Traffic Engineering

Third Class / Highways and Bridges
Traffic engineering

1. Introduction to traffic engineering
   1.1 Defining traffic engineering
   1.2 Driver characteristics
   1.3 Vehicle characteristics

2. Characteristics of traffic flow
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   5.4 Speed flow and concentration relationship

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7. Traffic signal design

8. Parking
References

1. "Traffic Engineering, an Introduction", G.R. Wells

2. "Traffic Engineering Theory & Practice" by Louis, J. Pignataro, 1973

3. "Traffic and Highway design" by Nicholas, J. Garber and Lester, A. Hoel

4. "Highway Engineering" Vol. 1 by O'Flaherty, C.A.

5. "Highway Engineering" by Clarkson, H. Oglesby
Definition of traffic engineering

is that part of engineering which deals with traffic planning and design of roads, of frontage development and of parking facilities and with the control of traffic to provide safe, convenient and economical movement of vehicles and pedestrians.

Phases of traffic engineering

1. The road user
2. The vehicle
3. Traffic volume
4. Speed, travel time, Delay
5. Origin and destination
6. Traffic capacity
7. Parking
8. Accident (as a measure of failure)
9. Public transit
Chapter (1)
Characteristics of the Driver, the pedestrian, the vehicle, and the road

The four main components of the highway mode of transportation are:
- The driver
- The pedestrian
- The vehicle
- The road

**Driver characteristics**

1. The human response process
   - Visual reception: The receipt of stimuli by the eye is the most important source of information for both the driver and pedestrian.
     a. Visual acuity
     b. Peripheral vision
     c. Color vision
     d. Glare vision and recovery
   e. Depth perception

- Hearing perception
  - تكّن وصوت نطق الرُئْراء ويعدّ سبّابات المُعَظَّم (الأخذالدَّة)
Pedestrian Characteristics

Some characteristics of driver, with addition of others which influence the design and location of pedestrian control devices, such as:
- Special pedestrian signals
- Safety zones and islands at intersections
- Pedestrian underpasses
- Elevated walkways
- Crosswalks

Perception-and-Reaction process

The process begins with the onset of an event or stimulus. The driver then perceives the event and reacts to it. The process is divided into four stages:
1. Perception: Seeing the stimuli
2. Identification: Understanding the stimuli
3. Emotion: What he will do (to stop, blow horn, to pass)
4. Volition or Reaction: To do the decision

PIEV time or Perception Reaction time

It is used in the determination of braking distances of length of the yellow phase at signalized intersections.

PIEV time ≤ 2.5 sec (AASHTO)

Example: Example 15
Vehicle characteristics

Criteria for the geometric design of highways are partly based on

1. Static characteristics
   - Weight of veh. as a control of pavement design

2. Kinematic characteristics
   - Involve the motion of the veh., without considering the forces that cause the motion
   - Acceleration capability of the veh.
     - Braking
     - Power
     - Stopping
     - Fuel economy
     - Lighting
     - Operating cost

3. Dynamic characteristics
   - Involve the forces that cause the motion of the vehicle
   - Air resistance
   - Grade resistance
   - Rolling resistance
   - Curve resistance
   - Friction resistance

Designing a highway involves the selection of a design vehicle.
The vehicle

Cars range from compact cars to articulated trucks. They differ in their
- max. acceleration (kinematic characteristics)
- turning radii (static characteristics)
- weight and size
- the ability to climb grades (dynamic characteristics)
Definitions

**Passenger Cars**: All free wheeled, self-propelled vehicles generally designed for the transportation of persons, but limited in seating capacity to not more than nine passengers including:
- taxicabs
- limousines
- station wagons

**Trucks**: All free wheeled, self-propelled vehicles, design for transportation of persons and having a seating capacity of ten or more passengers.

Or:
All free wheeled vehicles having dual tyres on one or more axles, or having more than two axles, designed for transportation of freight rather than passengers includes:

- *Tractor-Trailers*
- *Trailers*
- *Semitrailers*
Road characteristics

These affects:
- Stopping sight distance
- Passing
- Acceleration design
- Geometric design of the road
- Gradient
- Superelevation
- Geometric design of the road
Volume studies

Characteristics of traffic flow

Traffic composition: Vehicles of different types have different road space requirements and different effects on the capacity of highway and intersection because of variations in size and performance.

The overall effect on traffic operations by any vehicle can be expressed in terms of the effect of the basic unit—usually a passenger car. So vehicles should be converted to equivalent passenger car unit (PCU) as follow:

<table>
<thead>
<tr>
<th>Class of veh</th>
<th>Flat</th>
<th>Hill</th>
<th>Mountainous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private car</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Taxi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pick up, bus up to 24 passengers</td>
<td>1.25</td>
<td>1.75</td>
<td>3.00</td>
</tr>
<tr>
<td>Truck, bus above 24 passengers</td>
<td>2.00</td>
<td>3.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Heavy veh</td>
<td>3.0</td>
<td>5.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Example: A rural highway has the following traffic composition:

- Passenger car: 50%
- Heavy goods veh: 42%
- Buses & big vans passenger: 5%
- Motor cycles: 3%
Find the equivalent passenger car unit if the total number of vehicles passing is 6000.

**Solution**

No. 4 passenger cars = \(6000 \times \frac{50}{100} = 3000\)

No. 8 trucks and HGVs = \(6000 \times \frac{2}{100} = 2520\)

No. 8 buses = \(6000 \times \frac{5}{100} = 300\)

No. 8 motor cycles = \(6000 \times \frac{3}{100} = 180\)

Total No. 8 Pcu = \(3000 \times 1 + 2520 \times 3 + 300 \times 2.00 + 180 \times 1\)

= 11640

**Traffic Fluctuation**

The flow of traffic is changing throughout the day, the week and the year.

The pattern of hourly traffic through a full day (24 hrs) is indicative of the social pattern of our lives. There is a peak as we go to work in the morning, and another peak in returning from work.

![Traffic Fluctuation Graph](image-url)
Within the week the traffic stays constant from Saturday to Thursday but varies over the weekend.

The annual pattern shows considerable fluctuations through the year. Higher flow in summer.
Measurement of traffic flow

Traffic volume is the number of vehicles passing particular station during a given interval of time. Traffic volume can be expressed in terms of annual traffic or daily traffic or hourly traffic.

Average Annual Daily Traffic (AADT) متوسط.dayly Traffic (AADT)

It is the total No. & vehicles that pass over a given section of a lane or a roadway during one year divided by 365

\[
\text{AADT} = \frac{\text{Total traffic of the year}}{365}
\]

AADTs are used in several traffic & transportation analysis:

a - Estimation of highway user revenues
b - Computation of accident rates in terms of accidents per 100 million vehicle miles
c - Establishment of traffic volume and

d - Evaluation of the economic feasibility of highway projects

e - Development of freeway and major arterial street systems

f - Development of improvement and maintenance programs.
Vehicle Classification (VC): records volume with respect to the type of vehs. e.g. passenger cars, two axles trucks. (VC) is used in:

a. Design & geometric characteristics, with particular reference to turning radii requirements, max. grades, lane widths, etc.

b. Capacity analyses, with respect to passenger-car equivalents & trucks.

c. Adjustment of traffic counts obtained by machine.

d. Structural design of highway pavements, bridges, and so forth.

Vehicle Miles of Travel (VMT): is a measure of travel along a section of road. It is the product of traffic (average weekly vol. or ADT) and the length of roadway in miles to which the volume is applicable. VMT is used mainly as a base for allocating resources for maintenance and improvement of highways.

VMT = ADT x length of roadway (miles)
Average daily traffic (ADT)

ADT = total vol. during a given time period in whole days
     respective no. of days

It is often used for measuring traffic volumes when traffic volumes vary little from day to day over the course of the year.

Design Hour Volume (DHV): is the 30th highest hourly volume of the year (Abbreviated 30HV)

It is used for design purposes. The DHV is normally expressed as a percentage of ADT (about 15% ADT)

K = \frac{DHV}{ADT} 

K = 10 - 12 \% 
    two way
K = 7 - 12 \% 
    one way

Peak Hour Traffic: It is the highest number of vehicles per 60 min. and it is required for the design of traffic facilities, a-functional classification of highways, b-design of geometric characteristics of highways, c-development of programs related to traffic operations, especially one way system, d-design of parking regulations, e-capacity analysis

TH = TD 

TH: Percentage of trucks within peak hour
TD: percentage of trucks within daily traffic

TH = 0.7 TD
Directional Distribution

The hourly traffic load in each direction of traffic.

