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UNIVERSITY OF ANBAR
COLLEGE OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT

PERFORMANCE ANALYSIS OF DIVIDED MULTILANE RURAL HIGHWAY

A THESIS
SUBMITTED TO THE COLLEGE OF ENGINEERING OF THE UNIVERSITY OF ANBAR IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

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جمـهـوريـة العـراق
وزارة التعليم العالي والبحث العلمي
جامعة الأنبار
كلية الهندسة ـ قسم الهندسة المدنية

تحليل أداء الطريق الرئيسي المتعدد الممرات المفصولة بجزرة وسطية

رسالة مقدمة إلى كلية الهندسة- جامعة الأنبار كمتطلب جزئي لنيل درجة الماجستير في علوم الهندسة المدنية

مقدمة من قبل

أمجـد رمضـان حمـيد ألدلـيـمي
(بكالوريوس هندسـة مـدنيـة 2010)

بإشراف

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ربيع الاول/١٤٣٤ هـ   كانون الثاني /٢٠١3 م

بسم الله الرحمن الرحيــم

(نَرْفَعُ دَرَجَاتٍ مِّن نَّشَاء وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ)

سورة يوسف ,الاية:76

Dedication

To....My parents with my Gratitude and Love

Amjed

Certification of the Supervisor

I certify that the preparation of this thesis entitled "**Performance Analysis of Divided Multilane Rural Highway"** was made under my supervision at civil engineering department, University of Anbar in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering.

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Head of Civil Engineering Dept.

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Date: / / 2013

Certification of the linguistic supervisor

I certify that this thesis entitled "**Performance Analysis of Divided Multilane Rural Highway**" was prepared under my linguistic supervision. Its language was emended to meet the style of the English language.

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Examining Committee

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ABSTRACT

This research represents an evaluation of divided rural highway sections. The objectives of this study are to evaluate the fundamental parameters and service quality of traffic flow for highway sections between Ramadi and Falluja. Such, evaluation is going to be made by developing a statistical models to improve capacity and level of service by the speed-flow-density basic relationships.

Forty sections (twenty for each bound) are selected to satisfy the objectives and specifications of this study. Data of traffic flow and traffic composition were collected during peak periods by using video recording techniques for all selected sections in both directions during morning and evening periods. Free Flow Speed data were collected by the same technique and for all section in off peak periods. These collected data were then abstracted by the aid of computer programs developed by researcher and others for those purposes. The video recording of data collection was started on Sunday in (2nd ,Oct.,2011) and it was recorded for three months.

The data are abstracted by using the "EVENT" program, then analyzed and processed by using computer programs, which were written by Visual Basic programming language. While road geometric data are collected at the site.

The produced data indicated that the vehicles average speed are (81 and 80 km/hr) for northbound and southbound respectively for all highway sections. The speed frequency distributions show that they follow normal distributions for all sections.

Field surveys are made to collect new data that were abstracted and processed to build statistical regression models, which were used to improve highway capacity, level of service and predict speed models in horizontal alignments. Sections had LOS (C) were improved according to the predicted regression models.

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LIST OF ABBREVIATIONS

Symbol	Title of Symbol	Page
LOS	Level Of Service	3
FHA	Federal Highway Administration's	4
AASHTO	American Association of State Highway and Transportation Officials	6
HCM	Highway Capacity Manual	8
AADT	Average Annual Daily Traffic	9
ADT	Average Daily Traffic	9
PHV	Peak Hour Volume	9
VMT	Vehicle Mile of Travel	9
CCTV	the Closed Circuit Television	35
VIVDS	Video Image Vehicle Detection System	36
RTMS	Remote Traffic Microwave Sensors	36
HCS	Highway Capacity Software	38
TRB	Transportation Research Board	38
NB	North Bound	43
SB	South Bound	43
VBTC	Visual Basic Traffic Composition	56
VBSS	Visual Basic Speed Studies	59
FFS	Free Flow Speed	61
HV	Heavy Vehicle	62
R	Radius of Curve	66

OPERATIONAL ANALYSIS

Analyst:	AMJAD R. HAMEED
Agency/Co:	Master Student
Date:	20/1/2012
Analsis Period:	one hour
Highway:	Ramadi - Fallujah Highway
From/To:	Sjarea - Heseba
Jurisdiction:	
Analysis Year:	2012
Project ID:	Evaluation Level of Service for Ramadi - Fallujah Highway

FREE-FLOW SPEED

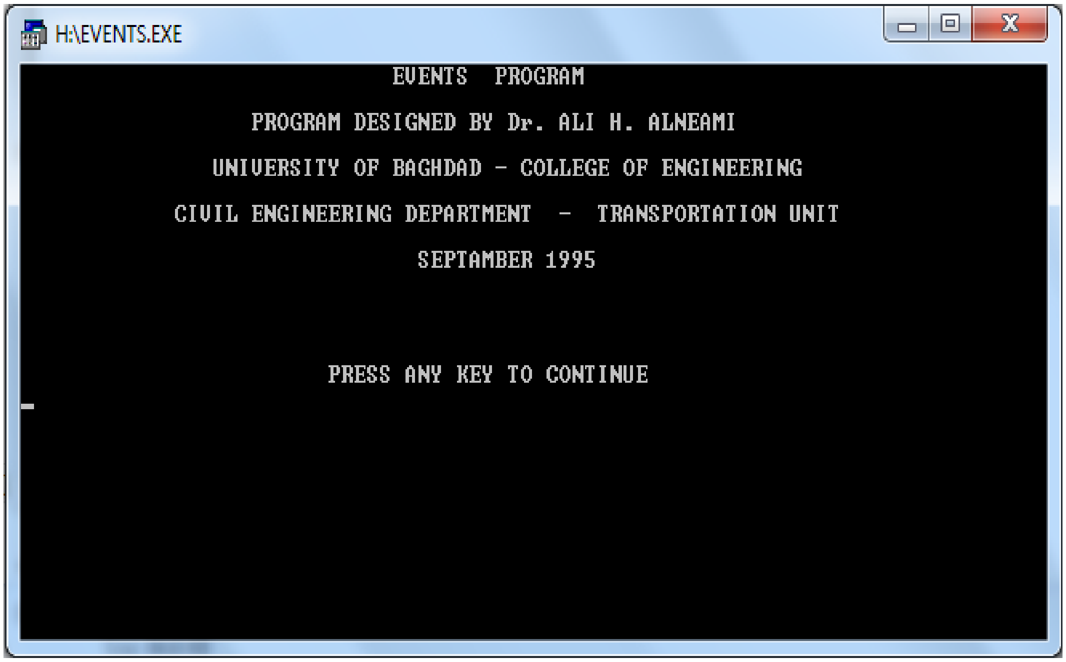
Direction	1		2	
Lane width	3.5	m	3.5	m
Lateral clearance:				
Right edge	1.8	m	1.8	m
Lem edge	1.8	m	1.8	m
Total lateral clearance	3.6	m	3.6	m
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	81.0	km/h	84.0	km/h
Lane width adjustment, FLW	0.0	km/h	0.0	km/h
Lateral clearance adjustment, FLC	0.0	km/h	0.0	km/h
Median type adjustment, FM	0.0	km/h	0.0	km/h
Access points adjustment, FA	0.0	km/h	0.0	km/h
Free-flow speed	85.0	km/h	84.0	km/h

VOLUME

Direction	1		2	
Volume, V	1470	vph	1580	vph
Peak-hour factor, PHF	0.88		0.87	
Peak 15-minute volume, v15	253		348	
Trucks and buses	13	%	13	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	km	0.00	km
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.930		0.930	
Flow rate, vp	898	pcphpl	957	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	898	pcphpl	957	pcphpl
Free-flow speed, FFS	81.0	km/h	84.0	km/h
Avg. passenger-car travel speed, S	81.0	km/h	84.0	km/h
Level of service, LOS	C		C	
Density, D	11.08	pc/km/ln	11.3	pc/km/ln



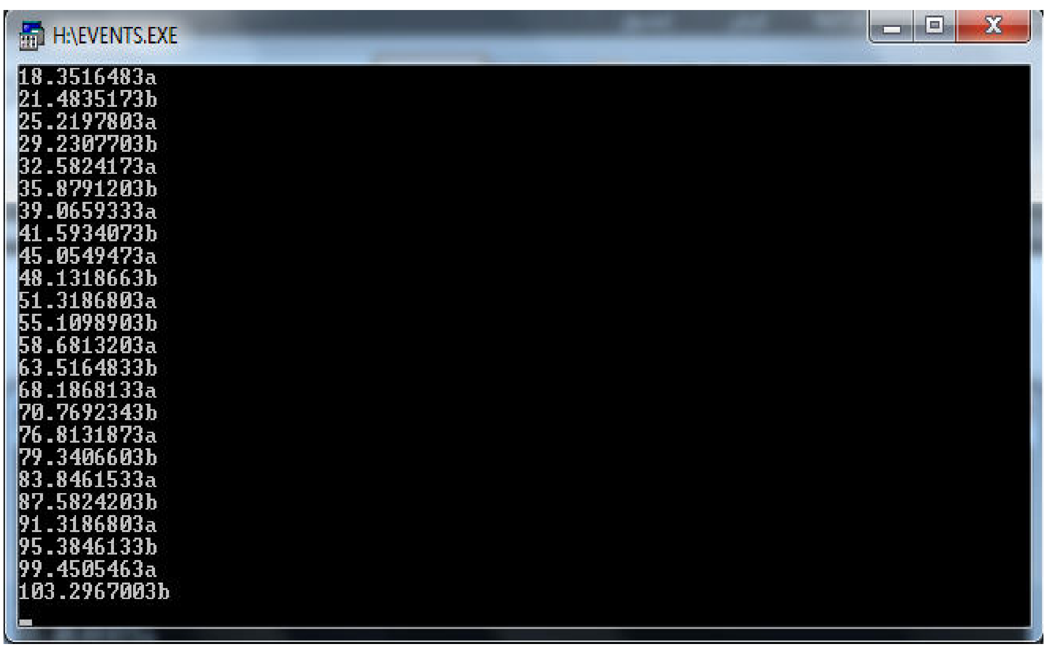


Fig.(B-1): Event software operation

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Questionnaire form of driver's age effect on speed

Form No. (   )   Survey Date: /   / 2011   Section No. (   ).

Gender : ☐ male   ☐ female.

Age of driver :

- ○ 21-25 year
- ○ 26-30 year
- ○ 31-35 year
- ○ 36-40 year
- ○ 41-45 year
- ○ 46-50 year
- ○ 51-55 year

Free speed: ☐ km/hr.

CHAPTER ONE

INTRODUCTION

1.1 General

Rural multilane highways are a key element in the highway system of most countries, where they provide a variety of transportation functions. They are located in all geographic areas, and serve a wide range of vehicle traffic.

The goal of transportation is generally stated as the safe and efficient movement of people and goods. During the last years, there have been tremendous increases in road traffic flow. This increasing had brought into focus many problems of the highway system such as congestion, insufficient of traffic management and movement safety and insufficient road design to carry this increase in volumes.

To achieve this goal, traffic engineers use many tools and techniques to improve traffic operations and controls on roadways and examine the consistency of the design. Design consistency refers to a highway geometry's conformance to driver expectancy.

Improvement of the effectiveness of the traffic control parameters would contribute to reduce congestion and relive those conditions causing reduction in capacity along the arterial rural highways as well as to increase road safety. In order to increase the traffic capacity and service level along the arterial streets, elements that play a role in traffic operation should be considered.

In general, Speed, flow, and density are macroscopic parameters for characterizing the traffic stream as a whole, while headway, and spacing are microscopic measures for distinguishing the individual vehicles.

The comprehensive statistical analysis of macroscopic parameters at highway segments are essential requirements in planning, designing, and operating the transportation systems. During this study values for speed, flow, density and predicted regression models are obtained to explain the traffic relationship in critical sections.

Typically the study is located in suburban communities, leading into central cities, or along high-volume rural corridors connecting two cities or two significant activities that generate a substantial number of daily trips.

Drivers make mistakes in the area of bad geometric features that conform their expectations. Worldwide, the design consistency on multilane rural highways has been assumed to be provided by the selection and application of a uniform design speed among the individual alignment elements.

1.2 Objectives of study project

The objectives of this study are to evaluate the operating condition of Ramadi – Falluja divided multilane rural highway by:

1. Analyzing traffic flow data collected on road sections varying in roadway and traffic conditions.
2. Studying the effect of basic influenced factors on free speed and capacity of multilane highway under those traffic conditions which are:
    - Road parameters: lane width, number of lanes per direction, shoulder width, median width and curvature.
    - Traffic composition and the percentage of heavy vehicle.
    - Driver characteristics, age and gender.
    - Environment conditions, visibility (day and night) and rainy weather.
3. Evaluating the level of service (LOS) of the highway sections, depending on traffic values that obtained from field data.

4. Estimating the capacity in divided multilane rural road.
5. Predicting speed models to represent the actual free speed relationships with the road geometric elements of traffic features these method will be used to improve the service quality of some low service level sections.

1.3 Structure of the thesis

To achieve the objectives of the study, six chapters are conducted which represent the structure of this study. A brief description of the contents of each chapter is presented as in the following:

Chapter 1: Contains the introduction, objectives of the study project and the structure of this thesis.

Chapter 2: Explains the review of literature for previous studies similar to this study.

Chapter 3: Discusses the objectives, specifications, descriptions of the survey sites, techniques and procedures for data collection, as well as, the abstraction and processing of the required data.

Chapter 4: Discusses the presentation and analysis of traffic flow operations, speed analysis, evaluated geometric design parameters, capacity and level of service determination and the factors which affect free flow speed and capacity developing of the general regression models for improving level of the service at critical sections and the speed at horizontal alignments.

Chapter 5: Presents the conclusions, and recommendations for further studies.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Introduction

In order to set the scope for this study, a comprehensive literature review was taken. The objectives of this review were to evaluate the previous research undertaken in this field and to use this information to establish the study data collection methodologically. This information would also be used in the analytical stages of the study to facilitate the development of the models.

2.2 Highway classification

There are three primary federal highway functional classifications: arterial, collector, and local roads. All streets and highways are grouped into one of these classes, depending on the character of the traffic (i.e., local or long distance) and the degree of land access that they allow. These classifications are described in table (2-1). Typically, travelers use a combination of arterial, collector, and local roads for their trips. Each type of road has a specific purpose or function. Some travelers provide land access to serve each end of the trip. Others provide travel mobility at varying levels, which is needed in route. The functional classification system can be further broken down into “rural’ and “urban” classifications, and there are sub-classifications within these groupings as well. Figure (2-1) shows the functional classification system (**The Federal Highway Administration’s, 1989**).

Table (2-1): Functional classification systems (FHA,1989)

Functional System	Services Provided
Arterial	Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control.
Collector	Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.
Local	Consists of all roads not defined as arterials or collectors; primarily provides access to land with little or no through movement.

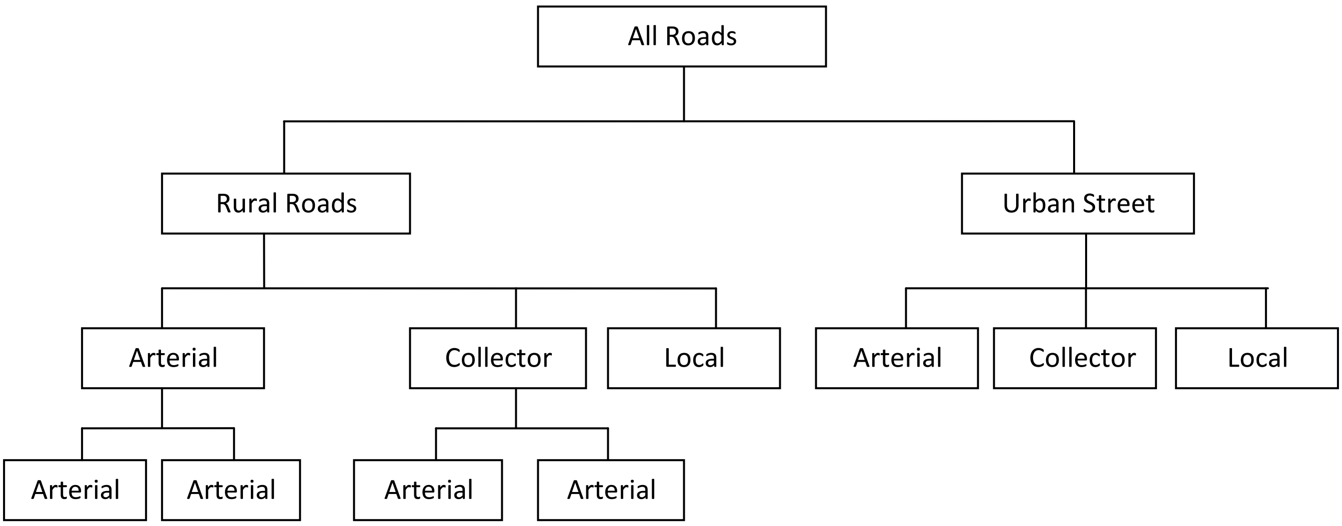


Figure: (2-1): Functional classification systems (FHA, 1989)

Arterial streets are an important resource in rural and urban areas .They represent significant expenditure of funds and they carry large volumes of traffic **(Kuner, R., 1988)**.

The classification of highways into different operational systems, functional classes, or geometric types is necessary for communication among engineers, administrators, and the general public.

Different classification schemes have been applied for different purposes in different rural and urban regions (**AASHTO, 2001**).

Interstate highways are a formalized system of principal arterial in which there are no access points other than high speed ramps. These interstate highways are used for the long trips. Freeway or expressway is a subclass of principal arterials that includes all other principal arterials with little or no direct access and very few at grade crossings.

The followings are definitions for the arterial types of highways (**AASHTO, 2001**):

1. Expressway
2. Freeway
3. Through street or through

Other principal arterials have comparatively more access points and traffic impediments than freeway/expressway routes (**Eric Foster, 2008**).

2.3 Traffic flow characteristics

Highway facilities can be divided into two categories (**Michael S. Bronzini, 2004**):

1. Uninterrupted flow facilities; are those in which there are no external controls interrupting the flow of the traffic stream. An example is the freeway, where there are no at grade intersections, no traffic lights, and stop and yield signs. The flow conditions are the result of interaction among the vehicles themselves and the roadway environment.
2. Interrupted flow facilities; traffic flow is regularly interrupted as a result of external control which play a major role in defining such flow, for

example, the existence of traffic lights, stop and yield signs, un signalized intersections and other types of interruptions.

The traffic analysis for this type is more complex than the uninterrupted flow facilities, because the impact of the external control must be considered.

Three basic variables volume or flow rate, speed, and density can be used to describe traffic on any roadway. Some parameters related to flow rate, such as spacing and headway, are also used in the uninterrupted flow facilities.

2.4 Traffic stream parameters

A highway traffic stream consists of drivers and vehicles interacting with each other and with roadway environment. Traffic stream parameters represent the engineer's quantitative measure for understanding and describing traffic flow. Traffic stream parameters fall into two broad categories (**Myer Kuts, 2004**):

1. Macroscopic parameters which describe the behavior of the traffic stream as a whole. The most important parameters are:
   - Flow
   - Speed
   - Density
2. Microscopic parameters which describe the behavior of individual vehicles. The most important parameters are:
   - Headway
   - Spacing

2.4.1 Traffic flow measures

Usually traffic volume and flow are associated with traffic demand. The term volume generally is used for operating conditions below the threshold of capacity and it is related to vehicles discharging. Volume and flow rates are two measures that quantify the amount of traffic passing at point on a lane or roadway during the interval of a given time

Traffic flow rate in pc/hr/ln were calculated by the formula below **(HCM, 2000):**

$$Vp\ (pc/hr/ln) = (volume\ (veh/hr)\ /\ \mathit{PHF}\ /N.of\ lanes/\ f_{HV}/\ f_p) \ldots.\ (2\text{-}1)$$

where:

Vp = flow rate (pc/h/ln),

PHF = peak-hour factor

N = number of lanes

f_{HV} = heavy-vehicle adjustment factor

f_p = driver population factor. (0.85-1)

Traffic volume is expressed by the number of vehicles using the facility at a particular interval of time, while the traffic flow, is the hourly rate of traffic which is using that facility **(Victor Muchuruza, 2003).**

Traffic volumes studies are conducted to collect data on the number of vehicles and/or pedestrians that pass a point on a highway facility during a period of specified time. This period of times varies from as little as 15 min to as much as a year, depending on the anticipated use of the data. The traffic volume studies are usually conducted when certain volume characteristics are needed. These characteristics **(Garber and Hoel, 2003):**

1- Average Annual Daily Traffic (AADT)

2- Average Daily Traffic (ADT).

