suh et al., 1990).

As long as the relationships between the variables of traffic flow are monitored at any roadway, the level of performance of that roadway is obtained (Mannering & Kilareski, 1998). As a result, if there are problems related to the roadway performance, also the roadway components such as signal settings, traffic markings, lane distribution can be properly designed for future by taking into account the monitored traffic flow variables. For instance; the vehicle drivers today face the traffic congestion in many cities. This is also related to the factors affecting roadway performance. Therefore, the appropriate locations of the traffic components are only determined by monitoring and developing link capacity functions on the roadways.

1.2. Formulation of the Problem and the Research Objective

The important point is that the traffic characteristic of any city or network is distinct from the others in the world. The different traffic characteristics stem from the existence of the different factors such as diversification of the social, cultural, economic, spatial patterns in every one of the cities or around the transportation network (Suh et al., 1990). Shortly, there is not a unique link capacity function to be applied to all links due to the different characteristics of cities. Thus, engineers and planners try to identify a particular link capacity function that is peculiar to each link or network.

In this thesis the main research objective is to develop link capacity functions at the urban arterials in Izmir. Depending on this, what the variables or the data that are utilized to develop the link capacity functions are discussed. Additionally, the essential statistical analyses concerning this study data are conducted to build a suitable link capacity function for the specified links that are selected in Izmir.

1.3. Organization of the Thesis

This thesis is divided into six chapters. The first chapter gives a brief background and it describes the problem statement and research objective of this thesis study. The second chapter focuses on the traffic flow facilities, the concept of the capacity and approaches for the link capacity functions given in literature. The third chapter explains the speed-density-flow and travel time-flow relationships by referring to Greenshields' hypothesis. The fourth chapter discusses the site selection, the data collection methodology and the brief results of data collection about this study. The fifth chapter discusses the relationships between speed-density-flow rate at the selected links in İzmir, data analyses, modeling and the modeling results. Lastly, in the sixth chapter this thesis concludes with the ultimate remarks about this study.

CHAPTER 2

LITERATURE REVIEW: TRAFFIC FLOW FACILITIES, THE CAPACITY CONCEPT AND APPROACHES FOR LINK CAPACITY FUNCTIONS

This chapter clarifies the traffic flow facilities, reviews the fundamental concepts especially the capacity concept and basic relationships of vehicular traffic flow. In this chapter, after the traffic flow facilities and the fundamental concepts are reviewed, the link capacity functions proposed in literature are presented in two forms.

2.1. A Review of Traffic Flow Facilities

The traffic facility refers to the length of roadway that is composed of sections, segments and points (Transportation Research Board [TRB], 2000). In this context, the traffic flow facilities are divided into two groups: interrupted flow facilities and uninterrupted flow facilities.

2.1.1. Interrupted Flow Facilities

In traffic engineering, the interrupted flow is defined as the flow that encounters some impedance in the traffic stream and it is periodically stopped due to these factors such as stop & yield signs, intersections and traffic signals (Roess, Mcshane, & Prassas, 1998). For instance; the interrupted flow can be observed at urban arterials and collectors especially in downtown areas.

2.1.2. Uninterrupted Flow Facilities

The traffic flow may not face to the external interruptions at some roadways. If the traffic flow is not impeded by any factors, it is defined as uninterrupted flow. More precisely, intersections, traffic signals, stop & yield signs, curbside parking areas and such external causes do not exist at this group of the flow facilities (Roess et al., 1998). Thus, the uninterrupted flow is generally observed at the highways and the rural roads.

To sum up, the external interruptions have a great effect and cause much more traffic conflict on the interrupted flow facilities. Thus, when developing the link capacity functions especially at urban roads, the flow interruptions should be taken into account. For instance; traffic signal cycles at signalized intersections do affect the capacity calculations on the interrupted flow facilities.

2.2. The Concept of the Capacity

This part explains the concept of the capacity and the determinants of the capacity on the interrupted flow facilities.

The capacity is defined as "the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions" (TRB, 2000, ch.2.2). In this context, the prevailing roadway, traffic and control conditions are the determinants of the capacity. These determinants refer to many factors set out below:

Roadway conditions include geometric features of the facility. More precisely, roadway factors are: "number of lanes, the type of facility and its development environment, lane widths, shoulder widths and lateral clearances, design speed, horizontal and vertical alignments, and availability of exclusive turn lanes at intersections" (TRB, 2000, ch.2.4).

Traffic conditions affecting the capacities and service level mainly embrace the "vehicles types, directional and lane distribution" (TRB, 2000, ch.2.4).

Control conditions are also important in terms of their impact on the capacities and service level of the roadway. Further, traffic signals are the most significant control for the interrupted flow facilities. TRB mainly describes them as "signal phasing, allocation of green time, and cycle length" (TRB, 2000, ch.2.5). Moreover, stop and yield signs have an impact on the capacity values.

As a result, the prevailing conditions have significant role while defining the capacity. Since the prevailing conditions become different at any roadway segment, they affect the capacity differently. Thus, each link segment at the roadway can be examined independently to reach exact capacity calculation.

2.3. Determining the Capacity at the Interrupted Flow Facilities

Some variables identify the capacity calculations at the interrupted flow facilities. Thus, at the interrupted flow facilities the capacity is related to the effective green time and the signal cycle length at the signalized intersections. Moreover, the total saturation flow rate is another variable affecting the capacity calculations at each lane group. So, the capacity on the interrupted flow facilities is calculated as below:

$$c = s * (\frac{g}{C}) \qquad (2.1)$$

Where

c = capacity (vph),

s = saturation flow rate (vphg)

g = effective green time (sec),

C = cycle length (sec)

$s = s_0 N f_w f_{HV} f_g f_p f_{bb} f_a f_{LT} f_{RT}$

Where

s = total saturation flow rate for lane group (vphg)

s_0 = ideal saturation flow rate per lane, pcphgpl, usually taken to be 1900 pcphgpl

N = number of lanes in the lane group

f_w = adjustment factor for lane width

f_{HV} = adjustment factor for heavy vehicle presence

f_g = adjustment factor for grade

f_p = adjustment factor for parking conditions

f_{bb} = adjustment factor for local bus blockage

f_a = adjustment factor for area type

f_{LT} = adjustment factor for left turning vehicles

f_{RT} = adjustment factor for right turning vehicles (Roess et al., 1998, p.478)

2.4. Mathematical and Theoretical Approaches for the Link Capacity Function

This part reviews the main properties of the mathematical and theoretical functional approaches proposed as the link capacity function in literature. They are classified as follows;

2.4.1. Mathematical Approach

In literature it is interpreted that the mathematical approach has ease. However, due to its simplicity, it is not more successful in integration with the link features. Mathematical approach provides simple relationship between travel speed and flow on the link (Branston, 1976).

Branston (1976) represents a few functional forms in terms mathematical approach. For instance;

Branston (1976) stated that Irwin, Dodd, and Von Cube proposed a function of two straight line segments in 1961.

$$T = T_A + \alpha(Q' - C'_p) \text{ for } Q' < C'_p \quad (2.2)$$

$$T = T_A + \beta(Q' - C'_p) \text{ for } Q' \geq C'_p \quad (2.3)$$

Where

$T_A = T_0 + \alpha C'_p$

Q: flow on a link,

α, β, γ : parameters,

T: travel time at flow Q,

Q' : flow on a link per lane on a link,

C_p : practical capacity of a link,

T_0 : travel time at zero flow,

C'_s : steady state capacity per lane,

C'_p : practical capacity per lane.

Branston (1976) stated that this two-line segment function was developed by adding a third-straight line later by Irwin and Von Cube in 1962.

$$T = T_A + \alpha(Q' - C'_p) \text{ for } Q' < C'_p \quad (2.4)$$

$$T = T_A + \beta(Q' - C'_p) \text{ for } C'_p \leq Q' \leq C'_s \quad (2.5)$$

$$T = T_B + \gamma(Q' - C'_s) \text{ for } Q' > C'_s \quad (2.6)$$

Where

$T_A = T_0 + \alpha C'_p$

$T_B = T_A + \beta(C'_s - C'_p)$

Branston (1976) discussed that the parameters of the linear relationships have manifested the difficulties in the applications. Thus, Smock proposed a curvilinear link capacity function. The main feature of this type of the functions is to manifest the discontinuity at the practical capacity in comparison to the former functions (Branston, 1976). Smock's curvilinear function is expressed as:

$$T = T_0 \exp[Q/C_s] \quad (2.7)$$

Branston (1976) stated that Mosher defines logarithmic and hyperbolic link capacity functions in 1963:

$$T = T_0 + \ln(\alpha) - \ln(\alpha - Q) \text{ where } Q \leq \alpha \quad (2.8)$$

A hyperbolic capacity function is defined as:

$$T = \beta - [\alpha(T_0 - \beta)/Q - \alpha] \text{ where } Q \leq \alpha \quad (2.9)$$

According to Branston (1976), Mosher set up these functions "because they have desired property that the change in time per unit flow with increasing flow is small for low flows, but large as capacity is approached" (Branston, 1976, p.229).

In 1964, Bureau of Public Roads (BPR) developed the most widely used link capacity function, usually known as the BPR formula (Branston, 1976). BPR function is:

$$T = T_0 [1 + \alpha(Q/C_p)^{\beta}] \quad (2.7)$$

Where $\alpha = 0.15$, $\beta = 4$

In 1967, Overgaard proposed a general functional form that is expressed below: (Branston, 1976)

$$T = T_0 * \alpha^{(Q/Cp)^{\beta}} \quad (2.8)$$

According to Branston (1976), Steenbrink substituted the practical capacity of BPR formula with steady state capacity and calibrated α and β parameters. Thus, Steenbrink proposed a link capacity function in 1974 (Branston, 1976). This function is below:

$$T = T_0 [1 + \alpha(Q/C_p)^{\beta}] \quad (2.9)$$

Where $\alpha = 2.62$, $\beta = 5$

2.4.2. Theoretical Approach

In contrast to the mathematical approach, the theoretical approach more complicated. Further, the link features such as signal spacing, signal settings and street widths are inevitably embodied in the theoretical approach (Branston, 1976).

Branston (1976) represents a few functional forms in terms of the theoretical approach. For instance;

In 1959 Campbell, Keefer and Adams proposed a function in Chicago Area Transportation Study (Branston, 1976). The form of this function is below:

$$T = T_0 \quad \text{for } Q/C_s \leq 0,6 \quad (2.10)$$

$$T = T_0 + \alpha(Q/C_s - 0,6) \quad \text{for } Q/C_s > 0,6 \quad (2.11)$$

In 1966 Davidson expressed a common link capacity function depending on theoretical approach (Suh et al., 1990).

$$T = t^*[1+J^*(C/1-C)] \qquad C = Q/S \qquad (2.12)$$

Where

S = Saturation parameter,
J = Delay parameter,
t = Zero flow time.

In 1968 Wardrop developed a network capacity function that is shown below (Suh et al., 1990):

$$T = T_0/(1- \gamma Q) + \alpha^*\beta/(\alpha-Q)D \qquad (2.13)$$

Where

D link length, $\alpha > C$, $\gamma < 1/C$

To sum up, there are many equations as shown above in the mathematical and the theoretical approaches. Especially, according to the literature, the most preferable and the most widely used link capacity function is BPR type formula proposed by BPR in 1964.

CHAPTER 3

BASIC RELATIONSHIPS BETWEEN THE VARIABLES OF TRAFFIC FLOW

Traffic flow theory tries to obtain the fundamental relationships of the traffic flow variables. Furthermore, the algebraic expressions of the obtained fundamental relationships can assist the engineers and planners in estimating future values of the traffic flow characteristics on the roadways.

This part examines the relationships between speed-density-flow and travel time. The variables in these relationships can also determine the link capacity functions. Thus, the accurate mathematical forms of these theoretical relationships can take part in the estimation of the traffic flow.

3.1. Speed-Density-Flow Relationships

In literature there are a few models about speed-density-flow relationships. In this chapter, the general forms of the speed-density-flow relationships are explained with reference to Greenshields' hypothesis (models). Greenshields' models, having been proposed in 1934, are one of the earliest recorded studies on the speed-density-flow relationships (Wohl & Martin, 1967).

The graphically representation of these relationships are depicted in the following part.

3.1.1. Speed-Density Relationships

The traffic density, flow and travel speed are the cornerstones of the traffic flow theory. Before Greenshields' speed-density relationships are depicted here, it is essential to emphasize how the density is defined and what is the algebraic equation among the density, flow, speed variables.

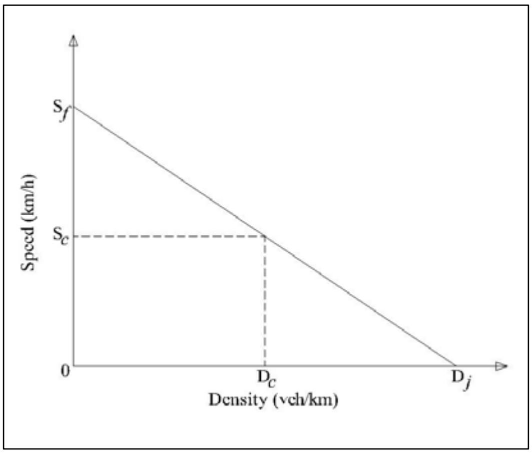
To measure the density is very difficult act on a roadway. It is defined as the number of vehicles existing at the specified length of the roadway. The density is generally expressed as the number of vehicles per kilometer per lane (Ergün, Gün, & Çalışkan, 2007).

The algebraic equation among the density, flow and speed is below;

$$V = S*D \tag{3.1}$$

Where
V = Rate of flow (veh/h),
S = Space Mean Speed (km/h)
D = Density (veh/km)

Graphically representation of the speed-density relationship is displayed below:



C = Capacity, the maximum rate of flow,

S_c = Critical speeed, the speed at which capacity occurs,

D_c = Critical density, the density at which capacity occurs,

D_j = Jam density, the density at which all movement stops,

S_f = Free-flow speed, the theoretical speed of traffic when density is zero.

Figure 3.1 Linear Speed-Density Relationship

The relationship between speed and density shows the perfect linear model, that is to say, when the density increases, the speed decreases. Algebraically, such a relationship can be expressed below by Greenshields:

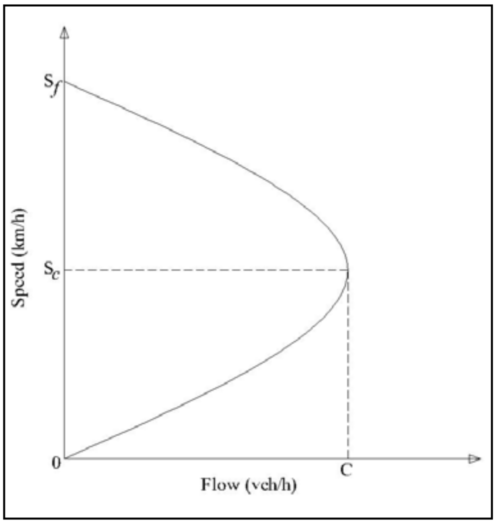
$$S = S_f*(1 – D/D_j) = S_f - S_f*D/D_j \tag{3.2}$$

The important point is that “the linear model is simple and straightforward. Both free-flow speed and jam density are easily determined. Most recent studies, however, have indicated that speed-density data are not perfectly linear" (Roess et al., 1998, pp.286).

3.1.2. Speed-Flow Relationships

This part discusses the speed-flow relationships depending on Greenshields' hypothesis. First of all, in traffic flow theory there are two terms that are necessarily distinguished one from the other. These are the volume and flow rate. The volume is the number of vehicle observed to traverse specified point during a time interval (for instance; monthly, hourly, sub-hourly periods). But, the flow rate is the number of vehicles traversing the specified point during less than one hour interval, generally 15 minutes interval. Besides, it is expressed as an equivalent hourly rate (TRB, 2000). For instance; at a roadway the volumes are observed within four successive 15 minutes' period. Therefore, if the four counts are 2000, 2400, 2500, 2100, total hourly volume is obtained as 2000+2400+2500+2100 = 9000 vehicles. Nonetheless, the flow rate is considered differently. That is to say, the flow rate changes within different 15 minutes' period and the maximum flow 2500 vehicles in this example are taken into account. Since there are four 15 minutes interval within one hour, the flow rate is computed as 2500*4 = 10000 vehicles. This score cannot be observed at the specified observation point. However, they pass at that rate for 15 minutes' interval (TRB, 2000).

Moreover, graphically representation of the speed-flow relationship is displayed below:



S_f : Free-flow speed, the theoretical speed of traffic when flow is zero,

S_c : Critical speeed, the speed at which capacity occurs,

C : The point at which the capacity occurs.

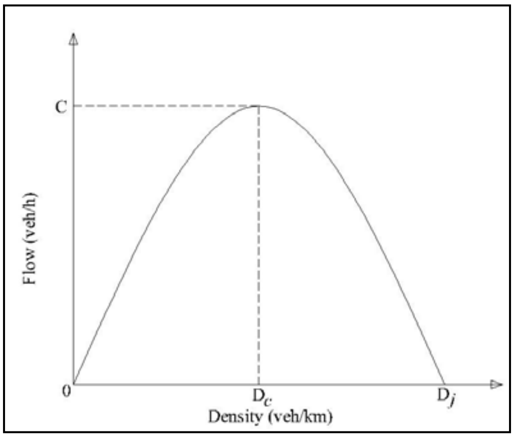
Figure 3.2 Parabolic Speed-Flow Relationship

The speed-flow relationships in Figure 3.2 manifest a parabolic form function. The Figure 3.2 shows that when the flow increases, traffic speed starts to decrease a few times later. When the flow reaches the capacity point (C), the speed decreases with an increasing rate. If the flow exceeds the capacity, decrease in both flow and speed is observed and the congested situation occurs. In this relationship the travel speed is considered as the average travel speed depending on the average travel time of the vehicles on the roadway.

In Figure 3.2, if flow is zero, it means there are no vehicles at the route or the density does not occur (zero) and there are no vehicles that can be observed. Under these conditions, the speed corresponds to the free flow speed (S_f) referring to theoretical and the highest speed along the roadway.

3.1.3. Flow-Density Relationships

If the flow and density is considered, their relationship is occurred in the figure below:



C = Capacity, the maximum rate of flow,

D_c = Critical density, the density at which capacity occurs,

D_j = Jam density, the density at which all movement stops.

Figure 3.3 Parabolic Flow-Density Relationship

To find the flow-density equation, S = V/D is substituted into the speed-density model and the parabolic equation of flow-density relationship is obtained as:

$$V = S_f * D - (S_f / D_j * D^2) \quad (3.3)$$

The Figure 3.3 represents the parabolic flow-density relationships proposed by Greenshields. At this figure the important point is when the flow is observed as zero, the density may be extremely high due to the traffic jam on the road. In this context, this description of density is called the jam density.

At the inflection point of the flow-density curve in Figure 3.3 and the speed-flow curve in Figure 3.2 as well, the maximum possible rate of flow or capacity (C) occurs. At this time, the speed and density stand at the critical point.

3.2. Travel Time-Flow Relationships

The observation of the change in the travel time gives information on the traffic quality of a roadway. Moreover, the observed travel time is utilized as the dependent variable in the link capacity functions. The relationship between travel time and flow is depicted below.

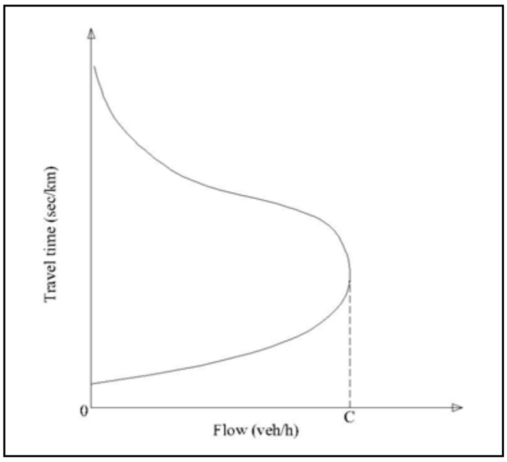


Figure 3.4 The Travel Time-Flow Relationship

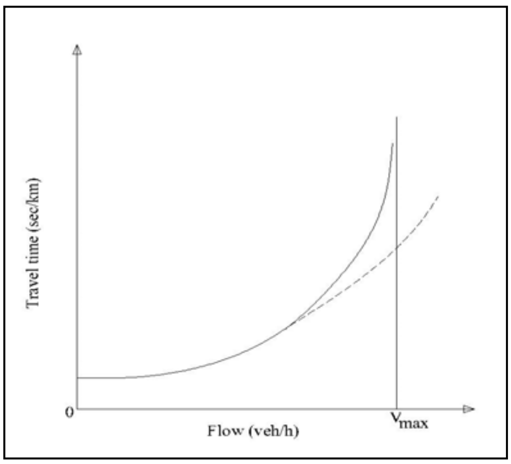


Figure 3.5 A typical Monotonically Increasing Capacity Function

The travel time-flow (capacity) function in Figure 3.4 has a main restriction. That is, the function cannot provide a unique flow solution. If the function is considered as monotonically increasing as displayed in Figure 3.5; therefore, a unique flow solution could be provided. Further, increasing flow rate extends the travel time. Thus, the general attitude of the researches depends on the monotonically increasing link capacity function. Further, the function should express the overloaded region since the infinite generation of travel time is undesirable event (Suh et al., 1990).

