Advanced Traffic Engineering

TE-504A/ TE-504

Lecture-5

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Dr. Zia-ur-Rehman

DTEM

Spot Speed Studies

Spot speed studies are conducted to estimate the distribution of speeds of vehicles in a stream of traffic at a particular location on a highway.

The speed of a vehicle is defined as the rate of movement of the vehicle; it is usually expressed in miles per hour (mi/h) or kilometres per hour (km /h).

A spot speed study is carried out by recording the speeds of a sample of vehicles at a specified location. Speed characteristics identified by such a study will be valid only for the traffic and environmental conditions that exist at the time of the study.

Speed Characteristics

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

• Establish parameters for traffic operation and control, such as speed zones, speed limits (85th-percentile speed is commonly used as the speed limit on a road), and passing restrictions.

• Evaluate the effectiveness of traffic control devices, such as variable message signs at work zones.

• Monitor the effect of speed enforcement programs, such as the use of drone radar and the use of differential speed limits for passenger cars and trucks.

• Evaluate and or determine the adequacy of highway geometric characteristics, such as radii of horizontal curves and lengths of vertical curves.

• Evaluate the effect of speed on highway safety through the analysis of crash data for different speed characteristics.

• Determine speed trends.

• Determine whether complaints about speeding are valid.

Locations for Spot Speed Studies

The following locations generally are used for the different applications listed:

1. Locations that represent different traffic conditions on a highway or highways are used for basic data collection.

2. Mid-blocks of urban highways and straight, level sections of rural highways are sites for speed trend analyses.

3. Any location may be used for the solution of a specific traffic engineering problem.

Time of Day and Duration of Spot Speed Studies

The time of day for conducting a speed study depends on the purpose of the study. In general, when the purpose of the study is to establish posted speed limits, to observe speed trends, or to collect basic data, it is recommended that the study be conducted when traffic is free-flowing, usually during off-peak hours.

However, when a speed study is conducted in response to citizen complaints, it is useful if the time period selected for the study reflects the nature of the complaints.

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.

Sample Size for Spot Speed Studies

The calculated mean (or average) 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. The larger the sample size, the greater the probability that the estimated mean is not significantly different from the true mean.

It is therefore necessary to select a sample size that will give an estimated mean within acceptable error limits.

Statistical procedures are used to determine this minimum sample size.

Average Speed

Average speed is the arithmetic mean of all observed vehicle speeds (which is the sum of all spot speeds divided by the number of recorded speeds). It is given as

$$\bar{u} = \frac{\sum fiui}{\sum fi}$$

Where

$\bar{u}$ =arithmetic mean

f_i =number of observations in each speed group

u_i =mid value for the i_{th} speed group

N=number of observed values

Average Speed

The formula also can be written as

$$\bar{u} = \frac{\sum ui}{N}$$

where

u_i =speed of the i_{th} vehicle

N=number of observed values

Median, Modal, The i_{th} percentile Spot Speed

2. Median Speed is the speed at the middle value in a series of spot speeds that are arranged in ascending order. 50 percent of the speed values will be greater than the median; 50 percent will be less than the median.

3. Modal Speed is the speed value that occurs most frequently in a sample of spot speeds.

4. The i_{th} percentile Spot Speed is the spot speed value below which i percent of the vehicles travel; for example, 85th-percentile spot speed is the speed below which 85 percent of the vehicles travel and above which 15 percent of the vehicles travel.

Pace

5. Pace is the range of speed—usually taken at 10-mi/h intervals-that has the greatest number of observations.

For example, if a set of speed data includes speeds between 30 and 60 mi/h, the speed intervals will be 30 to 40 mi/h, 40 to 50 mi/h, and 50 to 60 mi/h, assuming a range of 10 mi/h.

The pace is 40 to 50 mi/h if this range of speed has the highest number of observations.