3- Peak Hour Volume (PHV)

4- Vehicle Mile of Travel (VMT).

Gordon Wells (1979) showed that there are three primary types of the count in which we are interested when we are dealing with traffic flow:

- Non–directional count is a count of traffic passing a point, irrespective of which way it is traveling. This is the basic count, from which a road–use map of an area can be produced.
- Directional count is similar to non–directional count, but more detailed. This is the normal type of detailed count for an urban area, intended to provide particulars of traffic flow by direction; this would be particularly important if, for instance, we are watching the introduction of a one–way system.
- Classified count is essential to all forms of the traffic survey. Also it is necessary to know the composition of traffic flow for many design purposes.

Garber and Hoel (2003) mentioned that there are different types of carried out traffic volume counts, depending on the anticipated use of the collected data:

- Cordon Counts.
- Screen line Counts.
- Intersection Counts.
- Pedestrian Volume Counts.
- Periodic Volume counts , which divided in to :
    - Continuous Counts.
    - Control Counts.
    - Coverage Counts.

2.4.2 Traffic speed studies

Speed is one of the most important factors considered by a traveler in selecting alternative routes or transportation modes. Travelers assess the value of a transportation facility in moving people and goods by its convenience and economy, which are directly related to its speed **(AASHTO, 2001)**.

Speed is an important measure of the quality of travel and safety of road network. Speed is defined as the rate of movement of vehicle in distance per unit time.

Basically, there are two types of speed **(Garber and Hoel, 2003):** the Time-Mean Speed (TMS) and the Space-Mean Speed (SMS). The space-mean speed is the length of a road section divided by the average travel time of several vehicles over this specific section. The time-mean speed is the average spot speed of several vehicles measured at a given spot.

In addition to capabilities of the drivers and their vehicles, upon four general conditions: the physical characteristics of the highway and the amount of roadside interference, the weather, the presence of other vehicles, and the speed limitations (established either by law or by traffic control devices). Although any one of these factors may govern travel speed, the effect of these general conditions is usually interrelated **(AASHTO, 2001)**.

2.4.2.1 Speed characteristics

Garber and Hoel, (2003) defined certain significant values that are needed to describe speed characteristics, these values are:

- **Time mean speed (Average speed)** is the arithmetic mean of speeds of vehicles passing a point on a highway during an interval of time, as in equation below :

$$\overline{u}_t = \frac{\sum fi * ui}{\sum fi} \text{ .... (2-3)}$$

where:

$\overline{u}_t$ = Time mean speed or arithmetic mean.

fi = Number of observations in each speed group.

ui = Mid. value for the ith speed group.

- **Space mean speed** is the harmonic mean speed of vehicles passing a point on a highway during an interval of time. It is obtained by dividing the total distance traveled by two or more vehicles on a section of highway by the total time required by these vehicles to travel that distance .This speed is found by :

$$\overline{u}_s = \frac{N * L}{\sum t_i} = \frac{L}{\frac{1}{N}\sum \frac{L}{u_i}} = \frac{1}{\frac{1}{N}\sum \frac{1}{u_i}} \text{ .... (2-4)}$$

where:

$\overline{u}_s$ = Space mean speed.

N = Number of observations.

t_i =The time for vehicle i to cross distance L.

- **Median speed** is the speed at the middle value in a series of spot speeds that are arranged in ascending order.
- **Modal speed** is the speed value that occurs most frequently in a sample of spot speeds.
- **The ith–percentile spot speed** is the spot speed value below which **i** percent of the vehicles travel; for example 85th percentile spot speeds the speed below which 85 percent of the vehicles travel and above which 15 percent of vehicles travel.

- **Pace** is the range of speed–usually taken at 10 mi/h intervals that have the greatest number of observations.
- **Standard deviation of speed** is a measure of the spread of the individual speeds. It estimates as:

$$S = \sqrt{\frac{\sum fi(ui - \overline{u})^2}{N - 1}} \quad \text{.................. (2-4)}$$

where:

S = Standard deviation.

ui = Mid value of speed class i.

fi = Frequency of speed class i.

N = Number of observations.

2.4.2.2 Speed types

Usually speed studies are made in free flowing conditions when vehicles interactions are minimal. According to the Highway Capacity Manual (HCM, 2000), free flow condition occurs when there is a minimum of 4-seconds headway between vehicles. **AASHTO (2001)** has been classified speed types into three categories:

1) Deign speed

Design speed is a selected speed used to determine the various geometric design features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of highway. Some design features, such as curvature, superelevation, and sight distance, are directly related to, and vary appreciably with, design speed.

Other features, such as widths of lanes and shoulders and clearances to walls and rails, are not directly related to design speed, but they do affect vehicle speeds. Therefore, wider lanes, shoulders, and clearances should be considered for higher design speeds. Thus, when a change is made in design speed, many elements of the highway design will be changed according. There are three factors affect on design speed which are **(AASHTO, 2001)**:

- Vertical and horizontal alignment
- Sight distance.
- Other features such as widths of pavement and shoulders, horizontal clearances, etc., are generally (not directly) related to design speed.

The choice of design speed is influenced principally by the character of terrain, economic considerations, environmental factors, type and anticipated volume of traffic, functional classification of the highway, and whether the area is rural or urban.

2) Running speed

Running speed is the length of the highway section divided by the running time required for the vehicle to travel through the section. The average running speed of all vehicles is the most appropriate speed measure for evaluating level of service and road user costs. The average running speed is the sum of the distances traveled by vehicles on a highway section during a specified period of time divided by the sum of their running times **(AASHTO, 2001)**.

3) Operating speed

Operating speed is the speed at which drivers are observed when they are operating their vehicles during free flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature (**AASHTO, 2001**).

2.4.2.3 Free flow speed

The free speed of any vehicle can be defined as the speed adopted by the driver when he is not restricted by other vehicles in the stream under a given set of highway and environmental conditions. It occurs when no obstructions to flow either in terms of operational delays (congestion) or other adverse prevailed conditions (**Bang,1997**).

Free flow speed can be defined as the drivers' desired average speed in a low volume traffic stream when the density and flow theoretically tend to zero as mathematically represented by the fundamental traffic equation :

$$Q = U_f K \qquad (2\text{-}5)$$

where:

Q : traffic flow (veh/hr),

K : density (veh/km) and

U_f: free speed (km/hr).

Highway capacity manual defines the free flow speed as the speed of traffic at low volume and low density. It is the speed at which drivers feel comfortable when they are travelling under the physical, environmental, and traffic-control conditions on an uncongested section of multilane highway.

Recent research suggests that free-flow speed on multilane highways under base conditions is approximately 11 km/h higher than the speed limit for 65 km/h to 70 km/h speed limits, and it is 8 km/h higher for 80 km/h to 90 km/h speed limits.

According to **(HCM, 2000)** free flow speed can be estimated indirectly when there are no field data as:

$$FFS = BFFS - F_{LW} - F_{LC} - F_{A} - F_{M} \ldots\ldots(2\text{-}6)$$

where:

FFS = estimated FFS (km/h);
BFFS = base FFS (km/h);
F_{LW} = adjustment for lane width, from table (2-2);
F_{LC} = adjustment for lateral clearance, from table (2-3) ;
F_{M} = adjustment for median type, from table (2-4) ; and
F_{A} = adjustment for access points, from table (2-5) .

Table: (2-2): Adjustment for lane width (HCM, 2000)

Lane width (ft)	Lane width (m)	Reduction Free Speed (mi/hr)	Reduction Free Speed (km/hr)
12	3.65	0	0
11	3.35	1.9	3.05
10	3.04	6.6	10.62

Table (2-3): Adjustment for lateral clearance(HCM, 2000)

Total lateral clearance(m)	Total lateral clearance (m)	Reduction Free Speed (mi/hr)	Reduction Free Speed (km/hr)
12	3.657	0	0
10	3.048	0.4	0.643
8	2.438	0.9	1.4484
6	1.828	1.3	2.092
4	1.219	1.8	2.890
2	0.60	3.6	5.793
0	0	5.4	8.690

Table (2-4): Adjustment for median type (HCM, 2000)

Median type	Reduction Free Speed (km/hr)
Divided highway	0
Undivided highway	2.5749

Table:(2-5): Adjustment for access point[HCM, 2000]

Access point (km)	Reduction Free Speed (mi/hr)	Reduction Free Speed (km/hr)
0	0	0
10	2.5	4.023
20	5	8.046
30	7.5	12.070
≥ 40	10	19.093

2.4.2.4 Factors affecting free flow speed

The speed of a vehicle on a road is completely influenced by a lot of factors. These factors can be categorized as (E. Madhu, et al., 2011): that the free speed is influenced by many factors that can be categorized into five main groups including driver, road, vehicle, environment, traffic operations and control. These influencing factors of free speed in detail under the above-said categories are described in Figure (2-2).

The driver characteristics such as age, gender, aggressiveness, condition of the driver (fatigue), etc. have significant influence on the free speed. Road geometry facilities such as road width, number of lanes, width and position, curvature, gradient, roughness, lateral clearance, sight distance, etc. and surface type and condition, shoulder type and condition, service road presence, frequency of intersections, etc. will also play a vital role on the free speeds.

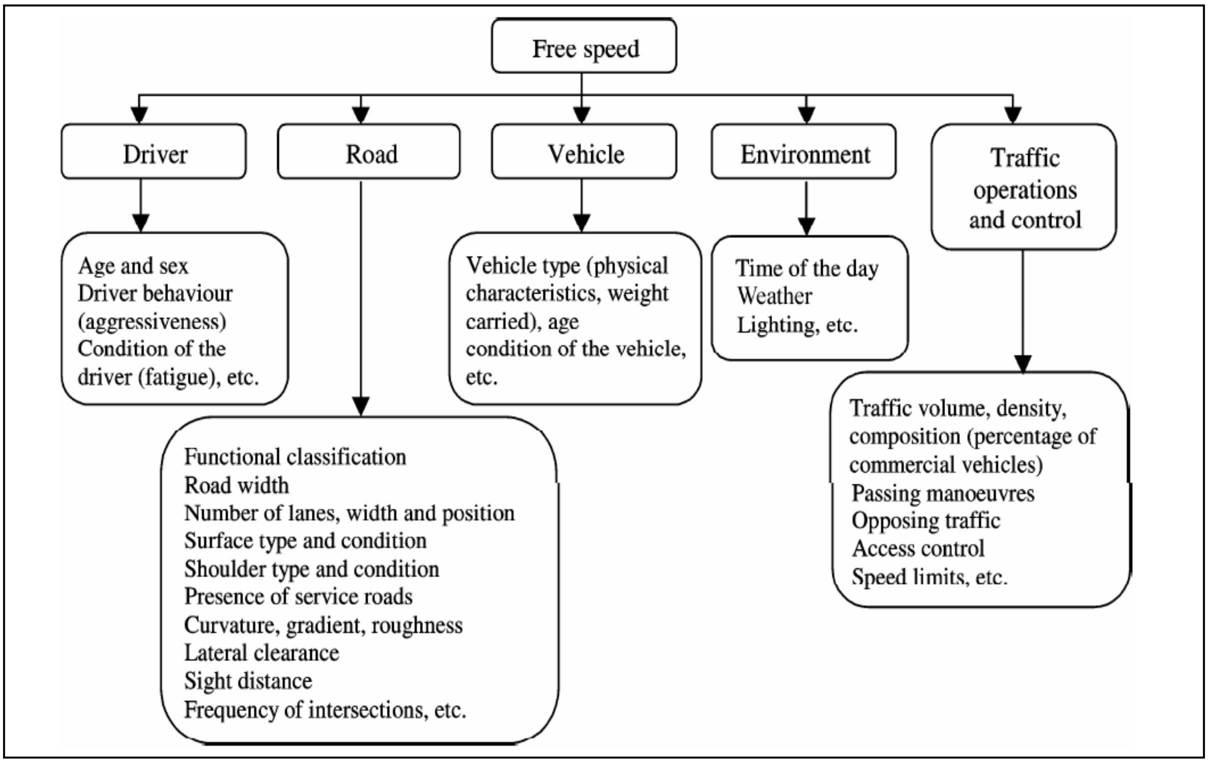


Figure (2-2): Factors affecting FFS (source: E. Madhu, 2011)

The studies reveal that free speed of vehicles is significantly different for different types of highways as these geometric parameters vary when they are based on functional classification of highways. The vehicle travelling position on a highway (inner or outer lane) influences free speed significantly **(E. Madhu, et al., 2011)**.

1) Environmental factors

There are principal factors of roadway geometry and condition. (Lamm, et al., 1990) examined 24 curved road sections of rural two lane highways during both dry and wet conditions. They found no statistical difference in the operating speeds between those two conditions. Their data were collected when visibility was not affected by heavy rain and that may explain the lack of difference in the measured speeds.

Ibrahim and Hall (1994) studied the effect of adverse weather on freeway operations in Canada. They conducted tests on the effects of rain and snow on speed-flow-occupancy relationships.

They summarized their findings into three categories: clear and rainy weather, clear and snowy weather, and rainy and snowy weather. They found the following reductions in the free-flow speed:

- Light rain caused a 2 km/h drop.
- Light snow caused a 3 km/h drop.
- Heavy rain caused a 5 to 10 km/h drop.
- Heavy snow caused a 38 to 50 km/h drop.

Brilon and Ponzlet (1996) investigated 15 sites in Germany to assess the effects of weather conditions, daylight or darkness, and other factors on speed-flow relationships. They concluded that darkness reduces driver speeds by 5 km/h. They also found a drop of 9.5 km/h and 12 km/h on two-lane and three-lane wet roadway segments, respectively.

Kyte. et. al. (2000) studied the impact of environmental factors on free flow speed. They focused their experiments on how the average speed is changed according to visibility, road surface conditions, rainfall, and wind speed, It was found that a linear relationship exists between free flow speed and environmental factors.

Ibrahim usuf (2010) presented relationships of the quantitative evaluation of the influence of some factors on the free flow speed on an arterial road such as: driver's age, number of passenger in car, car age, number of parked car, weather condition, geometric design condition and pavement condition. It was found that changes in the road geometry on the arterial road in terms of shoulder width, number of lanes, road/carriageway width and distance of nearest obstruction to the edge of the road do affect the instantaneous speeds and a linear relationship exists between free flow speed of commuter vehicles and drivers' age.

The average free flow speed of commercial saloon cars is lower on wet pavement than on dry pavement.

2) Driver characteristics

Drivers attributes and environment have been reported to influence the values in the American urban traffic streams and highways (Kyte, et. al.1998). These showed by different studies that the percentage reduction is respected occurred due to the environment in the free flow speed for wet pavement, high wind, low visibility and rains; with a combined effect of all.

Liang, et. al. (1998) presented a chapter of detailed analysis of the effect of human factors (drivers') on the free flow speeds in the premise of person-machine control system.

Lamm, et. al. (1999) observed that a principle affect on the free flow speed are heavy vehicle percent and weather, he also adjusted speeds by as much as 10km/hr less during heavy rains when visibility becomes substantially obstructed.

Younger drivers (in age), level of passenger occupancy, age of vehicles and trip purpose have impacted higher values on the speed while horizontal / vertical alignments and parked vehicles along the road impacted negatively on free flow speeds; **(M. Shane, 1999).**

3) Road characteristics

Many studies have dealt with roadway characteristics as speed factors on two-lane and multilane rural highways. **Yagar and Van (1993)** studied the effects of the geometric and environmental conditions on mean speeds. Mean speeds were found to be related to the roadway grade, the lane width, the land use, the highway access, and the speed limit.

These speeds were found to include the negative effect of the traffic volume on the 10^{th}, 50^{th}, and 90^{th} percentile speeds.

The models shared the same speed factors, although the magnitude of their coefficients varied for each speed.

Islam and Seneviratne (1994) investigated the relationships between the 85^{th} percentile speed at the beginning, middle, and ending points of horizontal curves and the degree of curvature and its squared term.

M.Fadden and Elefteriadou (2000) developed a model that estimates the 85^{th} percentile maximum speed reduction into horizontal curves as a function of the radius, the approach tangent length, and the 85^{th} percentile speed on the approach tangent.

Polus et. al. (2000) found that 85th percentile speeds on tangents depend primarily on the tangent length and the radius of the curves preceding and following the tangent segment. Other elements like spirals, the speed limit, the enforcement level, the cross-section width, the longitudinal slope, the side slope, the general terrain, the driver’s attitude, and the vehicle’s acceleration and deceleration capabilities were identified as less important factors. Prediction models of the 85th percentile speeds were developed for different combinations of tangent length and curve radius.

Ayman and Gandi (2008) found four equations to develop model for predicting speed equation on horizontal curves for two lane rural highway using data collected at 28 sites in north of Iraq. The data included the effect of curve radius and grade on the predicted 85th percentile curve speed which is developed and subsequently.

Shawky and Hashim (2010) presented a relationship between the characteristics of horizontal alignment and the traffic performance density.

Flow rate, horizontal alignment characteristics (curve radius, tangent length), and average speed are investigated.

The results showed that the horizontal alignment characteristics have a significant effect on the follower density, especially curve radius value, by decreasing radius, the follower density increases (i.e., traffic performance decreases).

Vehicular factors which have significant influence on free-speed characteristics include vehicle type, vehicle age, etc. and similarly, the traffic factors such as traffic volume, traffic density, trip distance, percentage of commercial vehicles, passing manoeuvres, opposing traffic, access control, etc. These factors may also affect the free speeds. Speed limits of a highway would also restrict free speeds of individual vehicles.

S. Ferzin, et al. (2011) analyzed multiple linear regression analysis to evaluate the effect of horizontal curve variables on the speed reduction, expressed as 85^{th} percentile speed reduction, as a dependent variable. The main independent variables entry in the regression analyses were radius of the curve (R), length of tangent (T) and deflection angle (Δ). Also the effect of curve radius on the predicted 85^{th} curve speed was investigated. These will help both designer and decision makers in evaluating different alignment alternatives.

4) Vehicle characteristics

(Deceleration and Acceleration at Curves)

As implemented the costs are based on a single vehicle starting at an initial speed and decelerating to a final speed. Since there is always a distribution of speeds associated with the traffic it would be better to model the costs from a mean initial speed to a mean final speed.

Christopher R. Bennett (1994) found that vehicles adopted higher deceleration rates from open road speeds than were found in a similar study in an urban area. The deceleration rate was found to be proportional to the approach speed, with faster drivers adopting a higher rate. The deceleration and acceleration behavior of vehicles in curves was investigated using the data from the various curve sites. It was found that there was generally a strong linear relationship between this behavior and the speed ratio which was defined as the ratio of speeds between two successive stations. A series of regression equations were developed for predicting this behavior

Garber and Hoel (2003) stated that the criteria for the geometric design of highways are partly based on the static, kinematic, and dynamic characteristics of vehicles. Static characteristics include the weight and size of the vehicle. Kinematic characteristics involve the motion of the vehicle without considering the forces that cause the motion. When a passenger car is maneuvered to take a curve, external forces act on the front wheels of the vehicle. These forces have components that have a retarding effect on the forward motion of the vehicle. The sum effect of these components constitutes the curve resistance. This resistance depends on the radius of the curve, the gross weight of the vehicle, and the velocity at which the vehicle is moving.

Alberto R. (2005) found that a deceleration rate of 0.85 m/s^2 can be used in a simplified operating speed-profile even if this value represents only a rough approximation of the real deceleration rates that depend, in fact, on many factors including the characteristics of the curve, of the upstream alignment, of the overall road environment. Therefore, additional data are studied to estimate a deceleration model more accurately.

2.5 Density

Density is the number of vehicles (or pedestrians) occupying a given length of a lane or roadway at a particular instant. For the computations in this manual, density is averaged over time and is usually expressed as vehicles per kilometer per lane (veh/km/ln) or passenger cars per kilometer per lane (veh/km/ln).