All in all, the fundamental features of the capacity functions should be:

> -The modeled travel times should be realistic enough,
> -The function should be non-decreasing and monotone; increasing flow should not reduce travel time,
> -The function should be continuous and differentiable,
> -The function should allow the existence of an overload region,
> -For practical reasons the cost-flow relationship should be easy to transfer from one context to another, the use of engineering parameters like free-flow speed, capacity, and number of junctions per kilometre is therefore desirable (Ortuzar & Willumsen, 2006, p.324).

CHAPTER 4

DATA COLLECTION AND METHODOLOGY

The research objective of this thesis is carried out by performing five successive tasks. These tasks are the site and links selection, data collection, data manipulation and data analysis, data modeling and lastly the comparisons of the model results. In this chapter the data collection of this study is briefly explained.

4.1. Site and Link selection

The city Izmir, which is located in the west of Turkey, is selected to perform this study. One of the objectives of this study is to provide a unique contribution to Izmir transportation studies. More precisely, this study could be beneficial for the vehicular traffic problems in Izmir. These are the important reasons why the city Izmir is selected for this study.

For this study ten links are two directionally selected from downtown Izmir. Also, they are located in different parts of Izmir. Moreover, the selected links are classified in two groups as two lane divided and one lane undivided links. Six of these links have two lanes at each direction and these are divided links, whereas the rest have only one lane at each direction and these links are undivided.

The selected links' names are given below:

Two-lane divided links:

Girne Street, Inonu Street, Sairesref Street, Talatpasa Street, Mithatpasa Street (in front of Dokuz Eylul University Hospital), Mustafa Kemal Street (Bornova).

One-lane undivided links:

Anadolu Street (in front of Tepekule Congress Center), Erdogan Akkaya Street (Semikler), Mithatpasa Street (Goztepe), Mithatpasa Street (Karatas).

Most of the links defined above are rather dense links in terms of occupying by the vehicular traffic flow. That is to say, those links are the main roadways in Izmir. Therefore, this can be showed as a criterion why those links are selected for this thesis work. The selected links are also displayed in the figures below. Moreover, in the figures below the cross marks (×) show the specified observation points and the black points (●) define the starting and ending points of the link. Furthermore, the names of the some locations around the links in the figures provide better understanding of the route and the specified observation points. Moreover, the letters WE, EW, SN, NS describes the direction of the links.

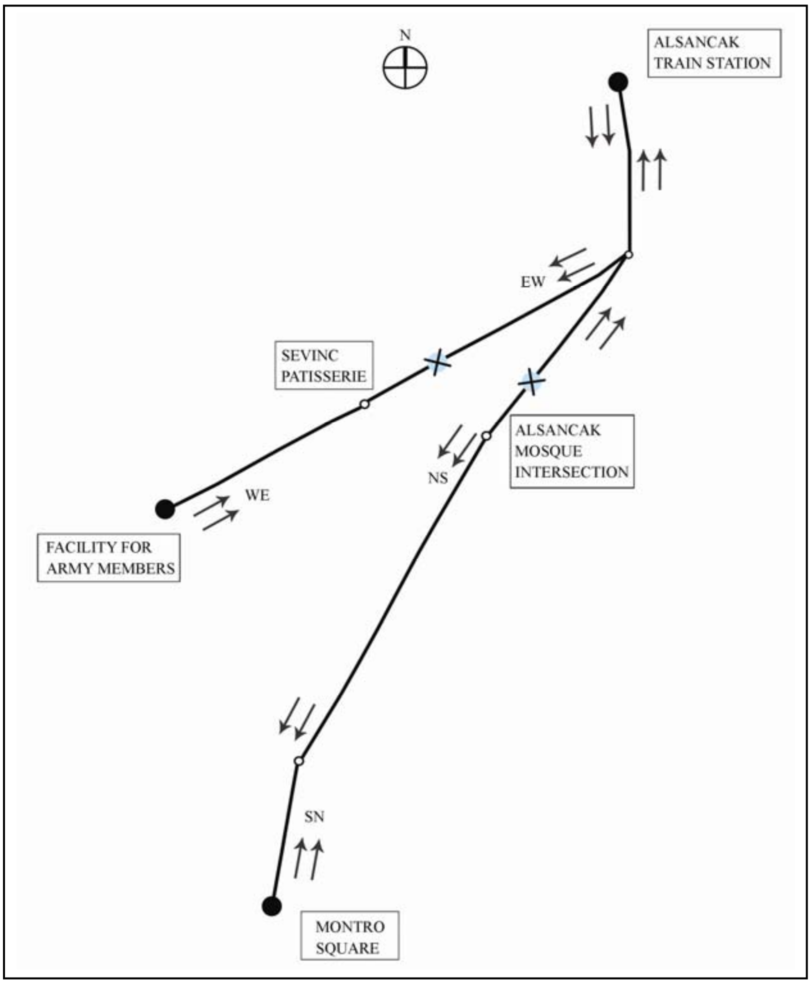


Figure 4.1 Two-lane Divided Links at Talatpasa Street and Sairesref Street

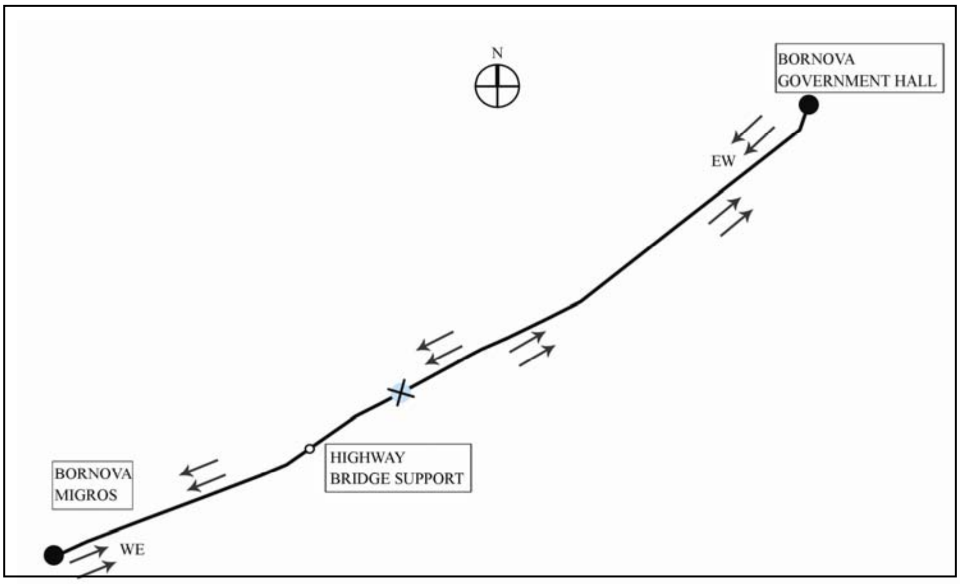


Figure 4.2 Two-lane Divided Link at Mustafa Kemal Street (Bornova)

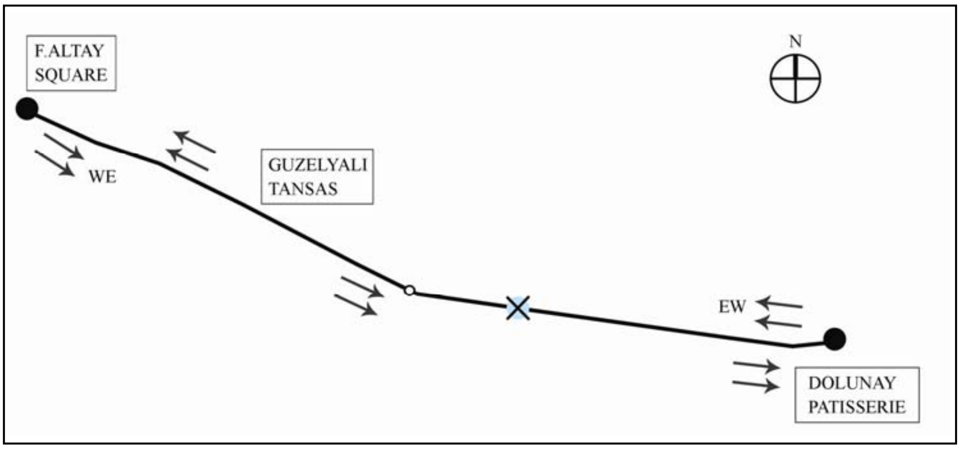


Figure 4.3 Two-lane Divided Link at Inonu Street

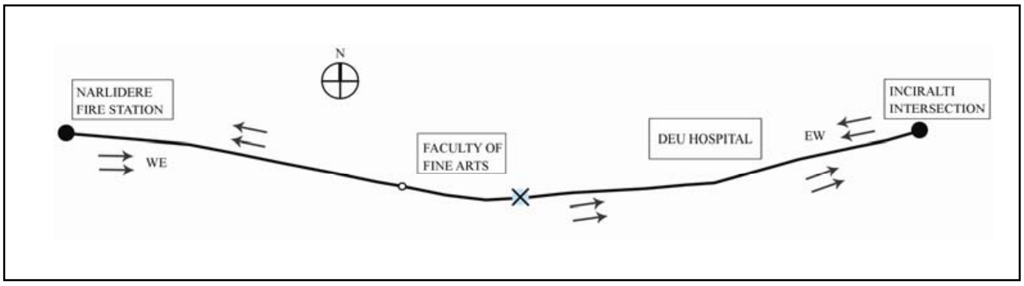


Figure 4.4 Two-lane Divided Link at Mithatpasa Street (DEU)

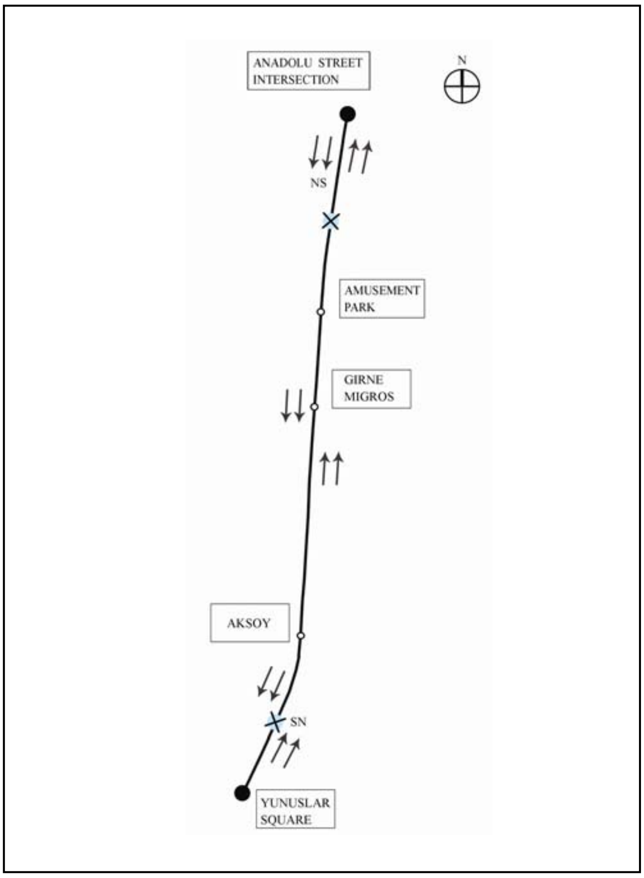


Figure 4.5 Two-lane Divided Link at Girne Street

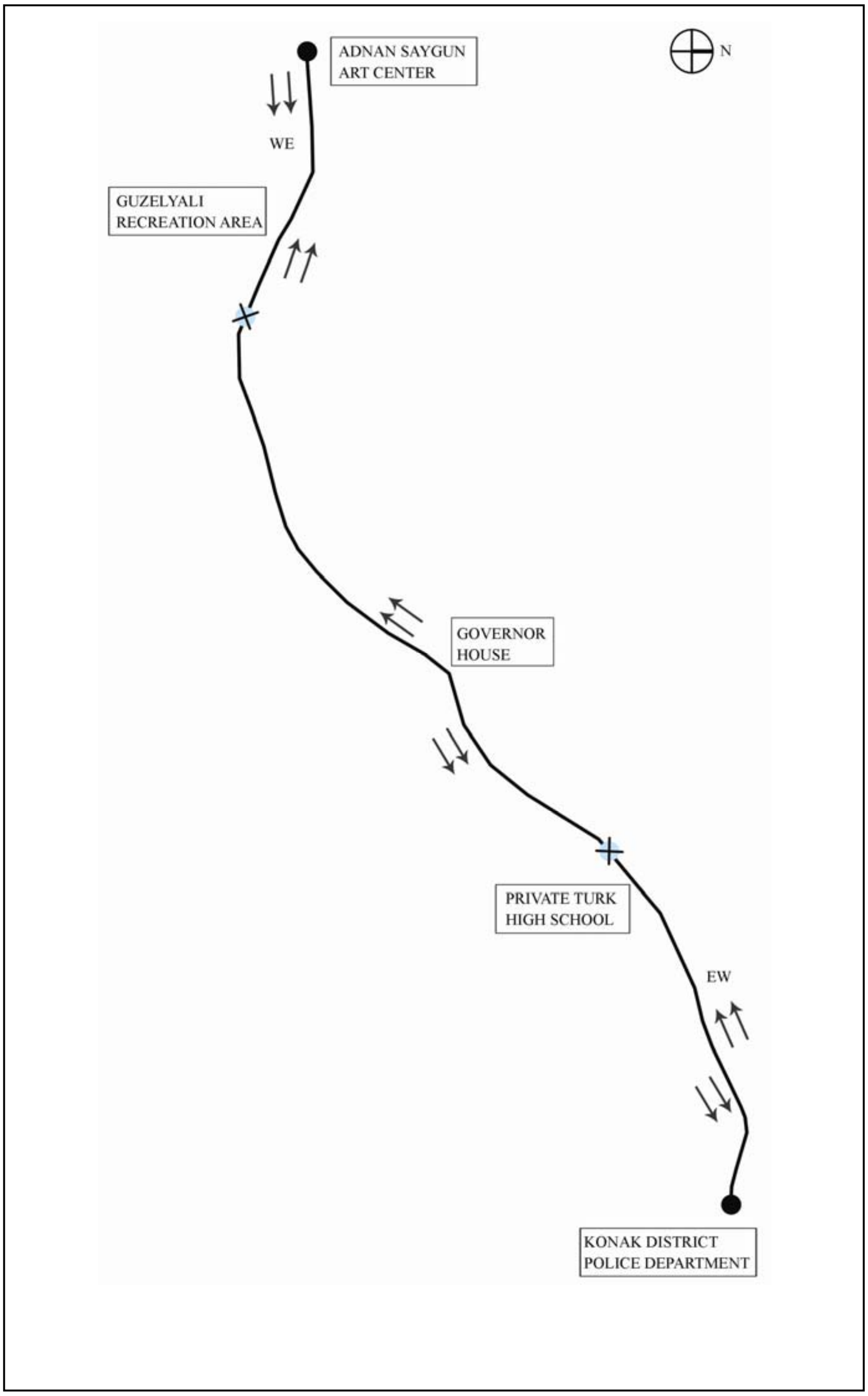


Figure 4.6 One-lane Undivided Link at Mithatpasa Street (Goztepe)

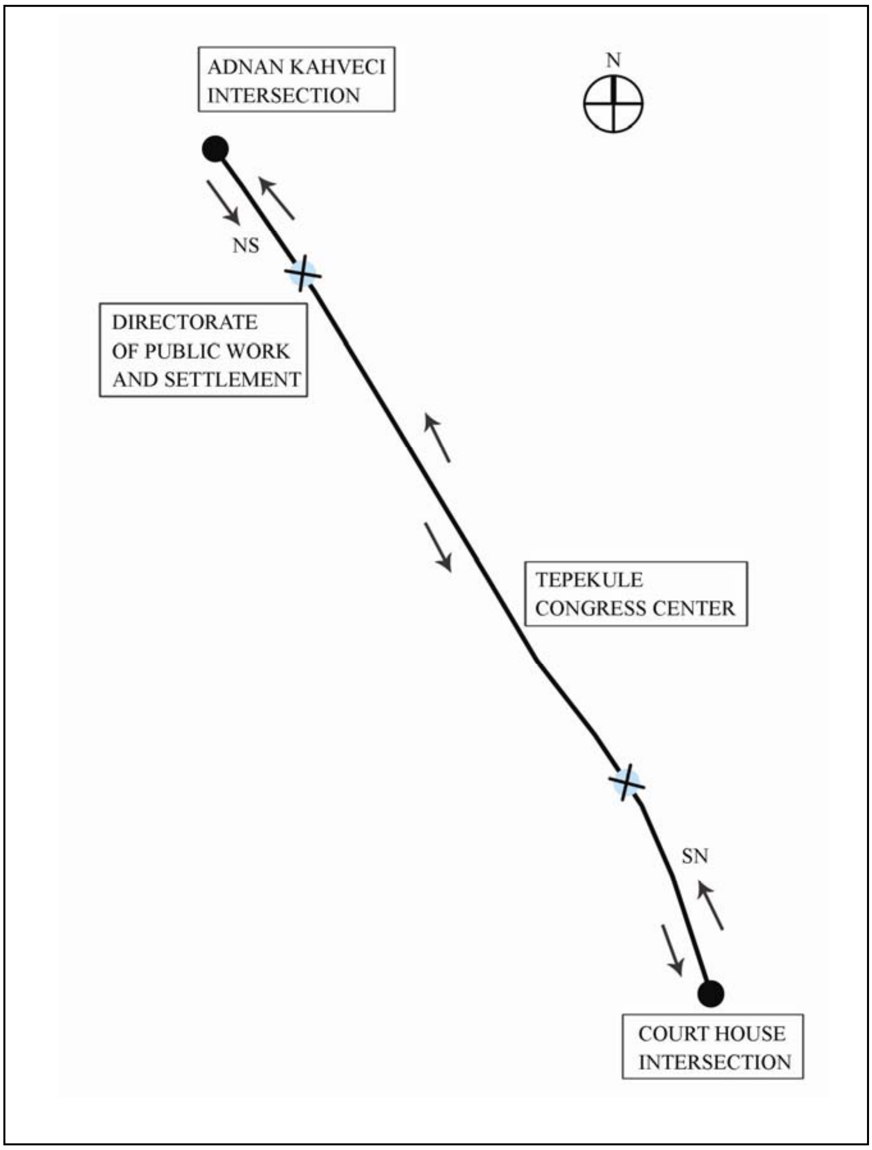


Figure 4.7 One-lane Undivided Link at Anadolu Street (Tepekule)

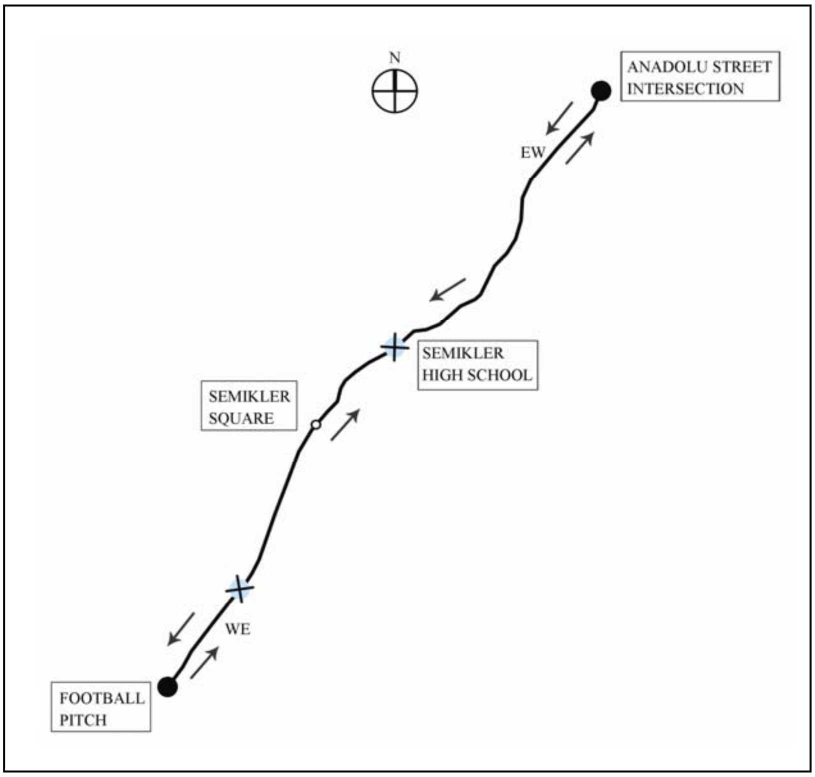


Figure 4.8 One-lane Undivided Link at Erdoğan Akkaya Street (Semikler)

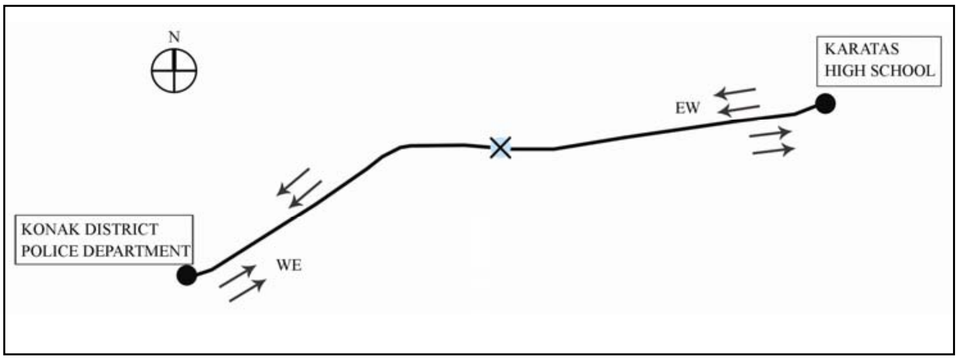


Figure 4.9 One-lane Undivided Link at Mithatpasa Street (Karatas)

4.2. Data Collection

It is necessary to collect some variables or data to develop the link capacity functions. Before the data was collected, the necessary variables and the inputs had been listed. Therefore, in this study, the fundamental variables to develop the link capacity functions are; directional travel time through the link, directional flow rate, directional green cycle ratio (g/C) and number of lanes at each direction. Apart from these, the presence of parking through the link, the presence of dense retail activity around the link, the number of the bus stops, the number of the signalized intersections and the link lengths data are collected for each link. Further, their statistically significance is tested in the modeling process.