It is expressed as a percentage of two directional volume for the particular peak hour and is calculated for both morning and evening peaks.

i.e 60/40 during the peak

\[
\begin{align*}
60\% & \quad \text{to} \\
40\% & \quad \text{from}
\end{align*}
\]

Grade Intersections (Grade Intersections) 

Grade Separated Intersection

AM Peak

[Diagram of a highway intersection]

2. At-grade intersection

[Diagram of an at-grade intersection]
Deriving representative traffic figures

As we said that the

$$AADT = \frac{\text{Total traffic of the year}}{365}$$

But it is difficult to do so.

Then

The alternative is to use a count at any point in the year, and from this derive an annual average figure if local traffic flow patterns, over at least one or two 12 months periods, are known, such as this one

<table>
<thead>
<tr>
<th>Month</th>
<th>Traffic Flow as a Percentage of Annual Average Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>84</td>
</tr>
<tr>
<td>F</td>
<td>82</td>
</tr>
<tr>
<td>M</td>
<td>94</td>
</tr>
<tr>
<td>A</td>
<td>97</td>
</tr>
<tr>
<td>M</td>
<td>107</td>
</tr>
<tr>
<td>J</td>
<td>107</td>
</tr>
<tr>
<td>J</td>
<td>116</td>
</tr>
<tr>
<td>A</td>
<td>118</td>
</tr>
<tr>
<td>S</td>
<td>107</td>
</tr>
<tr>
<td>O</td>
<td>103</td>
</tr>
<tr>
<td>N</td>
<td>92</td>
</tr>
<tr>
<td>D</td>
<td>90</td>
</tr>
</tbody>
</table>

Similarly, the traffic movement in the 16 hrs from 6.00 to 22.00 have been found to represent just under 93% of the 24 hrs flow, and the daily flows from Saturday to Thursday to be sensibly constant.
لحساب حجم مياه الأمطار، يمكن استخدام الصور التالي:

\[ AADT = \frac{\text{January 7 days flow} + \text{July 7 days flow}}{14} \]

استخدام هذه الصور مع مقياس الأمطار الجغرافي يعطي نتائج هامة.

ملاحظة: هذه الصور تم استخدامها في دراسة نموذج ليبرتال والبلديات المختلفة.

(النظام الزمني الأول والثاني والثالث)
The 7 day June flow is 118,768. The average flow August flow is 66,000 vph.

August flow could be converted to 16 hrs August flow

\[ \text{AADT} = \frac{118,768 \times 24}{16} = 10,382 \text{ VPH} \]

The 16 hr flow = 66,000 vps.

\[ \text{AADT} = \frac{10,382 \times 100}{10} = 1,038,200 \text{ vps} \]

The seven day 24 hrs flow = 709,680 vps.

\[ \text{AADT} = \frac{709,680 \times 0.98}{24} = 70,000 \text{ vps} \]

The seven day 12 hrs flow = 42,000 vps.

\[ \text{AADT} = \frac{66,000 \times 0.98}{24} = 66,000 \text{ vps} \]

The ADT for Thursday, Friday, and Saturday in June was 10,000, 8,000, and 10,000 in that order.

There was a need to know the ADT for the rural project where 16 hr flows were counted on Thursday and Friday. It was calculated by taking the average of the two counts.

The ADT for Thursday was 8,000 and for Friday was 10,000.

The ADT for Thursday was calculated as 8,000.

\[ \text{AADT} = \frac{8,000 \times 100}{10} = 800,000 \text{ vps} \]

The ADT for Friday was calculated as 10,000.

\[ \text{AADT} = \frac{10,000 \times 100}{10} = 1,000,000 \text{ vps} \]

The ADT for Thursday was calculated as 8,000.

\[ \text{AADT} = \frac{8,000 \times 100}{10} = 800,000 \text{ vps} \]
Traffic Forecast

Future traffic volumes for the design are normally derived from the current traffic level and the traffic growth in the future. For important projects, traffic forecasts should be based on through-traffic studies considering the analysis of:

- Zonal socio-economic variables (e.g., population, jobs, employees, school places, car ownership)
- Mobility
- Development of transport facilities and modal split.

It is a combined factor of normal traffic growth, generated traffic and development traffic:

\[ F = (1 + i)^n \]

Where:
- \( F \): Traffic forecast factor
- \( i \): Annual rate of traffic increase
- \( n \): Traffic analysis period

Also:

\[ F = \frac{\text{Future traffic}}{\text{Current traffic}} \]
components of future traffic

1. Current traffic: existing and attracted

Traffic already using the route plus traffic transferring to the new highway from less attractive routes.

2. Normal traffic growth: the increase of current traffic due to general increase in number and usage of motor vehicles.

3. Generated traffic:

- New trips not previously made by any mode of travel.
- Trips that previously were made by public transport.
- Trips attracted by the new or improved highway.

4. Development traffic: is traffic due to improvements on adjacent land.
example: Design data is required for the improvement of two-lane of a two-way highway with central reserve. 

The current traffic in 2004 expressed by AADT is 3000 vehicles in both directions. The improved road with a design life of 20 yrs will be opened to traffic in 2004. The estimated annual growth rate of traffic is 8%. K value = 12% of AADT

D (Direction distribution) = 55% of total traffic

\[ T_{ph}(peak\ hour\ truck\ percentage) = 18\% \text{ of hourly volume} \]

Solution

\[ F = (1+i)^n \]
\[ i = 8\% \]
\[ n = (2004 - 1999) + 20 = 25\ 
\]

\[ F = (1+0.08)^{25} \]
\[ = 6.848 \]

\[ 2004 \]

\[ \text{future traffic (No. of vehicles at 2024)} = 3000 \times 6.848 = 20544 \text{ vels. per day} \]

DHV (in the predominant direction) = ADT \times K \times D

\[ \text{DHV} = 20544 \times 0.12 \times 0.55 = 1356 \text{ (vph)} \]

taking in the account the composition of traffic

% of passenger cars in peak hr. = 100 - 18 = 82%

\[ \text{DHV (in pcu phr)} = 1356 \left[ 0.82 \times 1 + 0.18 \times 2 \right] \]

\[ = 1600 \text{ pcu ph} \]
Traffic engineering studies

The problems related to highway mode of transport are:

1. highway related accidents
2. parking facilities
3. congestion
4. delay

The three categories of traffic studies are:

1. Inventories: It provides a list or graphic display of existing information, such as street widths, parking spaces, transit routes, traffic regulations, and so forth.

2. Administrative studies: They use existing engineering records, available in government agencies and departments.

3. Dynamic studies: They involve the collection of data under operational conditions and include studies of speed, traffic volume, travel time, and delay, parking, and accidents.

These studies are essential for effective planning and evaluation of transportation systems.
There are two methods of measuring the flow of vehicles along a road:

- **Manual counting**: Simply to count every vehicle seen to pass a fixed point on a road. It is done by pen and paper and groups of five vehicles. PSV, HGV, Car, Van, Side car and Light Commercial vehicles.

- **Mechanical counting**: A mechanical counter is used.

### Table of Observations

<table>
<thead>
<tr>
<th>Time</th>
<th>Private Cars</th>
<th>HGV</th>
<th>PSV</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>To</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:30</td>
<td>10:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:30</td>
<td>10:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:00</td>
<td>10:30</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>10:00</td>
<td>10:30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Date:**

**Weather:**

**Traffic conditions:**
Advantages: 1. Flexibility  
2. Simple and quick  
3. Allows traffic classification by volume type  
4. Cheap for short sample counts  

Disadvantages: 1. Expensive for long counts or in unsocial hours  
2. Unpopular in inclement weather  
3. Accuracy depends on quality of observation  

THC / 48 electronic manual counter

Mechanical counter consists of two elements:
- A detector  
- A counter

Types of detectors:
6. Positive contact detector  
6. Pneumatic detector  
6. Hydraulic detector  
6. Magnetic loop detector
Advantages:

- 

Disadvantages:

- 

Mechanical counting are employed for continuous traffic counts, recording the distribution of traffic, how of the day, days of the week, months of the year, and from year to year. Such counts are important to establish traffic trends. There are several methods of carrying out such counting methods.