Direct measurement of density in the field is difficult, requiring a vantage point for photographing, videotaping, or observing significant lengths of highway **(HCM, 2000).**

Density can be computed from the average travel speed and flow rate, which are measured more easily under saturated traffic conditions **(HCM, 2000).**

$$D = Vp / FFS \quad \text{.................(2-4)}$$

where:

D : traffic density (veh/km/ln),

Vp : flow (veh/km) and

FFS : free speed (km/hr).

Generally, the minimum sample size required is greater than 30 measured spot speeds in order to reduce variations and increase precision. On higher volume roads, the minimum sample size for analysis has to be at least 100 measure spot speeds.

The following formula is used to determine the minimum sample size, n required for any statistical analysis (**Garber and Hoel, 2003**):

$$n = \left(\frac{Z * S}{E}\right)^2 \quad \text{............... (2–5)}$$

where:

Z = Confidence level.

S = Estimate of the standard deviation.

E = Range of error.

2.6 Traffic Stream Models (Speed-Flow-Density relationships)

Matthew J Huber, (1976) mentioned that the relationship among the three variables V, D and Q is called a traffic stream model. A dimensional analysis of the three variables gives the following relationship:

Q (veh/h) = V (mi/h) * D (veh/mi)

or …………(2-6)

Q (veh/h) = V (km/h)* D (veh/km)

where:

Q = mean rate of flow.

V = space mean speed.

D = mean density.

When considering the flow of traffic along a highway, three descriptors are of considerable significance **(Salter, 1990)**. They are the speed and the density, which describes the quality of service experienced by the stream, the flow or volume, which measures the quantity of the stream and the demand on the facility.

Obeid (2001) studied the development of mathematical models that deal with the three main characteristics of traffic: speed, flow, and density, in order to describe the intersection between these key variables for different types of facilities on selected arterial streets in Baghdad city.

Garber and Hoel (2003) noted that the traffic flow theory involves the development of mathematical relationships among the primary elements of a traffic stream: flow, density and speed. These relationships help the traffic engineer in planning, designing, and evaluating the effectiveness of implementing traffic engineering measures on a highway system.

Jotin Khisty, et al. (1998) mentioned as field measurements of speed, flow and density became available. Several researchers evolved traffic flow models that based on actual curve fitting and statistical testing, the evaluation of models proceeded a long two lines:

1- Relationships of speed-flow-density were tested in terms of goodness of fit to actual field data.

2- Relationships were supposed to satisfy certain boundary conditions:

- Flow is zero at zero density.
- Flow is zero at maximum density.
- Mean free speed occurs at zero density.
- Flow–density curves are convex (there is a point of maximum flow).

The following figures illustrate the typical speed–flow–density relationship:

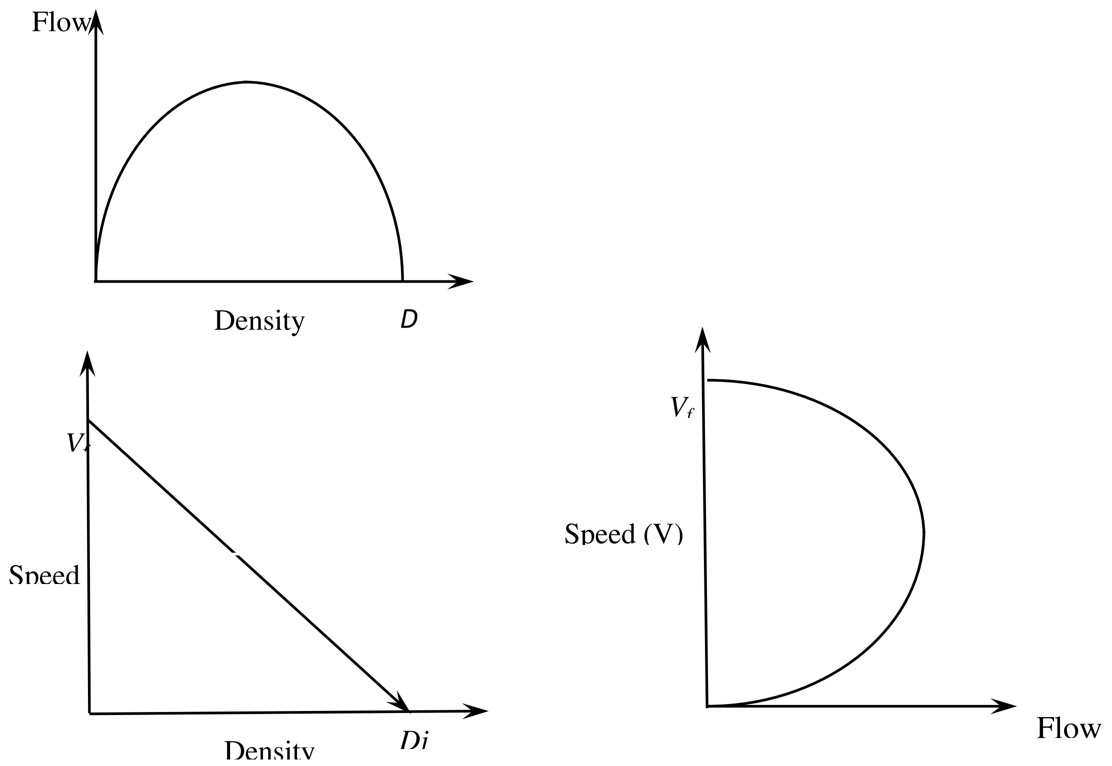


Figure (2-3): Speed–Flow–Density relationships (Jotin Khisty, , et al. ,1998)

Al-Ani (2010) presented the evaluation of the fundamental relationships and service quality of traffic flow for Al-Tharthar urban street in Falluja city and developed a statistical models to predict speed-flow-density relationships. Usually the experimenters have been interested in the relationship between speed and flow because of the desire to estimate the optimum speed for maximum flow. The developed regression models explained in equations (2-7), (2-8) and (2-9) may be used to predict the speed-density, flow-density and speed-flow relationships respectively for Al-Tharthar urban street section and the similar highways in the similar areas presented as in the following:

$$V = 57.065 - 0.9024 * D \text{ ……..…… (2–7)}$$

where:

V = the average space mean speed of traffic flow,

D_j = the jam density of the traffic stream.

The flow-density relationship can be derived as described below:

$$V = V_f - \frac{V_f}{D_j} D \quad \text{and;} \quad Q = VD$$

where:

$Q =$ The traffic flow, therefore, by substitution

$$Q = (V_f - \frac{V_f}{D_j} D)D \quad \text{and by simplification}$$

$$Q = V_f D - \frac{V_f}{D_j} D^2$$

Substituting the constant values of the above developed regression model, results in;

$$Q = 57.065 * D - 0.9024 * D^2 \text{ ……..................……(2-8)}$$

2.7 Highway Capacity

The capacity is defined as the maximum number of vehicles that have a reasonable expectation of passing over a given roadway in a given time period under the prevailing roadway and traffic conditions (**HCM, 1965**).

Carter (1976) said that the capacity of a single traffic lane is approximately (2400) passenger vehicle per hour under ideal roadway and environmental conditions and with the most homogeneous group of drivers and vehicles ever likely to in normal highway usage.

This volume would be produced by average headways of 1.5 sec. Such average headways have been observed for short periods of time and on rare occasions for an entire hour in the central lanes of a freeway built to high design standers.

Vuchic (1981) stated that the capacity is independent of demand in the sense that it does not depend on the total number of vehicles (or whatever) demanding service. It is expressed in terms of units of some specific thing, however. So that it does depend on traffic composition (for instance, for highways, the percentage of trucks or other heavy vehicles). It is also dependent on physical and environmental conditions, such as the geometric design of facilities or the weather.

HCM (2000) defined capacity of a facility 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 period of time under prevailing roadway, traffic, and control conditions.

Vehicle capacity is the maximum number of vehicles that can pass a given point during a specified period under prevailing roadway, traffic, and control conditions. This assumes that there is no influence made by downstream traffic operation, such as the backing up of traffic into the analysis point.

2.7.1 Factors affecting highway capacity

There are principal factors which effect on capacity of highway. These factors can be listed as stated by **(HCM, 2000):**

1) **The traffic conditions**,

Which are determined by traffic composition (type of travelled vehicle along highway and the percent of heavy and recreational vehicles).

2) **The ambient conditions**

Which include time (day or night), temperature conditions and environmental condition (wind speed, direction and visibility).

3) **The physical features of a highway**,

Which are not going to be changed unless the geometric design of the highway changes. These changes include:

- Lane width
- Shoulder width
- Lateral clearance
- Road alignment and geometry (curves, Super elevation etc)
- Existence of intersections.
- One way or two way traffic and number of lanes
- Flow speed
- Parking and Presence of pedestrians.

Prakash (1970) also observed that the highway capacity is considerably influenced by the type and width of shoulder he also stated that speed changes exponentially with change in lane width.

Leong (1978) measured speeds and capacity at 31 sites on rural highways in New South Wales. The sites had varying lane and shoulder width and all sites had gravel shoulders. The data were analyzed using multiple regression and it was suggested that speed increased with the increasing of shoulder width.

Chandra and Kumar (1996) studied the effect of shoulder condition on speed of different types of vehicles and their placement on road during passing and overtaking maneuvers on single and two-lane highways.

Parker (1996) observed that knowledge of increase in traffic volume decreases the speed of vehicles and traffic composition plays an important role in determining capacity.

Chandra (2005) presented study at more than 40 sections of two-lane roads to determine the effect of gradient, lane width, split, shoulder's condition and pavement roughness on capacity of two lane roads.

He found that the increasing in capacity makes the lane width increased, pavement roughness decreased, shoulder width increased and heavy vehicle percent decreased.

2.8 Level of Service (LOS)

HCM (2000) defines Level of service (LOS) as a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

The highway capacity manual gives six levels of service and defines six corresponding volumes for numbers of highway types. These volumes are referred to service volumes (hourly volume) which may be defined as the maximum number of vehicles that can pass over a given section of a lane during a specified time period while operating conditions are maintained correspondingly to the selected level of service. The following are the various levels of services **(HCM, 2000):**

1- LOS A
2- LOS B
3- LOS C
4- LOS D
5- LOS E
6- LOS F

7- A multilane highway is characterized by three performance measures as in table (2-6) **(HCM, 2000):**

- Density, in terms of passenger cars per kilometer per lane;
- Speed, in terms of free flow passenger car speed and
- Volume to capacity ratio (v/c).

Operations within queues are highly unstable, with vehicles experiencing brief periods of movement followed by stoppages. Travel speeds within queues are generally less than 50 km/h. Note that the term LOS F may be used to characterize both the point of the breakdown and the operating condition within the queue.

2.8.1 Prevailing Conditions

HCM (2000) explained the prevailing conditions effecting on capacity and (LOC) as follow:

1. Roadway conditions, which consist of the followings :
    - Geometric elements.
    - Number of lanes.
    - Type of facility.
    - Lane widths.
    - Shoulder widths.
    - Lateral clearance.
    - Design speed.
    - Horizontal and vertical alignment which depend on design speed and topography.
    - Availability of exclusive lanes at intersections.
    - Severity of terrain reduces capacity and service flow rates for individual vehicles and passing vehicles.

Traffic Conditions, which consist of the following:

a) Vehicle type; the entry of heavy vehicles like (trucks, buses, recreational Vehicles) into the traffic stream, affects the number of vehicles that can be served in two ways:

- Heavy vehicles adversely affect the traffic, which are larger than passenger cars and occupy more roadway space.

Also they have poorer operating capabilities than passenger cars, particularly with respect to acceleration, deceleration and ability to maintain speed on upgrades.

- The second impact is more critical. The inability of heavy vehicles to keep pace with passenger cars in many situations creates large gaps in the traffic stream, which are difficult to fill by passing maneuvers.

b) Vehicle type hindrances.

c) Directional distribution (the optimal conditions when the amount of traffic is the same in each direction.

d) Lane distribution (shoulder lane carries less traffic than other lanes).

2. Control Conditions, which consist of the followings:

- The most critical condition is traffic signal (signal phasing, allocation of green time, cycle length and relationship with adjacent controls).
- Stop-Yield (capacity on minor street depends on traffic conditions).
- Curb parking (restriction increases number of lanes available).
- Turn restrictions (eliminate conflicts increasing capacity).

Table(2-6): LOS Criteria for Multilane Highway [HCM, 2000]

Free Flow Speed	Criteria	LOS				
		A	B	C	D	E
100 km/h	Maximum density (pc/km/ln)	7	11	16	22	25
	Average speed (km/h)	100	100	98.4	91.5	88
	Maximum volume to capacity ratio(v/c)	0.32	0.50	0.72	0.92	1.0
	Maximum service flow rate (pc/h/ln)	700	1100	1575	2015	2200
90 km/h	Maximum density (pc/km/ln)	7	11	16	22	26
	Average speed (km/h)	90.0	90.0	89.8	84.7	80.8
	Maximum volume to capacity ratio(v/c)	0.30	0.47	0.64	0.89	1.0
	Maximum service flow rate (pc/h/ln)	630	990	1435	1860	2100
80 km/h	Maximum density (pc/km/ln)	7	11	16	22	27
	Average speed (km/h)	80.0	80.0	80.0	77.6	74.1
	Maximum volume to capacity ratio(v/c)	0.28	0.44	0.64	0.85	1.0
	Maximum service flow rate (pc/h/ln)	560	880	1280	1705	2000
70 km/h	Maximum density (pc/km/ln)	7	11	16	22	28
	Average speed (km/h)	70.0	70.0	70.0	69.5	67.9
	Maximum volume to capacity ratio v/c)	0.26	0.41	0.59	0.81	1.0
	Maximum service flow rate (pc/h/ln)	490	770	1120	1530	1900

2.9 Methods of Data Collection

Pignataro (1973) mentioned that in any traffic survey, the limitations in the amount of money and time which can be devoted to the task and the questions of public inconvenience must be seriously considered.

Baerwald (1975) explained that it should be remembered that all the data collected must be analyzed for any use, more extensive and complicated survey will increase not only the costs of conducting the survey but also the subsequent analysis. The investigators must therefore have a clear understanding of the purpose of the survey before commencing the work, moreover the survey should be planned accordingly to give no more than the relevant data. Generally counting may be carried out by the following means:

1. Manual Methods

Those are the simplest, most direct and in certain circumstances, the only satisfactory means of carrying out a volume survey **(Davies 1963).**

Pignataro1 (973) stated that the manual counts make use of field observers to obtain volume data and therefore they are subjected to the limitations of human factors generally precluding 24-hours' continuous counts. In fact, they are important for periodic checking of the accuracy of automatic devices. In addition, unusual conditions occurring during the time of the count cannot be recorded by the manual methods.

In other words, **Palanjian (1986)** mentioned in his study that the manual methods that can give vehicle classification very easily are suitable for short terms and non–continuous count.

2. Automatic Methods

Davies (1963) referred to the passing of vehicles which can be recorded automatically by using traffic counters, a traffic counter consists of two principle parts. These parts are the detector to sense the passage of a vehicle and the counter to record the pulses to it from the detector.

Since simplicity and reliability are two of the main considerations in the day to day operation of portable traffic counters, the type which is most commonly used the pneumatic detectors **(Glanville 1965).**

Detectors fall into several categories such as pneumatic detectors, electrical detectors, photoelectric detectors, radar detectors …etc **(Taylor, et al. 1987**).

Automatic methods of counting have the following advantages:

- They have a relatively low cost per hour of counting and little attendant labor is required, for installation and maintenance, and therefore measurements can be made for long periods **(Ashworth 1972).**
- They are accurate if regularly inspected and maintained (Gordon Wells, 1979).
- Cheap for long periods of counting which cover installation **costs (Gordon Wells, 1979).**

The disadvantages of automatic methods are:

- Difficulties occur in finding suitable sites for the equipment in localities where willful damage is likely to be encountered **(Ashworth, R., 1972).**
- Expensive installation for short sample counts **(Gordon Wells, 1979).**
- Frequent requires and skilled attention **(Gordon Wells, 1979).**
- Cannot make classified counts **(Gordon Wells, 1979).**
- Cannot compensate for e.g. three–axled Lorries **(Gordon Wells, 1979**).
- Equipment is relatively expensive, particularly as several units are usually required at the same time and may then not be used for some months **(Gordon Wells, 1979).**

3. Video Recording Technique

Lee D. Han, et al. (1989) mentioned that the Closed Circuit Television "CCTV" surveillance systems, installed at numerous locations in the highways, use television cameras to detect and verify incidents.

Advantages:

- CCTV systems can cover a large area, depending on installations.
- They have effective verification method.
- They provide reliable information.
- Current technology of cameras has made it possible to receive good video images in severe weather conditions.

- They can use video images in disseminating information to motorist.

Disadvantages:

- They have high capital cost to cover a large area.
- Incident identification is a function of coverage.
- They can be used for incident identification, but this is a labor-intensive process.

Baculinao (2001) mentioned that some agencies are cautious about the use of Video Image Vehicle Detection System "VIVDS" because of difficulties associated with the accurate detection of vehicles that are distant from the camera, experience with VIVDS in Texas indicates that acceptable advance detection can be achieved at distances up to 500ft (as measured from the camera to the most distant point of advance detection).

James Bonneson, et al. (2002) mentioned in his study that video imaging vehicle detection systems (VIVDS) become an increasingly common means of detecting traffic at intersections and interchanges in Texas. This interest stems from the recognition that video detection is often cheaper to install and maintain than inductive loop detectors at multi-lane intersections.

It is also recognized that video detection is more readily adaptable to changing conditions at the intersection. The benefits of "VIVDS" have become more substantial as the technology matures, its initial cost drop, and experience with it grows.

James Bonneson, et al. (2002) mentioned that "VIVDS" are used at intersection or interchange in the following conditions:

- When more than 12 stop-line detectors are needed at the intersection or interchange.
- When inductive loop life is short due to poor pavement or poor soil conditions.

- When extensive intersection reconstruction will last for one or more years.
- When the loop installation is physically impractical due to the presence of a bridge deck, rail road trucks, or underground utilities.
- When the pavement in which the loop is placed will be reconstructed in less than three years or during overlay projects at large intersections where the cost of replacing all loops exceeds the cost of installing the "VIVDS".

Shourie Kondagari (2006) stated that the Road-based traffic surveillance systems may also include other types of monitoring devices such as "CCTV", Video "VIDS", and sensors such as Remote Traffic Microwave Sensors "RTMS".

CCTV's and VIDS systems are more efficient and cost effective traffic monitoring equipment that provides real-time traffic information, but are sensitive to all weather conditions.

There are many issues associated with camera location and field of view calibration that must be taken in the consideration of video recording technique **(James Bonneson, et al., 2002)**:

1. **Camera location**: An optimal camera location is one that maximizes detection accuracy, as such; an optimal location is one that provides a stable, unobstructed view of each traffic lane as following:

   Occlusion: Detection accuracy is adversely affected by vehicle occlusion, occlusion refers to a situation where one vehicle blocks or obstructs the view of camera of a second vehicle. Three types of occlusion are presented with most camera locations: adjacent lane, same lane, and cross lane.

- Camera stability: Desirable camera heights and offset are often limited by the availability of structures that can provide a stable camera mount, most VIVDS products have an image stabilization feature that can compensate for some camera motions. However, excessive camera motion can adversely affect detection accuracy.

2. **Field of view calibration:** calibration of the camera field of view is based on a one–time adjustment to the camera pitch angle and the lens focal length. An optimal field of view is one that has the stop line parallel to the bottom edge of the view and in the bottom one-half of this view. The optimal view includes all approach traffic lanes. The focal length would be adjusted such that the approach width, as measured at the stop line equates to 90 to 100 percent of the horizontal width of the view; the factors that must be overcome to obtain an optimal field of view are:

a) Sun Glare and Reflection :

Detection accuracy is significantly degraded by glare from the sun and sometimes from strong reflections. Sun glare represents direct sunlight entering the camera (typically during dawn and dusk hours). Reflections emanate as "star" of bright light coming from vehicle corners or edge.

b) Image size :

Detection accuracy is dependent on the size of the detected vehicle as measured in the field of view. Accuracy improves as the video image size of vehicle increases. Image size in turn can be increased by increasing the lens focal length.

c) Other considerations :

Several additional design factors can compromise detection accuracy like light sources, power lines, and headlight glare.