4.2.1 The Variable Travel Time

The travel time is the dependent variable in the link capacity functions. There are many factors affecting the travel time. Thus, some of the important factors that affect the travel time set out below:

High demand of the drivers to the roadway that is the main connector route at that network, that the network is located at the high population area in which high number of the vehicles exist, the occurrence of the vehicle queue at the bottlenecks due to the reduction in the number of the lanes, number of the lanes, lane width, the presence parking and the land-use around the roadway, the number of the bus stops and buses at roadways, the intrusion of the minibuses, buses and taxis that stop for a while on the lanes, the lack of the required standard of the lay-bys or the inappropriate usages of the lay-bys, the number of the signalized and unsignalized intersections, the problems of the signal time and optimization, drivers' behaviour, not obeying to the traffic signs, physical features of the roadways, the number of the pedestrian stream, the weather conditions, traffic accidents, repair work on the roadway, division of the roadway by mid-barrier (Ergün et al., 2007).

For this thesis task, the travel time studies are conducted through the length of each direction at the link. The travel time study is also performed during the peak hours. The hourly intervals about these peak hours are 08:00-09:00 a.m., 12:00-13:00 p.m. and

18:00-19:00 p.m. Shortly, the travel time studies are only conducted during these hours' intervals.

The methodology that is used for the travel time studies is provided by running test car through the links. The observation results obtained by using stopwatch are recorded manually. These observation results are entered into a field sheet for each time interval. In each time interval the travel time study is repeated. Thus, the average travel time scores are obtained and they are taken into account for the data analysis.

4.2.2 The Variables Volume and Flow rate

For this study the flow rate is calculated depending upon the observed 15 minutes' volume values collected at the specified points on the selected links. According to the research assumption of this study, the hourly flow rates are obtained as directionally. In other words, the sum of each lane volume count (if the link is two-lane) is taken into account to obtain the hourly flow rates at one direction for all of the links. Furthermore, the number of lanes, peak hour factor (PHF), the heavy vehicle proportions are the necessary inputs to get the hourly flow rate values. When calculating the hourly flow rates, the importance of these inputs is indicated in more detail in the next chapter.

There are some methods to collect the traffic volume counts. In this study, the traffic volume counts are collected by the portable traffic counters that have the magnetic sensors. The magnetic sensing allows these portable traffic counters to measure many variables. Depending on this, the variables the volume, travel speeds, vehicle lengths are collected in every five minutes' period for the purpose of doing this study.

The portable traffic counters are installed on the road surface after the midnight when the traffic demand is very low. So that the vehicles pass over the portable traffic counters, these counters are installed in the middle of the traveled traffic lanes. Owing to the avoidance of undesirable counts, these counters are not installed to be too close to the signalized intersections, the bus stops and the curves. Moreover, these counters are installed on one or two selected observation points on the links as depicted in the former figures by the cross marks.

For the purpose of this thesis task, the counts and the travel time studies are performed on the specified weekdays within June-July 2009 on the selected links. Furthermore, the counters start to collect the vehicular data at 07:00 a.m. and it carries on with data collection to 20:00 p.m. The other point is that the counts and the travel time studies on the same links are performed simultaneously.

4.2.3 The Other Variables

The signal timing at the signalized intersections is another essential data to develop the link capacity functions at the interrupted flow facilities. That is to say, the green cycle ratio (g/C) data at each intersection on the links is necessary to calculate the capacity prior to developing the link capacity functions. Thus, the green, amber and red time data for each one of the signalized intersections on the links are obtained from Izmir Metropolitan Municipality. Depending upon these obtained data, the green cycle ratio (g/C) is obtained so that the capacity values at every direction can be calculated separately.

Lastly, the number of the lanes, the presence of the dense retail activity around the links, the presence of the parking through the links, the number of the bus stops, the number of the signalized intersections are observed manually and the link lengths are gauged by running test car at the field. Then, this information also is entered into the field sheets for every link and direction.

4.2.4 The Results of the Travel Time Study

The travel time study results are arranged with three different peak hour intervals as indicated in the next page.

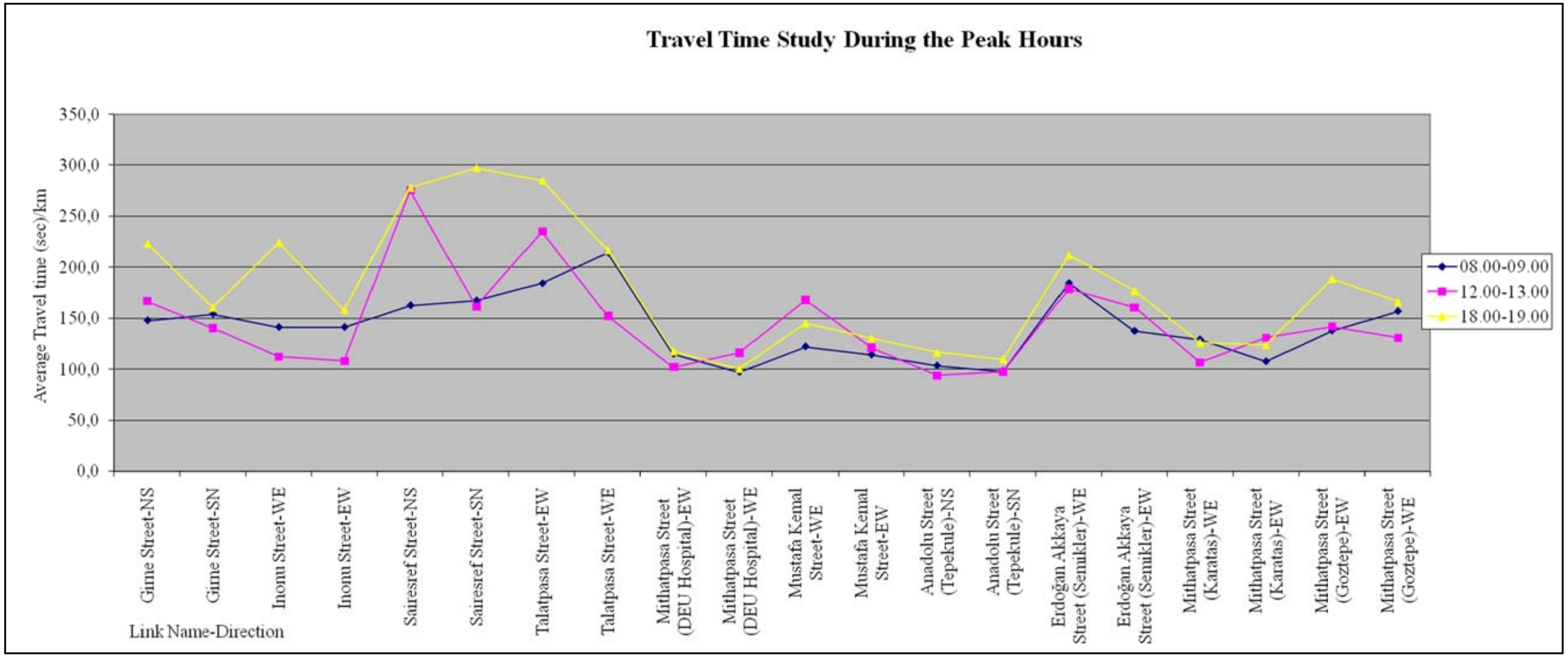


Figure 4.10 Travel Time Study Results At Each Link and Direction

According to the figure above, during the morning peak hour the minimum travel time is seemed on Mithatpasa Street (DEU Hospital)-WE. During the noon peak hour the minimum travel time is seemed on Anadolu Street (Tepekule)-NS. During the evening peak hour the minimum travel time is seemed on Mithatpasa Street (DEU Hospital)-WE.

In contrast to the minimum travel times, during the morning peak hour the maximum travel time is seemed on Talatpasa Street-WE. During the noon peak hour the maximum travel time is seemed on Sairesref Street-NS. During the evening peak hour the maximum travel time is seemed on Sairesref Street-SN.

Depending on the travel time study results, the average speed values on the link are computed and their bar diagram are indicated below:

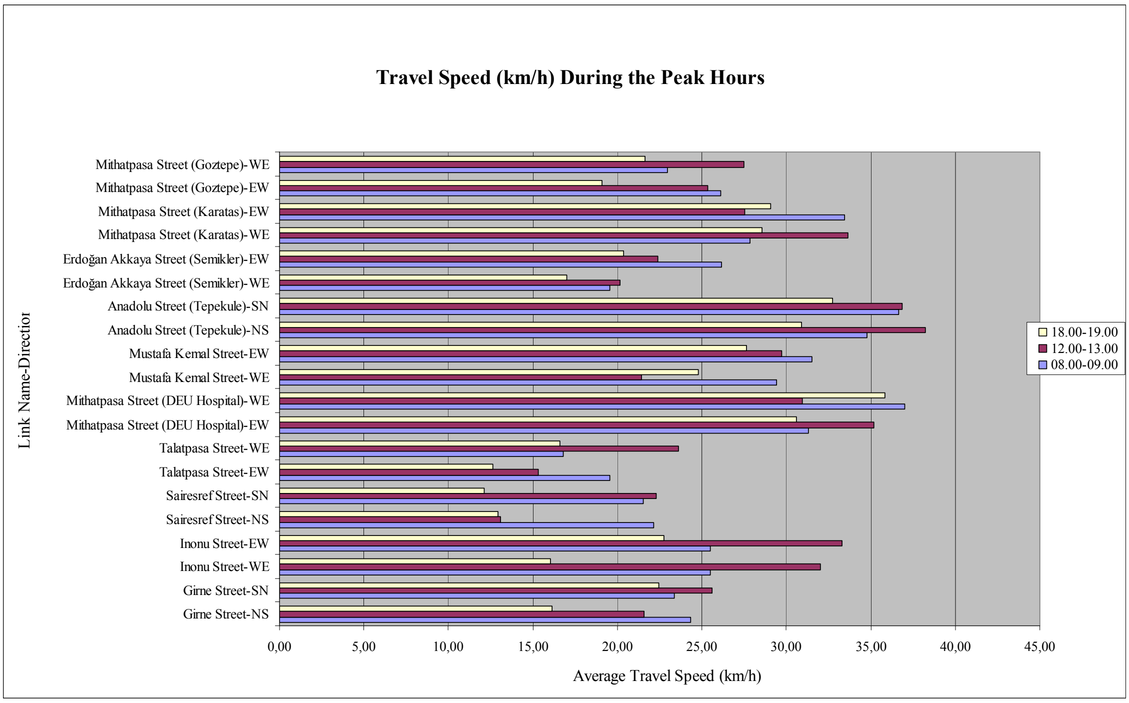


Figure 4.11 Travel Speed Computation Results at Each Link and Direction

According to Figure 4.11, during the morning peak hour the minimum average travel speed is seemed on Talatpasa Street-WE. During the noon peak hour the minimum average travel speed is seemed on Sairesref Street-NS. During the evening peak hour the minimum average travel speed is seemed on Sairesref Street-SN.

In contrast to the minimum average travel speed, during the morning peak hour the maximum average travel seem is seemed on Mithatpasa Street (DEU Hospital)-WE. During the noon peak hour the maximum average travel speed is seemed on Anadolu

Street (Tepekule)-NS. During the evening peak hour the maximum average travel speed is seemed on Mithatpasa Street (DEU Hospital)-WE.

The minimum, maximum and average travel speed values for divided and undivided link are summarized in the tables below:

Table 4.1 Travel Speed Values at the Peak Hours for the Divided Links

Travel Speed (km/h) for Divided Links	Minimum	Maximum	Average
Morning Peak Hour	16,8	37	25,65
Noon Peak Hour	13,07	35,2	25,34
Evening Peak Hour	12,1	35,83	20,87

Table 4.2 Travel Speed Values at the Peak Hours for the Undivided Links

Travel Speed (km/h) for Undivided Links	Minimum	Maximum	Average
Morning Peak Hour	19,52	36,64	28,43
Noon Peak Hour	20,13	38,25	28,96
Evening Peak Hour	16,99	32,72	24,91

CHAPTER 5

DATA ANALYSIS AND MODELING

5.1. Formulation of the Variables for Data Analysis

Before the data analysis is started for this thesis study, the data are tailored to meet the needs of the data analysis. Thus, some data is manipulated or converted to the applicable forms by some factors to start the data analysis. So, this part examines how the data are transformed to the applicable forms for the data analysis.

In this chapter, before developing the link capacity functions, the speed-density-flow rate relationships at the selected links are obtained. For this purpose, firstly, the variables existing in the speed-density-flow rate relationships are examined.

The first variable is the flow rate. The description of the flow rate is briefly explained in Chapter 3. Therefore, this part focuses on how the hourly passenger car equivalent flow rate is obtained.

In this study, the flow rate is obtained for each direction on the links via that equation shown below:

$$\text{v} = \frac{V}{PHF * N * f_{HV} * f_P} \tag{5.1}$$

Where

v= equivalent flow rate during peak 15 minutes (pcph)

V= hourly volume (vph)

PHF= peak hour factor

f_{HV}=adjustment factor for heavy vehicles in the traffic stream

f_p= adjustment factor for driver population

N= number of lanes (Roess et al., 1998, p.233)

The Equation 5.1 provides a conversion of the hourly volume into the flow rate that refers to the hourly passenger car equivalent flow rate. In the Equation 5.1, since in this study there are no data related to the adjustment factor for driver population, its value is taken as 1 that is a default value presented in *Highway Capacity Manual (HCM) 2000*. Furthermore, to calculate the adjustment factor for heavy vehicles in the traffic stream, the equation below is utilized.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \quad (5.2)$$

Where

P_T = proportion of trucks and buses in the traffic stream

E_T = passenger car equivalent for trucks and buses

P_R = proportion of recreational vehicles in the traffic stream

E_R = passenger car equivalent for recreational vehicles

(TRB, 2000, ch.20.8)

In this equation P_R becomes zero (0) owing to a lack of P_R data for this study. Additionally, E_T is taken as 1.5 that is proposed in HCM 2000. Lastly, P_T value is computed by taking into account the observed vehicle lengths. According to this study assumption, the vehicles that are at least 8.5 meters length are considered as the heavy vehicles. Depending on this, the heavy vehicle proportions in each direction on the links can be expressed as: the ratio of the number of the vehicles that are at least 8.5 meters length to the number of the total vehicles.

Another important input is the "peak hour factor (PHF)". Peak hour factor (PHF) expresses the change in the traffic flow during one hour. As it is mentioned in Chapter 3 the observed volume in each 15 minutes' period can vary considerably. For 15 minute periods, PHF is calculated as below:

For 15-minute periods; $$\text{PHF} = \frac{V}{V_{15} * 4} \quad (5.3)$$

Where

V= hourly volume (vph)

V_{15}= maximum 15-minute volume within the hour (veh) (Roess et al., 1998)

In this study, PHF is calculated directionally in every one of the hourly intervals at each link.

Another point is that the number of lanes is considered as 1 in Equation 5.1 because the flow rate values become directional by depending on the hourly total of each lane volume (at two-lane links).

As a result, to calculate the flow rate there are many inputs that are need to be taken into account. Thus, how each one of the inputs performs is explained above.

The second variable is the average travel speed. In the literature, the average travel speed is generally calculated by two different approaches. The first considers the average travel speed as time mean speed (TMS), and the second considers the average travel speed as space mean speed (SMS). There is a significant distinction between two different speed calculations. This distinction stems from the measurement of the travel speed. While TMS calculation focuses on the point measurement, SMS concentrates on the length of the links. As a result, TMS can be defined the mean of the all the vehicles' speed observed at specified point on the link during specified time interval. But, SMS can be defined the mean of the speed of all the vehicles that travel along the given section of the link during specified time interval (Roess et al., 1998).

In this study, the travel speed data are read as the time mean speed (TMS) from the portable traffic counters. But, in the theoretical relationship among the density, flow and speed, the travel speed is presented as the space mean speed (SMS). As expressed in Chapter 3, the algebraic equation among the density, flow and speed is:

$$V = S*D \tag{5.4}$$

Where
V = Rate of flow (veh/h),
S = Space Mean Speed (km/h)
D = Density (veh/km)

Therefore, the travel speed data (TMS data) read from the portable traffic counters should be transformed into the space mean speed.

This transformation is computed according to the following formula:

$$\text{SMS} = \frac{n * d}{\sum t_i} \quad (5.5)$$

Where

d= distance traversed (km)

n= number of travel times observed

t_i= travel time for the *i*th vehicle (sec) (Roess et al., 1998)

In this study, n value is taken as 12 since the counts are performed in five minutes' period, in other words; there are 12 unit five minutes' periods during one hour. The gauged link length corresponds to the d value. Lastly, Σt_i are computed as the sum of each 5 minutes' distance/TMS value. The important thing for the divided two-lane links is that this study assumes TMS value in each five minutes is the mean of the observed speed on both of two lanes during each five minutes period. Thus, the directional average travel speed values are obtained to calculate the SMS.

Obviously, the third variable is the density that is expressed in the equation among the density, flow and speed. Before the explanation of the density, it is essential to focus on another term that is called occupancy. The occupancy is the percentage of the time period during which the counter is occupied by the vehicles. In this study to calculate the hourly occupancy value, there should be several required variables. These variables are the flow rate, the vehicle length, the space mean speed within one hour. The occupancy value cannot be read from the portable traffic counters. Thus, the study assumption is that the occupancy is the time that a vehicle passes over the counters at the specified speed (the hourly space mean speed). To calculate the total occupancy, this assumption is utilized for the all vehicles passing a point within one hour. After the total occupancy time for one hour is obtained, this occupancy time is divided by 3600 seconds; the occupancy percentage is to be found, therefore. However, since the occupancy result is computed according to the total directional flow rate, the result is shared between two lanes for the two-lane divided links.

If the total length occupied by the vehicles in terms of through a kilometer is divided by the average vehicle length, the density is obtained. Also, the density is interpreted as the number of vehicles per kilometer.

The fourth important variable is the capacity. Its definition and determinants are briefly explained in Chapter 2. Now, the important point is how the green cycle ratio, saturation flow rate and the adjustment factors are taken into account for this thesis study. This consideration is explained below.