Standard Deviation of Speeds

Standard Deviation of Speeds which is a measure of the spread of the individual speeds. It is estimated as

$$S=\sqrt{\frac{\sum(uj-\overline{u})^2}{N-1}}$$

where

S= standard deviation

$\bar{u}$ = arithmetic mean

u_j =jth observation

N=number of observations

Standard Deviation of Speeds

However, speed data are frequently presented in classes where each class consists of a range of speeds. The standard deviation is computed for such cases as

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

where

u_i =mid value of speed class i

f_i =frequency of speed class i

Standard Deviation of Speeds

The basic assumption made in determining the minimum sample size for speed studies is that the normal distribution describes the speed distribution over a given section of highway. The normal distribution is given as

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2} \text{ for } -\infty < x < \infty$$

μ = true mean of the population

σ = true standard deviation

σ^2=true variance

The properties of the normal distribution are then used to determine the minimum sample size for an acceptable error d of the estimated speed.

Properties

1. **The normal distribution is symmetrical about the mean.**

2. The total area under the normal distribution curve is equal to 1 or 100%.

3. The area under the curve between μ+ σ and μ- σ is 0.6827.

4. The area under the curve between μ+ σ 1.96μ and μ- 1.96 σ is 0.9500.

5. The area under the curve between μ+ 2σ and μ- 2σ is 0.9545.

6. The area under the curve between μ+ 3σ and μ-3σ is 0.9971.

7. The area under the curve between μ+ ∞and μ- ∞ is 1.0000.

Properties

The last five properties are used to draw specific conclusions about speed data. For example, if it can be assumed that the true mean of the speeds in a section of highway is 50 mi/h and the true standard deviation is 4.5 mi/h, it can be concluded that95 percent of all vehicle speeds will be between (50 - 1.96×4.5)=41.2 mi/h and (50+1.96×4.5)=58.8 mi/h. Similarly, if a vehicle is selected at random, there is a 95 percent chance that its speed is between 41.2 and 58.8 mi/h. The properties of the normal distribution have been used to develop an equation relating the sample size to the number of standard variations corresponding to a particular confidence level, the limits of tolerable error, and the standard deviation.