2.10 Highway Capacity Software (HCS2000)

Highway capacity software (HCS) is developed and maintained by Mc Trance center, University of Florida, as a part of its user-supported software maintenance as a faithful implementation of the highway capacity manual (HCM) procedures.

Shamel Ahmed (2003) defined (HCS) as a public domain package that automates the procedures of Highway Capacity Manual (HCM). It is one of the most widely used software packages that include Basic Freeway segments, Ramps and Ramp junction, signalized intersections, urban and sub urban Arterials, Two lanes Highway and Multilane Highway.

Mc Trans has upgraded modules of the highway capacity software (HCS) to add new features and to incorporate the modified procedures in the new capacity **(HCM, 2000)**. The Transportation Research Board (TRB) distributed this exciting new release (HCS 2000 TM) immediately following the publication of the **(HCM, 2000).**

2.11 HCM procedures for determining level of service

Determination the level of service for multilane highway involves three steps **(HCM, 2000)**:

1- Determine of free-flow speed
2- Determine of flow rate
3- Determine of level of service.

CHAPTER THREE
DATA COLLECTION, ABSTRACTION AND PROCESSING

3.1 Introduction

This chapter presents selected sections of segments which explain available methods of traffic data collection in addition to the objectives and specifications of data collection for the purpose of this research project.

The selected sites for data collection are described and the encountered problems during their stages of data collection are presented. Data abstraction and processing are also presented in this chapter.

One of the important objectives of this research is to determine capacity, LOS and speed prediction for divided multilane in rural highway. To achieve this objective, it was necessary to collect data about the traffic behavior during different conditions and different alignments. Sufficient data had to be collected to assist in the prediction of these parameters.

In this chapter, data of traffic flow and traffic composition were collected during peak periods by using video recording techniques for all selected sections in both directions during morning and evening periods.

Free Flow Speed data were collected by the same technique and for all section in off peak periods. These collected data were then abstracted by the aid of computer programs developed by researcher and others for those purposes. The video recording of data collection was started on Sunday in : 2^{nd}/ Oct./2011. The data required fell into the following three main categories:

1. Traffic speed data.
2. Traffic flow characteristics which include traffic volume and traffic composition.

3. Highway geometry which includes type of section, carriageway width, cross section, number of lanes ,their widths and another marginal elements.

3.2 Specification of Suitable Site for Data Collection

To collect corrected and sufficient data that satisfy the requirements of statistical calculations and representations, it was necessary to select sites which have level of traffic flow, speed and section geometry that give realistic results that can be analyzed statistically, accordingly,

1. Selected sites should satisfy the followings as suggested by **(Al-Neami and Al-kubaisi, 2000)**:
   - Existence of an accessible vantage point allows for data collection to be made without effect on the observed traffic behavior.
   - Vehicle flow varies over the times of the day and the days of week.
   - Range in the percentage of vehicle movement types and traffic compositions is to be considered.
2. Along times of days, visits were made to all of highway sections along Ramadi - Falluja divided multilane rural highway. A check was made to ensure that the selected highway will conform the listed above requirements.

Based on surveys, divided multilane rural highway sections, that links between Ramadi and Falluja both directions were selected since these were found to satisfy the objectives and specifications of data collection. The location of this highway is presented in figure (3-1).

Figure (3-1): The location of highway sections

3.3 Description of Survey Sites

The selected highway was classified into eight segments. Every segment was divided into number of sections depending on the change of the highway geometry and alignment for each direction. This process results in 40 sections, 20 for each direction. A brief description of the dimension for each section is illustrated in figure (3-2) as a sample for the main geometric dimension and listed in tables (3-1) and (3-2).

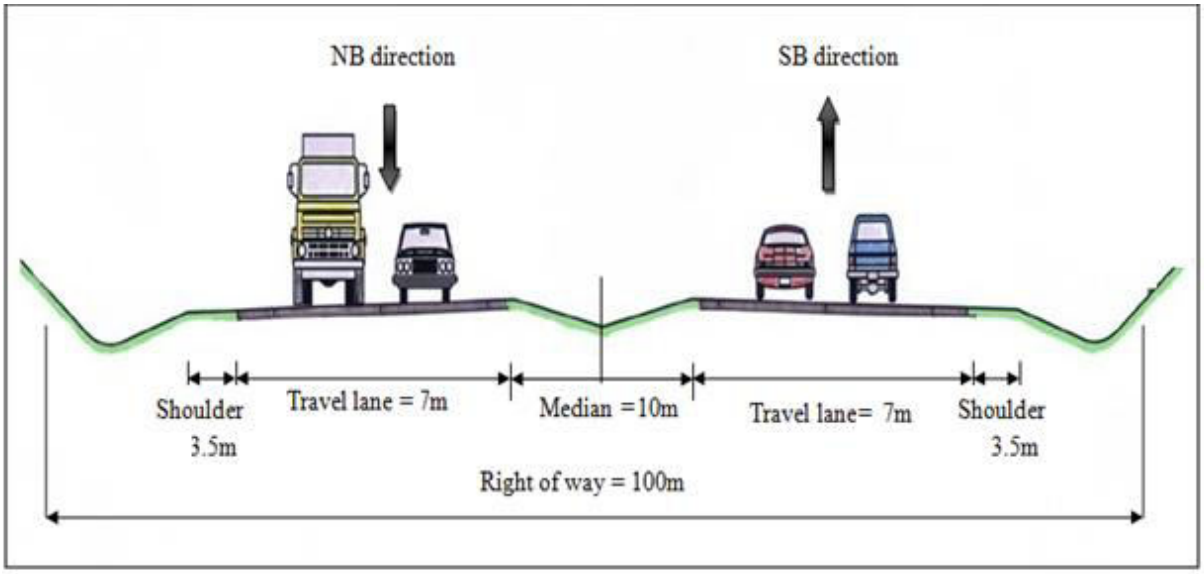


Figure (3-2): The main geometric features for section two

Description of each segment is presented below:

Segment one*:* is located at Hseeba rural area. It starts from station (6+300m to 8+500 m) east " Al-Ramadi east gateway" (00+000 m) . This segment has (6) sections, three for each direction: the NB direction sections include horizontal curve, straight and horizontal curve consecutively; while the SB direction sections are identical to the NB direction sections. Directions are divided by a (10) m width earth median (granular materials). The pavement carriageway width is (7m) with (3.5m) of granular materials as a shoulder width .A plan for section three is presented in figure (3-3).

Figure (3-3): Plan of section (3).

Segment two*:* is located at Matheeq rural area from station (10+500m to 12+500m). This segment has three sections for each direction: both directions (NB and SB) include horizontal curve, straight section and horizontal curve in consecutively. Directions are divided by an earth median (granular materials) with of (10m) width for sections: (4,6,35,37) while the median at sections. (5,36) is curbs with of (2m) width, carriageway width is (7m) and (3m) of granular materials as a shoulder width. A plan for section four is presented in figure (3-4).

Figure (3-4): Plan of section (5).

Segment three*:* is located at Sedeqia rural area from station (13+000m to 14+400m). Both directions (NB and SB) consist of two sections, straight and curve section. Directions are divided by a (10m) earth median. Pavement widths for the two directions and their shoulder widths are (7m) and (3-3.5m) respectively. A plan for section eight is presented in figure (3-5).

Figure (3-5): Plan of section (8).

Segment four: is located at Khaldia suburban area from station (15+000m to 17+500m). This segment has three straight sections for every direction. NB and SB are divided by a concrete median (curbs) with dimension of (3m*0.3m), carriageway width of (7m) and (2.5-3.5m) of granular materials as shoulder width. A plan for section ten is presented in figure (3-6).

Figure (3-6): Plan of section (10).

Segment five: is located at AL- Nadhim rural area from station (18+800m to 19+000m). This segment has two sections for each direction: (NB and SB) have grade horizontal curve and straight sections consecutively. NB and SB for grade curve section are divided by a (10m) earth median with a steel barrier, the pavement widths is (7m) ends by steel fence with the shoulder. For straight sections (NB and SB) are divided by an earth median (granular materials) with width of (10) m , pavement carriageway width of (7m) and (3m) of granular materials as a shoulder width. A plan for section twelve is presented in figure (3-7).

Figure (3-7): Plan of section (12).

Segment six: is located at Habania area from station (21+800m to 22+300m). This segment has three sections for each direction: both directions (NB and SB) have straight and horizontal curve section consecutively. (NB and SB) are divided by an earth median (granular materials) with width of (10) m , pavement carriageway width of (7m) and (2-3m) of granular materials as a shoulder width. A plan for section is presented in figure (3-8).

Figure (3-8): Plan of section (14).

Segment seven*:* is located at Kolecam rural area from station (24+000 to 24+400m). This segment has two sections for each direction: (NB and SB) have straight and curve sections consecutively. NB and SB are divided by an earth median (granular materials) with width of (10) m , pavement carriageway width of (7m) and (3m) of granular materials as a shoulder width. A plan for section eighteen is presented in figure (3-9).

Figure (3-9): Plan of section (15).

Segment eight*:* is located at Falahat rural area from station (36+100 to 37+200m). This segment has two sections for each direction: (NB and SB) have straight and curve sections consecutively. NB and SB are divided by an earth median (granular materials) with width of (18) m , pavement carriageway width of (7m) and (2.5-3m) of granular materials as a shoulder width. A plan for section twenty is presented in figure (3-10).

Figure (3-10): Plan of section (20).

Table(3-1) : Observed of field geometric data for NB direction

Sections			Geometric Data								
Sec. No.	Station NB	Alignment type	No. of lanes	Lane width m	Shoulder width m	Shoulder's drop cm	Median m	Median Type	Curve Length m	Curve Radius m	Field super elevation
1	6+300	Curve	2	3.5	3.5	10	10	Earth	307	1370	0.021
2	6+900	Straight	2	3.5	3.5	4	10	Earth	---	---	---
3	8+500	Curve	2	3.5	3	15	10	Earth	458	740	0.057
4	10+500	Curve	2	3.25	3	8	10	Earth	330	520	0.051
5	11+000	Straight	2	3.5	3	7	2	Concrete	---	---	---
6	12+500	Curve	2	3.5	3	7	10	Earth	532	850	0.042
7	13+000	Straight	2	3.5	3	4	10	Earth	---	---	---
8	14+400	Curve	2	3.75	3.5	9	2	Concrete	677	900	0.057
9	15+000	Straight	2	3.5	3	4	2	Concrete	---	---	---
10	15+700	Straight	2	3.5	2.5	10	2	Concrete	---	---	---
11	17+500	Straight	2	4	4	8	2	Concrete	---	---	---
12	18+800	Curve	2	3.5	*	*	*	*	454	770	Grade
13	19+000	Straight	2	4.6	3	4	10	Earth	---	---	---
14	21+800	Straight	2	3.5	2	7	10	Earth	---	---	---
15	22+000	Straight	2	3.5	2	4	10	Earth	---	---	---
16	22+300	Curve	2	3.5	3	5	10	Earth	442	1040	0.05
17	24+000	Straight	2	3.5	3	4	10	Earth	---	---	---
18	24+300	Curve	2	3.4	3	7	10	Earth	383	600	0.054
19	36+100	Straight	2	3.5	2.5	9	4	Concrete	---	---	---
20	37+200	Curve	2	3.5	3	13	18	Earth	476	570	0.06

(*) refer to the steel barrier on the roadside.

Table(3-2) : Observed of field geometric data for SB direction

Sections			Geometric Data								
Sec. No.	Station SB	Alignment type	No. of lanes	Lane width m	Shoulder width m	Shoulder's drop cm	Median m	Median Type	Curve Length m	Curve Radius m	Field super elevation
21	2+800	Curve	2	3.5	3	3	18	Earth	476	570	0.06
22	3+900	Straight	2	3.5	2.5	2.5	4	Concrete	---	---	---
23	15+700	Curve	2	3.5	3	3	10	Earth	383	600	0.054
24	16+000	Straight	2	3.5	2.5	5	10	Earth	---	---	---
25	17+700	Curve	2	3.5	3	3	10	Earth	442	1040	0.05
26	18+000	Straight	2	3.5	2	12	10	Earth	---	---	---
27	18+500	Straight	2	3.5	1.5	2.5	10	Earth	---	---	---
28	21+000	Straight	2	4.5	3	13	10	Earth	---	---	---
29	21+500	Curve	2	3.5	*	*	*	*	454	770	Grade
30	22+500	Straight	2	3.5	3	9	2	Concrete	---	---	---
31	24+300	Straight	2	4.25	3	6	2	Concrete	---	---	---
32	25+000	Straight	2	3.5	2.5	5	2	Concrete	---	---	---
33	25+600	Curve	2	3.5	3	4	2	Concrete	677	900	0.057
34	27+000	Straight	2	3.5	3.5	5	10	Earth	---	---	---
35	27+500	Curve	2	3.5	3	5	10	Earth	532	850	0.042
36	29+000	Straight	2	3.5	3	3	2	Concrete	---	---	---
37	29+500	Curve	2	3.5	3.5	8	10	Earth	330	520	0.051
38	31+500	Curve	2	3.5	3	3	10	Earth	458	740	0.057
39	33+100	Straight	2	3.5	3.5	9	10	Earth	---	---	---
40	33+700	Curve	2	3.5	3.5	10	10	Earth	307	1370	0.021

(*) refer to the steel barrier on the roadside.

3.4 Technique used in traffic data collection

A method of data collection required: types of vehicles (traffic composition), speed, density, direction and the distance that vehicle travels which was suitable for the measurement of the various activities of traffic movements throughout providing data about a number of vehicles (traffic volume).

According to the currently available methods of traffic data collection, the video recording is the most suitable method due to the following factors:

1. Shortening time and cost.
2. The large size of required activities and traffic behaviors which may be achieved.
3. The manual method allows only the partial information about traffic movements to be collected during an observation period.

So, the researcher uses video recording technique to collect the data. This technique has the following advantages **(Al-kubaisy, 2000):**

- To allow a large number of events to be recorded at one time.
- To record any incident that may occur during the recorded session which may result in abnormalities in the observed data.

The data were collected using a digital video camera with direct display. The camera was put in front of the segments to collect the data associated with vehicle traffic flow parameter. A good vantage point was selected by researcher to give the best view to record each two adjacent NB and SB segments. The camera was fixed and located on high places beside the site.

The choice of this vantage point helped the researcher to ensure wide coverage areas for the two directions. The camera used was with wide range and high length of focal lens to get the best zoom.

The camera was connected to transfer video recording from videotape to the personal computer by abstracting and processing the observed data.

The data collected by video recording technique were made in sessions for each segment at peak hours in the morning and evening for each direction. The total duration of video recording for the every segment was (10) ten hours. Listed tables (3-4) and (3-5) represent typical traffic data volume collections . The observations were restricted to a typical weekdays, clear sky and sunny days (good weather conditions).

The pavement edge width about (50cm) was divided into 5 sections of 10cm using yellow self adhesive tape to measure the loss in lane width **(Chandra PP:498,2004)**. These sections were marked transversally in white color for a distance of 60m. Speeds in straight section were measured ordinary at any distance, while at the horizontal alignment speeds were measured at the center of the curve.

But unfortunately some troubles happened during the periods of video recording, as in the followings:

1. Great difficulties were faced to get permission from the policemen at the check points along the highway because it should be taken from the commander of Al- Anbar operations only which took for one month.
2. All the police stations surrounded the area of survey and also all the police patrols that exist in the area of survey were to be informed that there is a process of video recording and site dimension measuring. Also obligation was signed in police station that the appearance of any police or military patrols in the films is prohibited.
3. Burning plans and design data base profiles for this rural highway by American occupation when they stormed the directorate of highway and

bridges building in Al-Anbar province. For this reason ;geometric data were measured on-site by Total Station and Level devices.

4. Difficulties for finding best location for camera that provides the appropriate length to compute time headway and is not to be affected by sun glare.

3.5 Technique used in geometric data collection

The geometric data for this study were collected for 40 sections , 22 of them were straight sections and 18 were horizontal curve sections. The method included several techniques:

1- Measuring tape was used to compute sections dimensions such as (median, shoulder ,carriage way widths and length of recorded section by video).

2- Total station was used to determine geometric data of horizontal alignment on-site such as: curve length, radius and super elevation)

3.6 Data abstraction and processing

3.6.1 Data abstraction

The recorded data were abstracted from video films with the aid of computer program called "EVENT" program. This program was developed by **(Al-Neami , 2000)**. The program produces time accuracy values of the recorded data. The procedure of how this program works is as the following:

The program starts displaying a message that press ESC key to start and ESC key again to finish. Then the pressing of ESC key the program will starts counting time for successive events. The observer allocates a specified key to be pressed for each vehicle passed and vehicle type.

Then a tag character is appeared for each pressed key together with the recorded time of the successive events. Data then can be stored for future use.

Other statistical programs were written using Microsoft Visual Basic 6.0 to put the data in groups of intervals to simplify the statistical analysis of the data. Video films were played back a number of times to get the required information. The abstracted data include the following:

1. Time headway between successive vehicles measured on a specific point on the segment.
2. Sufficient speed data measured for individual vehicles and should be statistically meaningful.
3. Vehicular traffic flow and traffic composition.

3.6.2 Data processing

1. Traffic flow data processing

Data were abstracted using again "EVENT" program and another computer program developed for this purpose. This program is called "VBFS". The program was written using Visual Basic language.

It was developed to calculate the time headway between successive vehicles passing a specified point and arrange them in a class width to be satisfied for the calculation of the frequency distribution of the observed data.

The different number of vehicles and traffic composition can be distinguished from the tag character produced by the "EVENT" program. Appendix "A" illustrates the "EVENT" program interface. This process was made for the eight segments, for morning and evening periods of time.

2. Traffic composition data processing

The abstracted data for traffic composition were processed by using again "EVENT" program and a program called visual basic traffic composition "VBTC". The program was written using Visual Basic language. It was developed to calculate the type of vehicles that pass the section of highway to be satisfied for the calculation. The vehicles types were classified into four general classes as in table (3-3) below.

Table (3-3): Traffic flow counts and composition.

Time (15 min)	**Passenger cars (V/15 min)**	**Heavy vehicles**		**Others**	**Total (15 min)**
		Buses (V/15 min)	***Trucks (V/15 min)***		
7:30-7:45	202	1	32	1	236
7:45-8:00	210	1	25	1	237
8:00-8:15	285	1	36	1	323
8:15-8:30	199	1	38	1	239
8:30-8:45	175	0	13	1	189
8:45-9:00	190	0	11	1	202
9:00-9:15	174	1	13	0	188
9:15-9:30	181	0	17	0	198
9:30-9:45	298	1	29	0	328
9:45-10:00	212	0	25	0	237
10:00-10:15	134	0	25	0	159
10:15-10:30	207	0	21	0	228
10:45-11:00	134	1	22	1	157
11:00-11:15	147	0	24	0	171
11:15-11:30	173	0	17	1	190
11:30-11:45	154	0	25	0	179
11:45-12:00	163	0	29	0	192
12:00-12:15	157	1	33	1	191
12:15-12:30	192	0	37	1	229
12:30-12:45	162	1	31	1	194
12:45-1:00	194	1	23	1	218
1:00-1:15	220	0	18	0	238

1:15-1:30	181	0	16	1	197
1:30-1:45	173	0	28	0	201
1:45-2:00	178	0	22	1	200
2:00-215	202	0	31	1	233
2:15-2:30	180	1	24	1	205
2:30-2:45	227	3	23	1	253
2:45-3:00	177	2	20	0	199
3:00-3:15	150	2	21	0	173
3:15-3:30	148	2	24	0	174
3:30-3:45	156	0	18	0	174
3:45-4:00	126	0	27	0	153
4:00-4:15	111	0	28	0	139
4:15-4:30	133	0	34	1	167
4:30-4:45	136	0	26	1	162
4:45-5:00	114	0	37	1	151
5:15-5:30	100	0	20	1	120
Summation					**7504**

Tables (3-4) and (3-5) show the abstracted , processed and resulted data for all sections along NB and SB.

Table (3-4): Traffic data for the NB sections.