This study performs the capacity calculation segment by segment for every one of the direction. At first, the green cycle ratio for each one of the signalized intersections is calculated depending on the signal timing data. Moreover, the ideal saturation flow rate for per lane is considered as 1900 pcphgpl. Furthermore, depending on the downstream and upstream, it is assumed that the last signalized intersection (signal timing) passed by the vehicles at each direction has no effect to the capacity calculations. Ultimately, the average of the obtained capacities at each segment corresponds to the total capacity value per direction.

The important point is that the adjustment factors affecting the total saturation flow rate is not taken into account in this study. It is assumed that the adjustment factors have not any great effect on the capacity calculations. Moreover, this assumption is supported by some researches in literature. For instance; a research by Dheenadayalu, Wolshon and Wilmot compare the capacity values obtained by including the adjustment factors. As a result, the adjustment factors can be ignored for the capacity calculations for their case since the adjustment factors have hardly any effect on the capacity calculations in their particular research (Dheenadayalu, Wolshon, & Wilmot, 2004).

Another research by Ergün, Gün and Çalışkan do not utilize the adjustment factors to compute the total saturation flow rate so as to obtain the capacity values (Ergün et al., 2007).

5.2. Speed-Density-Flow Rate Relationships at all the Selected Divided and Undivided Links

This part begins with the interpretations of Greenshields' speed-density-flow rate algebraic equations. Then, each pair of the speed-density-flow rate relationships, namely; flow rate-speed, flow rate-density and density-speed relationships are displayed on the scatter diagrams. These scatter diagrams manifest all of the values directionally. Moreover, the links are examined in two groups to construct the scatter diagrams. Thus, the first group consisting of the divided links includes the whole data of the divided links. The second group consisting of the undivided links includes the whole data of the undivided links.

After each pair of the data of the speed, density, and flow rate are represented on the scatter diagrams, the main aim is to estimate the regression coefficients that are β_0 and β_1. Additionally, depending upon the estimated regression coefficients, the fitted values of the dependent variable are calculated by corresponding to each value of the regressor variables.

5.2.1 The Interpretations of Greenshields' Speed-Density-Flow Rate Algebraic Equations

Greenshields' algebraic equations of the speed-density-flow rate relationships are theoretically examined in Chapter 3. Depending on Greenshields' speed-density-flow rate relationships, firstly; the flow rate-speed equation takes the form as below:

$$V = \beta_0 S - \beta_1 S^2 \tag{5.6}$$

where: V = flow rate (pcph)
S = travel speed (km/h)
β_0, β_1 are the model parameters

In this equation, the critical speed at which the capacity occurs is determined by differentiating this equation with respect to S and setting the result equal to zero. The equation is therefore,

$$\frac{dV}{dS} = \beta_0 - 2\beta_1 S = 0 \tag{5.7}$$

Then the critical speed is obtained as below:

$$S_{critical} = \frac{\beta_0}{2\beta_1} \tag{5.8}$$

To find the capacity, the value of the critical speed is substituted in the flow rate-speed equation:

$$V_{capacity} = \beta_0 S_{critical} - \beta_1 (S_{critical})^2 \quad (5.9)$$

In the flow rate-speed equation, when the flow rate equates to zero (0), the free flow speed is obtained. Thus,

$V = 0$ then,

$\beta_0 S - \beta_1 S^2 = 0$, and free flow speed takes the form as:

$$S_{freeflow} = \frac{\beta_0}{\beta_1} \quad (5.10)$$

Returning to Greenshields' algebraic equations, secondly; the flow rate-density equation is written as:

$$V = \beta_0 D - \beta_1 D^2 \quad (5.11)$$

Where

V = flow rate (pcph)

D = density (veh/km)

β_0, β_1 are the model parameters

Lastly, depending on Greenshields' algebraic equations, the density-speed relationship takes the form as:

$$D = \beta_0 - \beta_1 S \quad (5.12)$$

Where

D = density (veh/km)

S = travel speed (km/h)

β_0, β_1 are the model parameters

Considering the density-speed relation, when the travel speed is zero (0), the jammed density is obtained. Namely;

$D = \beta_0 - \beta_1 0$ then,

$$D = \beta_0 \tag{5.13}$$

Therefore, the jammed density at which all movement in traffic stream stop is found in this way.

5.2.2. Flow Rate-Travel Speed Relationship for all the Selected Divided and Undivided Links

The basic form of the flow rate-speed relationship fits a quadratic function. For the purpose of the model building, the flow rate data are selected as a dependent variable, while the travel speed is performed as the regressor variable. Furthermore, to find the best regression model fitting the flow rate-travel speed data, the variables are utilized in the regression analysis. Then, the regression results are obtained as below:

Table 5.1 Flow Rate & Travel Speed Regression Results for the Divided Links

Regression Statistics	
Multiple R	0,962571412
R Square	0,926543724
Adjusted R^2	0,920580078
Standard Error	249,4118318
Observations	182

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	141235418	70617709	1135,218657	2,04E-102
Residual	180	11197127,1	62206,2618		
Total	182	152432545			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
X Variable 1	56,24150677	2,37604352	23,6702343	3,6502E-57
X Variable 2	-0,82803044	0,05460959	-15,162729	5,37197E-34

So, for the divided links the fitted regression equation is:

$$V = 56{,}24151 * S - 0{,}82803 * S^2 \qquad (5.14)$$

In this equation, as explained before, the required manipulations are conducted. Therefore, the critical speed value is obtained as 33,96 km/h and depending on the critical speed value, the capacity value is found as 955 pcph at the divided links.

The scatter diagram below shows the actual data and the fitted model values for the divided links.

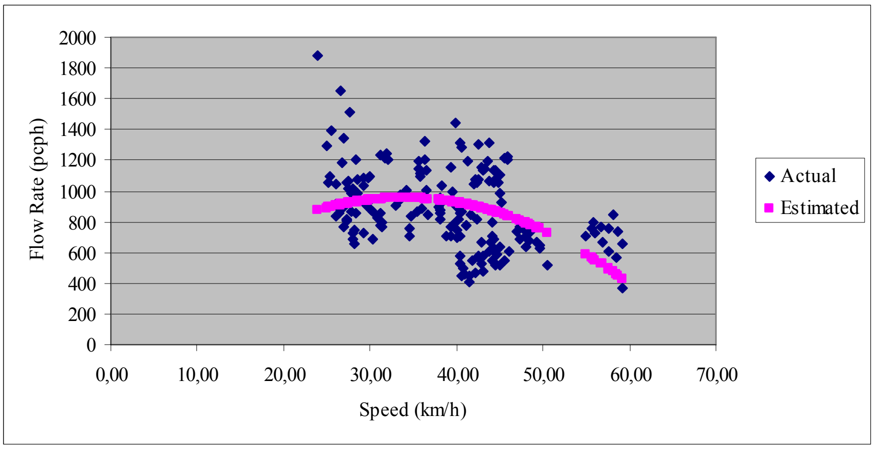


Figure 5.1 Flow Rate-Speed Relationship at the Divided Links

When the corresponding pairs of the flow rate-speed data of the undivided links are utilized in the regression analysis, the regression results are obtained as below:

Table 5.2 Flow Rate & Travel Speed Regression Results for the Undivided Links

Regression Statistics	
Multiple R	0,962665883
R Square	0,926725603
Adjusted R^2	0,920762967
Standard Error	104,09366
Observations	182

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	24667206,5	12333603,3	1138,259849	1,63E-102
Residual	180	1950388,21	10835,49		
Total	182	26617594,7			

(cont. on next page)

Table 5.2 (cont.)

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
X Variable 1	23,88674955	0,98444681	24,2641341	1,21578E-58
X Variable 2	-0,35832772	0,02357869	-15,1971	4,2691E-34

Therefore, for the undivided links the fitted regression equation is:

$$V = 23,8867*S - 0,35833*S^2 \qquad (5.15)$$

Depending on the equation above, the critical speed value is obtained as 33,33 km/h. Moreover, the capacity value is found as 398 pcph.

The scatter diagram below shows the actual data and the fitted model values for the undivided links.

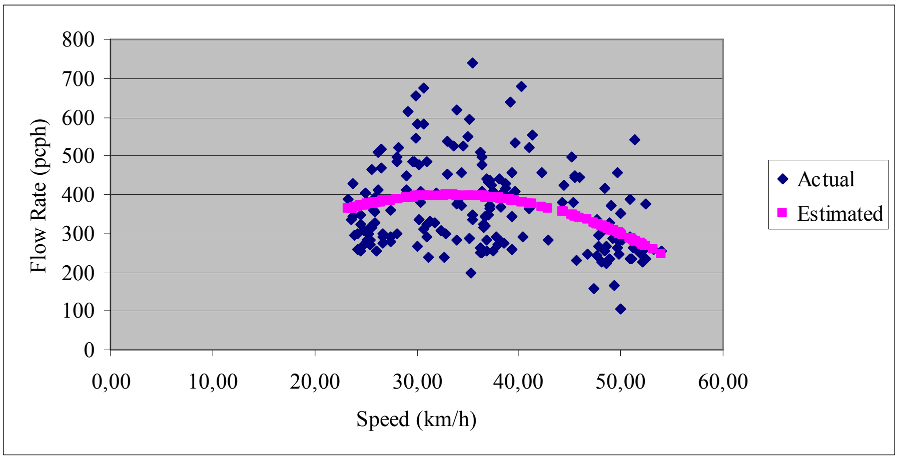


Figure 5.2 Flow Rate-Speed Relationship at the Undivided Links

5.2.3. Flow Rate-Density Relationship for all the Selected Divided and Undivided Links

The flow rate-density relationship also fits a quadratic function. In the flow rate-density equation, the flow rate is the dependent variable, whereas the density is the regressor variable. Moreover, the regression analysis is performed to analyze the flow rate-density data. So, the obtained regression results are shown in the table below:

Table 5.3 Flow Rate & Density Regression Results for the Divided Links

Regression Statistics	
Multiple R	0,981977764
R Square	0,964280328
Adjusted R^2	0,95852633
Standard Error	173,9227239
Observations	182

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	146987705	73493852,3	2429,620008	1,89E-130
Residual	180	5444840,5	30249,1139		
Total	182	152432545			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
X Variable 1	92,16534041	2,50143753	36,8449499	9,12654E-86
X Variable 2	-1,63534407	0,1266933	-12,907897	2,08269E-27

For the divided links the best regression equation fitting to the flow rate-density data is below:

$$V = 92{,}16534*D - 1{,}63534*D^2 \tag{5.16}$$

The scatter diagram below shows the actual data and the fitted model values for the divided links.

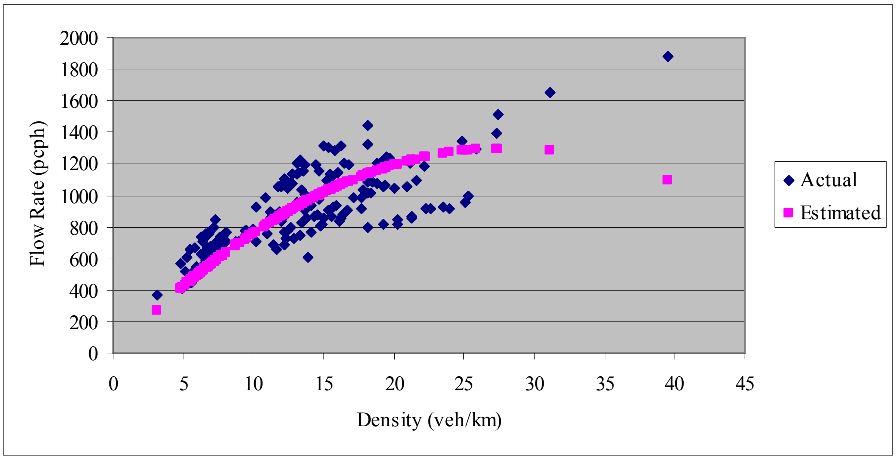


Figure 5.3 Flow Rate-Density Relationship at the Divided Links

According to the flow rate & density model result for the divided links, the estimated flow rate values are computed depending on the density values. Thus, the estimated and actual flow rate values are compared with each other at the diagram below. Moreover, the best regression equation is obtained for the data on the scatter diagram.

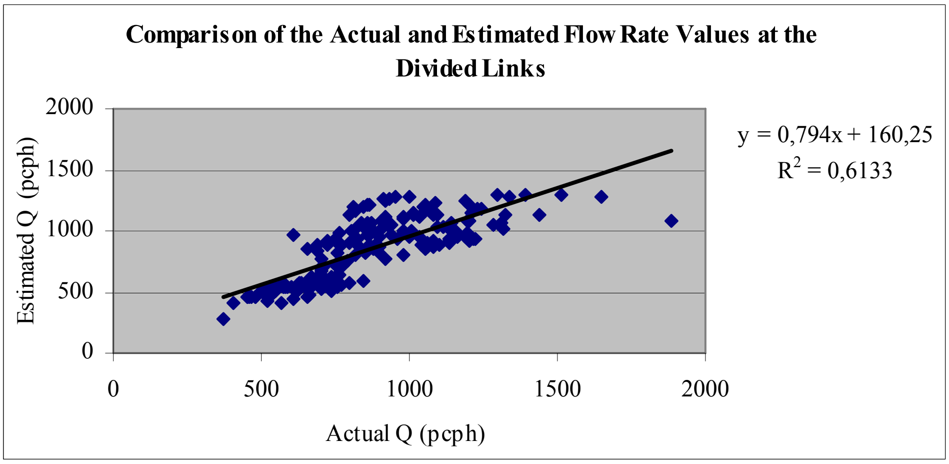


Figure 5.4 Comparison of Actual and Estimated Flow Rate Values at the Divided Links

Moreover, to find the best fit regression equation, the regression analysis is performed for the undivided flow rate-density data as well. Thus, the regression results are given below:

Table 5.4 Flow Rate & Density Regression Results for the Undivided Links

Regression Statistics	
Multiple R	0,984107043
R Square	0,968466673
Adjusted R^2	0,962735932
Standard Error	68,28621642
Observations	182

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	25778253,4	12889126,7	2764,12318	2,69E-135
Residual	180	839341,323	4663,00735		
Total	182	26617594,7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
X Variable 1	44,3607886	1,52307187	29,125867	4,99008E-70
X Variable 2	0,85611637	0,10479078	-8,169768	5,29122E-14

Therefore, for the undivided links the best regression equation fitting to the flow rate-density data is:

$$V = 44,36079*D - 0,85612*D^2 \quad (5.17)$$

The scatter diagram below shows the actual data and the fitted model values for the undivided links.

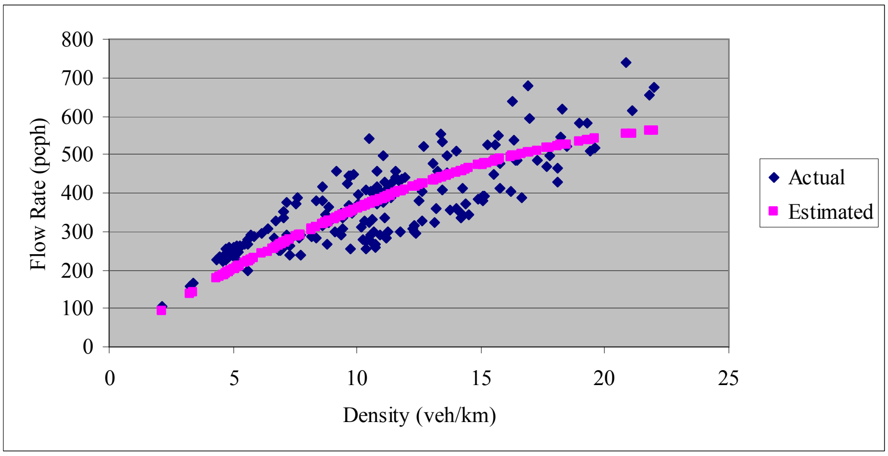


Figure 5.5 Flow Rate-Density Relationship at the Undivided Links

According to the flow rate & density model result for the undivided links, the estimated flow rate values are calculated like for the divided links. Thus, the comparison of the actual and estimated flow rate values is depicted in Figure 5.6. Also, the regression equation is displayed in the figure below.

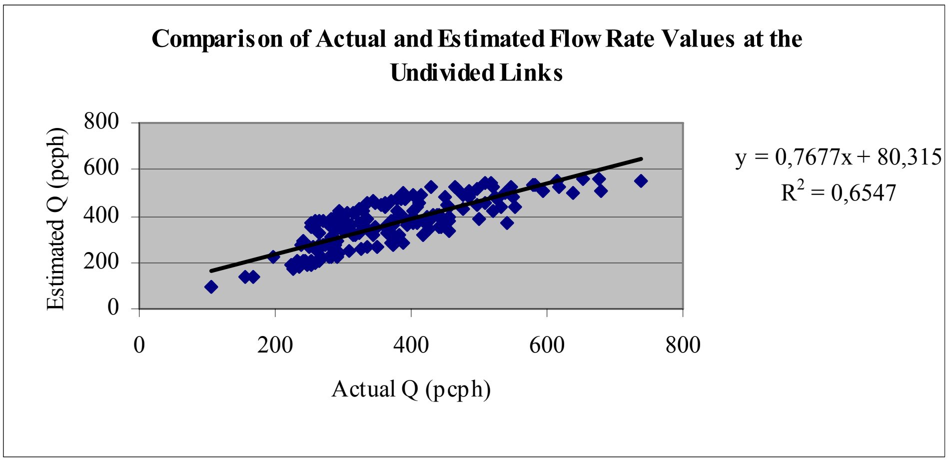


Figure 5.6 Comparison of Actual and Estimated Flow Rate Values at the Undivided Links

5.2.4. Density-Travel Speed Relationship for all the Selected Divided and Undivided Links

The form of the density-speed relationship manifests a linear first-order function. Thus, in the density-speed relationship the density is selected as the dependent variable, whereas the travel speed is selected as the regressor variable. Then, the regression analysis is performed for the corresponding pairs of density-travel speed data and the regression results are displayed in the following page:

Table 5.5 Density & Travel Speed Regression Results for the Divided Links

Regression Statistics	
Multiple R	0,673101858
R Square	0,453066111
Adjusted R^2	0,45002759
Standard Error	4,429863733
Observations	182

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2926,03815	2926,03815	149,1074182	2,275E-25
Residual	180	3532,26469	19,6236927		
Total	181	6458,30284			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	31,2848075	1,53930138	20,32403	1,7638E-48
X Variable 1	0,47049202	0,03853032	12,210955	2,27468E-25

Therefore, the straight line model function for the divided links is obtained as below:

$$D = 31,28481 - 0,47049*S \qquad (5.18)$$

To find the jammed density via the density-travel speed model function, the travel speed is expressed as zero in the equation above. Thus, the jammed density is computed as 31,28 veh/km.

The density-speed relationship diagram of the divided links depicts the actual data and the fitted model values in the next page.

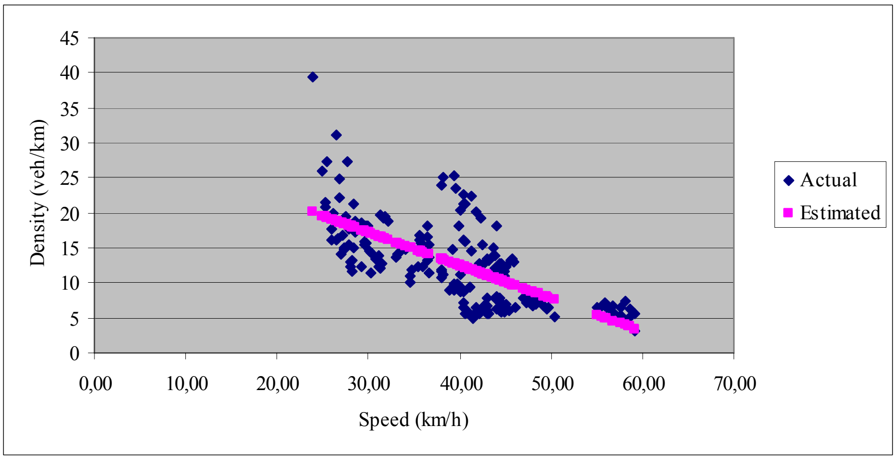


Figure 5.7 Density-Speed Relationship at the Divided Links

When the corresponding pairs of the density-travel speed values of the undivided links are utilized in the regression analysis, the regression results are obtained as below:

Table 5.6 Density & Travel Speed Regression Results for the Undivided Links

Regression Statistics	
Multiple R	0,707914563
R Square	0,501143029
Adjusted R^2	0,498371601
Standard Error	3,044086078
Observations	182

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1675,6064	1675,6064	180,8248665	5,486E-29
Residual	180	1667,96281	9,26646005		
Total	181	3343,56921			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	23,28874208	0,96277894	24,1890855	1,86421E-58
X Variable 1	-0,34326116	0,02552675	-13,447114	5,48554E-29

The straight line model function for the undivided links is obtained as below:

$$D = 23{,}28874 - 0{,}34326*S \tag{5.19}$$

Then, for the undivided links the jammed density is calculated as 23,28 veh/km.