The formula is

$$N=\left(\frac{Z\sigma}{d}\right)^2$$

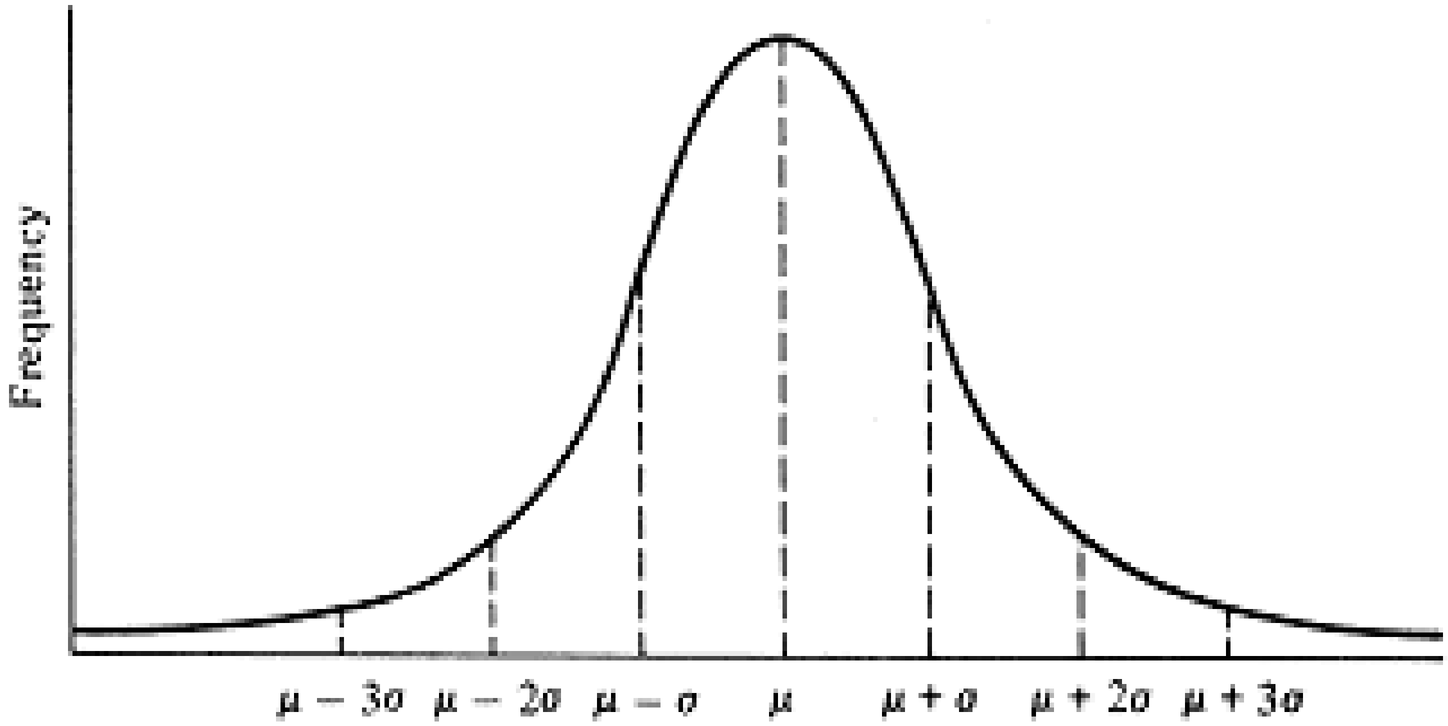
N=minimum sample size

Z=number of standard deviations corresponding to the required confidence level 1.96 for 95 percent confidence level (Table)

σ=standard deviation (mi/h)

d=limit of acceptable error in the average speed estimate (mi/h)

Shape of the Normal Distribution



Constant Corresponding to Level of Confidence

Confidence Level (%)	Constant Z
68.3	1.00
86.6	1.50
90.0	1.64
95.0	1.96
95.5	2.00
98.8	2.50
99.0	2.58
99.7	3.00

Problem

As part of a class project, a group of students collected a total of 120 spot speed samples at a location and determined from this data that the standard variation of the speeds was $\pm$ 6 mi/h. If the project required that the confidence level be 95% and the limit of acceptable error was $\pm$1.5 mi/h, determine whether these students satisfied the project requirement.

Solution

Use Eq. to determine the minimum sample size to satisfy the project requirements.

$$N=(\frac{Z\sigma}{d})^2$$

where

Z=1.96 (from Table)

$\sigma = \pm 6$

d= 1.5

$$N=(\frac{1.96\times 6}{1.5})^2=61.45$$

Solution

Therefore, the minimum number of spot speeds collected to satisfy the project requirement is 62.

Since the students collected 120 samples, they satisfied the project requirements.

Methods for Conducting Spot Speed Studies

The methods used for conducting spot speed studies can generally be divided into two main categories: manual and automatic.

Several automatic devices that can be used to obtain the instantaneous speeds of vehicles at a location on a highway are now available on the market. These automatic devices can be grouped into three main categories:

(1) those that use road detectors,

(2) those that are radar-based, and

(3) those that use the principles of electronics.

Road Detectors

Road detectors can be classified into two general categories: pneumatic road tubes and induction loops. These devices can be used to collect data on speeds at the same time as volume data are being collected. When road detectors are used to measure speed, they should be laid such that the probability of a passing vehicle closing the connection of the meter during a speed measurement is reduced to a minimum. This is achieved by separating the road detectors by a distance of 3 to 15 ft.

The advantage of the detector meters is that human errors are considerably reduced.

The disadvantages are that

(1) these devices tend to be rather expensive and

(2) when pneumatic tubes are used, they are rather conspicuous and may, therefore, affect driver behaviour, resulting in a distortion of the speed distribution.