Sec. No.	**Total flow v/h**	**PHF**	**Flow rate pc/hr/ln**	**Av. running speed km/hr**	**Min. Speed km/hr**	**Max. Speed km/hr**	**Standard Deviation**	**F.F.S km/hr**
1	1470	0.88	898	73	60	127	13.6	81
2	1011	0.83	655	79	68	102	8.7	82
3	1180	0.84	772	72	60	127	15	75
4	917	0.82	616	67	60	123	14.6	70
5	1128	0.89	674	80	70	94	6	88
6	1084	0.85	693	73	50	105	13	78
7	946	0.89	584	73	50	108	13	80
8	1064	0.86	676	73	50	140	12	78
9	1372	0.88	848	67	50	100	12	75
10	1360	0.89	840	64	50	104	14	75
11	1147	0.87	724	78	50	118	14	80

12	1045	0.80	768	73	50	127	15	75
13	980	0.87	625	83	68	102	8.7	95
14	966	0.87	616	81	60	126	13.6	98
15	920	0.89	587	81	60	126	13.5	94
16	1055	0.89	630	69	60	104	14	80
17	920	0.87	529	80	55	93	10.3	90
18	925	0.88	598	69	50	105	14.3	72
19	1422	0.84	920	75	55	106	12.6	82
20	1080	0.88	659	68	50	112	13.2	70

Table (3-5):Traffic data for SB sections.

Sec. No.	Total flow v/h	PHF	Flow rate pc/hr/ln	Av. running speed km/hr	Min. Speed km/hr	Max. Speed km/hr	Standard Deviation	Field F.F.S km/hr
21	1004	0.84	656	70	55	91	10.8	70
22	1050	0.87	681	70	61	107	10.6	78
23	1250	0.85	808	72	55	95	10.2	75
24	904	0.88	570	82	50	116	14	88
25	1140	0.88	727	72	55	95	10.3	82
26	815	0.87	520	82	60	109	10.3	85
27	805	0.85	515	82	60	108	10.2	88
28	967	0.87	610	79	50	118	14.6	88
29	866	0.87	656	77	60	100	10.4	78
30	980	0.86	612	75	50	122	14.5	76
31	1317	0.82	949	73	70	101	8.7	84
32	1288	0.87	774	68	50	95	10.2	70
33	1189	0.82	805	75	50	104	12	78
34	933	0.86	590	80	66	107	8.6	82
35	887	0.86	572	72	50	93	9.5	80
36	1203	0.88	742	81	70	102	8.8	86
37	1310	0.86	818	72	50	93	9.5	69
38	1138	0.89	770	70	50	105	12	76
39	1285	0.86	803	64	51	123	14	74
40	1580	0.88	957	70	72	108	9.3	84

3. Vehicular speed data processing

The speed calculation is resulted by dividing distance over time. To achieve that, the researcher located two points with known distance of (60m) for each section on the road before the start of video recording. Transversally on carriage way painted marks were put on these points which represent the start and the end for the observed vehicles which their speeds are to be measured.

The length between these two points represents the distance that the observed vehicles traveled on. Figure (3-11) shows how the field distance were allocated for straight and horizontal sections.

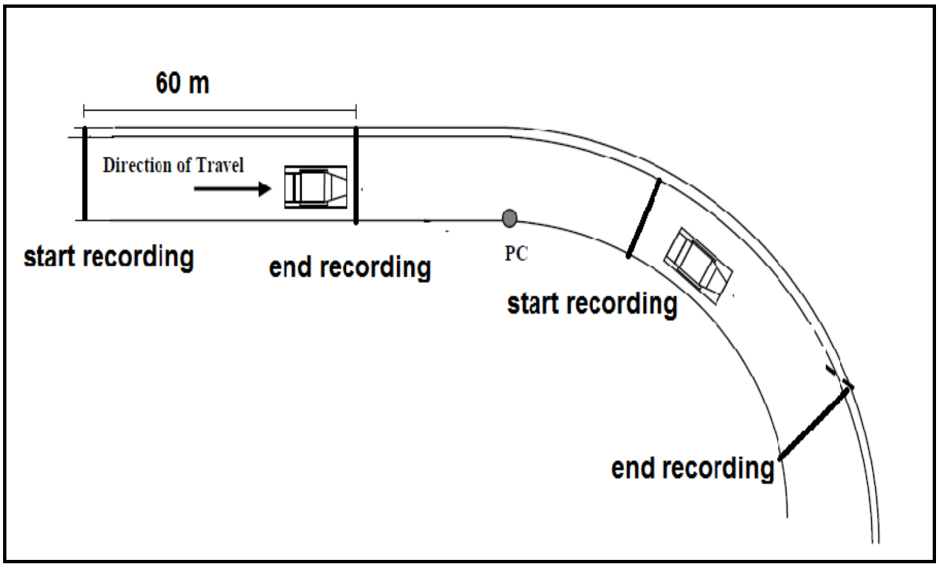


Figure (3-11): Distance allocation for straight and horizontal sections

The time duration for each observed vehicle was calculated by "EVENT" and "VBSS " visual basic speed studies programs. The programe used to find the difference between the two times (the start and the end recording lines). Speed is then calculated for each observed vehicle by dividing the traveled distance by its travel time duration.

Two hundred (200) random samples of vehicles (N) were observed to calculate their speeds for each direction (both morning and evening peak) in each segment. The results were put in 40 excel sheets as the followings:

1. Section 1 , Northbound, Speed, Morning (7:30-12:30) AM and (2:00-5:00) PM. And so for the other 19th of NB sections.
2. Section 21 , Southbound, Speed, Morning (7:30-12:30) AM and (42:00-5:00) PM. And so for another 19th of SB sections. Table (3-6) is a typical sample of cumulative speed calculations.

Table (3-6): Sample of cumulative speed calculations section (1)

No.	Mid speed km/hr	Freq. in class *fi*	*fi**ui	*fi**ui^2	Cumulative freq. %
1	50	4	200	10000	2
2	55	6	330	18150	4
3	60	26	1560	93600	16
4	70	42	2940	205800	34
5	75	66	4950	371250	63
6	80	50	4000	320000	85
7	85	10	850	72250	93
8	90	14	1260	113400	96
9	95	6	570	54150	98
10	100	4	400	40000	100

CHAPTER FOUR
DATA ANALYSIS AND RESULTS

4.1 Introduction

The procedures which presented in this chapter are used to analyze the traffic flow, free flow speed, capacity, and level of service (LOS), under different feature requirements, and impacts of different factors of traffic and geometry on the rural and suburban area of divided multilane highways. Analysis of the results was mainly achieved under the following phases:

1- Traffic flow operations and control.
2- Speed analysis and studies, which includes the determination of operating, running, and free flow speeds.
3- Geometric design parameters, horizontal curve alignments, and other conditions that affect the highway performance and capacity.
4- Capacity and level of service determination and the factors that effect on them.

4.2 Traffic operations and control

Traffic volume and traffic composition for all sections within the two directions were computed and analyzed by the observed traffic data. These data are highly affecting determination of highway FFS, capacity, density, and finally LOS. Table (4-1) indicates the traffic volumes, compositions (percentage of heavy vehicles).

Table (4-1): The percentage of HV% for each section

Sec. no.	Vol. v/h	HV%	Sec. no.	Vol. v/h	HV%	Sec. no.	Vol. v/h	HV%	Sec. no.	Vol. v/h	HV%
1	1470	13.0	11	1147	15.1	21	1004	11.0	31	1317	13.2
2	1011	14.8	12	1045	21.8	22	1050	11.8	32	1288	12.2
3	1180	11.4	13	980	7.3	23	1250	15.2	33	1189	11.5
4	917	23.0	14	966	91.0	24	904	12.2	34	933	10.0
5	1128	14.3	15	920	12.3	25	1140	11.8	35	887	11.3
6	1084	16.3	16	1055	12.5	26	815	12.8	36	1203	12.0
7	946	19.0	17	920	8.6	27	805	11.3	37	1310	13.4
8	1064	18.04	18	925	22.1	28	967	10.3	38	1138	12.5
9	1372	20.05	19	1422	7.7	29	866	9.8	39	1285	13.6
10	1360	7.2	20	1080	10.0	30	980	11.8	40	1580	11.8

The effect of heavy vehicles presented in roadway is important to estimate density and LOS. Vehicles other than passenger cars (a category that includes small trucks and vans) into the traffic stream affects the number of vehicles that can be served in the traffic stream. Heavy vehicles are vehicles that have more than four tires touching the pavement (HCM, 2000). Heavy vehicles adversely affect traffic in two ways:

- They are larger than passenger cars and occupy more road space.
- They have poorer operating capabilities than passenger cars, particularly with respect to acceleration, deceleration, and the ability to maintain speed on upgrades.

The total traffic volumes for all highway sections in the two directions (NB, and SB) are represented graphically in figures (4-1) and (4-2).

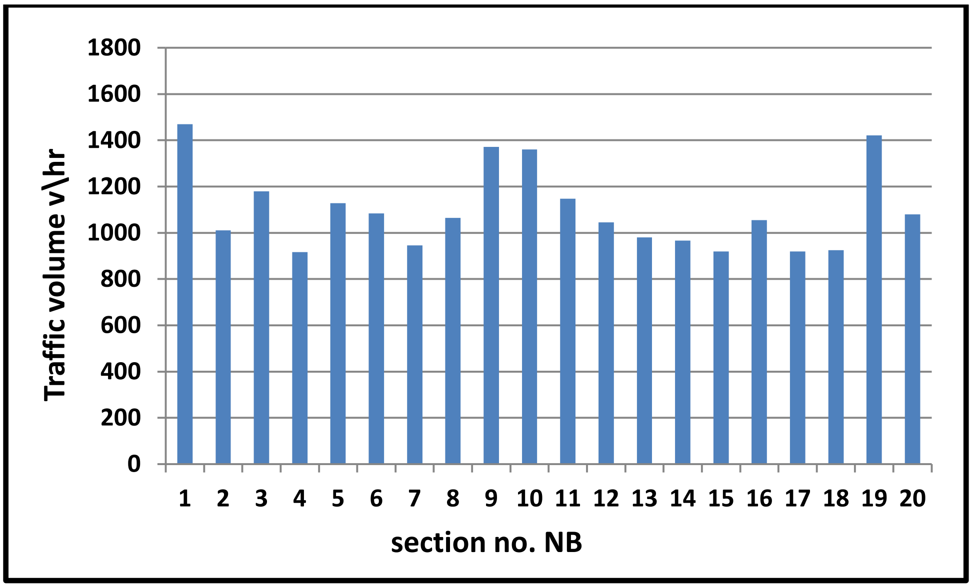


Figure (4-1): The traffic volume for NB

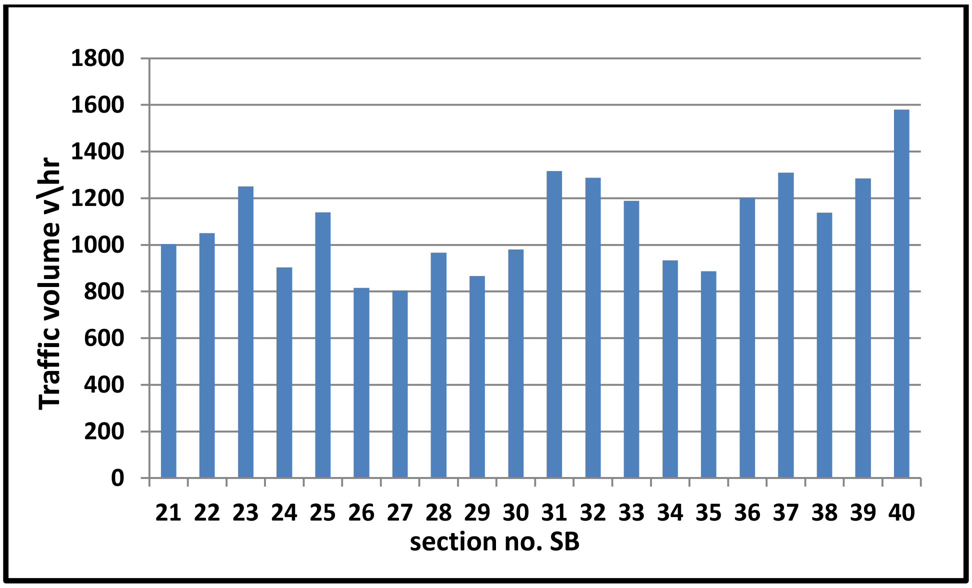


Figure (4-2): The traffic volume for SB

From table (4-1) above, the percentage of heavy vehicle (Hv%) is ranging between (7.2 to 23) depending on the land use adjacent to the studied sections, figures (4-3 and 4-4) show the graphically values as in below:

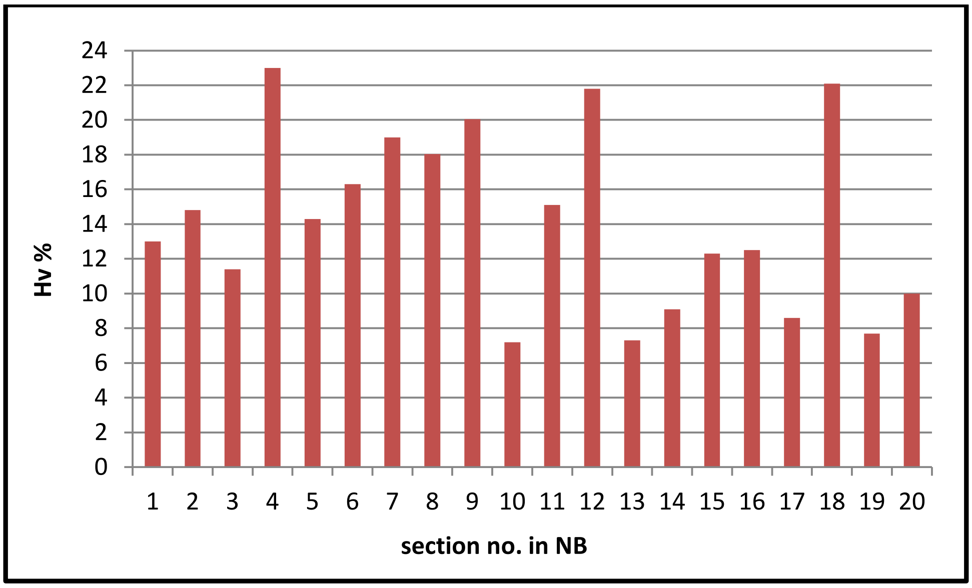


Figure (4-3): The heavy vehicle percentage for NB

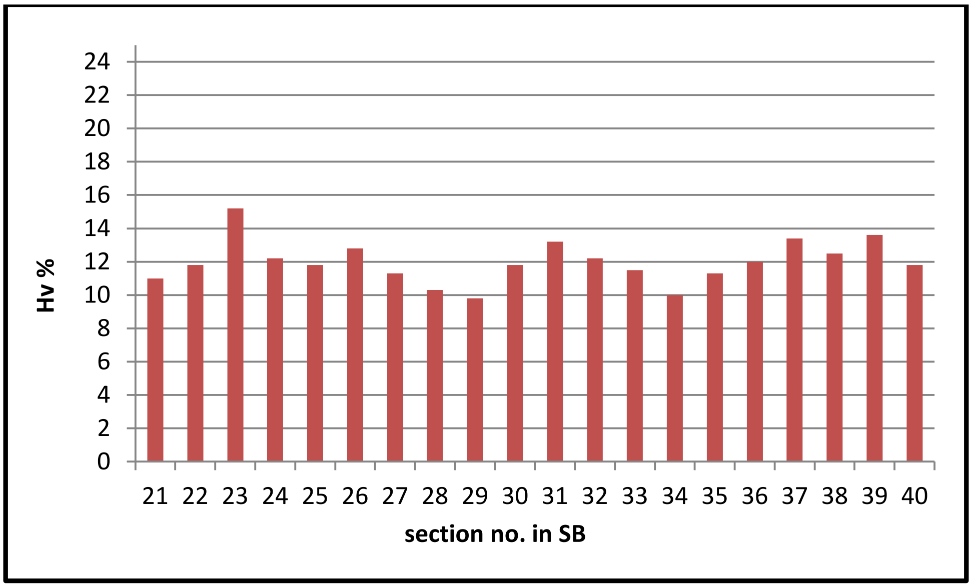


Figure (4-4): The heavy vehicle percentage for SB

Sample of traffic composition determination is illustrated in table (4-2) and graphically in figures (4-5) for section four.

Table (4-2): shows traffic composition for sec.(4)

Category	no.	Percent %
Passenger car	690	48.5
Semi-buss	521	36.7
Heavy vehicle	188	13.2
Others	21	1.47

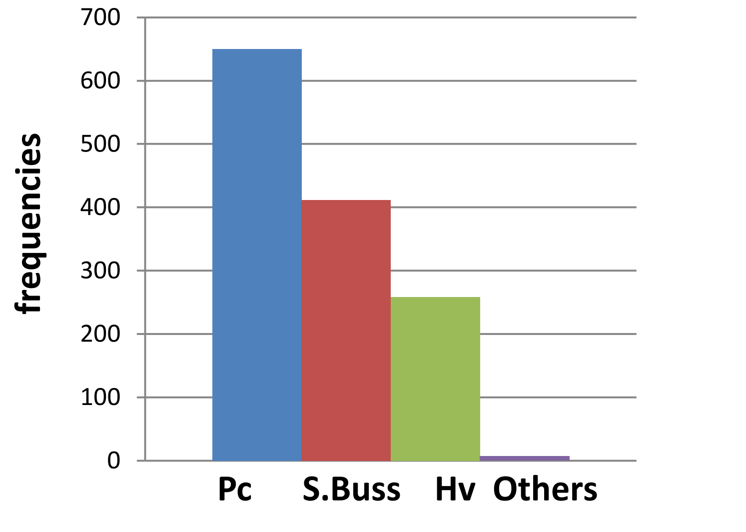


Figure (4-5): Traffic composition for sec.(4)

4.3 Sample size of speed studies

The calculated mean speed is used to represent the true mean value of all vehicle speeds at that location. The accuracy of this assumption depends on the number of vehicles in the sample. Therefore it is necessary to select a sample size that will give an estimated mean with an acceptable error limits. Statistical procedures are used to determine minimum sample size as Mentioned that the duration of the study should be such that the minimum number of vehicle speeds required for statistical analysis is recorded. Typically, the duration is at least (1) hour and the sample size is at least (30) vehicles, the minimum sample size can be estimated according to the following equation: **(Garber and Hoel, 2003).**

$$N = \left(\frac{Z\,S}{E}\right)^2 \quad \text{...............(4-1)}$$

where:

N = Minimum sample size.

Z = Confidence level.

S = Estimate of the standard deviation.

E = Range of error, which is equal to 2.5 (km/hr).

At 95% level of significance, the confidence level (z) is equal to (1.96) in **(Garber and Hoel, 2003 table 4-1)** :

Therefore, the minimum sample size:

$$N = \left(\frac{1.96*14.5}{2.5}\right)^2 = 130 \quad \text{samples}$$

The minimum number of collected speed that satisfies the requirement of this case is less than the actual sample size that collected in the field which is (200). Therefore, the observed speed vehicle number may be considered satisfied to give an estimated mean.

4.4 Speed analysis and studies

Speed data were abstracted by the output files of "EVENT" and "VBSS" programs and analyzed. The analysis of the entire period of video recordings represents the all segments in ten hours of morning and evening for both directions (NB and SB) which produced various cases of flow. During the analysis of these cases, speed data were classified and grouped. The following types of speed were obtained:

1. Design speed
2. Running and operating speed.

1. Design speed

Design speed is a selected speed used to determine the various geometric design features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of highway. The following equation was applied to compute speeds at horizontal curves (**AASHTO, 2001**):

$$e + f = \frac{V^2}{127\,R} \quad \text{........} \quad (4\text{-}2)$$

Where: R: curve radius in (m)

e: superelevation rate

f: side friction factor

V: design speed (km/hr).

The design speed according to the existing and collected road geometry can be obtained for the curved sections of the highway. The obtained critical value then compared with the designed value at the stage of roadway design and construction. Table (4-3) illustrates these results.

Table (4-3): Determination of speed at horizontal curve

Sec.	R (m)	e	f	V (km/hr)
1&40	1370	0.021	0.12	158
3&38	740	0.04	0.12	122
4&37	520	0.05	0.12	106
6&35	850	0.042	0.12	132
8&33	900	0.047	0.12	138
12&29	770	0.043	0.12	126
16&25	1050	0.045	0.12	148
18&23	600	0.045	0.12	112
20&21	570	0.05	0.12	110

From calculations above, it was found that the critical (minimum speed) is (106 km/h) or radius of (570 m).This value is greater than the base design value of the highway which is (80 km/h) according to the document of Al-Anbar directorate of roads and bridges which is. The difference is attributed to the followings:

- The selected rural highway was single carriage way (two way two lane) at the stage of construction.
- A change in the geometric design of the highway (horizontal or/and vertical alignment) may occurred.

