Spot Speed Studies

Introduction

- Speed data is needed for a variety of traffic analyses.
- Spot speed data refers to measurement of individual speeds of vehicles passing a point on a roadway.
- Care must be taken to conduct the study appropriately so that the sample data will adequately reflect speed characteristics of the population.

Dynamic Studies/ 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.
- Speed: the rate of movement of a vehicle (mi/h) or (km/h).
- Carried out by recording the speeds of samples of vehicles at specified location.
- Speed characteristics will be valid only for the traffic and of environment conditions that exist at the time of the study.

Location for Spot Speed Studies

Depends on the anticipated use of the results and include:

1. Locations that represent different traffic conditions on highways: used for basic data collection.
2. Midblock for urban highways and straight level sections of rural highways: used for speed trend analysis.
3. Any location can be used for the solution of a specific traffic engineering problem.

Unbiased data should be obtain which require that:

4. Drivers should be unaware of the study being conducted.
5. Equipment's (radars) are concealed from drivers.
6. Observers conducting the study should be inconspicuous.
7. Statistically adequate number of vehicle speeds be recorded.

Time of Day and Duration of Spot Speed Studies

- Time of day for conducting a speed study depends on the purpose of the study.
- When purpose is to establish posted speed limits, observe speed trends, or collect basic data: It is recommended to conduct the study when traffic is free-flowing (i.e. Off-peak hours).

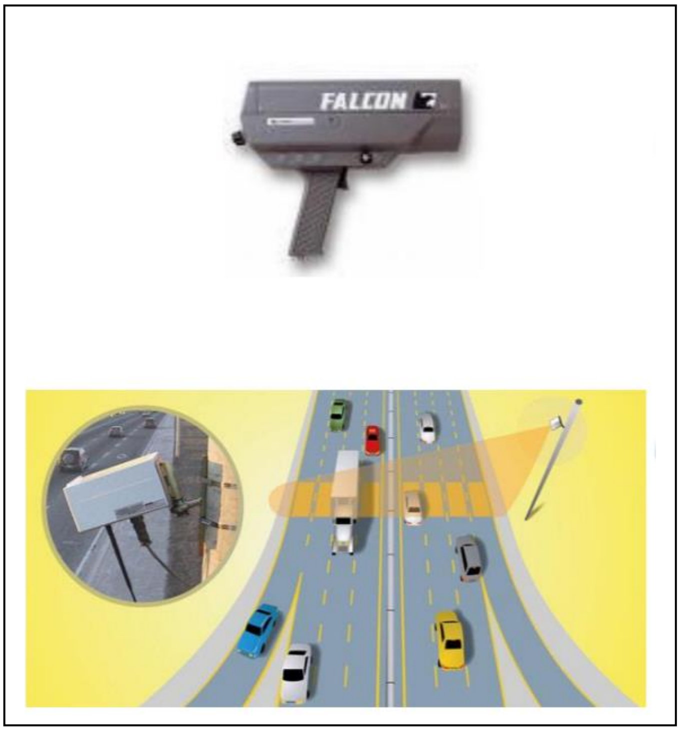
- When speed study is conducted in response to citizen complaints: It is useful if the time period selected reflect the nature of the complaints.
- Duration of the study should be such that the minimum number of vehicle speeds required for statistical analysis is recorded.
- Duration is typically at least 1 hour and the sample size is at least 30 vehicles.

***Spot Speed Studies used for*:**

- Monitoring speed trends
- Establishing traffic operation and control parameters
- Establishing highway design elements
- Evaluating highway capacity
- Assessing highway safety
- Measuring effectiveness of changes

Parameters of Interest:

- Median spot speed
- Mean spot speed
- Modal spot speed
- Pace – 10 mi/hr increment in speed in which the higher percentage of drivers is observed
- 85th percentile speed
- Standard Deviation