The scatter diagram of the density-speed relationship for the undivided links below depicts the actual data and the fitted model values.

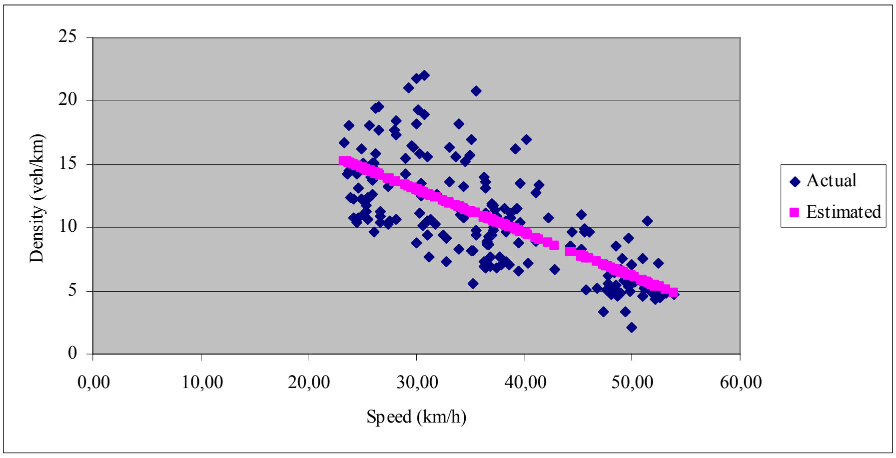


Figure 5.8 Density-Speed Relationship at the Undivided Links

5.3. Utilized Functional Forms to Develop the Link Capacity Functions

In literature, there are a few functional forms to develop the link capacity functions as given in Chapter 2. In this study, widely used BPR type and Overgaard functional forms expressed in mathematical approach are utilized for this study data. Additionally, the function that consists of V/C ratio and the dummy variables considered for this study is utilized in the regression analysis.

5.3.1. Modeling with the Function of V/C Ratio and Dummy Variables

In this study, after the flow rate and the capacity values of each direction are obtained, their ratio is used as the independent variable in the regression equation. Moreover, the dummy variables and the other variables are utilized as the independent variables in the same regression equations as well. The presence of the dense retail activity around the links (D_RETAIL) and the presence of the parking through the links (PARKING) are selected as the dummy variables. Besides, the number of the bus stops

(BUS_STOP) and the number of the signalized intersections (SIGN_INT) are entered into the regression analysis as the other independent variables. However, the travel time data is performed as the dependent variable in the regression analyses.

The various regression analyses are performed with respect to V/C ratio and the other independent variables for both the divided and undivided links in this study. Thus, the best regression results are taken into account to build the best model for this study. Shortly, the best regression results and the obtained regression model equations are indicated in this part.

Since the number of the independent variables is not considerable, the selected method of the regression analysis is "enter method" to develop the link capacity functions.

5.3.1.1 Modeling Results for all the Selected Divided Links

When all the independent variables are added into the regression analysis, the regression results for the divided links are obtained as below:

Table 5.7 Tentative Model Summary for the Divided Links

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,663[a]	,440	,362	42,23684

a. Predictors: (Constant), D_RETAIL, SIGN_INT, PARKING, VBOLUC, BUS_STOP

Table 5.8 Tentative Regression Results for the Divided Links

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	103,507	40,443		2,559	,015
	VBOLUC	92,716	39,486	,325	2,348	,024
	PARKING	-85,731	29,758	-,574	-2,881	,007
	SIGN_INT	1,493	5,143	,039	,290	,773
	BUS_STOP	20,095	15,543	,274	1,293	,204
	D_RETAIL	27,664	22,281	,185	1,242	,222

a. Dependent Variable: T_TIME

The results in Table 5.8 show that some variables have no statistically significance to build a model equation. For instance; when considering t-values of the independent variables, the variables SIGN_INT, BUS_STOP, PARKING, D_RETAIL are statistically insignificant.

Obviously, the variable PARKING indicates a sign distortion. This variable indicates the same distortion in the alternative regression analysis as well. Additionally, since the data related to the signal intersections are utilized in the capacity calculations, the variable SIGN_INT can be dropped from the model equation.

To sum up, every one of the variables is dropped and added in the regression analysis to obtain the best model. After the different combinations of the independent variables are entered into the regression analysis, the best model results are obtained as follow:

Table 5.9 Ultimate Model Summary for the Divided Links

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,525[a]	,276	,239	46,13303

a. Predictors: (Constant), D_RETAIL, VBOLUC

Table 5.10 Ultimate ANOVA Table for the Divided Links

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	31611,657	2	15805,828	7,427	,002[a]
	Residual	83001,986	39	2128,256		
	Total	114613,643	41			

a. Predictors: (Constant), D_RETAIL, VBOLUC

b. Dependent Variable: T_TIME

Table 5.11 Ultimate Regression Results for the Divided Links

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	77,125	24,359		3,166	,003
	VBOLUC	82,899	41,237	,291	2,010	,051
	D_RETAIL	52,442	21,575	,351	2,431	,020

a. Dependent Variable: T_TIME

The ultimate regression analysis results indicate that R Square is 0,276, so 27,6% of the variance is accounted for. Moreover, t-values are statistically significant even though they are low values for 95% confidence interval. Therefore, the best model equation for the divided links is:

$$T\_TIME = 77{,}125 + 82{,}899*VBOLUC + 52{,}442*D\_RETAIL \qquad (5.20)$$

If all of the coefficients are considered as zero (0) in the model equation above, in other words; there are not any traffic flow and the dense retail activity, the travel time equals to 77,125 sec/km at the divided links. Moreover, if VBOLUC equals to 1 and the effect of the dense retail activity is not considered in the model equation, the travel time is obtained as 77,125 + 82,899 = 160,024 sec/km. Depending on this, the travel speed is at 22,5 km/h when VBOLUC is 1.

In Figure 5.9 the estimated travel time values found via Equation 5.20 are compared with the observed travel time values.

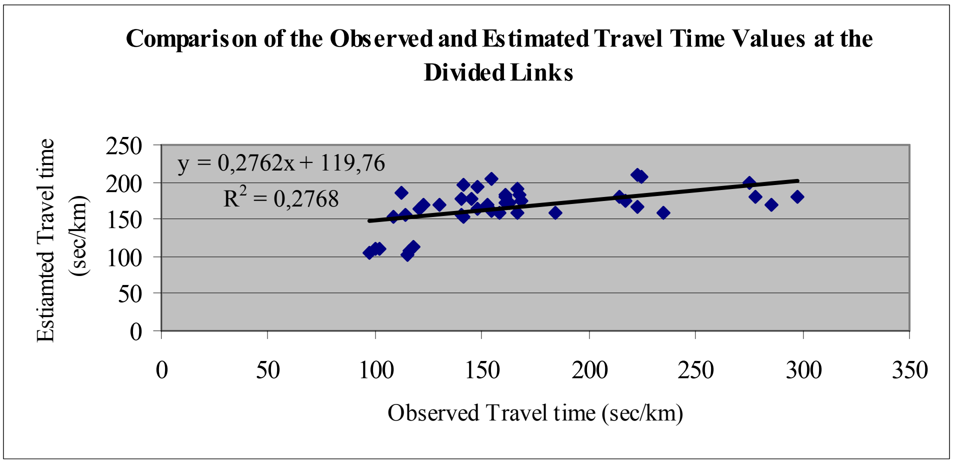


Figure 5.9 Comparison of the Observed and Estimated Travel Time Values via V/C Ratio and Dummy Variable Model at the Divided Links

Furthermore, the relationship between the estimated travel time values at the divided links and V/C ratio is depicted in Figure 5.10. In model building process there is also a statistically significant dummy variable that is the dense retail activity as well as V/C ratio. Thus, its effect is taken into account when the relationship in Figure 5.10 is displayed.

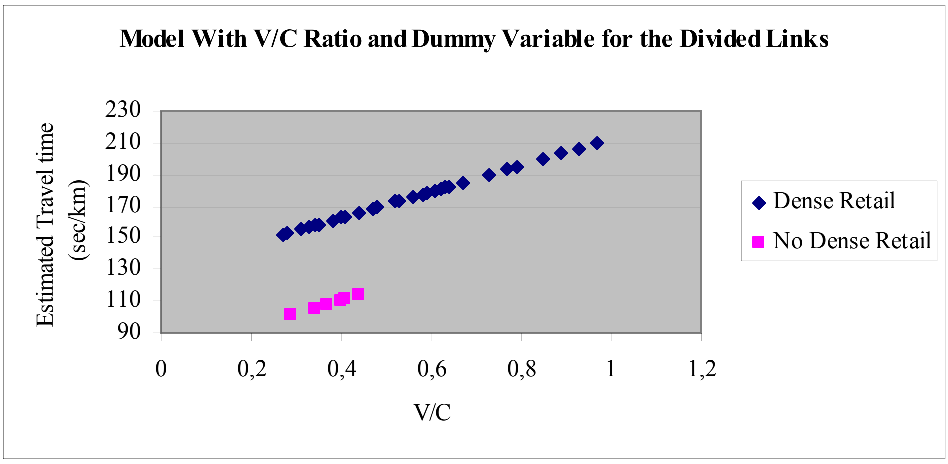


Figure 5.10 Estimated Travel Time Values and V/C Relationship via V/C Ratio and Dummy Variable Model at the Divided Links

5.3.1.2. Modeling Results for all the Selected Undivided Links

When all the independent variables are added into the regression analysis, the regression results for the undivided links are obtained in the following tables.

Table 5.12 Tentative Model Summary for the Undivided Links

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,895[a]	,802	,774	16,14756

a. Predictors: (Constant), D_RETAIL, VBOLUC, BUS_STOP, SIGN_INT, PARKING

Table 5.13 Tentative Regression Results for the Undivided Links

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	91,130	8,954		10,177	,000
	VBOLUC	38,226	14,959	,208	2,555	,015
	PARKING	18,469	8,706	,249	2,122	,041
	SIGN_INT	-9,371	2,811	-,349	-3,333	,002
	BUS_STOP	-,394	2,337	-,016	-,169	,867
	D_RETAIL	51,094	8,358	,753	6,114	,000

a. Dependent Variable: T_TIME

Depending on the regression results in Table 5.13, the variables SIGN_INT and BUS_STOP indicate sign distortion, whereas the t-values of the other independent variables are seemed to be statistically significant. Thus, the variables SIGN_INT and BUS_STOP are dropped and the remaining independent variables (VBOLUC, PARKING, D_RETAIL) are utilized in various combination in the regression analysis. Consequently; the variable PARKING is dropped because of its statistical insignificance. Furthermore, square of VBOLUC is obtained more reasonable for the modeling and the dummy variable D_RETAIL is seen to be statistically significant. Thus, the best model results are obtained as follows:

Table 5.14 Ultimate Model Summary for the Undivided Links

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,841[a]	,707	,692	18,86081

a. Predictors: (Constant), D_RETAIL, VBOLUC2

Table 5.15 Ultimate ANOVA Table for the Undivided Links

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	33457,262	2	16728,631	47,026	,000[a]
	Residual	13873,481	39	355,730		
	Total	47330,743	41			

a. Predictors: (Constant), D_RETAIL, VBOLUC2

b. Dependent Variable: T_TIME

Table 5.16 Ultimate Regression Results for the Undivided Links

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	98,576	6,251		15,771	,000
	VBOLUC2	37,035	15,397	,209	2,405	,021
	D_RETAIL	54,497	5,889	,803	9,254	,000

a. Dependent Variable: T_TIME

Depending on the ultimate regression analysis results shown above; R square is 0,707. This model accounts for 70,7% of the variance, therefore. Moreover, when the regression results in Table 5.16 are compared with the regression results for the divided links, the t-values are more reasonable in 95% confidence interval. Thus, the model for the undivided links seems more desirable. As a result, the best model equation for the undivided links is manifested as below:

$$T\_TIME = 98,576 + 37,035*VBOLUC2 + 54,497*D\_RETAIL \quad (5.21)$$

If the coefficients are considered as zero (0) in the model equation above, the travel time value is 98,576 sec/km at the undivided links. If VBOLUC2 is equals to 1 and the effect of the dense retail activity is not considered in the model equation, the travel time is obtained as 98,576 + 37,035 = 135,611 sec/km. Moreover, the travel speed is at 26,54 when VBOLUC2 is 1.

In the figure below the estimated travel time values obtained via Equation 5.21 are compared with the actual travel time values observed at the undivided links. Depending on the regression results in Figure 5.11, it is interpreted that the undivided links' model is more desirable than the model of the divided links.

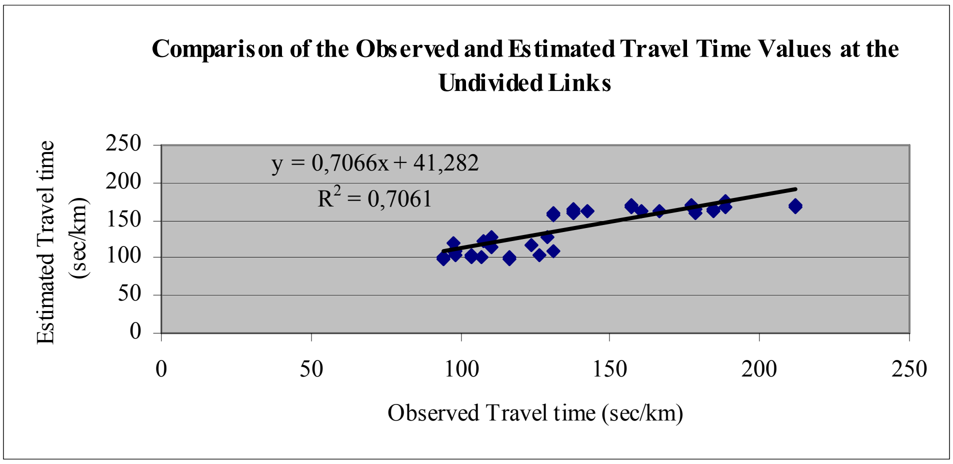


Figure 5.11 Comparison of the Observed and Estimated Travel Time Values via V/C Ratio and Dummy Variable Model at the Undivided Links

Apart from the comparison of the observed and estimated travel time values, the relationship between the estimated travel time values and V/C ratio is displayed in Figure 5.12. In this figure, the effect of the dense retail activity on the travel time is also displayed.

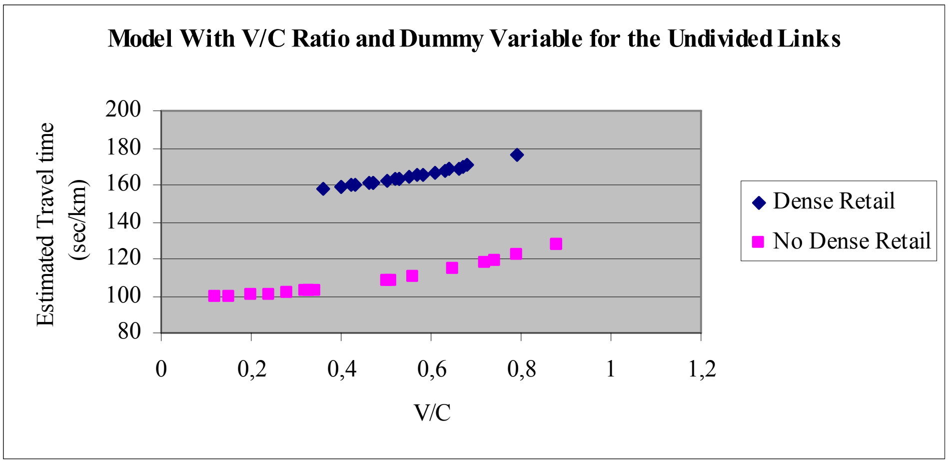


Figure 5.12 Estimated Travel Time Values and V/C Ratio Relationship via V/C Ratio and Dummy Variable Model at the Undivided Links

5.3.2. Modeling with BPR Type Function and Results

BPR type function is performed alternatively to develop the link capacity functions in this study. As displayed in Chapter 2 BPR type function is expressed below:

$$T = T_0*[1 + \alpha*(V/C)^{\beta}] \tag{5.22}$$

Where

T = Travel time (sec/km)

T_0 = Free flow travel time/km

V/C = Flow rate/capacity

Starting points of the model parameters $\alpha = 0.15$, $\beta = 4$

Since this function is not linear in the parameters, non linear regression analysis is utilized. Therefore, after a few iterations, the obtained non-linear regression results for the divided links as shown below:

Table 5.17 Non-Linear Regression Results (with BPR) for the Divided Links

Dependent Variable T_TIME

Source	DF	Sum of Squares	Mean Square
Regression	2	1170092,47352	585046,23676
Residual	40	95134,95833	2378,37396
Uncorrected Total	42	1265227,43185	
(Corrected Total)	41	114613,64308	

R squared = 1 - Residual SS / Corrected SS = ,16995

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
A	2,007900528	,302204152	1,397123154	2,618677901
B	,652019683	,232426043	,182269127	1,121770239

Asymptotic Correlation Matrix of the Parameter Estimates

	A	B
A	1,0000	,8535
B	,8535	1,0000

Thus, the obtained model is:

$$T\_TIME = T_0 * (1 + 2 * (V/C)^{0,652}) \qquad (5.23)$$

The model constant T_0 is computed by free flow speed value. Free flow speed is assumed as 50 km/h at the divided links.

Depending upon BPR type model result, the estimated travel time and observed travel time are compared with each other in Figure 5.13. Consequently, the regression results in this figure state that the modeling via BPR function for the divided links is less reasonable than the modeling with V/C ratio and the dummy variable.

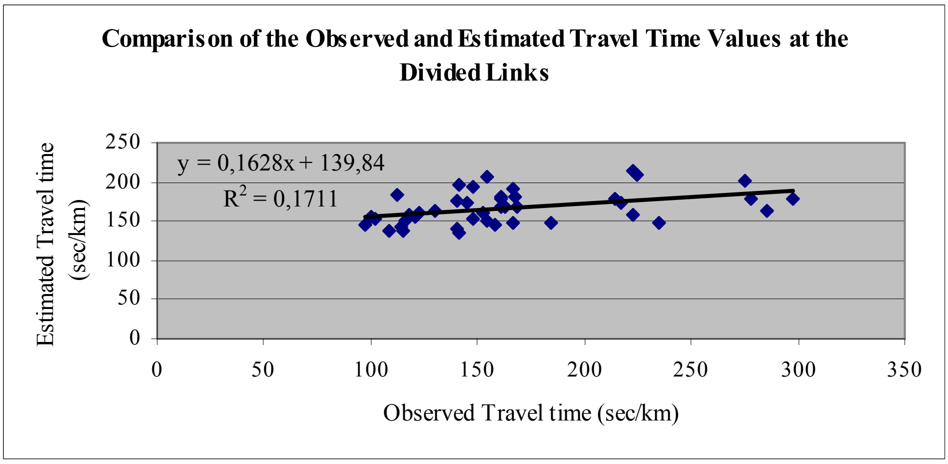


Figure 5.13 Comparison of the Observed and Estimated Travel Time Values via BPR Model at the Divided Links

The relationship between the travel time estimated via BPR model function and V/C ratio is displayed in Figure 5.14. Since the modeling via BPR model function does not include any dummy variable, the only thing stressed is the free flow speed in Figure 5.14.