2. Running and operating 85th percentile speed

The speed at which an individual vehicle travels over a highway section is known as its running speed. The running speed is the length of the highway section divided by the running time required for the vehicle to travel through the section (**AASHTO, 2001**).

The average running speed of vehicles is the most appropriate speed measure for evaluating level of service and road user costs. The average running speed is the sum of the distances traveled by vehicles on a highway section during a specified time period divided by the sum of their running times.

Operating speed is the speed at which drivers are observed operating their vehicles during free flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature **(AASHTO, 2001).**

The running speed values of all highway sections were calculated by dividing the length of highway section by travelling time for (≥ 200) vehicles as a sample size. Speeds classes had been classified into ten groups, the center of the class intervals were taken in calculations. Table (4-4) and figures (4-6),(4-7) are samples of calculation for section one in NB direction. Operating speed values were determined by the 85th percentile of the cumulative frequencies.

Table (4-4): Observed values of arrival speeds for section one

No.	Mid speed km/hr	Obs. freq. in class *fi*	*fi**ui	*fi**ui^2	Cumulative freq. %
1	50	4	200	10000	2
2	55	6	330	18150	4
3	60	26	1560	93600	16
4	70	42	2940	205800	34
5	75	66	4950	371250	63
6	80	50	4000	320000	85
7	85	10	850	72250	93
8	90	14	1260	113400	96
9	95	6	570	54150	98
10	100	4	400	40000	100

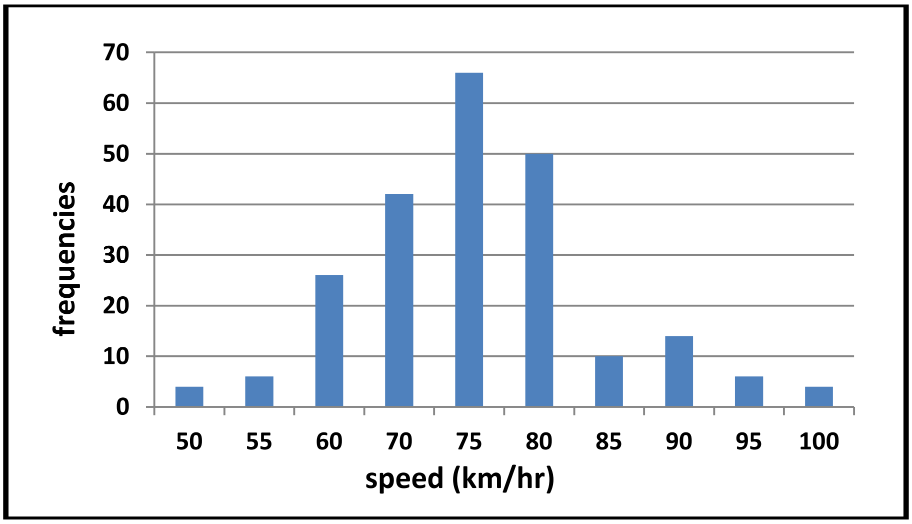


Fig.(4-6):Observed vehicles speed for section one

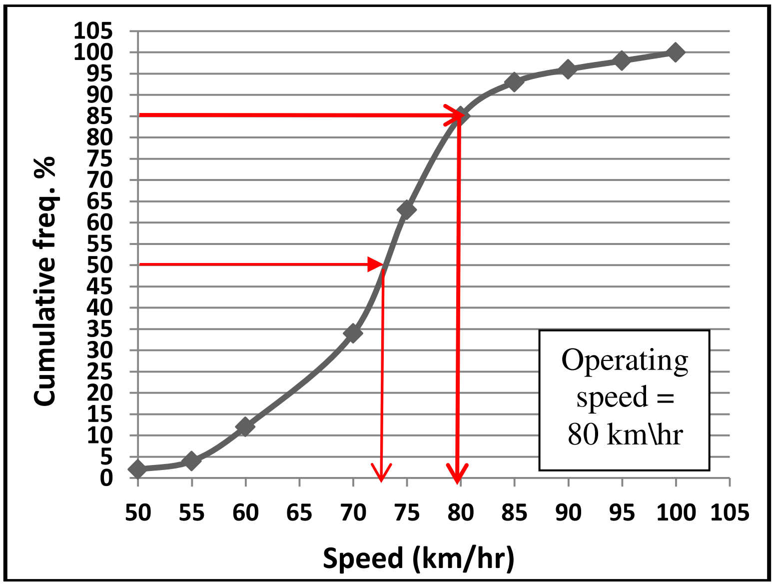


Fig.(4-7):Cumulative distribution for section one

Based on figure (4-7), the average running speed and 85th percentile speed for section one were obtained as (73 km/h) and (80 km/h) respectively.

The obtained speed data for all highway sections are illustrated in tables (4-5) and (4-6) for NB and SB directions respectively.

Table (4-5): Speed values for all sections in NB direction

Sec. No.	Min. Speed km/hr	Max. Speed km/hr	Standard Deviation km/hr	Running speed km/hr	Operating speed km/hr
1	60	127	9.6	72	80
2	68	102	9.7	79	85
3	60	127	9.5	72	75
4	60	123	13.2	67	70
5	70	94	6	80	88
6	50	105	13	73	78
7	50	108	13	73	80
8	50	140	12	73	78
9	50	100	12	67	74
10	50	104	14	64	76
11	50	118	14	78	80
12	50	127	15	73	78
13	68	102	8.7	83	95

14	60	126	13.6	81	98
15	60	126	13.5	81	94
16	60	104	14	69	80
17	55	93	10.3	80	90
18	50	105	14.3	69	72
19	55	106	12.6	80	82
20	50	112	13.2	68	70
Av.	**56.3**	**112.45**	**12.06**	**74.1**	**81**

Table (4-6): Speed values for all sections in SB direction

Sec. No.	Min. Speed km/hr	Max. Speed km/hr	Standard Deviation km/hr	Running speed km/hr	Operating speed km/hr
21	55	91	10.8	64	72
22	61	107	10.6	70	78
23	55	95	10.2	72	75
24	50	116	14	82	88
25	55	95	10.3	72	82
26	60	109	10.3	82	85
27	60	108	10.2	82	88
28	50	118	14.6	79	85
29	60	100	10.4	77	78
30	50	122	14.5	75	76
31	70	101	8.7	73	84
32	50	95	10.2	65	70
33	50	104	12	75	78
34	66	107	8.6	80	82
35	50	93	9.5	72	80
36	70	102	8.8	81	86
37	50	93	9.5	72	78
38	50	105	12	70	77
39	51	123	14	64	74
40	72	108	9.3	70	82
Av.	**56.75**	**104.6**	**10.92**	**74.3**	**80**

From tables (4-5) and (4-6), it can be concluded that both the average running and the operating speed are approximately the same for both sides of the highway. This result indicates that the geometry and road conditions in addition to the traffic flow and behavior are identical.

4.5 Free flow speed analysis

Free flow speed is the speed of traffic at low volume and low density. It is the speed at which drivers feel comfortable traveling under the physical, environmental, and traffic-control conditions on road section [HCM, 2000].

FFS was measured at off peak periods for all sections. Sections were marked transversally in white color lines for a distance of (60m). The recording time starts while the vehicle is in touch with the first line and ends at the second one. Speeds in the horizontal alignment were measured at the center of the curve.

There is a wide array of factors influencing the FFS speed. These factors can be classified into five main categories:

1. Driver
2. Road
3. Vehicle
4. Environment, and
5. Traffic operations and Control.

1. Driver Characteristics:

The effect of driver's age and gender will be studied in this section. The range of drivers' ages is usually between (20 to 60 yrs) for male gender. Sight and hearing vary considerably across age groups. The ability to hear and to see is usually decreasing after age of (65yrs) **(Ibrahim, 2010).**

The features of the selected sections to analyze the effect of driver's age on free speed, in suburban and rural areas with the absence of others factors at free traffic speed. A form has been designed and distributed to drivers at sections by the research team, sections (1&13) as a sample of calculations. The questioner's forms were then collected and analyzed according to two parameters only: driver age and his free speed. Appendix "B" contains a sample of this questioner's form. Table (4-7) below, shows speed values for two sections with respect to the driver's age classes.

The average speeds plotted against driver's age and represented graphically in figure (4-8).

Table (4-7): Free speed with driver's age

Age Classes	Mid (year)	Suburban section km/hr (1)	Rural section km/hr (13)
21-25	23	100	110
26-30	28	110	120
31-35	33	110	115
36-40	38	98	105
41-45	43	85	90
46-50	48	80	85
51-55	53	75	80

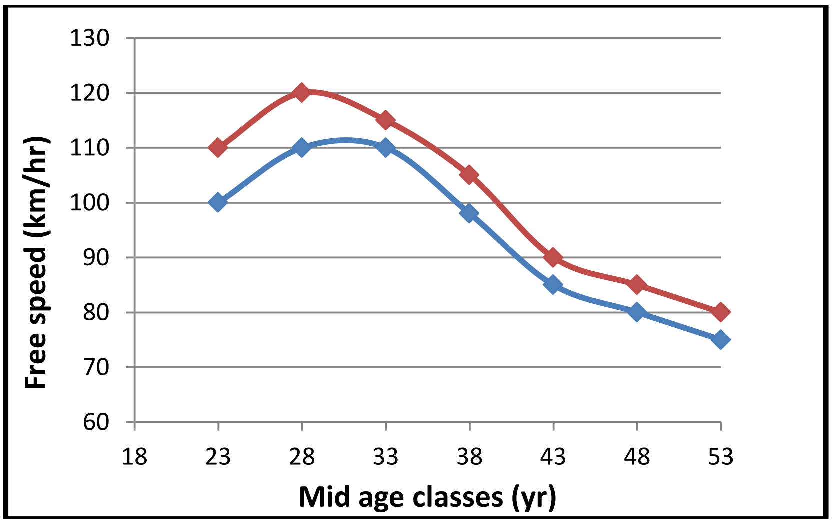


Figure (4-8): Effect of driver's age on FFS

It can be noticed by the figure (4-6) that:

1) Speed of drivers with age class of (20-25 yr) is less than the earlier one. This is attributed to the lack of experience and traffic education. In the other side, there is a tendency to decrease the speed limit with the age increasing. This is due to drivers who are more careful and more complaining more to the traffic regulations.
2) There is an overestimation in the speed for the rural section, this is attributed to the fact that at rural roads there is no community near the road as in the suburban road, which let the drivers to decrease their speed.
3) The maximum observed speed for drivers is for ages between (26-35 yrs) for the two sections.

2. Road characteristics

The influence of highway geometric features on the FFS will be reviewed in the following sections:

- **Carriage way and lane width**

To study the effect of carriage way and lane widths, data were collected at six sections with various carriage way widths and vehicle types (passenger cars and tippers)

The base width of the studied highway was (7.5m) for the both directions as it formed by the Directorate of AL-Anbar for Roads and Bridges as in appendix "D"

It has been concluded that the most of highway sections have carriage way width between (6.5-9m). This is attributed to the repeated pavement overlaying.

Figure (4-9) shows the overlaying phenomena along section three NB that may cause non- standard widths.

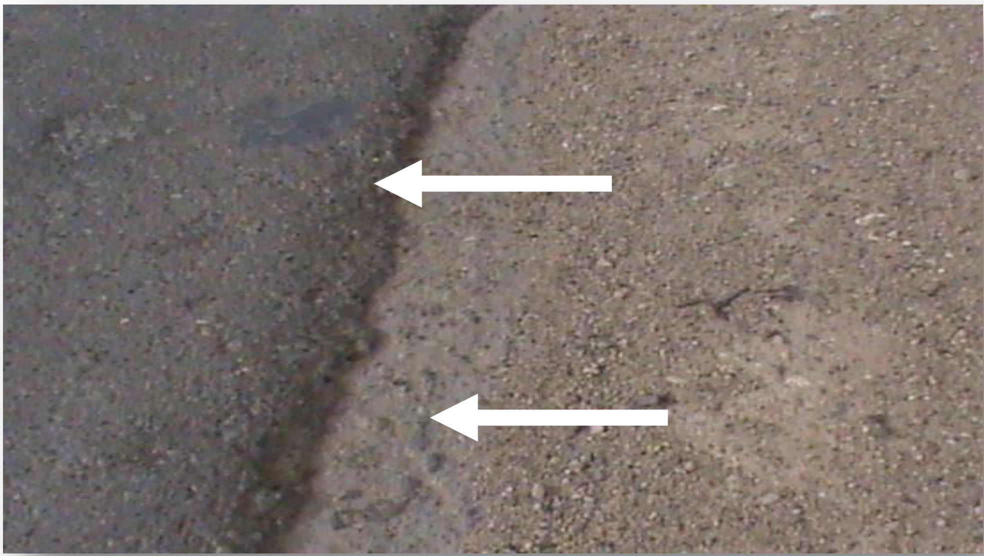


Figure (4-9): overlaying phenomena along section three NB

- ## Shoulder's width and drop condition

Shoulder widths for all sections of rural highway were ranging from (1.5m-3.5m) while the specification width is ranging from (0.6-3m) according to **(AASHTO, 2001)** and **(Iraqi general specifications for roads and bridges, 2003)**. Therefore, the shoulder widths for the studied rural highway can be considered within the range of the specification and will not affect the capacity and the highway performance.

The drop of shoulders were ranging from (0.025-0.15m), the increase in drop will make the driver confuse from the edge and don't use the carriage way width completely. Table (4-8) explains sections drop's values, these values were compared with **(Chandra, 1999)** classifications. Figure (4-10) shows the drop sample as in site:

Table (4-8): classification of shoulder drop

Sec. no.	Drop cm	Chandra class	Sec. no.	Drop cm	Chandra class	Sec. no.	Drop cm	Chandra class
1	10	Bad	15	4	Ave.	29	*	*
2	4	Ave.	16	5	Ave	30	9	Poor
3	15	Bad	17	4	Ave.	31	6	Poor
4	8	Poor	18	7	Poor	32	5	Ave
5	7	Ave.	19	9	Ave.	33	4	Ave.
6	7	Poor	20	13	Bad	34	5	Ave.
7	4	Ave.	21	3	Ave.	35	5	Ave.
8	9	Poor	22	2.5	Good	36	3	Ave.
9	4	Ave.	23	3	Ave.	37	8	Ave.
10	10	Bad	24	5	Ave	38	3	Ave.
11	8	Ave.	25	3	Ave.	39	9	Ave.
12	*	*	26	12	Bad	40	10	Bad
13	4	Ave.	27	2.5	Good			
14	7	Poor	28	13	Bad			

Figure (4-10): Shoulder's drop

- **Effect of curve radius on free speed**

Curve radius has been estimated to analyze curvature effect on free flow speed. Data were collected at (18) sections for NB and SB directions with radiuses range between (500m to 1400m). Speeds were measured at the midpoint of the curve with the same technique used in the straight sections.

Table (4-9) illustrates the field free speeds at the horizontal curved sections. Relation between curve radius and FFS for each NB and SB groups can be represented in figures (4-11) and (4-12).

Table (4-9): Free speeds at curves for NB and SB

Sec. no.	Curve Radius (m) NB	Free Speed (km/hr)	Sec. no.	Curve Radius (m) SB	Free Speed (km/hr)
1	1370	85	40	1370	88
16	1040	80	25	1040	82
8	900	78	33	900	78
6	850	78	35	850	80
12	770	75	29	770	78
3	740	75	38	740	76
18	600	72	23	600	75
4	570	70	21	570	70
20	520	70	37	520	69

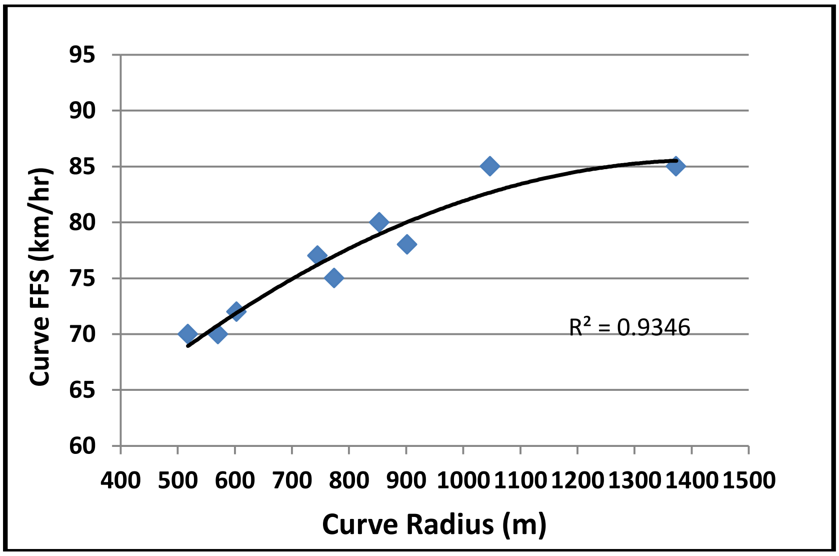


Figure (4-11): Relationship of free speeds and curves radiuses in NB

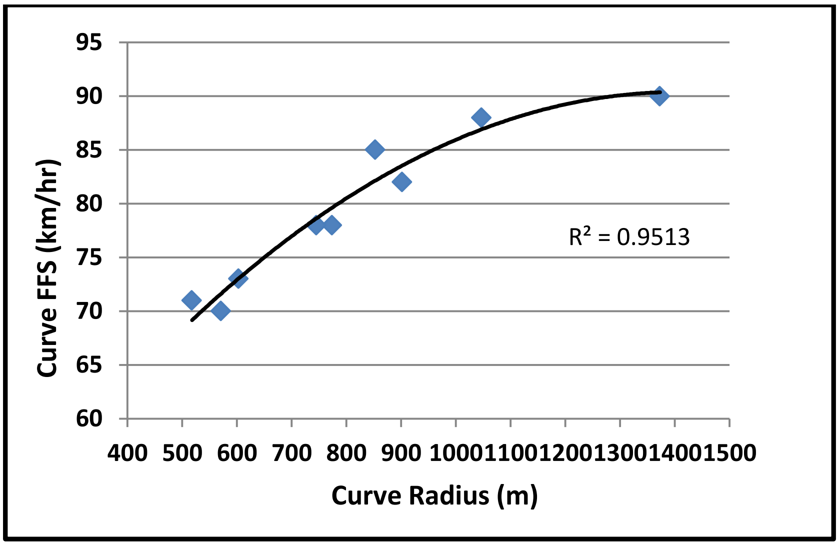


Figure (4-12): Relationship of free speeds and curves radiuses in SB

$Y_1 = 16.54X^{0.23}$……………………. (4-1)

$R_1^2 = 0.934$

$Y_2 = 11.75X^{0.286}$…………………..… (4-2)

$R_2^2 = 0.951$

where:

X = radius of curve in (m) for NB and SB groups,

Y_1,Y_2 = free flow speed km/hr for NB and SB groups respectively.

Figures (4-11), (4-12) demonstrate that the FFS increase with the increasing of curve radius.