Data Collection

Individual vehicle

- Manual
- Radar
- Video

All-vehicle sampling

- Road detectors
- Radar-based traffic sensors
- Electronic-principle detectors

Study Considerations

- Select roadway section with typical travel speed;
- Unless a specific requirement of the speed study, make an attempt to avoid the following, primarily to avoid accelerating/decelerating vehicles:
  - Traffic signals and other junctions
  - Intersections
  - Work zones
  - Curves
  - Parking zones
  - Active crosswalks
- Consider free flow vehicles only (those not impacted by speed of preceding vehicle, such as the first vehicle in a platoon)

- Consider date and time
  - Typical weekdays (Tues., Wed., Thur.) preferred
- Avoid unusual conditions, including:
  - Unique events
  - Inclement weather
  - Holidays
- If using Radar, consider:
  - the angle of measurement to assure accurate speeds
  - remain inconspicuous so as not to influence speeds

Spot Speed Study Analysis

- Data reduction (tabular and graphical presentation)
- Descriptive statistics (mean, median, mode, standard deviation, pace, etc.)
- Statistical inference (do significant differences exist between mean speeds for different conditions, etc.)
- A sample size of 100 veh per lane is acceptable for most circumstances
- Frequency distribution
- Cumulative frequency distribution
- Indicate central tendency and dispersion
- Evaluation depends on whether or not individual speeds or speed classes collected

Date: MM/DD/YY
Name: John Doe
Location: 6th Street and Main Street
Speed Limit: 35 mph

Start Time: 0700
End Time: 0725
Down Time: N.A.
Weather: Clear

Speed	Passenger Vehicles		Buses		Trucks		Total
	Record	No.	Record	No.	Record	No.	
15							
16							
17							
18							
19							
20							
21	II	2					2
22					I	1	1
23	I	1			II	2	3
24	IIII	4					4
25	I	1					1
26	III	3					3
27	II	2			I	1	3
28	II	2					2
29	~~IIII~~	5	II	2			7
30	II	2			I	1	3
31	III	3					3
32	~~IIII~~	5					5
33	III	3					3
34	III	3	I	1	I	1	5
35	~~IIII~~ I	6			II	2	8
36	~~IIII~~ I	6					6
37	~~IIII~~ I	6			II	2	8
38	IIII	4					4
39	~~IIII~~ I	6					6
40	IIII	4					4
41	~~IIII~~	5			II	2	7
42	III	3					3
43	II	2					2
44	IIII	4					4
45	II	2					2
46							
47	I	1					1
48							
49							
50							
Total							100

Uninterrupted Flow Conditions

- Sample Mean

$$\bar{\mu} = \frac{\sum_{i=1}^{N} \mu_i}{N}$$

- Sample Standard Deviation

$$s^2 = \frac{\sum_{i=1}^{N}(\mu_i - \bar{\mu})^2}{N-1}$$

Where,
μ: Sample mean speed, mph
μ_i: Speed of vehicle i, mph
N: Total number of speed observations
s^2: Sample variance
s: Sample standard deviation

- Grouped Observations

$$\bar{\mu} = \frac{\sum_{i=1}^{g} f_i \mu_i}{N-1}$$

- Sample Standard Deviation

$$s^2 = \frac{\sum_{i=1}^{g} f_i(\mu^2) - \frac{1}{N}\left(\sum_{i=1}^{g} f_i \mu_i\right)^2}{N-1}$$

Where,
μ: Sample mean speed, mph
μ_i: Speed of vehicle i, mph
N: Total number of speed observations
s^2: Sample variance
s: Sample standard deviation
f_i: Number of observations in speed group I
g: Number of speed groups

Descriptive Statistics

Common descriptive statistics may be computed from the data in the frequency distribution table or determined graphically from the frequency and cumulative frequency distribution curves. These statistics are used to describe two important characteristics of the distribution:

Central tendency-measures that describe the approximate middle or center of the distribution.

Dispersion-measures that describe the extent to which data spreads around the center of the distribution.
Measures of central tendency include the average or mean speed, the median speed, the modal speed, and the pace. Measures of dispersion include the 85th and 15th percentile speeds and the standard deviation.