- 

pneumatic

- 

pressure allowed to escape to avoid "beamed" return signal.

- 

shock wave

- 

transducer

- 

one car axles

- 

axles

- 

depth of the water.
Types of Volume Counts

1. Cordon Counts
   - Central Business District
   - Involves counting vehicles at intervals around the CBD
   - Data collected at fixed points
   - Useful for traffic management and planning

2. Screen Line Counts
   - Monitors traffic on specific road sections
   - Provides real-time data
   - Used for traffic forecasting and congestion analysis

The information are used for:
1. Planning parking facilities
2. Updating and evaluating traffic operational techniques.
3. Making long-range plans for freeway and arterial street systems.

Facilitates the detection of variations in traffic volumes and traffic flow direction due to changes in the land-use pattern of the area.
Intersection Counts

- data used in determining phase lengths and cycle times for signalized intersections, in the design of

Channelization at intersections and in the general design of improvements to intersections

- Pedestrian Volume Counts
- Periodic Volume Counts AADT

Traffic Volume data presentation

1. Traffic flow maps
2. Intersection summary sheets
3. Time-based distribution charts
4. Summary tables

Frictional Detail Data Sheets

Speed statistics

4. Pedestrian Volume Counts

4.4.2 Measuring Pedestrian Volume

5. Periodic Volume Counts

5.2 Receipt of Pedestrian Volume Data

Note: All counts should be made at the origin for the volume of the pedestrian AADT.
Origin-Destination survey (O-D)

Origin: The location of where the trip begins.

Destination: The location of where the trip ends.

(O-D) study: A measure of the patterns of movement of persons and vehicles within a particular area of interest.

Methods of conducting O-D studies

1. Road side interview
2. Postcard survey
3. Home interview
4. License renewal or Registration number check
5. Telephone
6. Vehicle tag system

Check point

1. Estimate the number of days the survey is required.
2. Select the days.
3. Design the form for data collection.
4. Analyze the data collected.
5. Prepare a report.
6. Submit the report to the appropriate authority.

Resources:
- 10% of the facilities
- 15% of the population
- 5% of the vehicles
- 2% of the time

Final report:
- Includes analysis and recommendations.
- Submitted to the authorities.
The information obtained from the O-D data follow:

A. Type of vehicle
B. No. of persons in vehicle / occupancy
C. Origin and Destination of trip
D. Purpose of the trip
E. Parking locations
F. Intermediate stops

Uses of O-D data

1. Travel demand on existing and future transport
2. Adequacy of existing parking, mass transportation
3. Location of new bridges
4. Feasibility of bypass route
Diagram showing zones and sectors of a city plan, including industrial estate and housing estate.
The observer counts and records vehicles turning left, going straight ahead, and turning right. The first column of the table records the number of vehicles of each category turning left. The second column records the number of vehicles going straight ahead, and the third column records the number of vehicles turning right. The table includes columns for cars, HGV, and PSV for each direction.
و للرد على الأمل، فإن تحقيق هذه الأهداف بالرسوم و رسوم التمثيل:

...... معنى رومانيا ما ستعمل الحفاظ على الميزة بين الاتجاهات كلاً. ص 44 أساتذة علماء.
4 TRAFFIC DATA

FIGURE 1-32  Typical Intersection Turning Movement Diagrams

A–Grade separated intersection

AM PEAK

B–At-grade intersection

ADT

Scale:
PCUs per hour

Scale:
Thousands of vehicles per 24 hours
These studies are conducted mainly for the following purposes:

1. Planning traffic control—establishing speed zones, traffic signals, location of warning, regulatory, and information signs—non passing zones—etc.

2. Determining the speed trends

3. For the accident studies
   a. Relation of accident to speed
   b. Analysis of high accident location
   c. Effectiveness of remedial measures put in

4. Used in capacity studies

5. Used for geometric design

Locations and limits of speed study

major highways

- General characteristics of traffic and volume
- Characteristics of speed
- Characteristics of accident location

Speed and delay studies

- Estimation of capacity
- Estimation of delay
- Estimation of delay due to signals
- Estimation of delay due to parking
- Estimation of delay due to weaving
- Estimation of delay due to merges
- Estimation of delay due to diverges
- Estimation of delay due to).'
Types of speeds are

1- Spot speed: The arithmetic mean of the speeds of all traffic at a specified point

2- Running speed: A speed over a specified section of highway

\[
\text{running speed} = \frac{\text{Distance}}{\text{running time (excluding delays at intersections)}}
\]

3- Journey speed: The total distance traversed divided by the total time required including all traffic delays.

\[
\text{Journey speed} = \frac{\text{Distance}}{\text{total time (including delays)}}
\]

There are five methods of measuring this speed:

1. Place a man at the starting point and give him a rope. He ties one end of the rope to his hand, then runs or drives his vehicle as he considers necessary. As he runs or drives, he straightens the rope as much as possible, and this straightening is a measurement of his speed. He should time his run or drive, and find the distance covered.

2. Suppose a man ties a rope to his hand, runs as fast as he can, and at the same time counts a certain number of beats that he considers necessary. If he has run for one hour, and covered 12 miles, then his speed is 

3. Suppose a man drives or runs as fast as he can, and a man opposite him observes how many beats of a rope the first man makes in one hour. Suppose he makes 53 beats in one hour. Then his speed is 

4. Suppose a man runs as fast as he can, and draws a line on the ground. He then counts the number of beats that pass over the line in one hour. Suppose he makes 53 beats in one hour. Then his speed is 

5. Suppose a man runs as fast as he can, and puts a mark on a board. He then counts the number of beats that pass over the mark in one hour. Suppose he makes 53 beats in one hour. Then his speed is
27.8 m x \frac{3600 \text{ sec/hr}}{1000 \text{ m/hr}} = 100 \text{ Sec} \cdot \frac{\text{km}}{\text{hr}}

S = \frac{90}{t} \quad \text{distance (m)}
S = \frac{180}{t} \quad 25
S = \frac{360}{t} \quad 50
S = \frac{720}{t} \quad 100

where \quad t = \text{time (sec)}
S = \text{speed (km/hr)}

2) Enoscope

3) Using electronics Truvelo and Venner speed meters

 snelheid met behulp van pneumatische tube Venner

Ordringsverstoringen en momenten met elkaar in coincidentie

Daarbij wordt de snelheid van de toestand van de bol die de bal in de bol een

Velleen Venner met Truvelo en truvelo
* Sample Size: The larger sample size, the greater the probability that the estimated mean is not significantly different from the true mean.

* Before analyzing spot speed informations statistically, we need to understand some definitions. These are:
  - average Travel speed
  - median speed
  - Modal speed
  - The 1st percentile spot speed
  - pace
  - standard deviation of speeds
Spot speed studies

Speed characteristics determined from a spot speed study may be used to:

1. Establish speed zones
2. Determine whether complaints about speeding are valid
3. Establish passing and no-passing zones
4. Analyze accident data
5. Evaluate the effects of physical improvements
6. Determine the effects of speed enforcement programs and speed control measures
7. Determine speed trends

Typically, the duration of spot speed studies are at least 1 hr and sample size is at least 30 vehs.

Some definitions:
* Average speed: is the arithmetic mean of all observed vehicle speeds (which is the sum of all spot speeds divided by the no. of recorded speeds).

\[ \bar{u} = \frac{\sum f_i u_i}{\sum f_i} = \frac{\sum u_i}{n} \]

where
\[ \bar{u} \] = arithmetic mean
\( f_i \) = number of observations in each group
\( u_i \) = midvalue for the ith speed group
\( n \) = number of observed values
* Median speed: is the speed at the middle value in a series of spot speeds that are arranged in ascending order. 50% of the speed values will be greater than the median; 50% percent will be less than the median.

* 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, 85% spot speed is the speed below which 85% of the vehicles travel and above which 15% of the vehicles travel.

* Range: is the range of speed—usually taken at 10 km/hr intervals—that has the greatest no. of observations.