Pneumatic road tubes

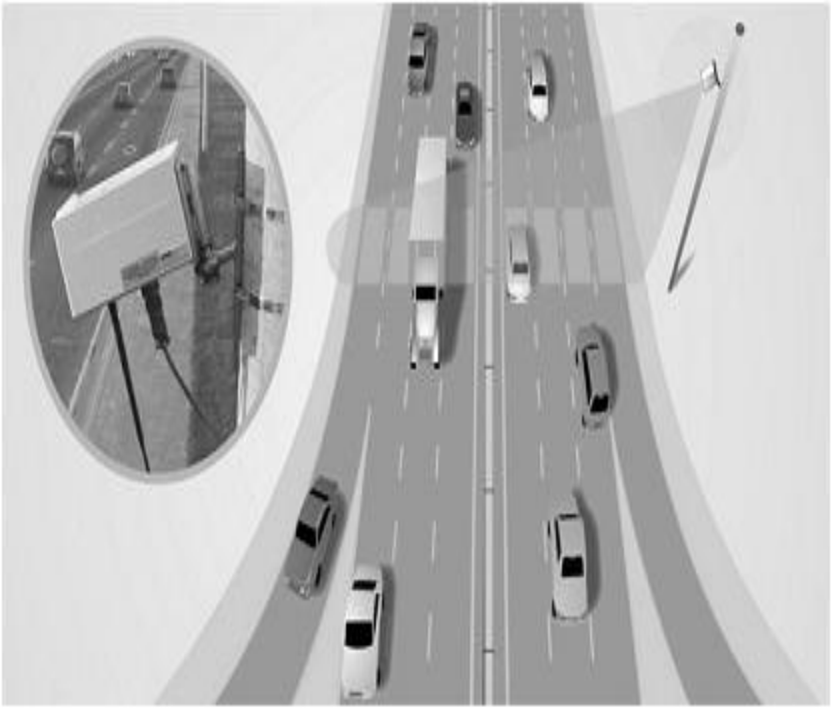
Pneumatic road tubes are laid across the lane in which data are to be collected. When a moving vehicle passes over the tube, an air impulse is transmitted through the tube to the counter. When used for speed measurements, two tubes are placed across the lane, usually about 6 ft apart. An impulse is recorded when the front wheels of a moving vehicle pass over the first tube; shortly afterward a second impulse is recorded when the front wheels pass over the second tube. The time elapsed between the two impulses and the distance between the tubes are used to compute the speed of the vehicle.

Inductive loop

An inductive loop is a rectangular wire loop buried under the roadway surface. It usually serves as the detector of a resonant circuit. It operates on the principle that a disturbance in the electrical field is created when a motor vehicle passes across it. This causes a change in potential that is amplified, resulting in an impulse being sent to the counter.

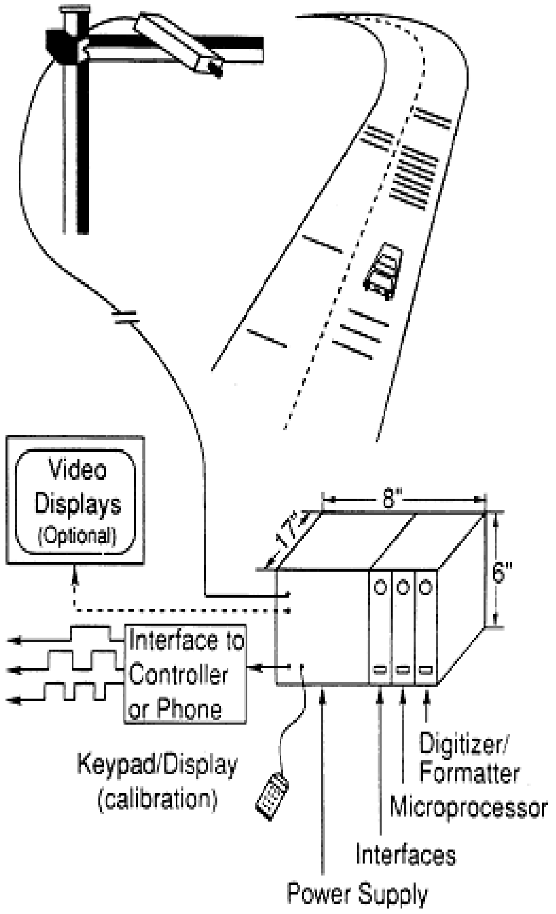
Radar-Based Traffic Sensors

Radar-based traffic sensors work on the principle that when a signal is transmitted onto a moving vehicle, the change in frequency between the transmitted signal and the reflected signal is proportional to the speed of the moving vehicle. The difference between the frequency of the transmitted signal and that of the reflected signal is measured by the equipment and then converted to speed in mi/h. In setting up the equipment, care must be taken to reduce the angle between the direction of the moving vehicle and the line joining the cent of the transmitter and the vehicle. The value of the speed recorded depends on that angle. If the angle is not zero, an error related to the cosine of that angle is introduced, resulting in a lower speed than that which would have been recorded if the angle had been zero. However, this error is not very large, because the cosines of small angles are not much less than one. The advantage of this method is that because pneumatic tubes are not used, if the equipment can be located at an inconspicuous position, the influence on driver behaviour is considerably reduced.