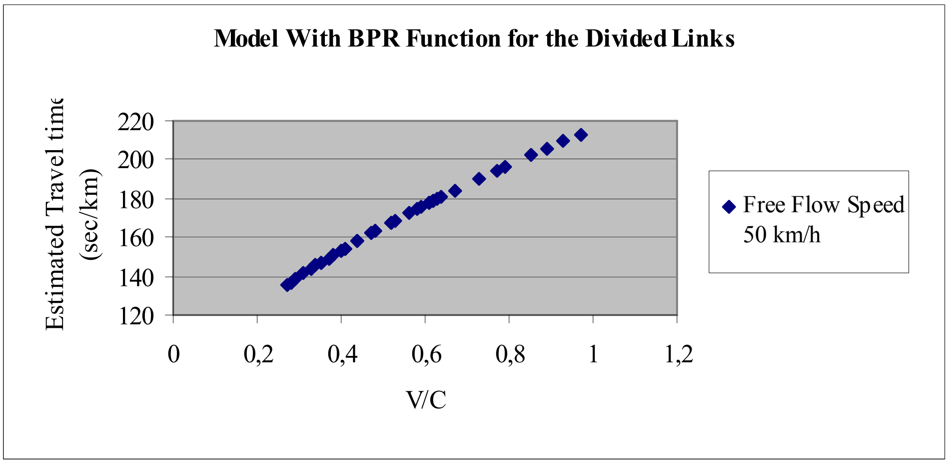


Figure 5.14 Estimated Travel Time Values and V/C Ratio Relationship via BPR Model at the Divided Links

Moreover, after a few iterations, the non-linear regression results for the undivided links are obtained in the following table:

Table 5.18 Non-Linear Regression Results (with BPR) for the Undivided Links

Dependent Variable T_TIME

Source	DF	Sum of Squares	Mean Square
Regression	2	851406,86958	425703,43479
Residual	40	27582,62715	689,56568
Uncorrected Total	42	878989,49673	
(Corrected Total)	41	47330,74294	

R squared = 1 - Residual SS / Corrected SS = ,41724

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
A	,187133447	,241591868	-,301141932	,675408826
B	2,858337212	3,282990151	-3,776833388	9,493507812

Asymptotic Correlation Matrix of the Parameter Estimates

	A	B
A	1,0000	,8758
B	,8758	1,0000

Thus, the model is obtained as:

$$T\_TIME = T_0 * (1 + 0,187 * (V / C)^{2,858}) \qquad (5.24)$$

In the modeling process of this study, the free flow speed values are assumed as 30 km/h and 20 km/h at the undivided links.

The travel time values estimated via BPR function are compared with the observed travel time values in Figure 5.15 in the next page. It is interpreted that the modeling via BPR function for the undivided links is more reasonable than the modeling via BPR function for the divided links.

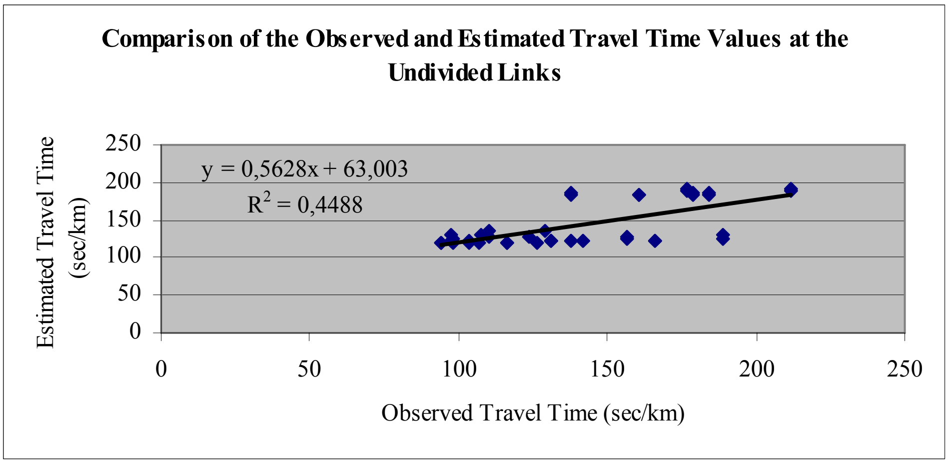


Figure 5.15 Comparison of the Observed and Estimated Travel Time Values via BPR Model at the Undivided Links

Furthermore, the travel time values estimated via BPR model function are related with V/C ratio in Figure 5.16. There are different free flow speed values in Figure 5.16. The assumption of the different free flow speed values at the undivided links stems from the different speed characteristics of the links. Therefore, the figure below shows the relationship between the estimated travel time and V/C ratio depending on the free flow speed values that are utilized in modeling process via BPR function.

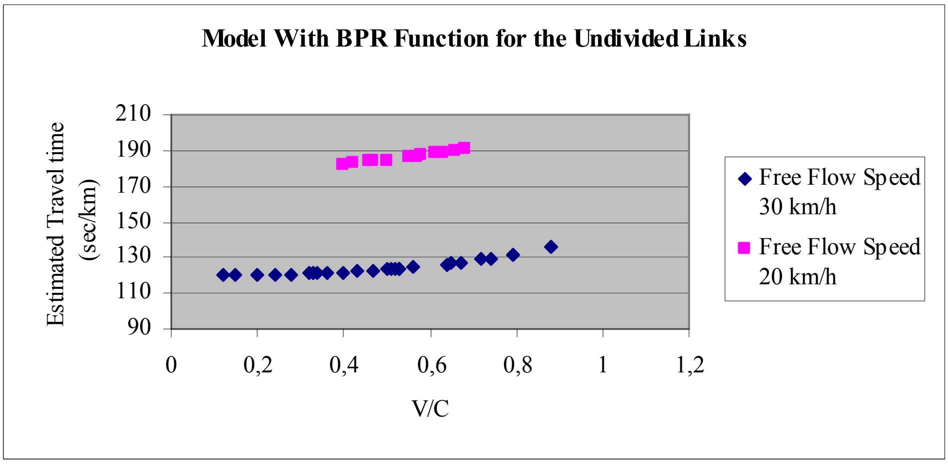


Figure 5.16 Estimated Travel Time Values and V/C Ratio Relationship via BPR Model at the Undivided Links

5.3.3. Modeling with Overgaard Type Function and Results

The Overgaard non-linear function is calibrated to obtain an alternative model for this study. The function proposed by Overgaard is:

$$T = T_0 * \alpha^{(Q/C)^\beta} \tag{5.25}$$

Where

T = Travel time (sec/km)

T_0 = Free flow travel time/km

Q/C = Flow rate/capacity

Presumed starting points of the model parameters $\alpha = 0.15$, $\beta = 4$

After a few iterations are carried out, the obtained non-linear regression analysis results for the divided links are indicated below:

Table 5.19 Non-Linear Regression Results (with Overgaard) for Divided Links

Dependent Variable T_TIME

Source	DF	Sum of Squares	Mean Square
Regression	2	1169918,59559	584959,29779
Residual	40	95308,83626	2382,72091
Uncorrected Total	42	1265227,43185	
(Corrected Total)	41	114613,64308	

R squared = 1 - Residual SS / Corrected SS = ,16843

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
A	3,027515371	,321030244	2,378689045	3,676341697
B	,433023254	,155259513	,119232072	,746814435

(cont. on next page)

Table 5.19 (cont.)

Asymptotic Correlation Matrix of the Parameter Estimates

	A	B
A	1,0000	,8391
B	,8391	1,0000

Thus, the model is obtained as:

$$T\_TIME = T_0 * 3{,}027^{(Q/C)^{0,433}} \tag{5.26}$$

The free flow speed is assumed as 50 km/h at the divided links to calculate the constant T_0.

In Figure 5.17 the travel time estimated via Overgaard model function are compared with the observed travel time at the divided links. The regression results in the figure below show the similar expression with BPR model for the divided links.

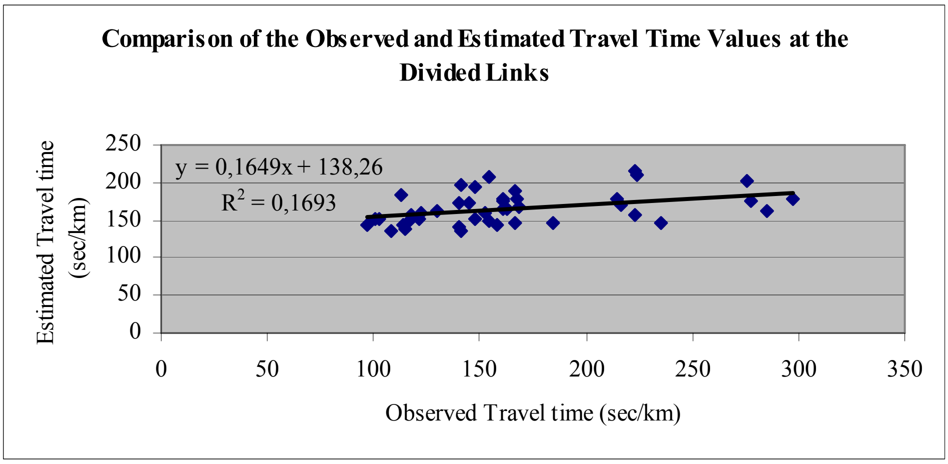


Figure 5.17 Comparison of the Observed and Estimated Travel Time Values via Overgaard Model at the Divided Links

Furthermore, Figure 5.18 shows the relationship between the travel time estimated via Overgaard model function and V/C ratio.

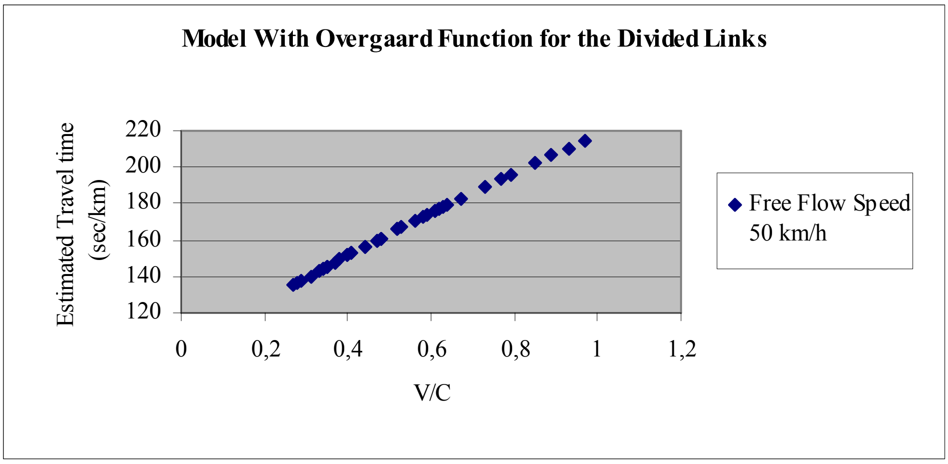


Figure 5.18 Estimated Travel Time Values and V/C Ratio Relationship via Overgaard Model at the Divided Links

After a few iterations are carried out, the obtained non-linear regression analysis results for the undivided links are indicated below:

Table 5.20 Non-Linear Regression Results (with Overgaard) for the Undivided Links

Dependent Variable T_TIME

Source	DF	Sum of Squares	Mean Square
Regression	2	851388,70573	425694,35287
Residual	40	27600,79100	690,01977
Uncorrected Total	42	878989,49673	
(Corrected Total)	41	47330,74294	

R squared = 1 - Residual SS / Corrected SS = ,41685

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
A	1,187940387	,253750862	,675090763	1,700790010
B	2,756177944	3,187682964	-3,686369647	9,198725534

Asymptotic Correlation Matrix of the Parameter Estimates

	A	B
A	1,0000	,8723
B	,8723	1,0000

Thus, the model equation is below:

$$T\_TIME = T_0 * 1{,}187^{(Q/C)^{2,756}} \tag{5.27}$$

The free flow speed is assumed as 30 km/h and 20 km/h at the undivided links to calculate T_0.

Figure 5.19 shows the comparison between the estimated travel time and observed travel time at the undivided links. Moreover, it is interpreted that there is a similarity between BPR and Overgaard models in terms of the regression results for the undivided links.

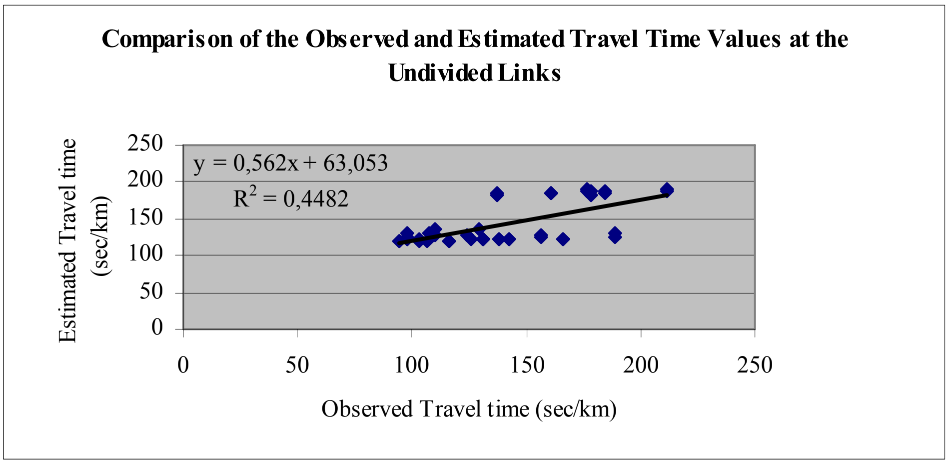


Figure 5.19 Comparison of the Observed and Estimated Travel Time Values via Overgaard Model at the Undivided Links

In Figure 5.20 the relationship between the travel time values estimated via Overgaard model function and V/C ratio is displayed. For the undivided links, there are two free flow speed values utilized in the modeling process. Thus, the different effects of those free flow speed values on travel time are depicted in Figure 5.20.

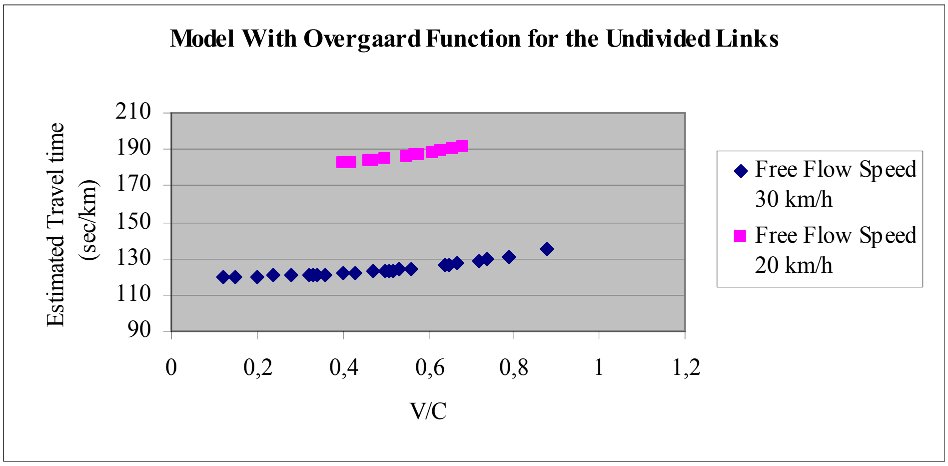


Figure 5.20 Estimated Travel Time Values and V/C Ratio Relationship via Overgaard Model at the Undivided Links

5.4. Comparison of the Modeling Results

This part compares the model results obtained with V/C & dummy variables, BPR function and Overgaard function. Thus, the actual values and different model results are depicted in the scatter diagrams for both divided and undivided links separately.

The scatter diagrams below indicate how the fitted values of the dependent variable (travel time) overlap the actual data.

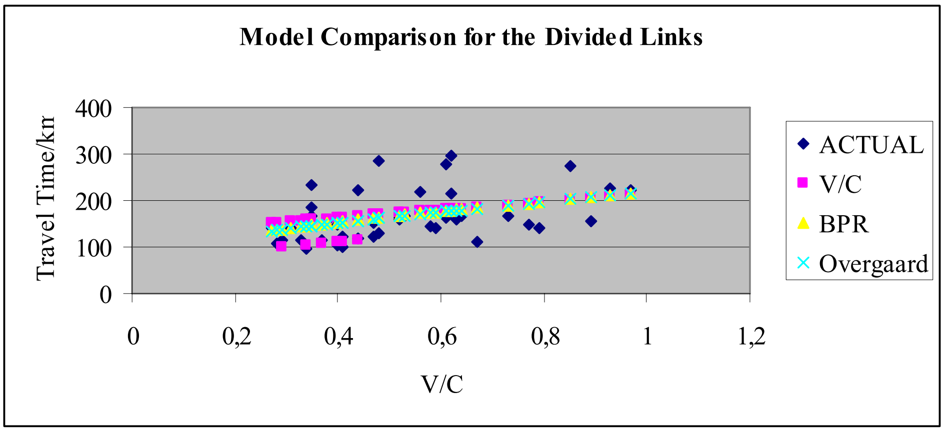


Figure 5.21 Model Comparisons for the Divided Links

In Figure 5.21 it is seen that BPR and Overgaard model results are fairly close to each other. Moreover, V/C model values can depict more appropriate overlapping the actual data since V/C model includes a dense retail dummy variable. So, V/C model can be the best model for the divided links.

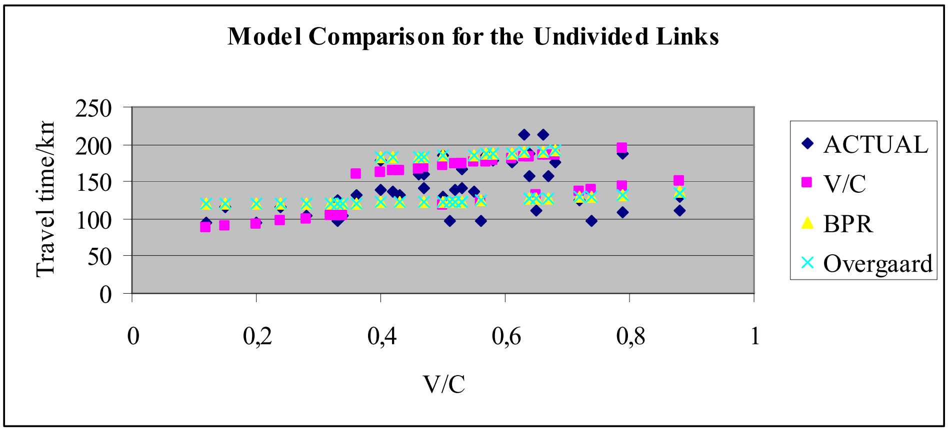


Figure 5.22 Model Comparisons for the Undivided Links

In Figure 5.22 BPR and Overgaard model results are fairly close to each other once more. But, for the undivided links BPR and Overgaard models depict better overlapping the actual data than for the divided links.

V/C model includes a dense retail dummy variable. Therefore, V/C model is able to provide more suitable overlapping the actual data. As a result, V/C model is preferred as the best model with 0,707 R square for the undivided links.

CHAPTER 6

CONCLUSIONS

This thesis study mainly answers what the link capacity functions are and how to develop the link capacity functions. Therefore, in the initial chapters, this study mainly tries to explain the concept of the link capacity functions depending on the literature. Besides, in the latter chapters it examines the data collection process, the data analyses and the modeling process in order to highlight how to develop the link capacity functions at the selected links in Izmir.

Depending on the literature review, the initial chapters have also focused on the proposed approaches related to link capacity functions, the concept of the capacity and the fundamental relationships among speed-flow rate, speed-density and flow rate-density. Furthermore, the relationships among speed-flow rate, speed-density and flow rate-density are at the divided and undivided links have been examined in the latter chapters. Moreover, the main algebraic equations concerning the speed-flow rate, speed-density and flow rate-density relationships have been built. Depending on this, the critical speed, the jammed density, the free flow speed and the capacity values are obtained for both the selected divided and undivided links.

After the literature review, the data collection part of this thesis has explained the necessary variables to develop the link capacity functions. Particularly, that part displays the marginal results of the gauged travel times and the computed travel speeds. The travel time studies were conducted at the morning, noon and evening peak hours on the selected links, and the obtained travel time data per kilometer were utilized in the modeling process directly. Additionally, according to the lowest and highest average travel time observations in this study, the lowest value is 94,01 sn/km observed at Anadolu Street (Tepekule)-NS within noon peak hour, and the highest value is 297,3 sn/km observed at Sairesref Street-SN within evening peak hour. Moreover, the lowest average speed is computed as 12,10 km/h at Sairesref Street-SN and the highest average speed is computed as 38,25 km/h at Anadolu Street (Tepekule)-NS during the peak hours.

Furthermore, the modeling methodology has adopted the regression analysis in which the various independent variables and the dependent variable that is the travel time are utilized. Moreover, it is interpreted that the modeling is much more responsive to V/C ratio and a dummy variable that is the presence of the dense retail activity. Therefore, the best link capacity function model is built with V/C ratio and the dummy variable that is the dense retail activity for both divided and undivided links. Furthermore, the alternative models obtained with BPR and Overgaard functions manifest similar fitting for both divided and undivided links. However, they have show worse overlapping to the actual data than V/C model.

Another point is that the modeling results for the undivided links are more desirable than the modeling results for divided links.

In the data analysis part of this thesis, Greenshields' models are utilized. That is to say, the analyses results can be different for this study if other models in the literature are used.