* Standard deviation of speeds: is a measure of the spread of the individual speeds. It is estimated as:

\[ s = \sqrt{\frac{\sum (y_i - \bar{y})^2}{N-1}} \]

where

- \( s \) : Standard deviation or \( s \) = \( \sqrt{\frac{\sum (x_i - \bar{x})^2}{N}} \)
- \( \bar{y} \) : Arithmetical mean
- \( y_i \) : jth observation
- \( N \) : Number of observations

For grouped data:

\[ s = \sqrt{\frac{\sum (f_i \cdot u_i^2) - (\sum f_i u_i)^2}{\sum f_i}} \]

where

- \( u_i \) : Mid-value of speed class i
- \( f_i \) : Frequency of speed class i
\[ \bar{u} = \frac{\sum_i^n u_i}{\sum_i^n c_i} = \frac{4260}{86} = 49.5 \text{ km/hr} \]

The standard deviation

\[ s = \sqrt{\frac{\sum_{i=1}^n (u_i - \bar{u})^2}{N-1}} = \sqrt{\frac{3632}{86-1}} = \pm 6.5 \text{ km/hr} \]

The median speed is obtained from the cumulative frequency distribution curve = 49 km/hr. It is the 50th-percentile speed.

The pace is obtained from the frequency distribution curve (Fig. 4.4) as 45 to 55 km/hr.

The mode or modal speed is obtained from the frequency histogram as 49 km/hr (Fig. 4.3). It may be obtained also from the frequency distribution curve shown in Fig. 4.4 where the speed corresponding to the highest point on the curve is taken as an estimate of the modal speed.
A list of 161 speed readings for vehicles in mph:
33, 29, 30, 30, 30, 28, 27, 32, 40, 40, etc.

The speed data can be used to calculate the mean speed. The following table shows the mean speed grouped into speed ranges.

<table>
<thead>
<tr>
<th>Speed Group</th>
<th>Midpoint (x)</th>
<th>No. of Speed Readings (f)</th>
<th>% of Speeds in groups (x) / 100</th>
<th>Cumulative % of total observations (2x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-17</td>
<td>16</td>
<td>2</td>
<td>1 - 2</td>
<td>32</td>
</tr>
<tr>
<td>18-20</td>
<td>19</td>
<td>6</td>
<td>4 - 6</td>
<td>114</td>
</tr>
<tr>
<td>21-23</td>
<td>22</td>
<td>12</td>
<td>8 - 12</td>
<td>264</td>
</tr>
<tr>
<td>24-26</td>
<td>25</td>
<td>20</td>
<td>12 - 24</td>
<td>500</td>
</tr>
<tr>
<td>27-29</td>
<td>28</td>
<td>30</td>
<td>19 - 32</td>
<td>840</td>
</tr>
<tr>
<td>30-32</td>
<td>31</td>
<td>32</td>
<td>20 - 62</td>
<td>992</td>
</tr>
<tr>
<td>33-35</td>
<td>34</td>
<td>28</td>
<td>17 - 56</td>
<td>952</td>
</tr>
<tr>
<td>36-38</td>
<td>37</td>
<td>15</td>
<td>9 - 59</td>
<td>555</td>
</tr>
<tr>
<td>39-41</td>
<td>40</td>
<td>10</td>
<td>6 - 92</td>
<td>400</td>
</tr>
<tr>
<td>42-44</td>
<td>43</td>
<td>6</td>
<td>4 - 100</td>
<td>258</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>161</td>
<td>100</td>
<td>4907</td>
</tr>
</tbody>
</table>

Mean = \( \frac{\sum f_x}{\sum f} = \frac{4907}{161} = 30.48 \)
The standard deviation is a measure of the average deviation of readings from their mean.

\[ S = \sqrt{\frac{\sum (fx^2) - (\sum f \cdot x)^2}{\sum f}} \]

\[ S = \sqrt{\frac{155255}{161} - (30.48)^2} \]

\[ S = \sqrt{96432.928} 

\[ = 5.94 \times 6 \]

To standardize the spread, i.e., to express it as a % of the mean value, known as the Coefficient of Variation (CV).

\[ CV = 100 \times \frac{S}{\bar{x}} \]

For 30-48 speed: 19.8% 
\[ \text{6 for 30-48 speed } = 19.8\% \]

For 15: 12% 
\[ \text{6 for 15 } = 12\% \]

For 50: 40% 
\[ \text{6 for 50 } = 40\% \]

\[ CV = 100 \times \frac{5.94}{30.48} = 19\% \]

The CV gives a clear impression not only of the spread of the speed readings, but also of the significance of this spread.
Ogive of speed readings

Median speed: is the middle or 50% speed from cumulative curve

85th percentile: is taken as the design speed mostly. Also, it is the speed below which 85% of the vehicles are being driven.

15th percentile: is the minimum speed limit.

Arithmetic mean or Average spot speed \( \bar{X} = \frac{\sum xi}{n} \)

where \( X \) = average spot speed

\( X_1, X_2, \ldots, X_n \) = \( i \)th spot speed

\( n \) = No. of observations

\( \bar{X} = \frac{\sum(C_i \times X_i)}{\sum C_i} \) for grouped data
**Example**: Determining speed characteristics from a set of speed data

Example: The table below shows the data collected on a rural highway in Virginia during a speed study. Develop the frequency histogram and the frequency distribution of the data, and determine

1. The arithmetic mean speed
2. The standard deviation
3. The median speed
4. The pace
5. The mode or modal speed

**Solution**

<table>
<thead>
<tr>
<th>Speed class (km/hr)</th>
<th>Class Midvalue</th>
<th>Frequency (f)</th>
<th>Fc</th>
<th>% of observation in class</th>
<th>Cumulative % of all observations</th>
<th>( f (x - \bar{x})^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>34-35.9</td>
<td>35</td>
<td>2</td>
<td>70</td>
<td>2.3</td>
<td>2.3</td>
<td>420.50</td>
</tr>
<tr>
<td>36-37.9</td>
<td>37</td>
<td>3</td>
<td>111</td>
<td>3.5</td>
<td>5.8</td>
<td>468.75</td>
</tr>
<tr>
<td>38-39.9</td>
<td>39</td>
<td>2</td>
<td>78</td>
<td>2.3</td>
<td>8.1</td>
<td>220.50</td>
</tr>
<tr>
<td>40-41.9</td>
<td>41</td>
<td>5</td>
<td>205</td>
<td>5.8</td>
<td>13.9</td>
<td>361.25</td>
</tr>
<tr>
<td>42-43.9</td>
<td>43</td>
<td>3</td>
<td>129</td>
<td>3.5</td>
<td>17.4</td>
<td>126.75</td>
</tr>
<tr>
<td>44-45.9</td>
<td>45</td>
<td>11</td>
<td>495</td>
<td>12.3</td>
<td>30.2</td>
<td>222.75</td>
</tr>
<tr>
<td>46-47.9</td>
<td>47</td>
<td>4</td>
<td>188</td>
<td>4.7</td>
<td>34.9</td>
<td>25.00</td>
</tr>
<tr>
<td>48-49.9</td>
<td>49</td>
<td>18</td>
<td>882</td>
<td>21.0</td>
<td>55.9</td>
<td>9.0</td>
</tr>
<tr>
<td>50-51.9</td>
<td>51</td>
<td>7</td>
<td>357</td>
<td>8.1</td>
<td>64.0</td>
<td>15.75</td>
</tr>
<tr>
<td>52-53.9</td>
<td>53</td>
<td>8</td>
<td>424</td>
<td>9.3</td>
<td>73.3</td>
<td>98.00</td>
</tr>
<tr>
<td>54-55.9</td>
<td>55</td>
<td>11</td>
<td>605</td>
<td>12.8</td>
<td>86.1</td>
<td>332.75</td>
</tr>
<tr>
<td>56-57.9</td>
<td>57</td>
<td>5</td>
<td>285</td>
<td>5.8</td>
<td>91.9</td>
<td>281.25</td>
</tr>
<tr>
<td>58-59.9</td>
<td>59</td>
<td>2</td>
<td>118</td>
<td>2.3</td>
<td>94.2</td>
<td>180.50</td>
</tr>
<tr>
<td>60-61.9</td>
<td>61</td>
<td>2</td>
<td>122</td>
<td>2.3</td>
<td>96.5</td>
<td>264.5</td>
</tr>
<tr>
<td>62-63.9</td>
<td>63</td>
<td>2</td>
<td>126</td>
<td>2.3</td>
<td>98.8</td>
<td>364.5</td>
</tr>
<tr>
<td>64-65.9</td>
<td>65</td>
<td>1</td>
<td>66</td>
<td>1.2</td>
<td>100</td>
<td>240.25</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td><strong>86</strong></td>
<td><strong>4260</strong></td>
<td></td>
<td><strong>100</strong></td>
<td><strong>3632.00</strong></td>
</tr>
</tbody>
</table>
Fig 4.3. Histogram of observed vehicle's speed.