Significant Values That Describe Speed Characteristics

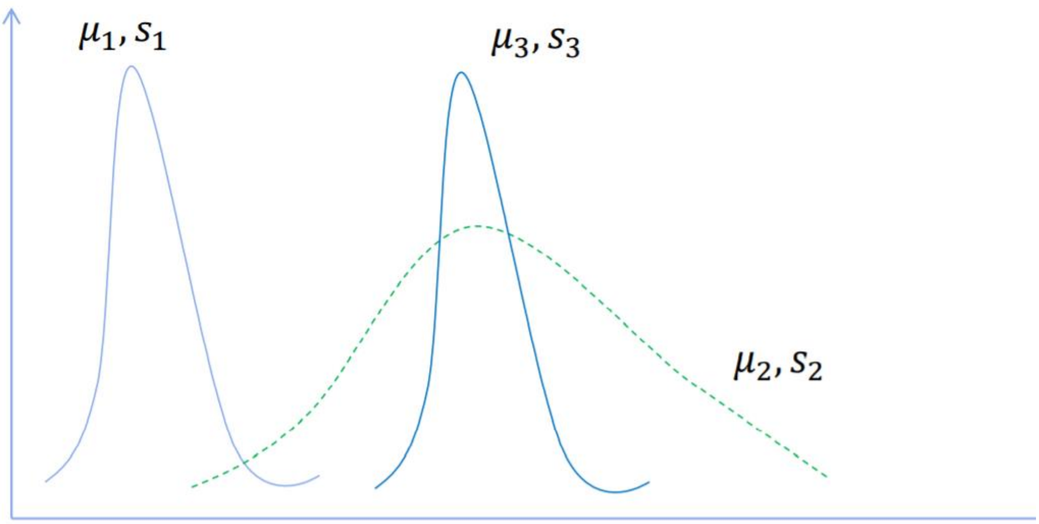
1. **Average Speed**: Arithmetic mean of all observed vehicle speeds at that location (Sum of all spot speeds divided by the number of recorded speeds).
$$\bar{\mu} = \frac{\sum_{i=1}^{N} \mu_i}{N}$$
2. **Median Speed**: the speed at the middle value in a series of spot speeds that are arranged in ascending order. 50% of the speed values will be greater than the median and 50% will be less than the median.
3. **Modal Speed**: The speed value that occur most frequently in a sample of spot speeds.
4. **The ith percentile spot speed**: The speed value below which i percent of the vehicles travel.
5. **Pace**: The range of speed (usually 10 mi/h interval) that has the greatest number of observations.
6. **Standard deviation of speeds**: A measure of the spread of the individual speeds.
$$s^2 = \frac{\sum_{i=1}^{g} f_i(\mu^2) - \frac{1}{N}\left(\sum_{i=1}^{g} f_i\mu_i\right)^2}{N-1}$$

Statistical inference

- ❖ Most speed data tends to follow normal distribution
- ❖ This can be evaluated using chi-square test for goodness of fit
- ❖ If the data is normally distributed, confidence intervals may be determined, and required sample sizes may be estimated

Normal Distribution

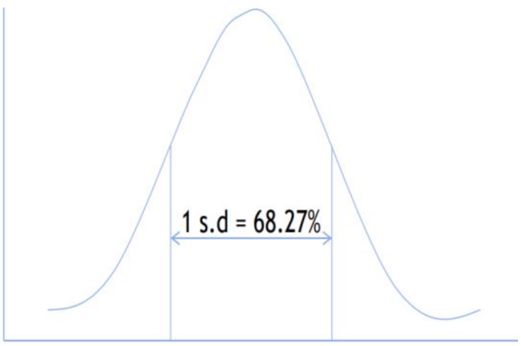
- A unique normal distribution is defined when mean and standard deviation are specified
- The normal distribution is
    - Symmetrical about the mean
    - Dispersion is a function of the standard deviation



$s_1 = s_2, but\ \mu_1 < \mu_2$
$\mu_2 = \mu_3$, but $s_2 < s_3$

The dispersion is such that:

- 68.27% of observations will be within 1 s.d
- 95.45% of observations will be within 2 s.d
- 99.73% of observations will be within 3 s.d



Two Issues with Normal Distribution

- Issue-1: Sample mean and sample s.d are known for most studies; population mean and population standard deviation are very difficult to estimate.
- Issue-2: Estimating population s.d from the sample s.d is even more complex.