Electronic-Principle Detectors

Electronic-Principle Detectors In this method, the presence of vehicles is detected through electronic means, and Information on these vehicles is obtained, from which traffic characteristics, such as speed, volume, queues, and headways are computed. The great advantage of this method over the use of road detectors is that it is not necessary to physically install loops or any other type of detector on the road. A technology using electronics is video image processing, sometimes referred to as a machine-vision system. This system consists of an electronic camera overlooking a large section of the roadway and a microprocessor. The electronic camera receives the images from the road; the microprocessor determines the vehicle's presence or passage. This information is then used to determine the traffic characteristics in real time. One such system is the autoscope.



Presentation and Analysis of Spot Speed Data

The data collected in spot speed studies are usually taken only from a sample of vehicles using the section of the highway on which the study is conducted, but these data are used to determine the speed characteristics of the whole population of vehicles traveling on the study site. It is therefore necessary to use statistical methods in analyzing these data. Several characteristics are usually determined from the analysis of the data. Some of them can be calculated directly from the data; others can be deter-mined from a graphical representation. Thus, the data must be presented in a form suitable for specific analysis to be carried out.

Presentation and Analysis of Spot Speed Data

The presentation format most commonly used is the frequency distribution table. The first step in the preparation of a frequency distribution table is the selection of the number of classes-that is, the number of velocity ranges-into which the data are to be fitted.

The number of classes chosen is usually between 8 and 20, depending on the data collected. One technique that can be used to determine the number of classes is to first determine the range for a class size of 8 and then for a class size of 20.

Finding the difference between the maximum and minimum speeds in the data and dividing this number first by 8 and then by 20 gives the maximum and minimum ranges in each class. A convenient range for each class is then selected and the number of classes determined. Usually the mid value of each class range is taken as the speed value for that class. The data also can be presented in the form of a frequency histogram, or as a cumulative frequency distribution curve. The frequency histogram is a chart showing the mid value for each class as the abscissa and the observed frequency for the corresponding class as the ordinate. The frequency distribution curve shows a plot of the frequency cumulative percentage against the upper limit of each corresponding speed class.

Problem

Table-1 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

6. The 85th-percentile speed

Table-1

Car No.	Speed (mi/h)	Car No.	Speed (mi/h)	Car No.	Speed (mi/h)	Car No.	Speed (mi/h)
1	35.1	23	46.1	45	47.8	67	56.0
2	44.0	24	54.2	46	47.1	68	49.1
3	45.8	25	52.3	47	34.8	69	49.2
4	44.3	26	57.3	48	52.4	70	56.4
5	36.3	27	46.8	49	49.1	71	48.5
6	54.0	28	57.8	50	37.1	72	45.4
7	42.1	29	36.8	51	65.0	73	48.6
8	50.1	30	55.8	52	49.5	74	52.0
9	51.8	31	43.3	53	52.2	75	49.8
10	50.8	32	55.3	54	48.4	76	63.4
11	38.3	33	39.0	55	42.8	77	60.1
12	44.6	34	53.7	56	49.5	78	48.8
13	45.2	35	40.8	57	48.6	79	52.1
14	41.1	36	54.5	58	41.2	80	48.7
15	55.1	37	51.6	59	48.0	81	61.8
16	50.2	38	51.7	60	58.0	82	56.6
17	54.3	39	50.3	61	49.0	83	48.2
18	45.4	40	59.8	62	41.8	84	62.1
19	55.2	41	40.3	63	48.3	85	53.3
20	45.7	42	55.1	64	45.9	86	53.4
21	54.1	43	45.0	65	44.7		
22	54.0	44	48.3	66	49.5		

Solution

The speeds range from 34.8 to 65.0 mi/h, giving a speed range of 30.2.
Choosing a range of 2 mi/h per class will give 16 classes.