Fig 4.4. Frequency distribution.
American cities have a better distribution of shopping centers, employment, and administrative facilities throughout the city and not centered heavily in the CBD as is the case of Baghdad. Fourthly, parking charges in the CBD of American cities are found to be much higher discouraging non-essential trips to that area.

The number of parking spaces available in the CBD in 1980 was 32400 or 9.6 space per 1000 population, compared to 15.9 parking spaces per 1000 population for the American cities of population more than one million (table 2-7). For that reason, the occupancy of their parking spaces never reached 100% even though their car ownership is much higher than ours.

It is worth mentioning also that the on-street parking spaces in the CBD accounted for 66% of total parking spaces while for those of American cities mentioned in table (2-8), was only 14%. It was recommended by BCTS to change the on-street parking spaces to off-street facilities in the area in order to improve the flow of traffic within the central area and minimize accidents caused by parked vehicles.

The surveys showed that percentage of work trips is the highest (33%) followed by shopping and business trips (both of 27%), while for American cities (table 2-9), work trips account for 41% which is also the highest number followed by business trips (30%). The shopping trips account for one thirds business trips (10%). This marked
Fig 4.5 Cumulative distribution curve

Vehicle speed (km/hr)

Cumulative frequency (C%)

85 km

Median speed

P_{85} = 50 km/hr

P_{50} = 49 km/hr
running speed is the average speed maintained over a given route while the vehicle is in motion. It is used as a measure of the load of service.

Journey speed is a direct method of traffic congestion. It is used for highway planning and economic studies.

Methods of measurement: There are three.

1. Registration number method
2. Plotters
3. Estimation by field work.
Elevated observer method

Moving observer method  page 38 (Wells)

This method is good for two way routes only and a minimum of six test runs should be made in each direction under same conditions.

Hourly volume for one directional flow is determined by the following

\[ Q_1 = \frac{1}{\alpha + \omega} (\alpha + \omega) \]

where

\[ Q_1 \] = Flow of vehicles in one direction

\[ \alpha \] = Average no. of vehicles counted in the direction when test car was travelling in opposite direction

\[ \omega \] = Average journey time when test car is travelling in the opposite direction to \( Q \)

\[ \omega = \frac{\alpha + \omega}{2} \]

\[ t = \frac{Q}{Q_1} \]

\[ y = \text{Net vehicles overtaking test car when it is travelling in the direction of \( Q \) - Overtaken by the test car} \]

\[ x = \text{Net vehicles being overtaken by the test car in the direction of \( Q \)} \]

Diagram:

- West
- East
- Test Car
Traffic engineering
worked examples & problems

Example 1

Six runs were made in each direction along a two-way highway between A and B square. Flows were measured both with and against the moving car and the following notes obtained. Distance from A to B square = 6.4 km. Calculate the flow and stream speed in each direction.

car travelling from A to B square

<table>
<thead>
<tr>
<th>Trip commences</th>
<th>Trip ends</th>
<th>Time taken to overtake</th>
<th>No. 46 vehicles</th>
<th>Average speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>16:05</td>
<td>16:16</td>
<td>11</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>16:34</td>
<td>16:44</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>17:05</td>
<td>17:17</td>
<td>12</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>17:35</td>
<td>17:44</td>
<td>9</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>18:05</td>
<td>18:18</td>
<td>13</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>18:35</td>
<td>18:45</td>
<td>10</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Average: 10.83 min 0.1805 hr 1.16 399 12

car travelling from B to A square

<table>
<thead>
<tr>
<th>Trip commences</th>
<th>Trip ends</th>
<th>Time taken to overtake</th>
<th>No. 46 vehicles</th>
<th>Average speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>16:19</td>
<td>16:31</td>
<td>12</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>16:30</td>
<td>17:03</td>
<td>13</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>17:20</td>
<td>17:32</td>
<td>12</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>17:30</td>
<td>17:59</td>
<td>10</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>18:02</td>
<td>18:33</td>
<td>13</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>18:30</td>
<td>19:17</td>
<td>11</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

\[
\frac{a}{t} = \frac{x + y}{u + v} = \frac{316.5 + 116}{0.195 + 0.180} = 845.96 \text{ veh/hr}
\]

\[
E_A = \frac{t - \frac{y}{v}}{\frac{v}{u}} = \frac{0.1805 - 1.16}{845.96} = 0.174 \text{ hr} = 10.47 \text{ min}
\]

\[
V_A = \frac{D}{t} = \frac{6.4}{0.174} = 36.7 \text{ km/hr}
\]

\[
\frac{a}{t} = \frac{299.12 + 2.83}{0.195 + 0.180} = 1070.52 \text{ veh/hr}
\]

\[
E_B = \frac{0.195 - 2.83}{1070.52} = 0.192 \text{ hr} = 11.54 \text{ min}
\]

\[
V_B = \frac{6.4}{0.192} = 33.27 \text{ km/hr}
\]
Example: Find the hourly volume and speed for a test section length of 1 km (urban road). Data are given below.

<table>
<thead>
<tr>
<th>North bound trip</th>
<th>time (min)</th>
<th>No. of vehs in opposing direction</th>
<th>No. of vehs overtaking test car</th>
<th>No. of vehs overtaken by the test car</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.65</td>
<td>85</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2.7</td>
<td>83</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>2.35</td>
<td>77</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>3.00</td>
<td>85</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>2.42</td>
<td>90</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>2.54</td>
<td>84</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total average</strong></td>
<td><strong>15.66</strong></td>
<td><strong>504</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
y_n = 9 - 6 = 3 \quad \text{avg } y = 0.5
\]

<table>
<thead>
<tr>
<th>South bound trip</th>
<th>time (min)</th>
<th>(X)</th>
<th>No. of vehs overtaking test car</th>
<th>No. of vehs overtaken by test car</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.33</td>
<td>112</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2.30</td>
<td>113</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>2.71</td>
<td>119</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>2.16</td>
<td>120</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>2.54</td>
<td>105</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>2.48</td>
<td>100</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total average</strong></td>
<td><strong>14.52</strong></td>
<td><strong>669</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
y_s = 3 - 6 = -3 \quad \text{avg } y = -0.5
\]

\[
g_n = \frac{x + y_n}{a + w} = \frac{(111.5 + 0.5) \times 60}{2.42 + 2.61} = 1336 \text{ veh/hr}
\]

\[
g_s = \frac{x + y_s}{a + w} = \frac{(84 - 0.5) \times 60}{2.61 + 2.42} = 996 \text{ veh/hr}
\]
The average travel time for one directional flow is determined by the following formula

\[ t = u - \frac{y}{q} \]

where

\( t \): average journey time for all traffic in direction \( q \)

\[ t_n = 2.61 - \frac{0.5}{1336/60} = 2.587 \text{ min} \]

\[ t_s = 2.42 - \frac{-0.5}{996/60} = 2.45 \text{ min} \]

Journey speed \( V_n = \frac{1 \times 60}{2.587} = 23.2 \text{ km/hr} \)

\[ V_s = \frac{1 \times 60}{2.45} = 24.5 \text{ km/hr} \]

\( y \): No. of vehs overtaking test car - No. of vehs. overtaken by the test car
Using moving observer method, seven runs have been made in each direction over a section of road 1.64 km in length with the following readings:
Calculate the flow & traffic & speed in each direction.