Road width, shoulder drop, shoulder width, horizontal alignment and heavy vehicle percentage can be concluded that; these may affect on speed as a percent value in increasing or decreasing the free speed as listed in table (4-10) below:

Table (4-10): Effect of basic factors on FFS

Section No.	Road width (m)	Shoulder drop (m)	Shoulder width (m)	Heavy vehicle %	Free Speed (km/hr)
4	6.5	20	2.5	25	70
18	6.75	17	2.75	22	72
9	7	15	3	20	75
8	7.5	12	3.25	18	78
11	8	19	3.5	15	80
31	8.5	7	3.75	13	84
28	9	5	4	10	88
13	9.5	2.5	4.25	7	95

According to the previous results which have been abstracted and noticed from the video recording, it can be predicted a model between the free flow speed and the factors which affect on it.

$$FFS = 43.032 + 6.044\ RW - 0.372\ SD + 0.034Hv - 0.01\ HC \quad \text{……. (4-3)}$$

where :

RW= Road width (m)

SD= Shoulder drop (cm)

Hv= Heavy vehicle (as a total percent from the traffic volume)

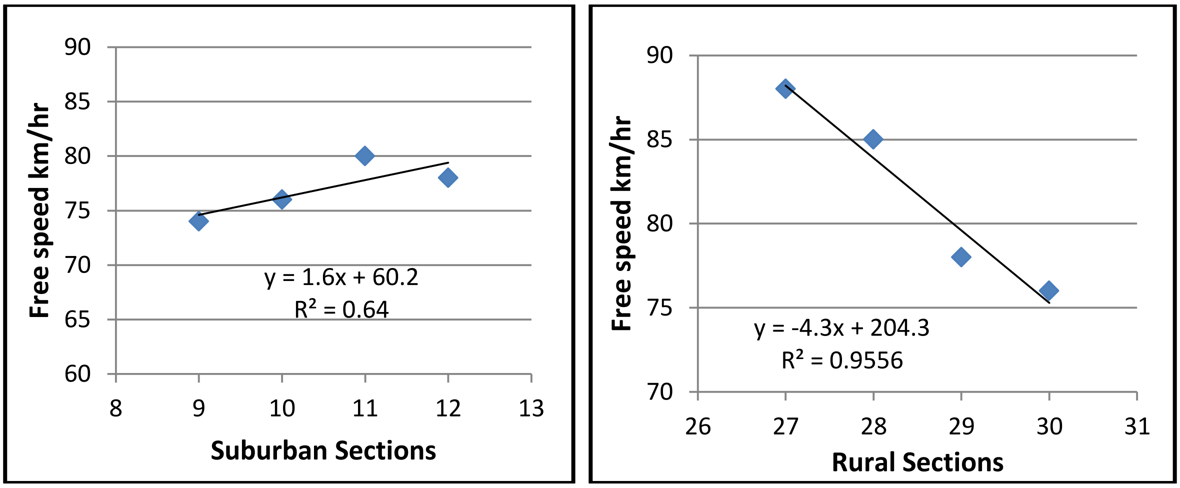
HC= Horizontal curve radius (m)

- **Adjacent area**

To study the effect of the adjacent area on FFS, data were studied at eight sections based on the adjacent type of the road and the speed for vehicles coming from the suburban area towards rural area and vice versa. Speeds data are shown in table (4-11). Figures (4-13) illustrates speed increasing and decreasing (acceleration and deceleration) from suburban towards rural section, while in speed from rural to suburban section due to the existence of shops and agricultural areas adjacent to the both sides.

Table (4-11) shows speeds data for adjacent area in NB

Sec. no.	Speeds suburban sec. km/hr (table:4-5,6)	Sec. no.	Speeds of rural sec. km/hr (table:4-5,6)
9	75	27	88
10	76	28	87
11	80	29	78
12	78	30	76



Figures (4-13): Speed variance at different adjacent area

Speed in suburban areas will be limited on population activity in addition to other previous factors; while as the speed rural area will be mostly limited on the geometric features.

3. Environmental effect

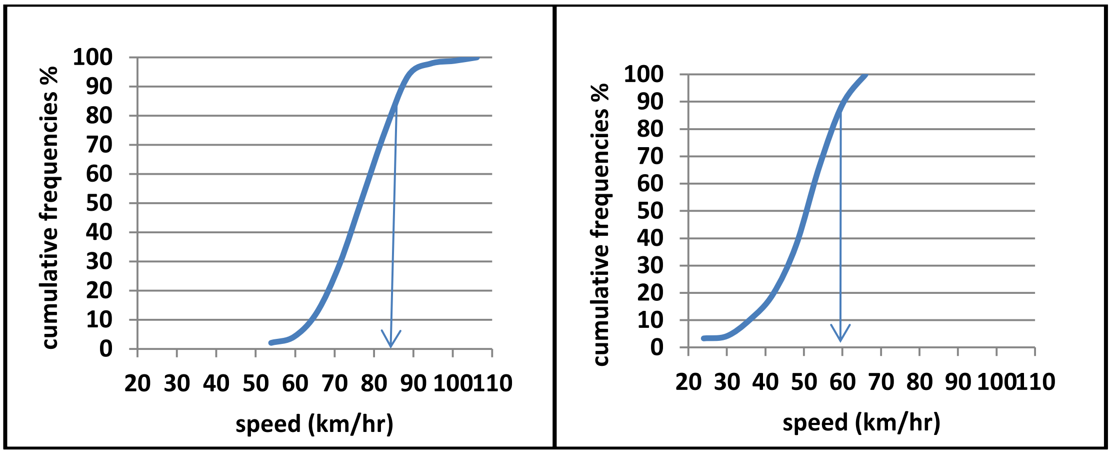
Free flow speed is affected by weather conditions. Three environmental factors effect FFS were studied in this research:

- Precipitation
- Dusty weather and visibility
- Day and night.

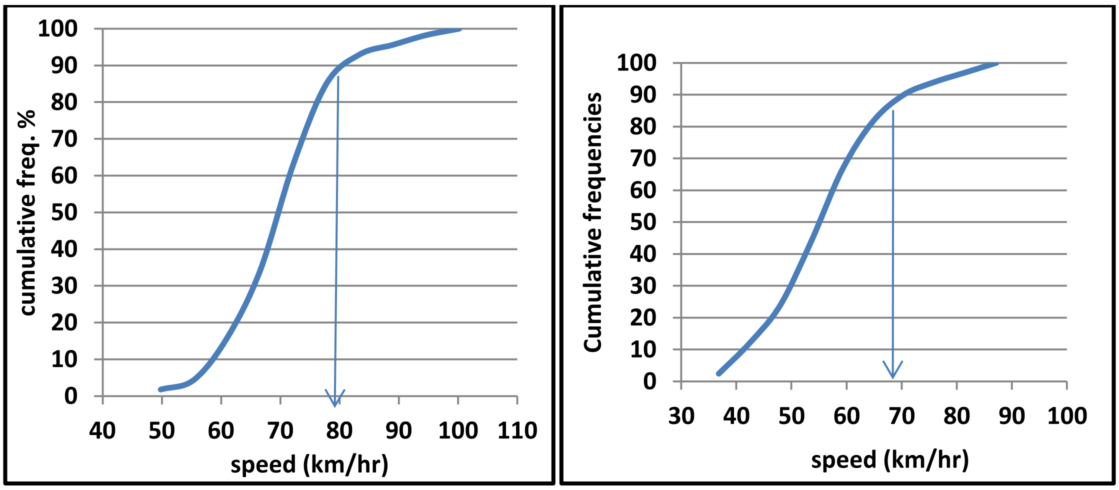
Data were collected during rainy weather at periods of day for sections (2,7and8). Collected speeds are shown in table (4-12) and figures (4-14),(4-15),and (4-15). Results were compared with the speed of the same sections in a dry and clear weather. Their values were drawn by the observed values at tables (4-5,6).

Table (4-12): effect of rainy weather on free speed

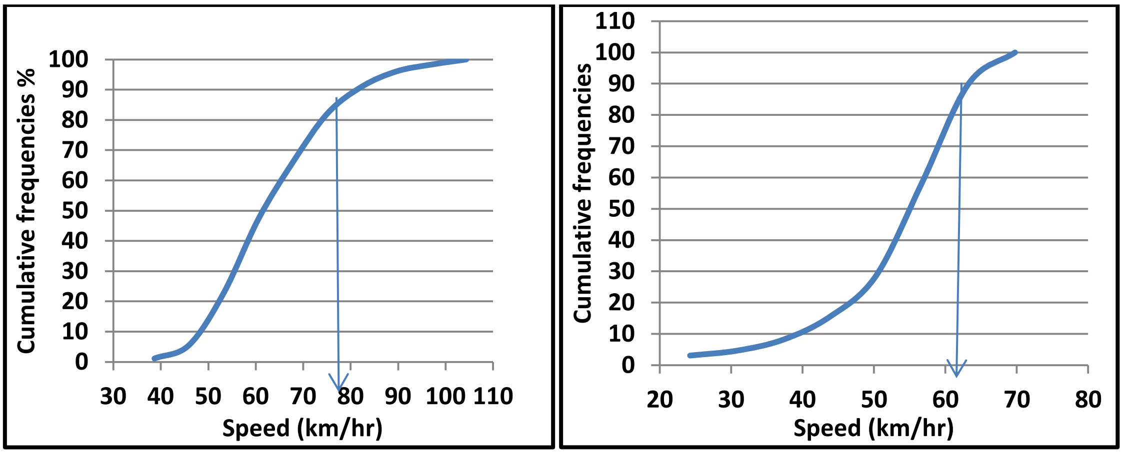
Section no.	FFS at clear weather km/hr	FFS at rainy weather km/hr
2	85	60
7	80	69
8	78	62



Figures (4-14): Speed in clear and rainy weather for section (2)



Figures (4-15): Speed in clear and rainy weather for section (7)



Figures (4-16): Speed in clear and rainy weather for section (8)

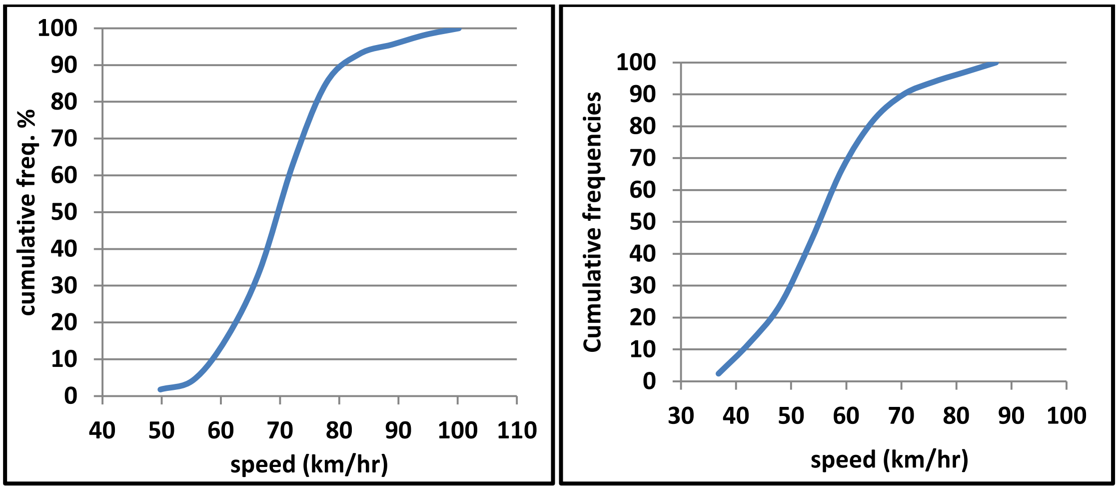
Rainy weather effected on the free speed and may be reduced by approximately (20-30 % km/hr) than clear conditions.

- **Day time (Visibility)**

Light conditions and visibility affected on the free speed on a road and can therefore be expected to influence capacity. Data were collected during evening periods for sections (1,40). Speed values are shown in table (4-13) and figures (4-17),(4-18). The day values were drawn by the observed values at tables (4-5,6).

Table (4-13): Effect of day and night on free speed

Section no.	FFS at day km/hr	FFS at night km/hr
1	80	68
40	82	60



Figures (4-17): Speed in morning and evening for section (1)

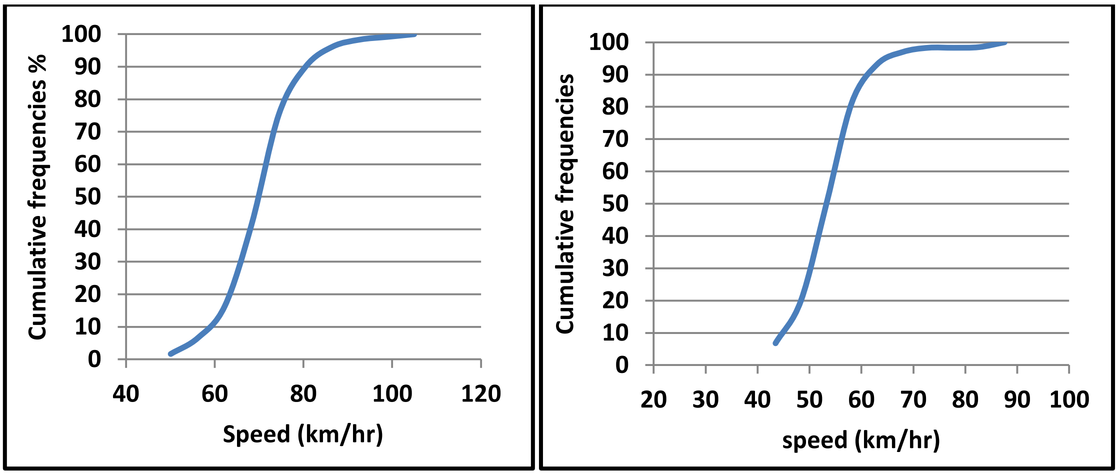


Figure (4-18): Speed in morning and evening for section (40)

It was found that a clear reduction at night speed compared with a day speed. Speeds were approximately reduced by (20-30% km/hr)

4.6 Capacity of multilane highway

HCM (2000) defines vehicle capacity as the maximum number of vehicles that can pass a given point in one or both directions during a specified period under prevailing conditions.

Divided multilane highways in suburban and rural settings have different operational characteristics from freeways, urban streets, and multilane highways.

Capacity was estimated for all sections by speed -flow relationship. Speed and flow were estimated during different periods and then relationship were plotted between speed versus flow. As an example, figures (4-19) and (4-20) illustrate the speed – flow relationship for sec.(1) and sec.(40) respectively.

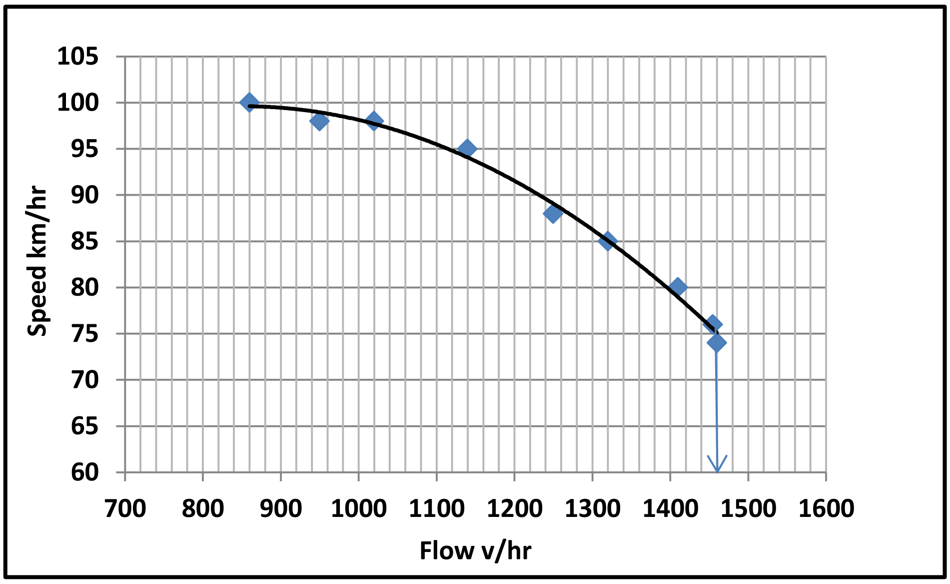


Figure (4-19): Speed – flow relationship for sec. (1) NB

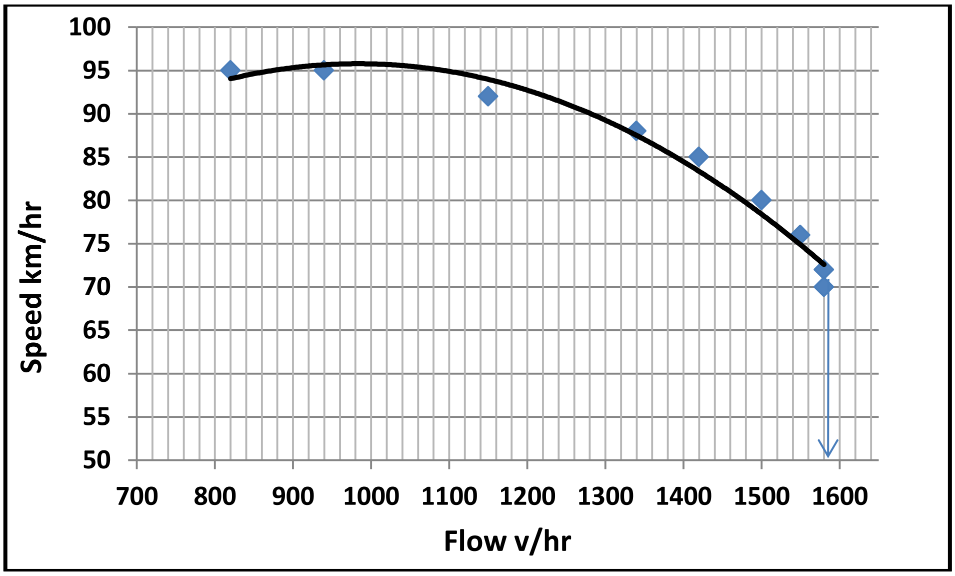


Figure (4-20): Speed – flow relationship for sec.40 SB

Capacities for section (1) and sec. (40) are (1460v/hr) and (1580v/hr) respectively. These are confirmed with the rural highway capacity as stated by **(HCM, 2000)**. Other sections were computed by the same procedure. Table (4-17) shows capacities for each section in NB and SB direction.

Table(4-14): Estimated capacity for sections NB and SB

Sec. no.	Max. Flow v/h	Sec. no.	Max. Flow v/h	Sec. no.	Max. Flow v/h	Sec. no.	Max. Flow v/h
1	1470	11	1147	21	1004	31	1317
2	1011	12	1045	22	1050	32	1288
3	1180	13	980	23	1250	33	1189
4	917	14	966	24	904	34	933
5	1128	15	920	25	1140	35	887
6	1084	16	1055	26	815	36	1203
7	946	17	920	27	805	37	1310
8	1064	18	925	28	967	38	1138
9	1372	19	1422	29	866	39	1285
10	1360	20	1080	30	980	40	1580

The estimated capacity for highway sections were ranged from (805–1550 v/hr). Flow may be affected by some factors which either cause increasing or decreasing in speed and capacity. These factors can be studied as capacity factors.

4.6.1 Factors affecting capacity

The capacity that a highway can accommodate is limited by the same factors that affecting free flow speed, when the free speed increased the traffic volume decreased **(HCM, 2000)**. These factors are:

1. The physical features of a highway, which do not change unless the geometric design of the highway changes.
2. The traffic conditions, which are determined by traffic composition.
3. The ambient conditions which include visibility, road surface conditions, etc.

4.7 Level of Service Determination

The (LOS) on a multilane highway can be determined directly from **(HCM 2000)** depending on the FFS and the service flow rate (Vp) in pc/hr/ln. The procedure is as the following:

- Step 1: Define and segment the highway as appropriate.
- Step 2: On the basis of the measured or estimated FFS, construct an appropriate speed-flow curve of the same shape as the typical curves shown in figure (4-21). Curve should intercept the y-axis at the FFS.
- Step 3: Based on the flow rate Vp, read up to the FFS curve identified in Step 2 and determine the average passenger-car speed and LOS corresponding to that point.
- Step 4: Determine the density of flow according to its formula and check with the table (4-15).

Figure (4-22) shows the multilane highway methodology for determining LOS.