Sample Size

- The relationship between sample and population is N
- As N increases to infinite, then sample s.d is equivalent to population s.d
- In practice it is found that
    - If N>30, then sample s.d = mean s.d
    - If N<30 then t-distribution rather than normal distribution is used.

Question

What is the probability of individual speeds between 35 and 40 mph?

$$\left(\frac{x}{\sigma}\right)_{35\rightarrow 52.3} = \frac{52.3 - 35}{6.3} = 2.75$$

$$\left(\frac{x}{\sigma}\right)_{40\rightarrow 52.3} = \frac{52.3 - 40}{6.3} = 1.95$$

- ✓ Probability value for 2.75, = 0.4970
- ✓ Probability value for 1.95, = 0.4744
- ✓ Probability of speed between 35 and 40 = 0.4970- 0.4744 = 0.0226
- ✓ With sample size of 200, the expected frequency is 0.0226*200 = 4 or 5

Evaluation of Selected Mathematical Distribution

Rule-1: The variance of measured speed distribution normally should be less than the variance of a random distribution (i.e. poisson)

s^2=6.3^2 = 39.3 mph

s^2 r= m = 52.3 mph

$s^2 < s^2_r$

Rule-2: The s.d should be approximately 1/6th of total range since plus or minus 3 s.d encompasses 99.73% of the observations of a normal distribution

s_{est} = total range/6 = 32/6 = 5.3 mph

$s \sim s_{est}$

Rule-3: The standard deviation should be approximately one half of the 15 to 85 percentage range

s_{est} = (15 – 85 percentile range) / 2

=12.3/2 = 6.15

s~ sest

Rule-4: The 10 mile per hour pace should be approximately equal to the sample mean
10 mile hour pace= 52 or 53
Mean = 52.3
Pace ~ Mean

Rule-5: The normal distribution has little skewness and the coefficient of skewness should be close to zero.
Coefficient of skewness = mean-mode/s
=52.3-53/6.3 = 0.1
Or
3[(mean-median)/s] = 3[(52.3-52.5)/6.3] =0.1

The numerical checks appear to support the assumption of a normal distribution.

Testing for Normality

Null Hypothesis: There is no statistical difference between the measured distribution and normal distribution.
Alternate Hypothesis: There exists statistical difference between the measured distribution and normal distribution.

Testing for Normalcy: The Chi-Square

Group the data and find the estimated frequency

Class Interval Limit	z	z/s	P	Pt	Ft
				0.0038	0.77
35.5	16.8	2.666667	0.4962	0.0104	2.08
38.5	13.8	2.190476	0.4858	0.0290	5.80
41.5	10.8	1.714286	0.4568	0.0646	12.92
44.5	7.8	1.238095	0.3922	0.1152	23.04
47.5	4.8	0.761905	0.2769	0.1645	32.90
50.5	1.8	0.285714	0.1125	0.1880	37.60
53.5	1.2	0.190476	0.0755	0.1720	34.40
56.5	4.2	0.666667	0.2475	0.1259	25.19
59.5	7.2	1.142857	0.3735	0.0738	14.77
62.5	10.2	1.619048	0.4473	0.0527	10.54

Class Interval Limit	f0	ft	f0-ft	(f0-ft)^2	[(f0-ft)^2]/ft
	4	0.766076			
35.5	2	2.082896			
38.5	4	5.798655	1.352373	1.828914	0.315403155
41.5	10	12.92045	-2.92045	8.529019	0.660117863
44.5	19	23.04361	-4.04361	16.35078	0.709558121
47.5	31	32.89801	-1.89801	3.602447	0.109503502
50.5	41	37.5967	3.403296	11.58242	0.308070208
53.5	40	34.39509	5.604908	31.41499	0.91335674
56.5	23	25.18872	-2.18872	4.79048	0.190183585
59.5	18	14.76609	3.233911	10.45818	0.708256568
62.5	8	10.5437	-2.5437	6.470419	0.61367619
				Sum	4.528125932

- χ 2 from the table for α = 0.05, and degrees of freedom=6; is 12.6
- Since χ 2 calculated is less than the table value, we fail to reject the hypothesis.
- The conclusion is
  - There is no statistical difference between the measured distribution and normal distribution.