<table>
<thead>
<tr>
<th>Journeytime</th>
<th>X-Count</th>
<th>Vehicles overtaking test car</th>
<th>Vehicles overtaken by test car</th>
</tr>
</thead>
<tbody>
<tr>
<td>min-sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-50</td>
<td>38</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2-02</td>
<td>42</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2-00</td>
<td>40</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>1-56</td>
<td>38</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1-58</td>
<td>38</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1-48</td>
<td>35</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>2-13</td>
<td>41</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>272</strong></td>
<td>9</td>
<td>28</td>
</tr>
</tbody>
</table>

Average 38.8: \((9-28) = -19\)
Average \(y = -2.7\)

Westbound trips

<table>
<thead>
<tr>
<th>Journeytime</th>
<th>X-Count</th>
<th>Vehicles overtaking test car</th>
<th>Vehicles overtaken by test car</th>
</tr>
</thead>
<tbody>
<tr>
<td>min-sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-05</td>
<td>27</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2-00</td>
<td>26</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2-10</td>
<td>28</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1-58</td>
<td>25</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>2-15</td>
<td>30</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2-07</td>
<td>28</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2-10</td>
<td>31</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>195</strong></td>
<td>20</td>
<td>28</td>
</tr>
</tbody>
</table>

Average 2.06

\(q = \frac{x + y}{a + w}\) \(t = w - y/2\)

\(q_e = \frac{27.9 + (-2.7)}{1.97 + 2.1}\times 60 = 37.1\) Veh/hr

\(t_e = 1.97 + \frac{2.7}{37.1\%} = 2.41\) min 2-24
\[ V_e = \frac{1.64}{2.4/60} = 40.8 \text{ km/hr} \]
\[ q_w = \frac{38.8 \times (1.1)}{1.97 + 2.1} \times 60 = 588 \text{ veh/hr} \]
\[ t_w = 2.1 + \frac{1.1}{588/60} = 2.22 \text{ min} \quad 2 - 12 \]
\[ V_w = \frac{1.64}{2.22/60} \approx 44.7 \text{ km/hr} \]

**Delays**

There are two types of delays:

1. **Fixed delays**: Occurs mostly at roadway intersections like:
   - Traffic signals
   - Railway crossing
   - Roundabouts
   - Stop signs
   - Pedestrian crossing

2. **Operational delays** or running delays:

   This delay is primarily a reflection of the interacting effects of traffic on the highway or street:
   - Parking
   - Pedestrians
   - Crossing & turning vehs.
   - Congestion caused by heavy traffic
Factors affecting delays

1. Fixed factors: width, no. of lanes, traffic signals

2. Traffic factors: congestion, parking & unparking

3. Control factors: give way sign, stop sign

Conclusions and recommendations

The fifth chapter, which is the last one discusses the
Delay Studies: Intersection is the major delay in the traffic stream. There are several factors affecting intersection delay.

1. Physical factors: such as the No. of lanes, width, grades, channelization, bus stop.

2. Traffic factors: such as Volume on each approach, turning movement, driver approach speed, parking & pedestrian.

3. Traffic controls: such as timing of signals, stop sign.

Example: to find the delay at intersection by using the stopped time delay method:

1. Count the No. of vehs. stopped in the intersection approach (every 15 secs)
2. Count the Vol. during the same time.
3. The results show below:

<table>
<thead>
<tr>
<th>Time</th>
<th>Stationary Vehs.</th>
<th>Approach Volume, stopping</th>
<th>Nonstopping</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00 15 30 45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:00</td>
<td>0 2 7 9</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>8:01</td>
<td>4 0 0 3</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>8:02</td>
<td>9 16 14 6</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>8:03</td>
<td>1 4 9 13</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>8:04</td>
<td>5 0 0 2</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>Subtotal</td>
<td>19 22 30 33</td>
<td>56</td>
<td>38</td>
</tr>
<tr>
<td>Total</td>
<td>104</td>
<td>94</td>
<td></td>
</tr>
</tbody>
</table>
computation

Total delay = 15 \times 104 = 1560

\text{Total No. of observed vehs.} \times \text{observation interval}

Average delay per stopped vehicle = \frac{\text{Total delay}}{\text{No. of stopping vehs.}}
= \frac{1560}{56} = 27.8 \text{ secs}

Average delay per approach veh = \frac{\text{Total delay}}{\text{approach vol.}}
= \frac{1560}{94} = 16.3 \text{ secs}

\text{Percent of stopped vehs.} = \frac{\text{No. of stopping vehs.}}{\text{approach vol.}} \times 100
= \frac{56}{94} \times 100 = 59.5 \%

Average delay 16.3 secs is taken for all approaches
and this figure is used for an economic analysis of the junction and the appraisal of any proposed improvements to it.
When the PHF is known, it can convert a peak-hour volume to a peak flow rate, as in Equation 7-3:

$$v = \frac{V}{PHF}$$

(7-3)

where

- PHF = peak-hour factor,
- V = hourly volume (veh/h), and
- $V_{15}$ = volume during the peak 15 min of the peak hour (veh/15 min).

Equation 7-3 does not need to be used to estimate peak flow rates if traffic counts are available; however, the chosen count interval must identify the maximum 15-min flow period. The rate then can be computed directly as 4 times the maximum 15-min count. When flow rates in terms of vehicles are known, a conversion to a flow rate in terms of passenger car equivalents (pce) can be computed using the PHF and the heavy vehicle factor.

**SPEED**

Although traffic volumes provide a method of quantifying capacity values, speed (or its reciprocal of travel time) is an important measure of the quality of the traffic service provided to the motorist. It is an important measure of effectiveness defining levels of service for many types of facilities, such as rural two-lane highways, urban streets, freeway weaving segments, and others.

Speed is defined as a rate of motion expressed as distance per unit of time, generally as kilometers per hour (km/h). In characterizing the speed of a traffic stream, a representative value must be used, because a broad distribution of individual speeds is observable in the traffic stream. In this manual, average travel speed is used as the speed measure because it is easily computed from observation of individual vehicles within the traffic stream and is the most statistically relevant measure in relationships with other variables. Average travel speed is computed by dividing the length of the highway, street section, or segment under consideration by the average travel time of the vehicles traversing it. If travel times $t_1$, $t_2$, $t_3$, ..., $t_n$ (in hours) are measured for vehicles traversing a segment of length $L$, the average travel speed is computed using Equation 7-4.

$$S = \frac{\sum_{i=1}^{n} t_i}{n} = \frac{1}{n} \sum_{i=1}^{n} t_i = \frac{L}{\sum_{i=1}^{n} t_i}$$

(7-4)

where

- $S$ = average travel speed (km/h),
- $L$ = length of the highway segment (km),
- $t_i$ = travel time of the $i$th vehicle to traverse the section (h),
- $n$ = number of travel times observed, and
- $t_a = \frac{1}{n} \sum_{i=1}^{n} t_i = \text{average travel time over } L$ (h).

The travel times in this computation include stopped delays due to fixed interruptions or traffic congestion. They are total travel times to traverse the defined roadway length.

Several different speed parameters can be applied to a traffic stream. These include the following:
Average running speed—A traffic stream measure based on the observation of vehicle travel times traversing a section of highway of known length. It is the length of the segment divided by the average running time of vehicles to traverse the segment. Running time includes only time that vehicles are in motion.

Average travel speed—A traffic stream measure based on travel time observed on a known length of highway. It is the length of the segment divided by the average travel time of vehicles traversing the segment, including all stopped delay times. It is also a space mean speed.

Space mean speed—A statistical term denoting an average speed based on the average travel time of vehicles to traverse a segment of roadway. It is called a space mean speed because the average travel time weights the average to the time each vehicle spends in the defined roadway segment or space.

Time mean speed—The arithmetic average of speeds of vehicles observed passing a point on a highway; also referred to as the average spot speed. The individual speeds of vehicles passing a point are recorded and averaged arithmetically.

Free-flow speed—The average speed of vehicles on a given facility, measured under low-volume conditions, when drivers tend to drive at their desired speed and are not constrained by control delay.

For most of the procedures using speed as a measure of effectiveness in this manual, average travel speed is the defining parameter. For uninterrupted-flow facilities not operating at level of service (LOS) F, the average travel speed is equal to the average running speed.

