Chapter 2
Traffic Engineering Studies

AN-NAJAH NATIONAL UNIVERSITY
NABLUS, PALESTINE

Outline: Chapter 2

Traffic Studies

- The availability of wide transportation network with developed facilities is associated with several problems such as:
  - Highway-related accidents
  - Parking difficulties
  - Congestion
  - Delay
- To understand the extent, location characteristics of each problem, adequate information is necessary.

Traffic surveys and studies

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2.1 Spot Speed Studies

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Spot Speed Studies

- It is conducted to estimate the distribution of vehicle speeds in a stream of traffic at a particular location
- Speed: rate of movement of a vehicle (mi/h) or (km/h)

Radar

Cameras

- Identified speed characteristics is valid only for the traffic and environmental conditions that exist at the time of the study.

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Purpose of Spot Speed Studies

- Establish parameters for traffic operation and control
  - Speed zones, speed limit and passing restrictions
- Evaluate the effectiveness of traffic control devices,
  - variable message signs at work zones.
- Monitor the effect of speed enforcement programs
- Evaluate and or determine the adequacy of highway geometric characteristics
- 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.

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Spot Speed Studies

- **Location:** In general the following locations are used
  - Represent different traffic conditions on a highway
  - Mid-blocks of urban highways and straight, level sections of rural highways
  - Any location may be used for the solution of a specific traffic engineering problem.

Collected data should be unbiased

- **Time and Duration:** depend on the purpose of the study
  - Establish speed limits ⇨ **Off peak hours**

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Speed Characteristics

- **Average Speed**: the arithmetic mean of all vehicle speeds (that is, the sum of all spot speeds divided by the number of vehicles).

$$\bar{u} = \frac{\sum f_i u_i}{\sum f_i} \quad \text{or} \quad \bar{u} = \frac{\sum u_i}{N}$$

- **Median speed**: the representation of the middle value in a series of spot speeds that are arranged in ascending order.
- **Modal speed**: the value of speed that occurs most frequently in a sample of spot speeds

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Speed Characteristics

- **<u>The i^{th} percentile spot speed</u>**: the value of spot speed below which i^{th} percent of the vehicles travel.

- **<u>Pace</u>**: range of speed, usually taken at 10 mph intervals, that has the greatest number of observations.

- **<u>Standard deviation of speeds</u>**: a measure of the spread of the individual speeds

$$\boxed{S = \sqrt{\frac{\sum (u_j - \overline{u})^2}{N - 1}} \quad \textbf{or} \quad S = \sqrt{\frac{\sum f_i(u_i - \overline{u})^2}{N - 1}}}$$

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Speed Characteristics

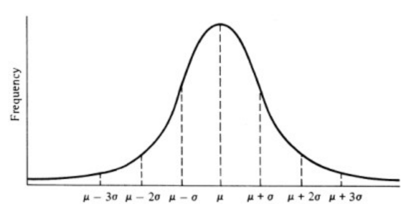
- **<u>Sample size</u>**: the minimum sample size depends on the precision level desired.
  - *Precision level*: the degree of confidence that the sampling error of a produced estimate will fall within a desired fixed range.
  - ***Level of significance (α) = 100 - Confidence level***

Commonly used confidence level for speed counts is 95%

  - Assuming that speeds follows normal:

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

Example 4.1



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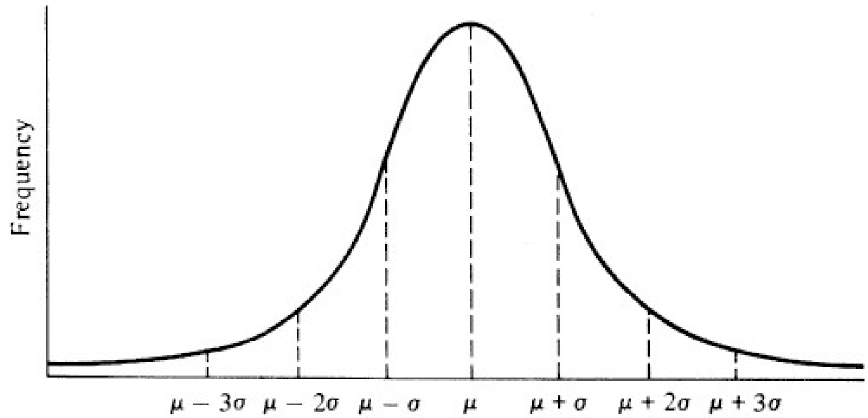

Figure 4.1 Shape of the Normal Distribution

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Table 4.1 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