Sample size

- $\mathbf{n = (\frac{ts}{\epsilon})^2}$

Where:
n > required sample size.
t- Coefficient of standard error that represents user specified probability level.
ϵ: user specified probable error – s: standard deviation.

Example
Table (2) 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 (2): Speed Data Obtained on Rural Highway.

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. For eight classes, the range per class is 3.75 mi/h; for 20 classes, the range per class is 1.51 mi/h. It is convenient to choose a range of 2 mi/h per class which will give 16 classes. A frequency distribution table can then be prepared, as shown in Table (3).

in which 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.

Table (3): Frequency Distribution Table for Set of Speed Data.

1 Speed Class (mi/hr)	2 Class Midvalue, u_i	3 Class Frequency (Number of Observations in Class), f_i	4 f_iu_i	5 Percentage of Observations in Class	6 Cumulative Percentage of All Observations	7 $f(u_i - \bar{u})^2$
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

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

Fig.4 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 (3) against the corresponding values in column 2. The total area under this curve is one or 100 percent.

Fig.5 shows the cumulative frequency distribution curve for the data given. In this case, the cumulative percentages in column 6 of Table (3) 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.

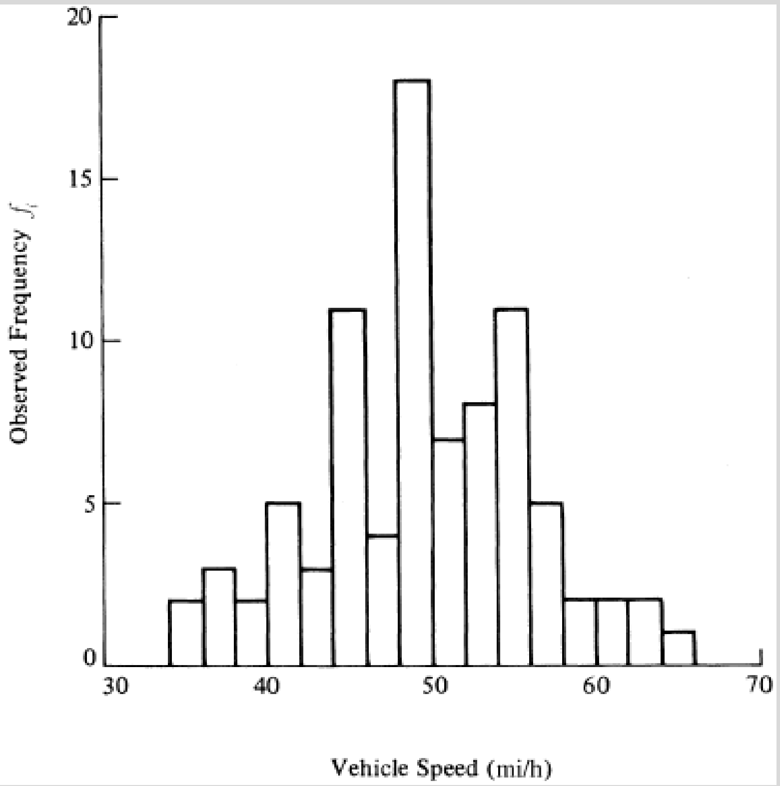


Fig.3 Histogram of Observed Vehicle Speed.