Exhibit 7-1 shows a typical relationship between time mean speed and space mean speeds. Space mean speed is always less than time mean speed, but the difference decreases as the absolute value of speed increases. Based on the statistical analysis of observed data, this relationship is useful because time mean speeds often are easier to measure in the field than space mean speeds.

**EXHIBIT 7-1. TYPICAL RELATIONSHIP BETWEEN TIME MEAN AND SPACE MEAN SPEED**

It is possible to calculate both time mean and space mean speeds from a sample of individual vehicle speeds. For example, three vehicles are recorded with speeds of 40, 60, and 80 km/h. The time to traverse 1 km is 1.5 min, 1.0 min, and 0.75 min, respectively. The time mean speed is 60 km/h, calculated as \(\frac{40 + 60 + 80}{3}\). The space mean speed is 55.4 km/h, calculated as \(\frac{40 + 60 + 80}{3 + 1.5 + 1.0 + 0.75}\).

### Exhibit 7-1

<table>
<thead>
<tr>
<th>Distance</th>
<th>Speeds (km/h)</th>
<th>Time Mean Speed (T.M.S)</th>
<th>Space Mean Speed (S.M.S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 km</td>
<td>40, 60, 80</td>
<td>(\frac{40 + 60 + 80}{3}) = 60 km/h</td>
<td>(\frac{1 \times 3}{40 + 60 + 80}) = 55.4 km/h</td>
</tr>
</tbody>
</table>
For capacity analysis, speeds are best measured by observing travel times over a
known length of highway. For uninterrupted-flow facilities operating in the range of
stable flow, the length may be as short as 50 to 100 m for ease of observation.

As measures of effectiveness, speed criteria must recognize driver expectations and
roadway function. For example, a driver expects a higher speed on a freeway than on an
urban street. Lower free-flow speeds are tolerable on a roadway with more severe
horizontal and vertical alignment, since drivers are not comfortable driving at high
speeds. LOS criteria reflect these expectations.

**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 (veh/km) or
passenger cars per kilometer (pc/km).

Direct measurement of density in the field is difficult, requiring a vantage point for
photographing, videotaping, or observing significant lengths of highway. Density can be
computed, however, from the average travel speed and flow rate, which are measured
more easily. Equation 7-5 is used for undersaturated traffic conditions.

\[ D = \frac{v}{S} \]  

where

- \( v \) = flow rate (veh/h),
- \( S \) = average travel speed (km/h), and
- \( D \) = density (veh/km).

A highway segment with a rate of flow of 1,000 veh/h and an average travel speed of
50 km/h would have a density of

\[ D = \frac{1000 \text{ veh/h}}{50 \text{ km/h}} = 20 \text{ veh/km} \]

Density is a critical parameter for uninterrupted flow facilities because it characterizes the
quality of traffic operations. It describes the proximity of vehicles to one another and
reflects the freedom to maneuver within the traffic stream.

Roadway occupancy is frequently used as a surrogate for density in control systems
because it is easier to measure. Occupancy in space is the proportion of roadway length
covered by vehicles, and occupancy in time identifies the proportion of time a roadway
cross section is occupied by vehicles.

**HEADWAY AND SPACING**

Spacing is the distance between successive vehicles in a traffic stream, measured
from the same point on each vehicle (e.g., front bumper, rear axle, etc.). Headway is the
time between successive vehicles as they pass a point on a lane or roadway, also
measured from the same point on each vehicle.

These characteristics are microscopic, since they relate to individual pairs of vehicles
within the traffic stream. Within any traffic stream, both the spacing and the headway of
individual vehicles are distributed over a range of values, generally related to the speed of
the traffic stream and prevailing conditions. In the aggregate, these microscopic
parameters relate to the macroscopic flow parameters of density and flow rate.

Spacing is a distance, measured in meters. It can be determined directly by
measuring the distance between common points on successive vehicles at a particular
instant. This generally requires complex aerial photographic techniques, so that spacing
usually derives from other direct measurements. Headway, in contrast, can be easily
measured with stopwatch observations as vehicles pass a point on the roadway.
The average vehicle spacing in a traffic stream is directly related to the density of the traffic stream, as determined by Equation 7-6.

\[ \frac{\text{Density (vehr/km)}}{\text{spacings (m/veh)}} = \frac{1000}{\text{spacings (m/veh)}} \]  

(7-6)

The relationship between average spacing and average headway in a traffic stream depends on speed, as indicated in Equation 7-7.

\[ \text{Headway (s/veh)} = \frac{\text{Spacing (m/veh)}}{\text{Speed (m/s)}} \]  

(7-7)

This relationship also holds for individual headways and spacings between pairs of vehicles. The speed is that of the second vehicle in a pair of vehicles. Flow rate is related to the average headway of the traffic stream with Equation 7-8.

\[ \text{Flow rate (veh/hr)} = \frac{3600}{\text{headway (s/veh)}} \]  

(7-8)

RELATIONSHIPS AMONG BASIC PARAMETERS

Equation 7-5 states the basic relationship among the three parameters, describing an uninterrupted traffic stream. Although the equation \( v = s + d \) algebraically allows for a given flow rate to occur in an infinite number of combinations of speed and density, there are additional relationships restricting the variety of flow conditions at a location. Exhibit 7-2 shows a generalized representation of these relationships, which are the basis for the capacity analysis of uninterrupted flow facilities. The flow-density function is placed directly below the speed-density relationship because of their common horizontal scales, and the speed-flow function is placed next to the speed-density relationship because of their common vertical scales. Speed is space mean speed.

EXHIBIT 7-2. GENERALIZED RELATIONSHIPS AMONG SPEED, DENSITY, AND FLOW RATE ON UNINTERRUPTED-FLOW FACILITIES

The form of these functions depends on the prevailing traffic and roadway conditions on the segment under study and on its length in determining density. Although the diagrams in Exhibit 7-2 show continuous curves, it is unlikely that the full range of the functions would appear at any particular location. Survey data usually show discontinuities, with parts of these curves not present (2).
The curves of Exhibit 7-2 illustrate several significant points. First, a zero flow rate occurs under two different conditions. One is when there are no vehicles on the facility—density is zero, and flow rate is zero. Speed is theoretical for this condition and would be selected by the first driver (presumably at a high value). This speed is represented by $S_f$ in the graphs.

The second is when density becomes so high that all vehicles must stop—the speed is zero, and the flow rate is zero, because there is no movement and vehicles cannot pass a point on the roadway. The density at which all movement stops is called jam density, denoted by $D_j$ in the diagrams.

Between these two extreme points, the dynamics of traffic flow produce a maximizing effect. As flow increases from zero, density also increases, since more vehicles are on the roadway. When this happens, speed declines because of the interaction of vehicles. This decline is negligible at low and medium densities and flow rates. As density increases, these generalized curves suggest that speed decreases significantly before capacity is achieved. Capacity is reached when the product of density and speed results in the maximum flow rate. This condition is shown as optimum speed $S_o$ (often called critical speed), optimum density $D_o$ (sometimes referred to as critical density), and maximum flow $v_{max}$.

The slope of any ray line drawn from the origin of the speed-flow curve to any point on the curve represents density, based on Equation 7-5. Similarly, a ray line in the flow-density graph represents speed. As examples, Exhibit 7-2 shows the average free-flow speed and speed at capacity, as well as optimum and jam densities. The three diagrams are redundant, since if any one relationship is known, the other two are uniquely defined. The speed-density function is used mostly for theoretical work; the other two are used in this manual to define LOS.

As shown in Exhibit 7-2, any flow rate other than capacity can occur under two different conditions, one with a high speed and low density and the other with high density and low speed. The high-density, low-speed side of the curves represents oversaturated flow. Sudden changes can occur in the state of traffic (i.e., in speed, density, and flow rate). LOS A though E are defined on the low-density, high-speed side of the curves, with the maximum-flow boundary of LOS E placed at capacity; by contrast, LOS F, which describes oversaturated and queue discharge traffic, is represented by the high-density, low-speed part of the functions.

### III. INTERRUPTED FLOW

Interrupted flow is more complex than uninterrupted flow because of the time dimension involved in allocating space to conflicting traffic streams. On an interrupted-flow facility, flow usually is dominated by points of fixed operation, such as traffic signals and stop signs. These controls have different impacts on overall flow.