From the perspective of city planning, the modeling results stress that the presence of the dense retail activity that are located along the selected links leads to increase in the travel time. Thus, it could be interpreted that the allocation of the sides of the arterials to the dense retail activity should be meticulously assessed in city planning studies in İzmir.

As a result, this study is thought to support the future tasks related to the traffic engineering and transportation modeling in İzmir. Especially, this study can become an appropriate source to the traffic assignment modeling process. Moreover, the obtained models for both the divided and the undivided links provide estimated travel time values basing on substituted (V/C) value and the dummy variable dense retail activity in the obtained model equations.

To sum up, after all of the steps of this study were explained, this thesis ultimately proposed the particular link capacity functions for both divided and undivided links in İzmir.

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APPENDIX A

LINK BY LINK FLOW RATE-SPEED-DENSITY RELATIONSHIPS

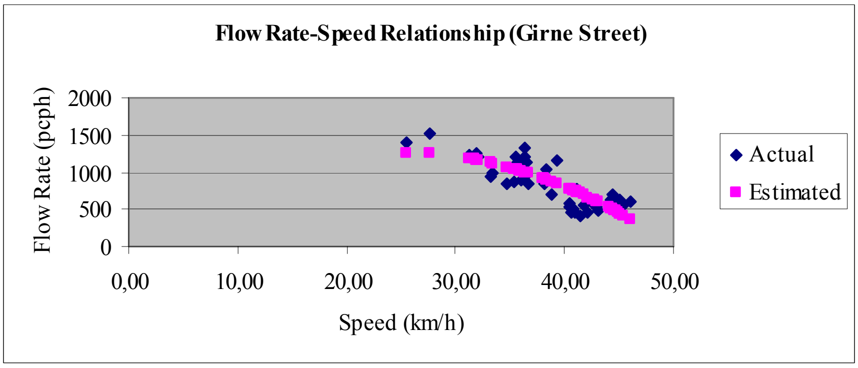

Figure A.1 Flow Rate-Speed Relationship at Girne Street

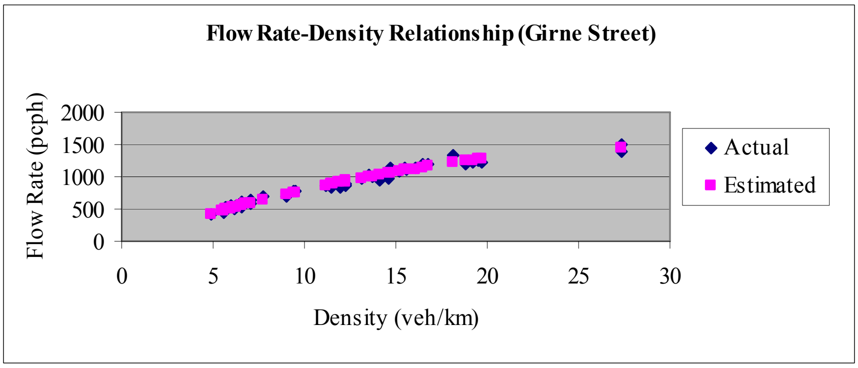

Figure A.2 Flow Rate-Density Relationship at Girne Street

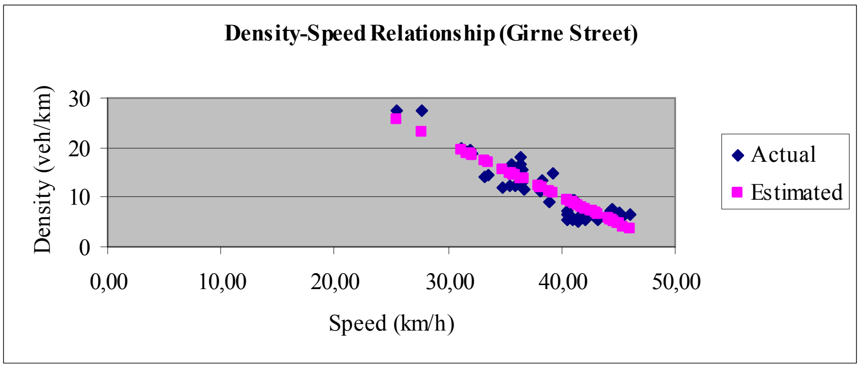

Figure A.3 Density-Speed Relationship at Girne Street

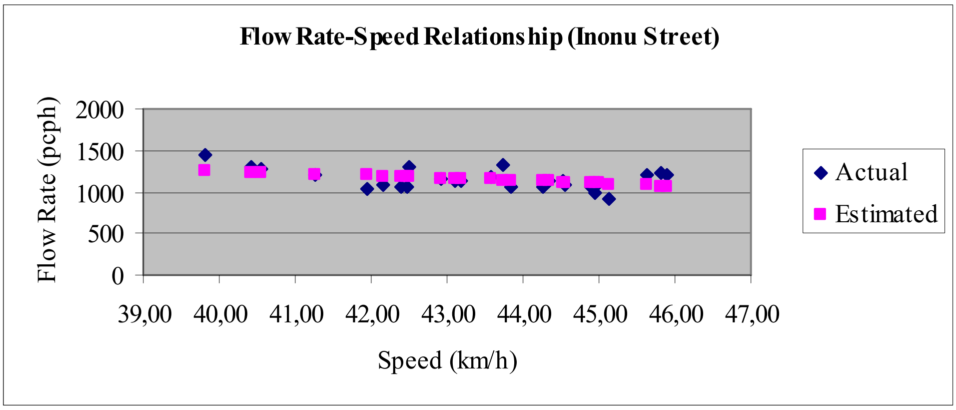

Figure A.4 Flow Rate-Speed Relationship at Inonu Street

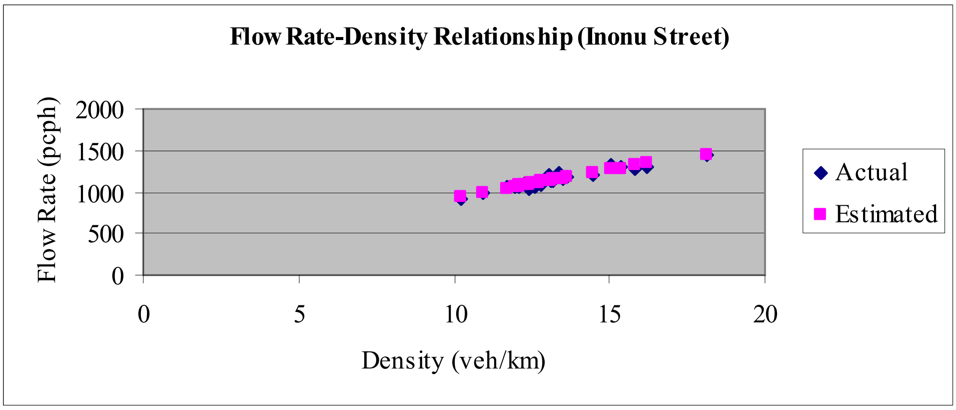

Figure A.5 Flow Rate-Density Relationship at Inonu Street

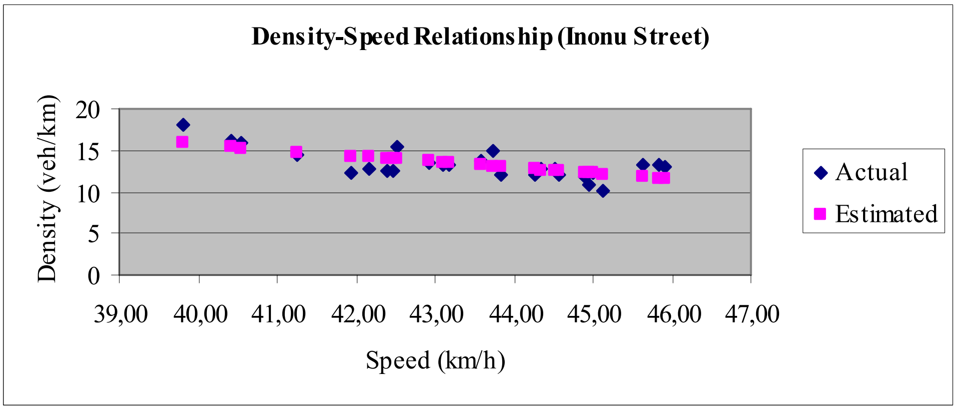

Figure A.6 Density-Speed Relationship at Inonu Street

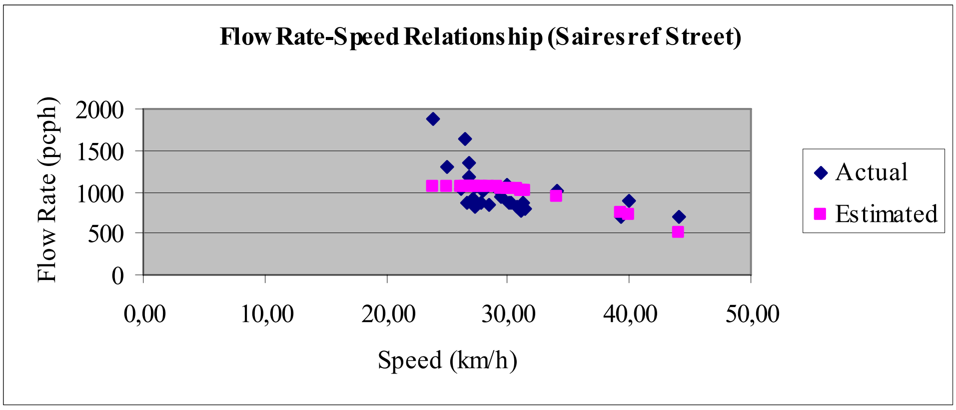

Figure A.7 Flow Rate-Speed Relationship at Sairesref Street

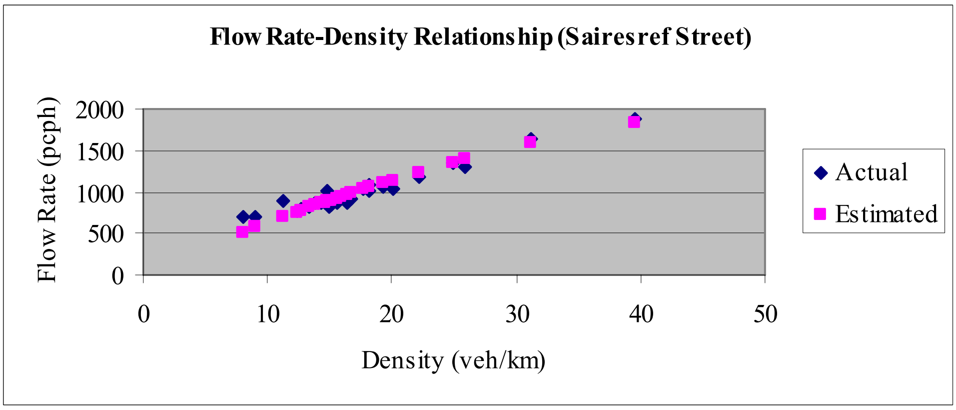

Figure A.8 Flow Rate-Density Relationship at Sairesref Street

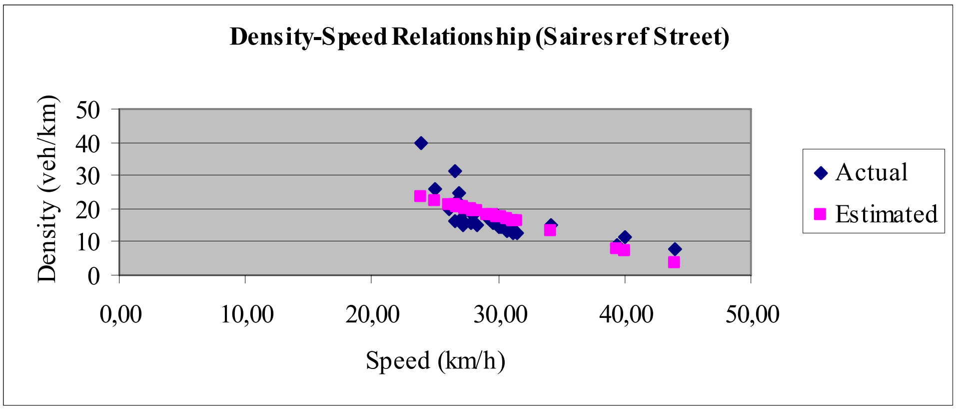

Figure A.9 Density-Speed Relationship at Sairesref Street

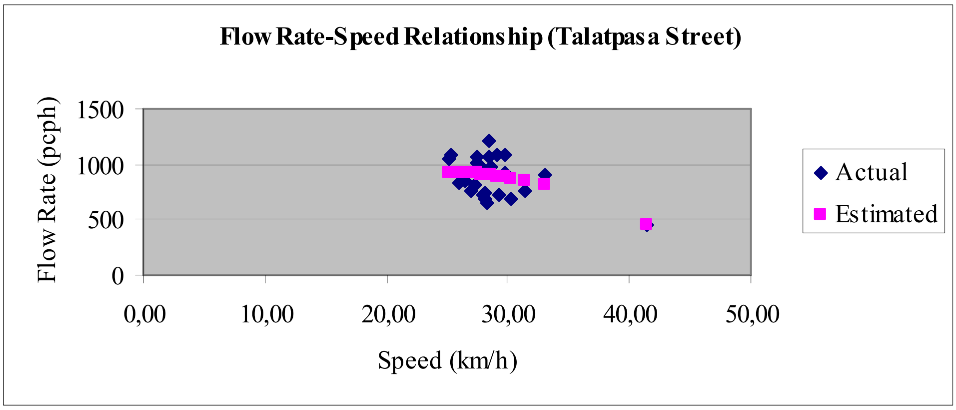

Figure A.10 Flow Rate-Speed Relationship at Talatpasa Street

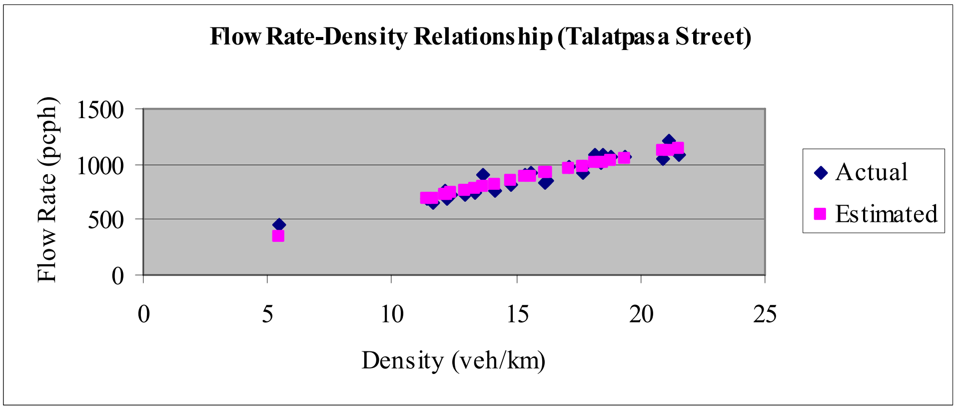

Figure A.11 Flow Rate-Density Relationship at Talatpasa Street

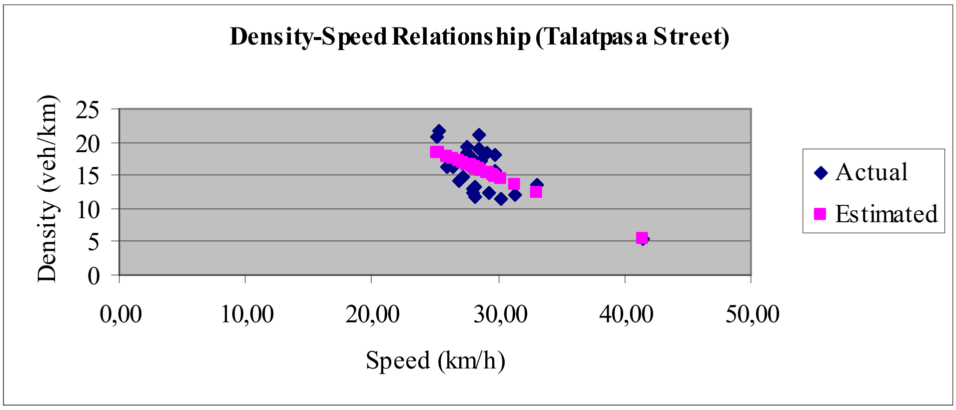

Figure A.12 Density-Speed Relationship at Talatpasa Street

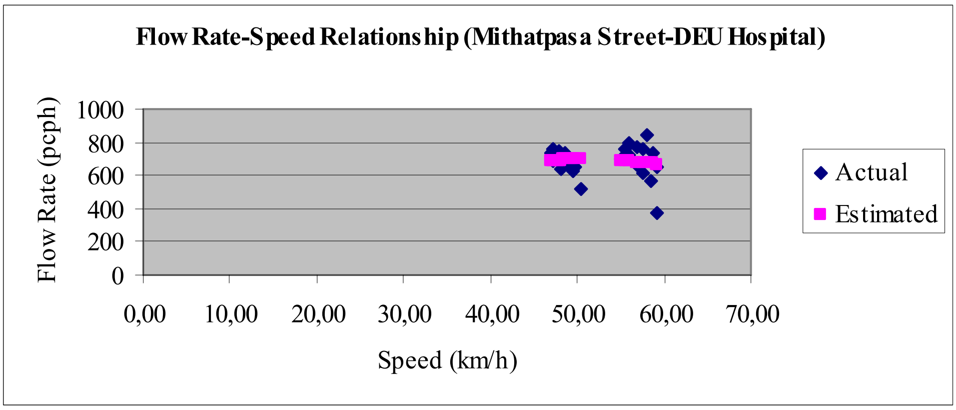

Figure A.13 Flow Rate-Speed Relationship at Mithatpasa Street (DEU Hospital)

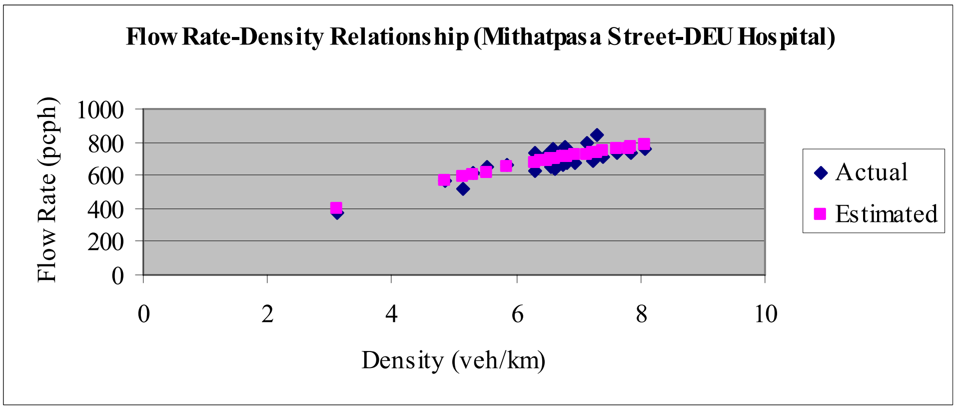

Figure A.14 Flow Rate-Density Relationship at Mithatpasa Street (DEU Hospital)

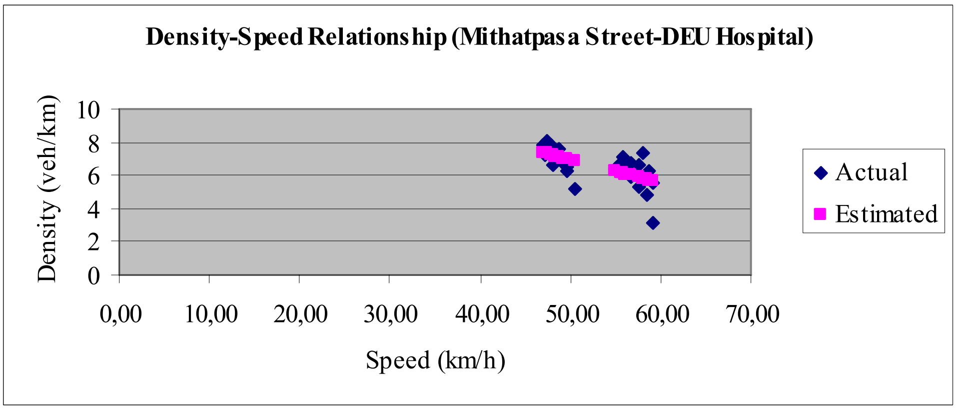

Figure A.15 Density-Speed Relationship at Mithatpasa Street (DEU Hospital)