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Table 4.2 Speed Data Obtained on a Rural Highway

Car No.	Speed (km/h)	Car No.	Speed (km/h)	Car No.	Speed (km/h)	Car No.	Speed (km/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		

Table 4.3 Frequency Distribution Table for Set of Speed Data

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

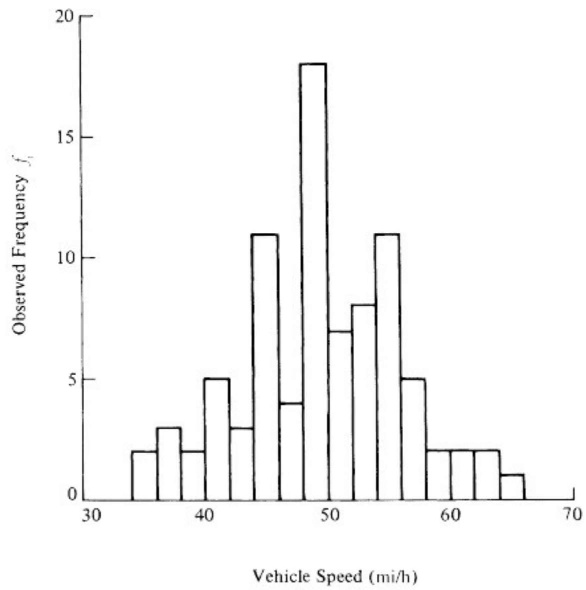


Figure 4.4 Histogram of Observed Vehicles' Speeds

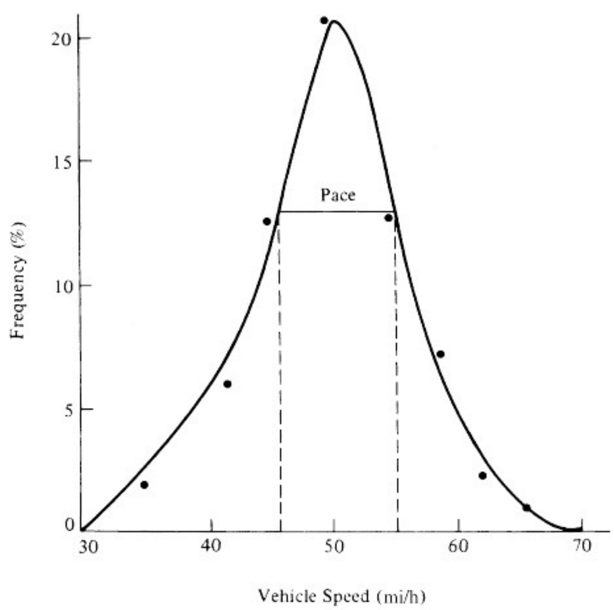


Figure 4.5 Frequency Distribution

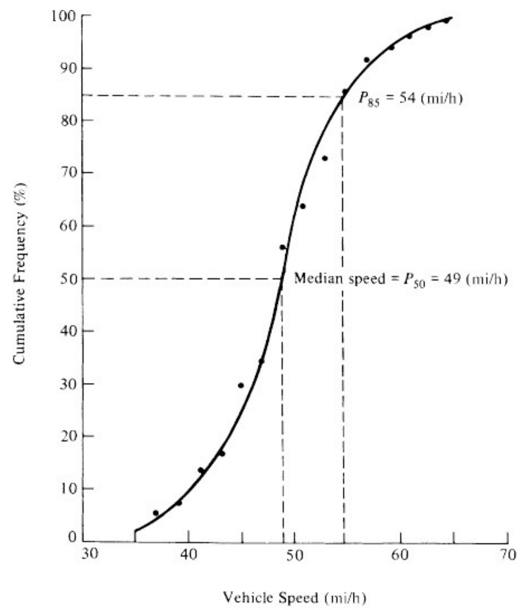


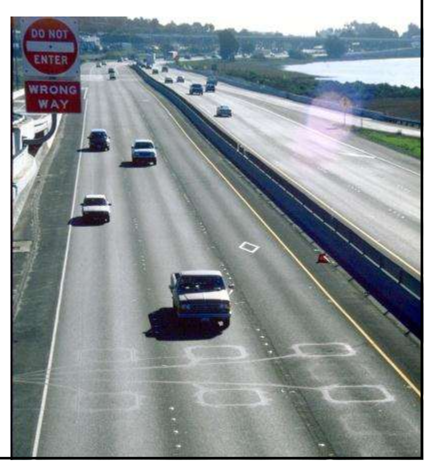
Figure 4.6 Cumulative Distribution

Methods of Conducting Spot Speed Studies

- Manual and Automatic
- Automatic devices can be grouped into three categories:

1. **Road Detectors:** Speed data can be collected and volume data as well.