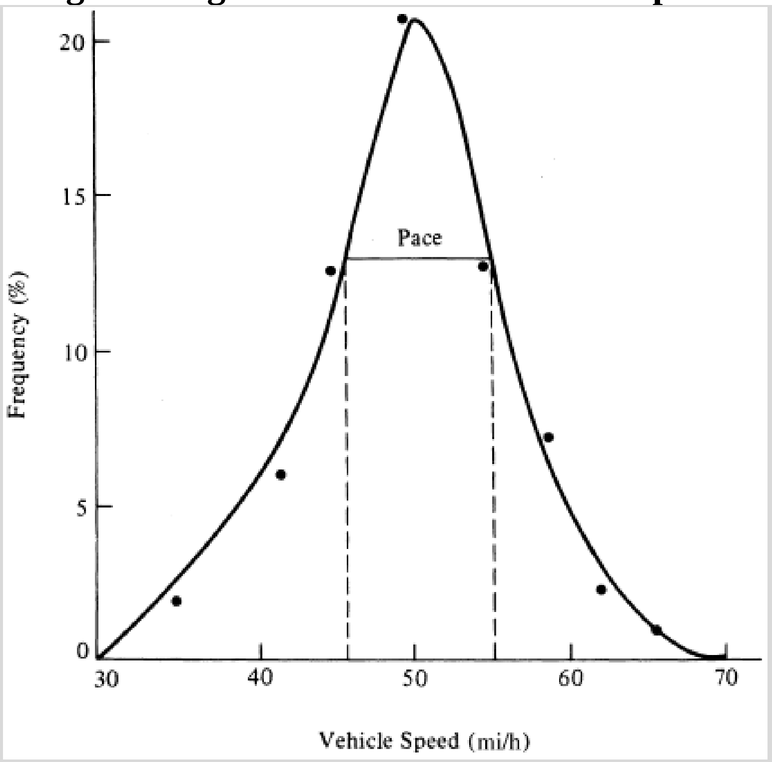


Fig.4 Frequency Distribution.

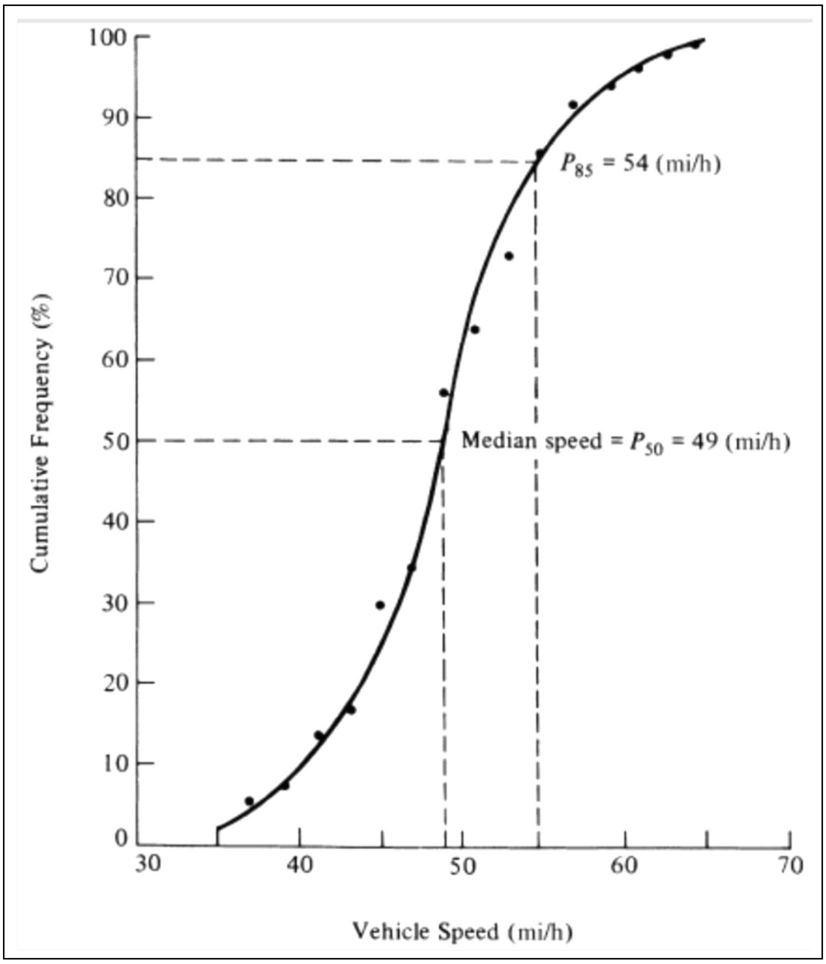


Fig.5 Cumulative Distribution.