The operational state of traffic at an interrupted traffic-flow facility is defined by the following measures:
- Volume and flow rate,
- Saturation flow and departure headways,
- Control variables (stop or signal control),
- Gaps available in the conflicting traffic streams, and
- Delay.

The discussion of volume and flow rate in the first part of this chapter also is applicable to interrupted-flow facilities. An important additional point is the screening at which the traffic volume or flow rate is surveyed. Traditional intersection traffic counts yield only the number of vehicles that have departed the intersection. The maximum flow is...
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.

Traffic flow theory is used in:

* Design to determine adequate lane lengths for storing left turn vehs. on a separate left turn lanes.

* The average delay at intersections and freeways ramp merging areas.

* Simulation, where mathematical algorithms are used to study the complex relationships that exist among the elements of a traffic stream or network.

Traffic flow elements:

Time space diagram: is a graph that describes the relationships between the location of vehs. in a traffic stream and the time as the veh. progress along the highway.

![Time-space Diagram](image-url)
CHAPTER FIVE  
CONCLUSIONS  
AND RECOMMENDATIONS

5.1 General

The study was concerned with parking characteristics in a 0.578 km² central part of Baghdad CBD, surrounded by Rashid, Kifah, Amin and Thowra streets. It contains important traffic generators because of its commercial, administrative, and industrial nature.

Four types of surveys were undertaken to collect data. The license plate survey and the driver interview were the most important ones. These surveys were conducted in two public car parks of total capacity 143 spaces and one private car park of capacity 220 spaces.

Number of parking spaces needed in the CBD was calculated by using the study results and compared to other studies.

5.2 Conclusions

It is useful to go into some important particulars observed through the study period.

(1). It was found from the parking inventory that 1035 parking spaces were available in the study area, of which 237 spaces were on-street (166 spaces in the main streets and 71 spaces in the alleyways) 660 spaces were off-street (338 in 9 private car parks and 322 in 7 public
Flow ($q$) is the equivalent hourly rate at which vehicles pass a point on a highway lane during a time period less than 1 hr. It can be determined by

$$q = \frac{n \times 3600}{t} \text{ (veh/hr)}$$

where

- $n$: No. of vehs. passing a point in the roadway in $T$ sec
- $q$: the equivalent hourly flow $v$/hr

Density ($k$) or concentration and it is the no. of vehs. traveling over a unit length of highway at an instant of time, and it is expressed by (veh/km)

**Speed ($u$):** is the distance traveled by a vehicle during a unit time and it is expressed (km/hr) or (m/sec)

**Time mean speed ($\bar{u}_t$):** is the arithmetic mean of the speeds of vehicles passing a point on a highway during an interval of time

$$\bar{u}_t = \frac{1}{n} \sum_{i=1}^{n} u_i = \frac{\sum_{i=1}^{n} u_i}{n}$$

where:

- $n$: No. of vehs. passing a point on the highway
- $u_i$: Speed of the $i$th veh.

**Space mean speed ($\bar{u}_s$):** is the harmonic mean of speeds of vehicles passing a point on a highway during an interval of time

$$\bar{u}_s = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{u_i} = \frac{2}{\sum_{i=1}^{n} \frac{1}{u_i}}$$

where:

- $\bar{u}_s$: Space mean speed (km/hr) or (m/sec)
- $n$: No. of vehs.
- $u_i$: Speed of the $i$th veh.
- $L$: Length of section of hwy
Location B is in sector 2, centering the study area. The car park will replace the parking facility (2-2) and extend to a larger area. This location will require expropriation of a number of old residential and commercial buildings. This location will make the car park serve all the parkers destined the study area.

### Example

Calculate the flow, density, time mean speed, and space mean speed for the four cars A, B, C, and D with their positions and speeds obtained by photography as in Fig below. The cars pass point X at 12:05:

![Diagram](image)

- **Flow**: 25, 30, 45
- **Distance to flow**: 500 m
- **Velocity**: 55 km/h

### Example

3 veles are recorded with speeds of 40, 60, and 80 km/h. The time to traverse 1 km is 15 min, 10 min, and 0.75 min, respectively. What is the time mean speed and space mean speed?

- **Time mean speed**: $\frac{40 + 60 + 80}{3} = 60$ km/h
- **Space mean speed**: $\frac{1 \times 3 \times 60}{(1.5 + 1 + 0.75)} = 55.4$ km/h
Time headway (h) is the difference between the time the front of the veh. arrives at a point on the highway and the time the front of the next veh. arrives at that same point. It is usually expressed in (sec).

The time headway between vehs. 3 & 4 at d₁ is h₃-₄

Space headway (d) or (spacing) is the distance between the front of a veh. and the front of the following veh. It is usually expressed in (m). The space headway between vehs. 3 & 4 at time t₅ is d₃-₄ see fig (6-11)

Example: Fig (6-2) shows vehs. traveling at constant speeds on a two-lane hwy between sections x and y with their positions and speeds obtained at an instant of time by photography. An observer located at point X observes the four vehs. passing point X during a period of T sec. The velocities of the vehs. are measured as 45, 40, 35 and 20 km/hr, respectively. Calculate the flow, the density, the time mean speed and the space mean speed.

Solution:

1. The flow 
   \[ q = \frac{n \times 3600}{T} = \frac{4 \times 3600}{T} = \frac{14400}{T} \text{ vph} \]
Fig (6-2) Locations and speeds of four vehrs. on a two-way hwy at an instant of time.

2. Density \( k = \frac{n}{L} = \frac{4 \times 1000}{300 \times 1000} = 133.3 \text{ veh/km} \)

3. Time mean speed \( \bar{U}_t = \frac{1}{n} \sum_{i=1}^{n} u_i \)
   \[ = \frac{1}{4} (20 + 35 + 40 + 45) \]
   \[ = 35 \text{ km/hr} \]

4. Space mean speed \( \bar{U}_s = \frac{L}{\sum_{i=1}^{n} t_i} = \frac{300}{\sum_{i=1}^{n} (1/u_i)} \)

   where \( t_i \) is the time it takes the \( i \)th veh. to travel from X to Y at speed \( u_i \), and \( L(m) \) is the distance between X and Y.

   \( t_A = \frac{L}{u_1} = \frac{300}{1000 \times 40} \times 3600 = 24 \text{ sec} \)
   \( t_B = \frac{300}{1000 \times 40} \times 3600 = 27 \text{ sec} \)
   \( t_C = \frac{300}{1000 \times 35} \times 3600 = 30.85 \)
   \( t_D = \frac{300}{1000 \times 20} \times 3600 = 54 \)

   \( \therefore \bar{U}_s = \frac{4 \times 300 \times 3600}{1000 (24 + 27 + 30.85 + 54)} = 31.8 \text{ km/hr} \)
Flow-Density relationship

Flow = density x space mean speed

\[ q = \rho \bar{u} \]  

(6.5)

each of these variables depends on
- characteristics of highway
- the vehicle
- the driver
- environmental factors such as weather
Fundamental diagram of traffic flow

It means the relationship between the density (veh/km) and the corresponding flow of traffic on a highway.

Fig (6-3)
Flow verses density

Fig (6-3)
Density verses flow

When we talk about the relationship between density and flow, we can see a graph that represents this relationship. The graph shows that as density increases, flow also increases, but at a decreasing rate. When density reaches a certain point, flow starts to decrease. This point is known as the traffic critical point.

When we talk about space mean speed, we can see another graph that represents this relationship. The graph shows that as density increases, space mean speed decreases. This is because as there are more vehicles in a given space, the vehicles have to slow down to avoid collisions.

When we talk about space mean speed verses volume, we can see another graph that represents this relationship. The graph shows that as volume increases, space mean speed decreases. This is because as the number of vehicles increases, the vehicles have to slow down to avoid collisions.

The equations that describe these relationships are:

\[ f(k) = \frac{C}{k + K_c} \]
\[ v(k) = \frac{C}{k + K_c} \]

Where:
- \( f(k) \) is the flow (veh/h)
- \( v(k) \) is the space mean speed (mph)
- \( k \) is the density (veh/km)
- \( C \) is the capacity of the road (veh/h)
- \( K_c \) is the critical density (veh/km)

These equations are used to model the traffic flow on a highway.