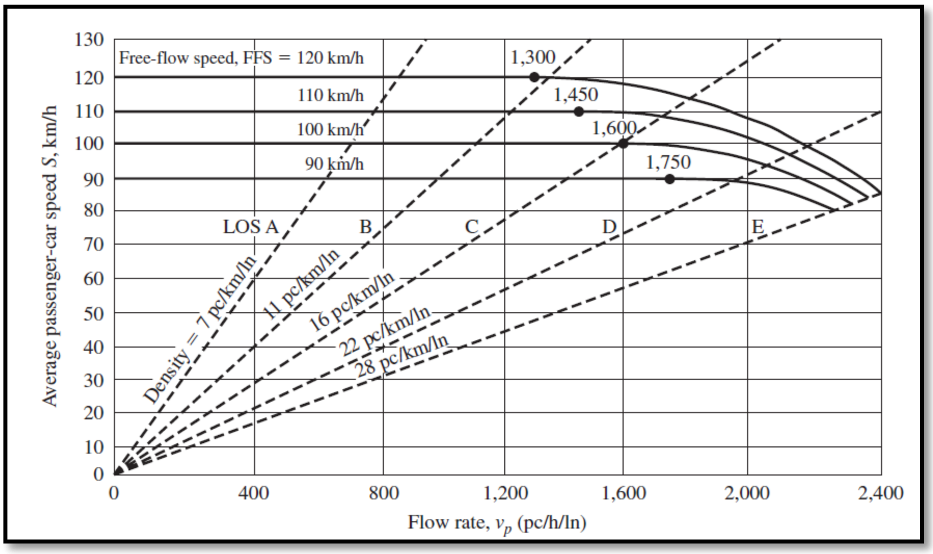


Figure (4-21): Speed-flow curves with LOS criteria

Source: (21-3 HCM 2000)

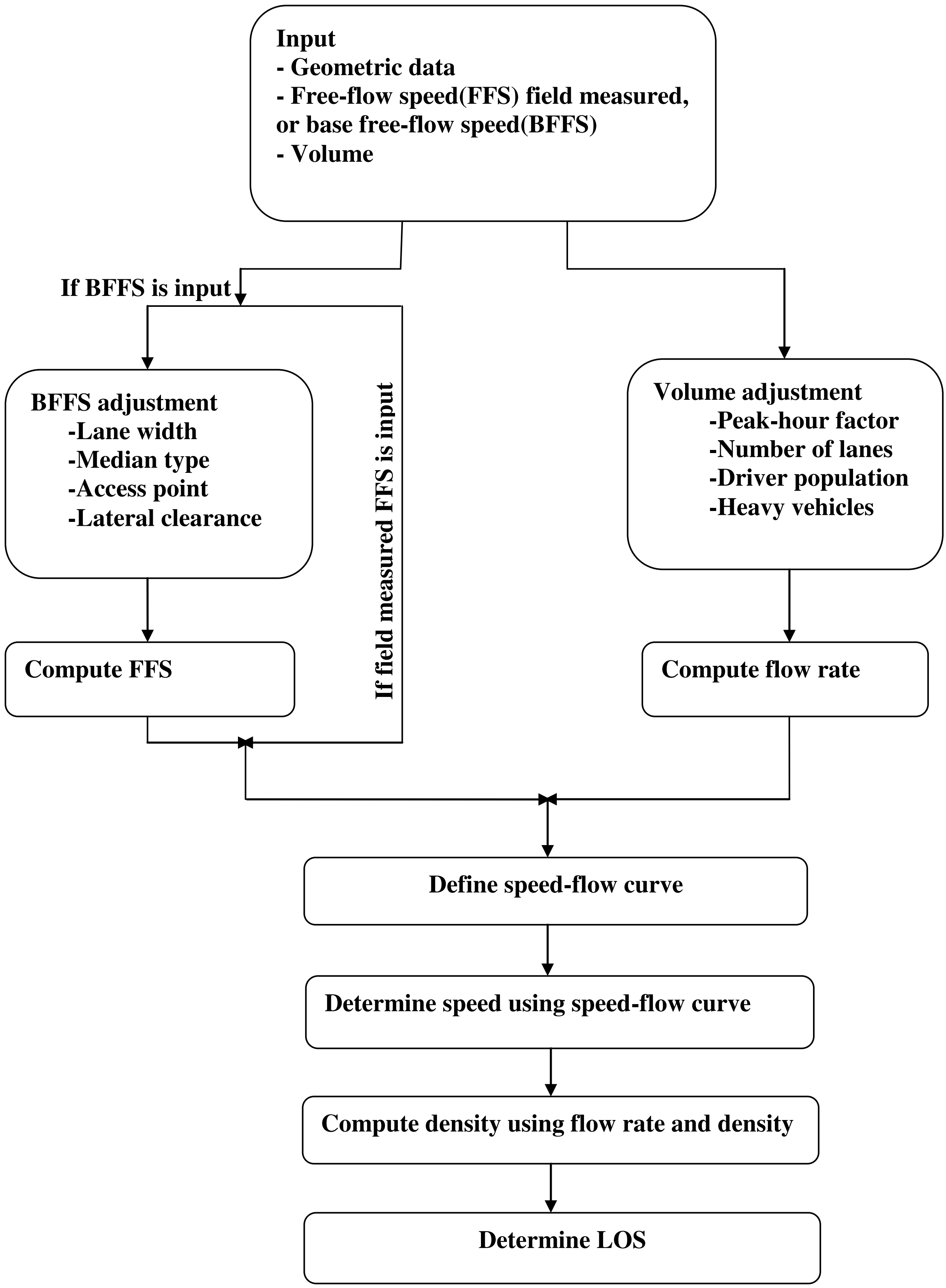


Figure (4-22): Multilane highway methodology. (HCM, 2000)

Table (4-15): Level of service criteria (HCM, 2000)

LOS	Density (pc/km/ln)	Density (pc/mile/ln)
A	0 - 7	< 11
B	7 – 11	$\geq 11 - < 18$
C	11 – 16	$\geq 18 - < 26$
D	16– < 22	$\geq 26 - < 35$
E	22– < 28	$\geq 35 - < 45$
F	>28	> 45

4.8 Determination of flow rate

Two adjustments must be made to hourly volume counts or estimates to arrive at the equivalent passenger-car flow rate used in LOS analyses.

These adjustments are the PHF and the heavy-vehicle adjustment factor. The number of lanes also is used so that the flow rate can be expressed on a per-lane basis. These adjustments are applied in the following manner using equation below **(HCM, 2000)**:

$$Vp = \frac{V}{PHF * N * FHV * Fp} \dots\dots\dots (4-4)$$

where:

Vp= flow rate (pc/h/ln),

V = Max. hourly volume (veh/h),

PHF = peak-hour factor (calculated and listed in tables 3-4 , 3-5)

N = number of lanes =2

FHV= heavy-vehicle adjustment factor

Fp= driver population factor. (0.85-1)

4.8.1 Heavy-Vehicle Adjustments

The presence of heavy vehicles in the traffic stream decreases the FFS because base conditions allow a traffic stream of passenger cars only. Therefore, traffic volumes must be adjusted to reflect an equivalent flow rate expressed in passenger cars per hour per lane (pc/h/ln). This is accomplished by applying the heavy-vehicle factor (f_{HV}) as equation **(HCM,2000):**

$$FH = \frac{1}{1 + PT(ET - 1) + PR(ER - 1)} \dots\dots\dots (4-5)$$

Where:

ET, ER = passenger-car equivalents for trucks and buses and for recreational vehicles (RVs), respectively;

PT, PR = proportion of trucks and buses, and RVs, respectively, in the traffic.

Values for (ET) have been determined, but (ER) was neglected because there are no recreational vehicle in this study. The adjustment factor for heavy vehicles will be computed as shown in the equations below:

$$\boldsymbol{FHV}\text{correct} = \frac{1}{1 + PT\ (ET - 1\ )} \dots\dots..\dots.... \quad (4-6)$$

4.9 Density

Density is the number of vehicles or pedestrians occupying a given length of a lane or roadway at a particular instant **(HCM, 2000)**. For the computations in this manual, density is averaged over time and is usually expressed as vehicles per kilometer (veh/km) or passenger cars per kilometer (pc/km).

Density can be computed, however, by the average travel speed (FFS) and flow rate, which are measured more easily under saturated traffic conditions **(HCM,2000)**

$$D=\frac{Vp}{FFS}\text{............}(4\text{-}7)$$

Where:

D = density (pc/km/ln).

Vp= flow rate (pc/hr/ln),

FFS = average free flow speed (km/h).

4.9.1 Highway sections LOS determination

The **(HCM, 2000)** methodology was adopted to calculate the LOS for the sections of the studied highway as an example of LOS. Section one is chosen to explain the procedure as the following :

- ✓ Level terrain, E_T = 1.5
- ✓ field-measured FFS = 81 km/h
- ✓ lane width = 3.5,
- ✓ peak-hour volume =1470 veh/hr
- ✓ percent trucks and buses = 13% ;
- ✓ PHF = 0.88.

From previous equations, flow rate must be estimated:

- ❖ F_{HV}= (1 / 1+0.13*(1.5-1)) =0.93,
- ❖ V_p = (1470 /0.88*2*0.93*1) = 898 pc/hr/ln,
- ❖ D = (898 /81) = 11.08 Pc/km/ln.

Enter table (4-15), with the density of (11.08 Pc/km/hr), the LOS for sec. one is "C". In addition to the other sections, LOS were estimated with the same procedure. Appendix "A" shows the "HCS" determination for sections (1 and 40). Table (4-16) illustrates results.

Table (4-16): Obtained LOS for all sections NB and SB directions

Sec. no.	Level of Service	Sec. no.	Level of Service	Sec. no.	Level of Service	Sec. no.	Level of Service
1	C	11	B	21	B	31	C
2	B	12	B	22	B	32	C
3	B	13	A	23	B	33	B
4	B	14	A	24	A	34	B
5	B	15	A	25	B	35	B
6	B	16	B	26	A	36	B
7	B	17	A	27	A	37	B
8	B	18	B	28	B	38	B
9	C	19	C	29	B	39	B
10	C	20	B	30	B	40	C

From above table, it has been found that the (LOS) for studied sections are A,B and C. The next chapter aims at improving the critical sections with "C" service level by improving regression models on the traffic speed and geometric features.

4.10 Results and Development Regression Model

Regarding the analysis which presented in chapter four, it has been estimated that seven sections along both directions have service level "C". The main objectives of this chapter are to improve these sections by improving factors which were affected on speed such as traffic composition and road geometric features.

Improvement will be in road geometry characteristics which will increase free flow speeds that will enhance the highway performance.

After that models will be developed to improve speeds in horizontal curves sections along rural highway.

In order to improve LOS "C" for sections, factors caused speed reduction must be discussed. From the previous chapter, it was found that the free speeds were affected by many factors such as road geometric features, traffic volumes and compositions.

Carriageway widths were the greatest factors affected on the free speed. Traffic data and affected factors for the seven sections can be listed in table (4-17) below:

Table (4-17): Observed traffic data for sections of "C" service level

Sec. no.	Flow v/hr	T.Flow rate pc/hr/ln	F.F.S km/hr	Density Pc/km/ln	Factors reduced service level
1	1460	891	80	11	Curvature, carriage way width ,drop of shoulder Hv% (traffic composition) and Unsystematic roads entrance.
9	1372	848	75	11.32	Carriage way width, Hv% (traffic composition) and Adjacent area (heavy population areas and presence of healthy and shopping centers).
10	1360	848	75	11.2	Carriage way width, Hv% and Adjacent area (heavy population, presence of healthy and shopping centers).
19	1422	920	82	11.2	Carriage way width ,drop of shoulder, Hv% (traffic composition) and Unsystematic shops adjacent to road.
31	1317	949	84	11.5	Carriage way width, Hv% (traffic composition) and Adjacent area (heavy population, healthy centers and shopping centers).
32	1288	774	70	11	Carriage way width, Hv% and Adjacent area (heavy population, healthy centers and shopping centers).
40	1550	957	84	11.4	Curvature, carriage way width ,drop of shoulder, Hv% and Unsystematic roads entrance.

4.11 Proposed improvement methods

The LOS may be improved by the following suggestions:

1. Increasing the number of lanes (increasing carriageway width)

Model needs to be developed for this study depends on speed-flow-density equations.

Increasing the number of lanes from two lanes to three in both directions along highway will increase free speed. Speed versus carriageway widths values were analyzed statistically in previous chapter. Table (4-18) shows the analyzed parameters.

Table (4-18): Effect of carriageway width on speed

Sec. no.	Road width (m)	Free Speed (km/hr)
18	6.75	72
9	7	75
8	7.5	78
11	8	80
31	8.5	84
28	9	88

The developed statistical model is shown in equation, below:

$Y = 7.090\,X + 23.6$ ……………….. (4-4)

$R^2 = 0.921$

where:

Y: free speed (km/hr)

X: carriage way width (m).

The determination coefficient (R^2) for this model is equal to (0.921). This higher (R^2) value indicates that the regressed data can be explained by this model. Figure (4-23) shows the scattered plot and the developed regression model for the relationship between average speed and road widths.

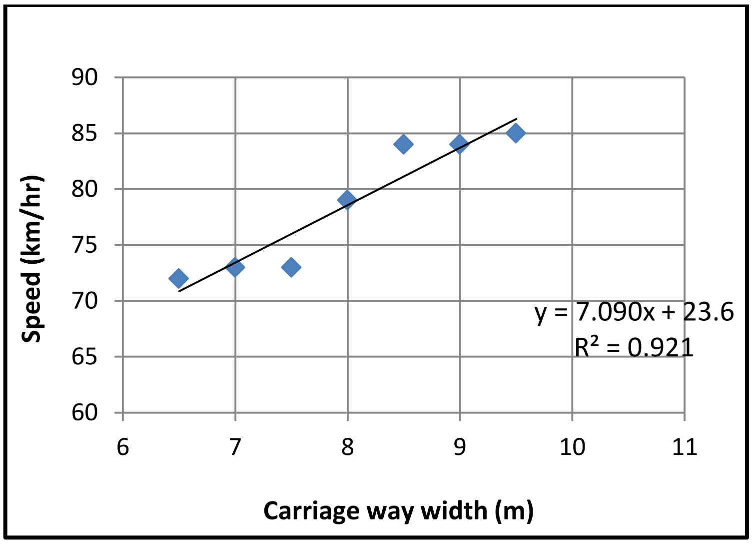


Figure (4-23):Improvement LOS model

By the above model, the new FFS(Y) will be calculated according to suggested number of lanes (3 lanes) which results in (X is10.5m) carriageway width, the produced FFS will be (98 km/hr). Depending on this value and considering the flow will remain the same, the new predicted density will be (14.72 v/km). According to table (4-15), the LOS for section one will be "A", the same procedure will be implemented for all sections with LOS "C". The new LOS for sections is presented in table (4-19).

Table (4-19): Improved results for LOS "C "

Sec. no.	Flow v/hr	(X) m	(Y) km/hr	Density per 3 lanes pc/km	Improved LOS
1	1470	10.5	80	14.72	A
9	1372	10.5	75	15.15	A
10	1360	10.5	75	15	A
19	1422	10.5	82	15	A
31	1317	10.5	84	15.4	A
32	1288	10.5	70	14.72	A
40	1550	10.5	84	15.26	A

2. Reducing the heavy vehicles percentage (Hv%)

The effect of heavy vehicles presented in roadway is important to estimate density and LOS. Vehicles other than passenger cars (a category that includes small trucks and vans) in a traffic stream affect the number of vehicles that can be served.

Reduction in Hv% will increase the flow rate and decrease density according to equations (4-4 and 4-7) that will improve LOS. By the previous determinations, flow rate can be estimated:

- ✓ Level terrain, E_T = 1.5
- ✓ field-measured FFS = 80 km/h
- ✓ lane width = 3.5,
- ✓ peak-hour volume =1470 veh/hr
- ✓ percent trucks and buses = 9% (new assumption) ;
- ✓ PHF = 0.88.

- ❖ F_{HV}= (1 / 1+0.09*(1.5-1)) =0.96,
- ❖ V_p = (1470 /0.88*2*0.96*1) = 866 pc/hr/ln,
- ❖ D = (866 /80) = 10.8 pc/km/hr.

Re- enter table (4-15), with the density of (10.8 pc/km/hr), the LOS for sec. one is A.

3. Improving speeds in horizontal alignments

The obtained regression models which represent the relation between FFS and curvature of the road was explained in equation (4-1) and (4-2). These equations can be seen at table (4-20).

Table (4-20): predicted speed for horizontal curves (NB and SB)

Prediction model for NB	R^2	Prediction model for SB	R^2
$V_{curve} = 16.54 X_1^{0.23}$	0.934	$V_{curve} = 11.75 X_1^{0.286}$	0.951

where:

X_1, X_2 = radius of curve in (m) for NB and SB respectively.

The determination coefficient (R^2) of these models are equal to (0.925), (0.915). These values suggest that the obtained regression models explain more than 90 % of the observed scattered data. The remaining 10% is not explained due to the random nature of other variables, which were drawn by statistical distribution.

The only suggested method to improve the FFS in the curved section and widen the carriage way of the road from the inner edge that result in increasing the radius and already the FFS will increase, that means the service level will be enhanced

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This chapter includes the conclusions, recommendations and proposals for future research. This is achieved under the following phases:

1- Traffic flow operations.

2- Geometric design parameters (horizontal alignments, and other conditions).

3- Capacity and level of service.

5.2 Conclusions

Based on the findings of this study, the followings can be concluded:

5.2.1 Heavy vehicle percent (Hv%)

1. Percent of heavy vehicles has the most effect on traffic volume. As (Hv%) decreases flow rate increases. (Hv%) was found between (7%-23%) the traffic volume.
2. Heavy vehicles have negative influence at horizontal alignments at the free flow conditions because of their slow acceleration rate.
3. Concerning lane-use restriction and driver behavior by vehicle type, the least effect of heavy vehicles on traffic at multilane highway is expected to occur when all heavy vehicles are restricted by the use of the left lane.

5.2.2 Geometric design parameters

1. The studied multilane highway has two lanes in each direction, with a lane width varies from (3.0 to 3.6 m). The narrow lanes do not provide an adequate margin of error for vehicles and, therefore, speeds of individual vehicles drop. The effect of lane width is more prominent under mixed traffic conditions when vehicles tend to move side by side.
2. There were linear relationships between speed carriage way and lane widths. As they increased the speed also increased.
3. The obtained average speeds for the horizontal alignment were (75 and 76 km/hr) and for straight sections they were (81 and 82 km/hr) for NB and SB directions respectively. This indicated that horizontal alignment has obvious speed and its relationships were predicted. In addition, the linear relationships of second degree were found to express the effect of the curve radius on speed.

5.2.3 Capacity and LOS

1. The capacity of the highway sections was calculated by the observed speed-flow relationship. The maximum flow was noticed at section (40) which is (1580 v/h) while as the minimum flow was at section (27) which is (805 v/h).
2. Divided multilane highway in suburban and rural settings has a traffic volume which varies from (7000 to 150000 v/day: HCM, 2000). Therefore, it can be concluded that the above obtained flow is laying within this range and the studied highway can be considered as a divided multilane rural highway.
3. This study confirmed in generally that traffic composition, geometric design and ambient condition are factors affect on capacity.
4. The obtained factors affected highway capacity are mainly,

- Lane and carriage way widths,
- Pavement drop,
- Shoulder widths,
- Lateral clearance,
- Weather condition and visibility,
- Horizontal and vertical alignments,
- Heavy vehicle percent, and
- Driver characteristics.

5. Along the multilane rural highway, most studied sections have the level of service (B) except seven sections that have (A) and six sections have (C).

5.3 Recommendations

1. It is recommended to change the road geometry, by increasing the lane widths to reach the standard widths as well as increasing one lane in both directions. Especially at sections that have LOS "C" in order to improve the traffic capacity along rural multilane highway sections. This leads to increase speed, increase traffic capacity and make the road more safe during the peak periods.
2. Because of the existence of shoulder widths along both sides of the highway, it is recommended to make an On-Street parking on sec.(9,10,31,31) highway section to prevent stopping on the street such stopping affects the capacity and speed on the road and increase safety.
3. It is recommended to increase the lateral clearance at the horizontal alignments, by removing the natural plants which reduced sight distance. The increasing of re-overlay pavement according to the specification of Iraqi Highway Design Manual
4. Paving the earth shoulders also drops to facilitate the stopping and enhance driving speed.

5. Constructing crossing bridge for pedestrians (students) between both sides and at different station to increase pedestrians safety.
6. Installing light columns along the road to improve visibility during evening periods which increase speed and safety.
7. Removing the police check points along highway to prevent pavement structure deformation and make free flow condition.
8. Suggesting running speed as (90 km/hr) and fixing traffic signs along highway to aware and prevent driver to make accident.
9. Obligating all people to follow the rules of general traffic directorate and increase driver traffic education.

5.4 Recommendations for Further Study

1. Further study is required by using the (ITP) application such as geographic information system "GIS" to select and design developed traffic network road system.
2. Improving the process of data collection and predicting a model for evaluating road safety in vertical and horizontal alignments.
3. Construct the railway and tram transportation to reduce the percent of buses and semi-buses as well as serving people transport between two cities.

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