$$\bar{u} = \frac{\sum f_i u_i}{\sum f_i}$$

$$\sum f_i = 86$$

$$\sum f_i u_i = 4260$$

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

$$S = \sqrt{\frac{\sum f_i (u_i - \bar{u})^2}{N - 1}}$$

$$\sum f_i (u_i - \bar{u})^2 = 3632$$

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

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

$$S = \pm 6.5 \text{ mi/h}$$

- The median speed is obtained from the cumulative frequency distribution curve (Fig. 5) as 49 mph, the 50th-percentile speed.
- The pace is obtained from the frequency distribution curve (Fig. 4) as 45 to 55 mph.

- The mode or modal speed is obtained from the frequency histogram as 49 mph (Fig. 3). It also may be obtained from the frequency distribution curve shown in Fig. 4, 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 mph (Fig. 5).

Example

Speed data were collected at a section of highway during and after utility maintenance work. The speed characteristics are given as, $\bar{u}_1$, S_1 and $\bar{u}_2$, S_2 as shown below. Determine whether there was any significant difference between the average speed at the 95% confidence level.

$$\bar{u}_1 = 35.5 \text{ mi/h} \qquad \bar{u}_2 = 38.7 \text{ mi/h}$$
$$S_1 = 7.5 \text{ mi/h} \qquad S_2 = 7.4 \text{ mi/h}$$
$$n_1 = 250 \qquad n_2 = 280$$

Solution:

$$S_d = \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}$$
$$= \sqrt{\frac{(7.5)^2}{250} + \frac{(7.4)^2}{280}} = 0.65$$

- Find the difference in means.

$$38.7 - 35.5 = 3.2 \text{ mi/h}$$
$$3.2 > (1.96)(0.65)$$
$$3.2 > 1.3 \text{mi/h}$$

It can be concluded that the difference in mean speeds is significant at the 95% confidence level.

Methods of Conducting Spot Speed Studies

- Two Methods available
  1. Manual: Seldom used
  2. Automatic: several automatic devices available to obtain instantaneous speed, which may be grouped into 3 categories:
     - Road detectors.
     - Doppler principle meters (Radars).
     - Devices that use principles of electronics.

Road Detectors

- Two groups:
  - Pneumatic road tubes.
  - Induction loops.
- These detectors can be used to collect data on speeds at the same time the volume data are being collected.
- They are laid with 3 to 15 ft distance between detectors
- Advantages: human errors are reduced.
- Disadvantages:
  - Expensive
  - When pneumatic tubes are used, they are conspicuous, which affect the driver behavior resulting in distortion of speed distribution.

Road Detectors/ Pneumatic Road Tubes

- Laid across the lane.
- When a 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 about 6 ft apart.
- Impulse recorded when front wheels passes over the first tube
- Shortly afterward a second impulse is recorded when the front wheel of the same car passes over the second tube.
- The time elapsed between the two impulses and the distance between the tubes are used to compute speed of the vehicle.

Road Detectors/ Inductive Loops

- Rectangular wire loop buried under the roadway surface.
- It 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 a cross it, which cause a change in potential that is amplified, resulting in an impulse being sent to the counter.

Doppler-Principle Meters (Radars)

- ☐ Works 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.
- ☐ Advantages: if equipment is located in In conspicuous position, the influence on driver behavior will be considerably reduced.
- ☐ Examples:
  - ■ Speed Ace Meter: pocket-sized, hand-held laser speed detection. Used to measure speed of individual vehicles at a range of up to 1312 ft.

  - ■ RTMS meter: multilane presence radar. Can be mounted on the side of the highway and obtain data on speeds of vehicles in up to 8 lanes separately.
- ☐ Example on such system is Autoscope.
- ☐ Autoscope developed in USA
- ☐ Autoscope: a wireless detector with a single camera that can replace many loops, thereby providing a wide area detection system.
- ☐ Advantage:
  - ■ Monitor many locations within the camera field of view. Location can be selected by user.
  - ■ Can be installed without disturbing traffic operations.
  - ■ Can extract traffic parameters like volume and queue length.