A frequency distribution table can then be prepared, as shown in Table 2.

Frequency Distribution Table (2)

The speed classes are listed in column 1 and the mid values are in column 2. The number of observations for each class is listed in column 3; the cumulative percentages of all observations are listed in column 6.

1	2	3	4	5	6	7
Speed Class (mi/hr)	Class Midvalue, u_i	Class Frequency (Number of Observations in Class), f_i	$f_i u_i$	Percentage of Observations in Class	Cumulative Percentage of All Observations	$f_i(u_i - \bar{u})^2$
34–35.9	35.0	2	70	2.3	2.30	420.5
36–37.9	37.0	3	111	3.5	5.80	468.75
38–39.9	39.0	2	78	2.3	8.10	220.50
40–41.9	41.0	5	205	5.8	13.90	361.25
42–43.9	43.0	3	129	3.5	17.40	126.75
44–45.9	45.0	11	495	12.8	30.20	222.75
46–47.9	47.0	4	188	4.7	34.90	25.00
48–49.9	49.0	18	882	21.0	55.90	9.0
50–51.9	51.0	7	357	8.1	64.0	15.75
52–53.9	53.0	8	424	9.3	73.3	98.00
54–55.9	55.0	11	605	12.8	86.1	332.75
56–57.9	57.0	5	285	5.8	91.9	281.25
58–59.9	59.0	2	118	2.3	94.2	180.50
60–61.9	61.0	2	122	2.3	96.5	264.50
62–63.9	63.0	2	126	2.3	98.8	364.50
64–65.9	65.0	1	65	1.2	100.0	240.25
Totals		86	4260			3632.00

Figure-1: Histogram of Observed Vehicles' Speeds

Figure 1 shows the frequency histogram for the data shown in Table 2. The values in columns 2 and 3 of Table 2 are used to draw the frequency histogram, where the abscissa represents the speeds and the ordinate the observed frequency in each class.