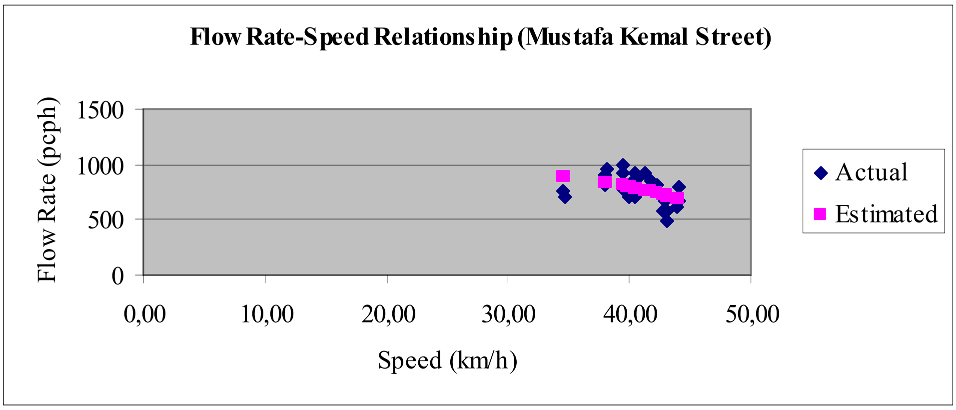

Figure A.16 Flow Rate-Speed Relationship at Mustafa Kemal Street

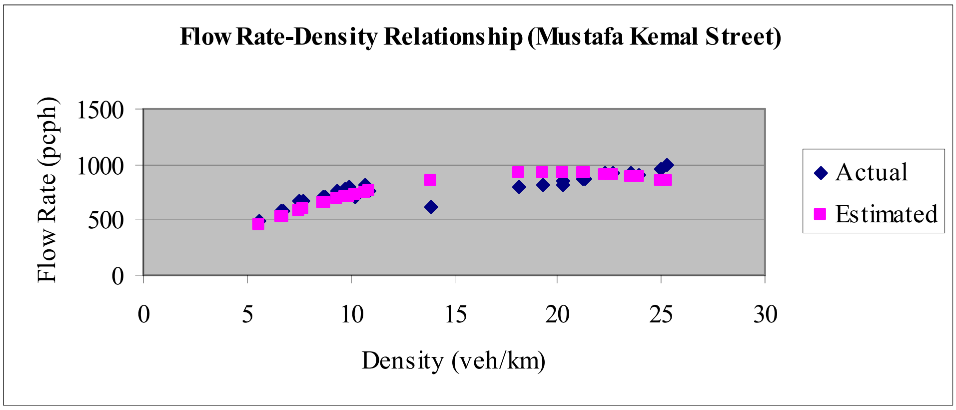

Figure A.17 Flow Rate-Density Relationship at Mustafa Kemal Street

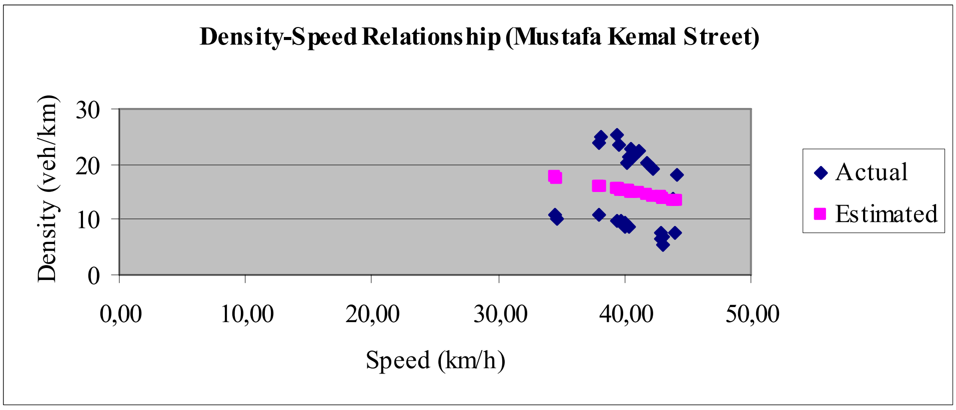

Figure A.18 Density-Speed Relationship at Mustafa Kemal Street

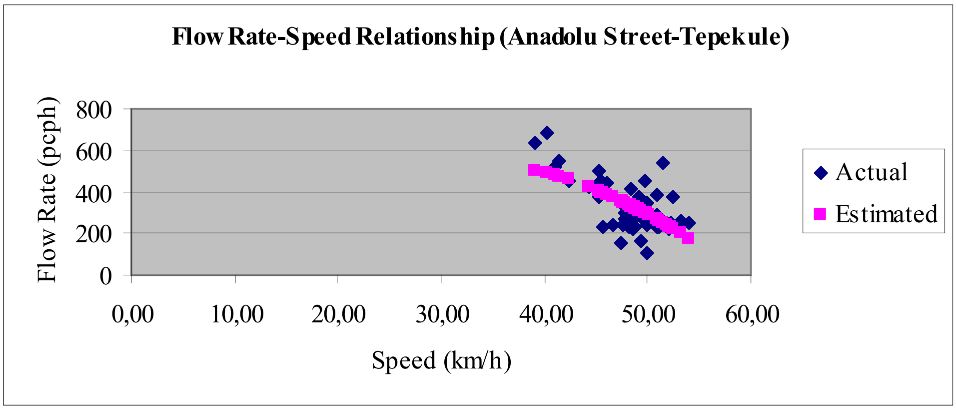

Figure A.19 Flow Rate-Speed Relationship at Anadolu Street (Tepekule)

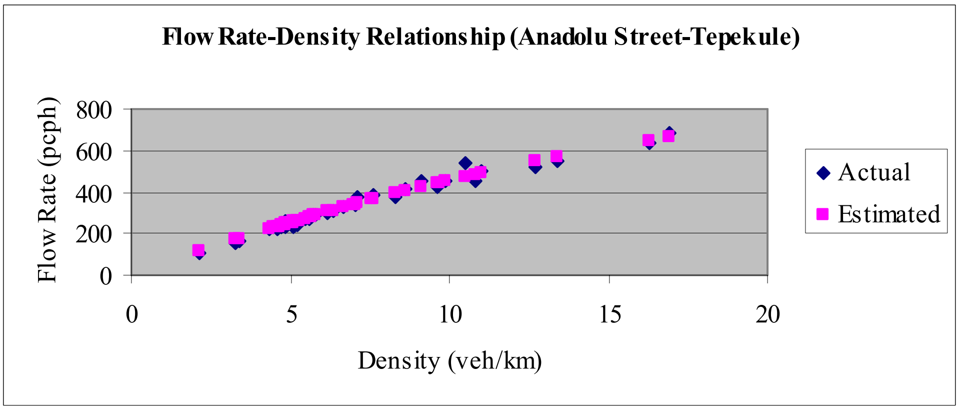

Figure A.20 Flow Rate-Density Relationship at Anadolu Street (Tepekule)

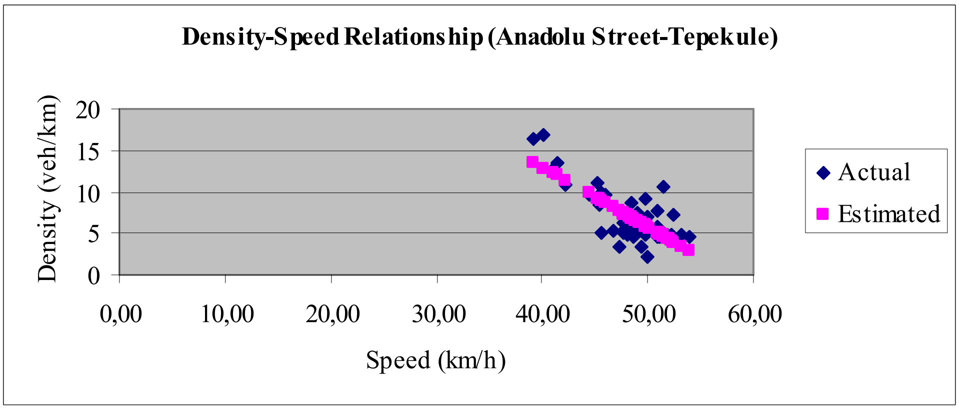

Figure A.21 Density-Speed Relationship at Anadolu Street (Tepekule)

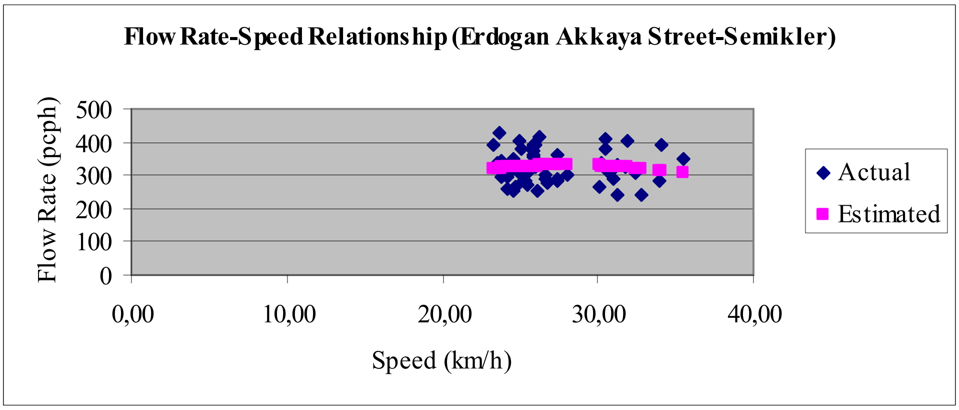

Figure A.22 Flow Rate-Speed Relationship at Erdogan Akkaya Street (Semikler)

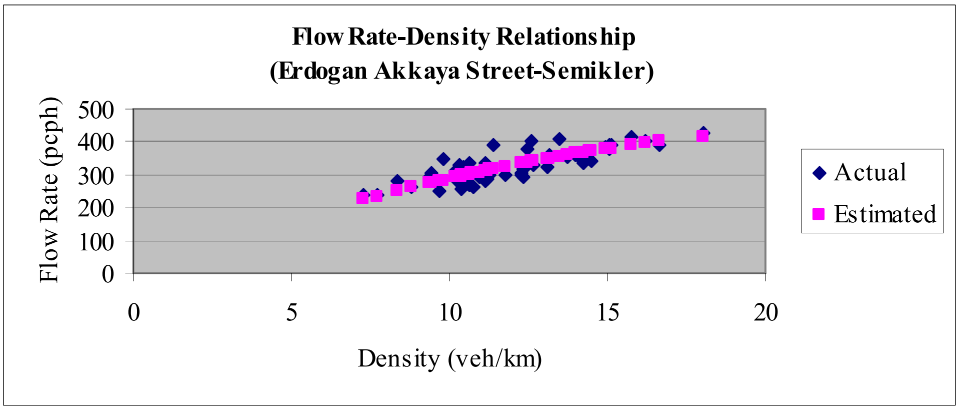

Figure A.23 Flow Rate-Density Relationship at Erdogan Akkaya Street (Semikler)

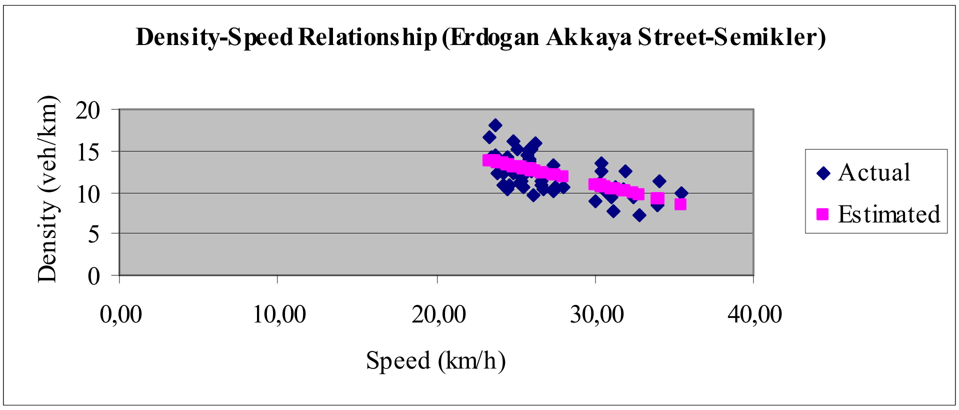

Figure A.24 Density-Speed Relationship at Erdogan Akkaya Street (Semikler)

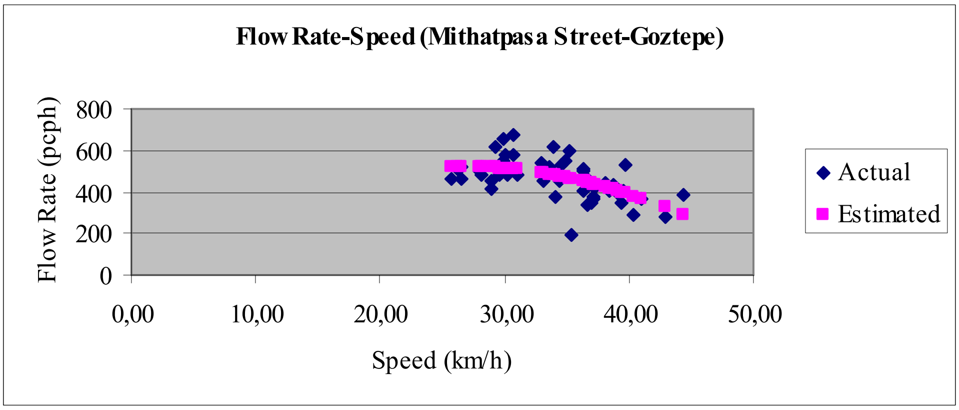

Figure A.25 Flow Rate-Speed Relationship at Mithatpasa Street (Goztepe)

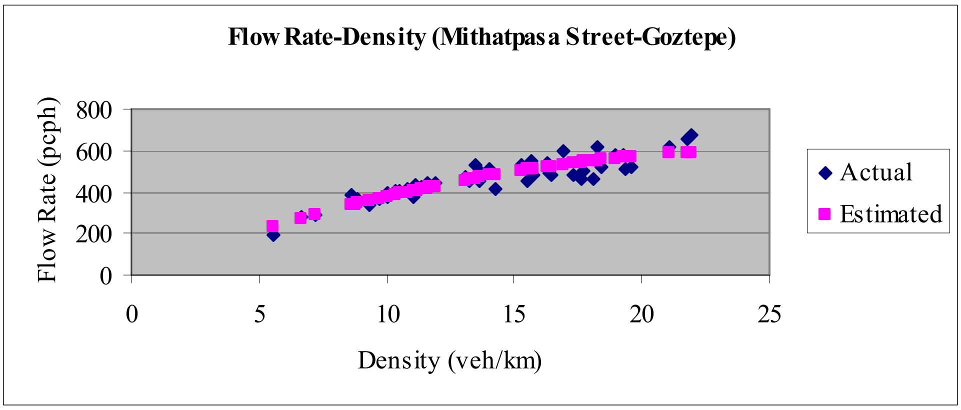

Figure A.26 Flow Rate-Density Relationship at Mithatpasa Street (Goztepe)

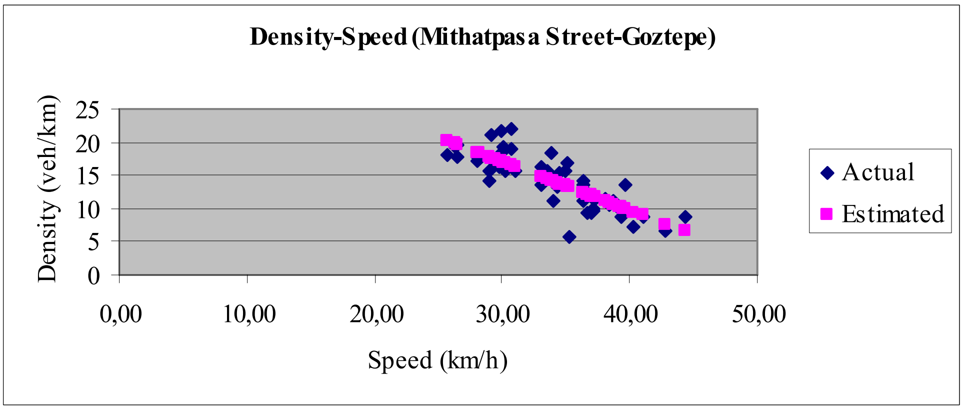

Figure A.27 Density-Speed Relationship at Mithatpasa Street (Goztepe)

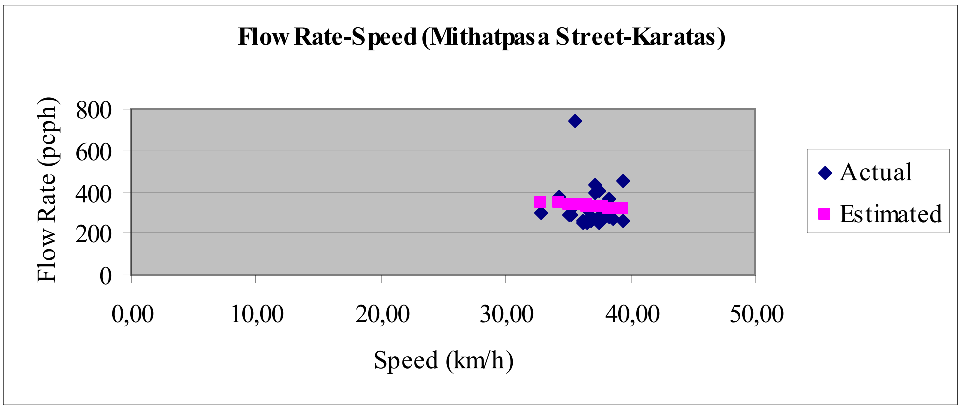

Figure A.28 Flow Rate-Speed Relationship at Mithatpasa Street (Karatas)

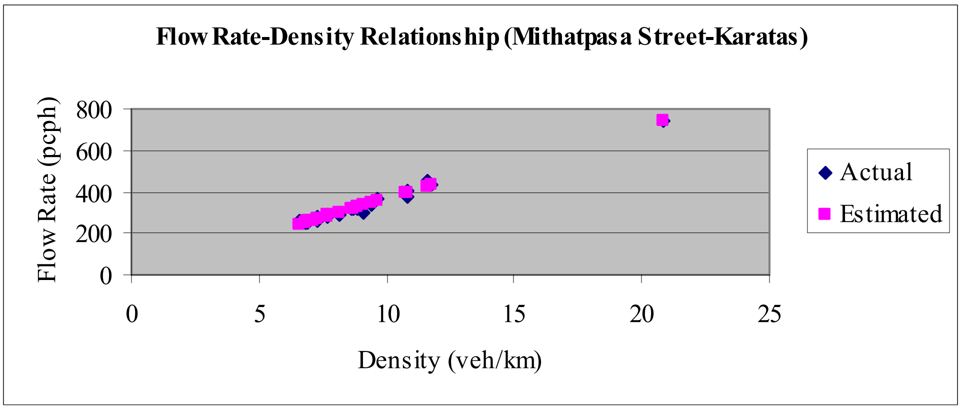

Figure A.29 Flow Rate-Density Relationship at Mithatpasa Street (Karatas)

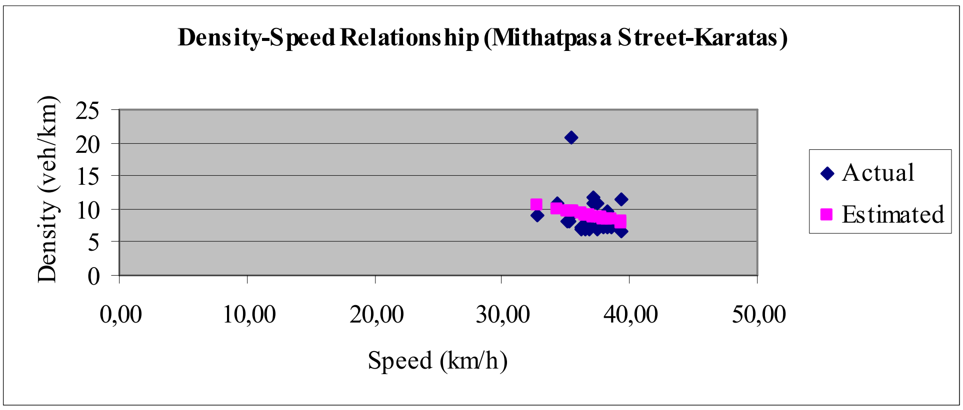

Figure A.30 Density-Speed Relationship at Mithatpasa Street (Karatas)