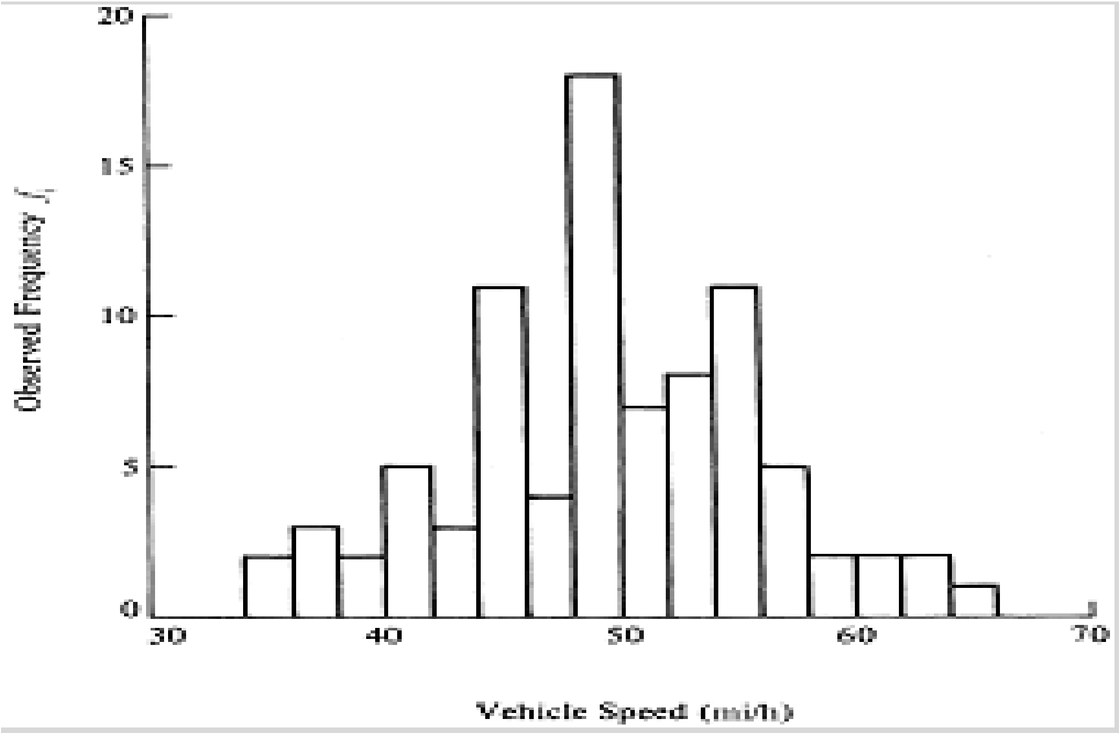


Figure-2:Frequency Distribution

Figure 2 shows the frequency distribution curve for the data given. In this case, a curve showing percentage of observations against speed is drawn by plotting values from column 5 of Table 2 against the corresponding values in column 2. The total area under this curve is one or 100 percent.

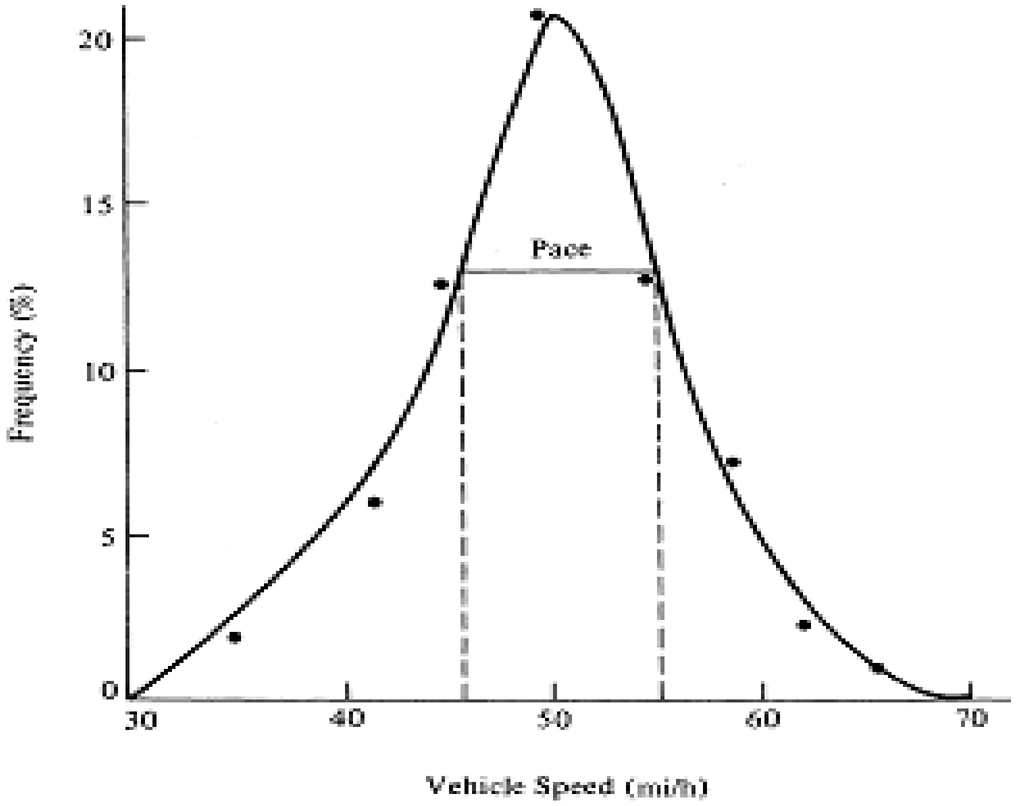
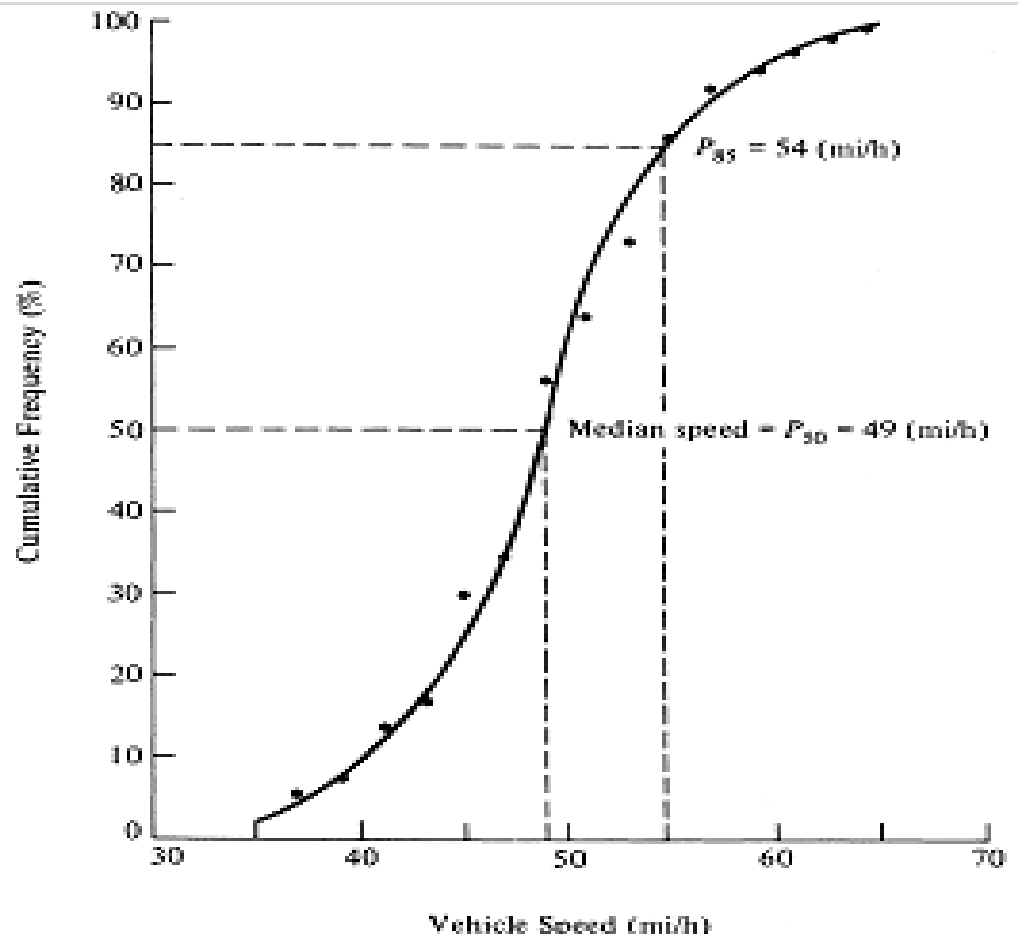


Figure 3: Cumulative Distribution

Figure 3 shows the cumulative frequency distribution curve for the data given. In this case, the cumulative percentages in column 6 of Table 2 are plotted against the upper limit of each corresponding speed class. This curve, therefore, gives the percentage of vehicles that are traveling at or below a given speed.



The arithmetic mean speed is computed from Eq.

$$\bar{u} = \frac{\sum fiui}{\sum fi}$$

$$\sum fi = 86$$

$$\sum fiui = 4260$$

$$\bar{u} = \frac{4260}{86} = 49.5 \text{mi/h.}$$

The standard deviation is computed from Eq.

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

$$\sum fi(ui-\overline{u})^2=3632$$

$$(N-1)=\sum fi-1=85$$

$$S^2=\frac{3632}{85}=42.73$$

$$S=\pm 6.5mi/h$$

- **The median speed is obtained from the cumulative frequency distribution curve (Figure 3) as 49 mi/h, the 50th-percentile speed.**
- **The pace is obtained from the frequency distribution curve (Figure 2) as 45 to 55 mi/h.**
- **The mode or modal speed is obtained from the frequency histogram as 49 mi/h (Figure 1). It also may be obtained from the frequency distribution curve shown in Figure 2, where the speed corresponding to the highest point on the curve is taken as an estimate of the modal speed.**
- **85th-percentile speed is obtained from the cumulative frequency distribution curve as 54 mi/h (Figure 3).**