   They are laid such that the probability of closing the connection of the meter by a passing vehicle during a speed measurement is reduced to a minimum
   Road detectors are usually separated by a distance of 1 to 5 meters



Methods of Conducting Spot Speed Studies

1. **Road Detectors:**
   - ***Pneumatic tubes:*** laid across the lane in which data are to be collected.
     - Air impulse
     - Two tubes are placed across the lane, usually about 6 ft apart
   - ***Induction loops:*** a rectangular wire loop buried under the roadway surface. It usually serves as the detector of a resonant circuit.

- When a motor vehicle passes across it, a disturbance in the electrical field is created.
- This results in an impulse being sent to the counter.

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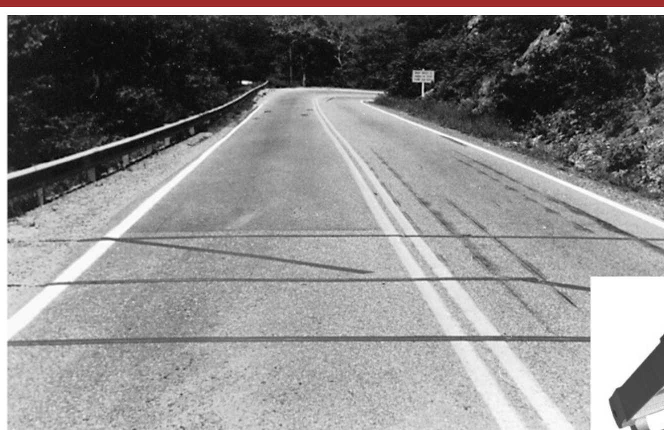

Figure 4.8 An Example of a Sensor Setup of a Surface Detector Using Pneuma

SOURCE: Photograph by Lewis Woodson, Virginia Transportation Research Council, Char

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Methods of Conducting Spot Speed Studies

2. Radar Based

- Difference between the frequency of the transmitted signal and that of the reflected signal is used to estimate vehicle speed
- Measurement accuracy dependents on the angle between vehicle direction and the line between the radar and the vehicle

  →→→ **underestimate the speed**

- Using radars at inconspicuous position, can significantly reduce the effects upon drivers .

Doppler Principle Meters

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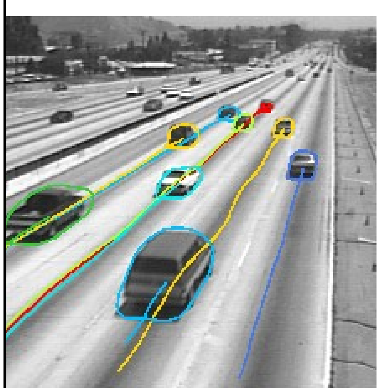
Methods of Conducting Spot Speed Studies

3. Those use the principles of electronics

- Video Image Processing or Machine Vision System
- Consists of: ① electronic camera covers large section of the roadway ② microprocessor



Autoscope

Presentation of Speed Data

- Histogram, Frequency distribution, Cumulative distribution
- Number of classes chosen is usually between 8 and 20
- To define class range calculate:

$$\frac{v_{\max} - v_{\min}}{8} \quad \text{and} \quad \frac{v_{\max} - v_{\min}}{20}$$

Choose a suitable range

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	$f(u_i - \bar{u})^2$
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
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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
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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

Example 4.2

Comparison of Mean Speeds

- To determine whether there is a significant difference between the mean speeds of two spot speed studies.

$$S_d = \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}$$

where

n_1 = sample size for study 1
n_2 = sample size for study 2
S_d = square root of the variance of the difference in means
S_1^2 = variance about the mean for study 1
S_2^2 = variance about the mean for study 2

$$|\bar{u}_1 - \bar{u}_2| > Z S_d$$

There is significant difference at the confidence level corresponding to Z

Example 4.3

- **Before:**
  - N = 100
  - U_{avg} = 67.4 km/hr
  - St. Dev. = 5.2 km/hr
- **After:**
  - N = 200
  - U_{avg} = 63.5 km/hr
  - St. Dev. = 7.1 km/hr

Example 4.3 Significant Differences in Average Spot Speeds

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:

- Use Eq. 4.6.

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

- 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.

2.2 Volume Studies

Volume Studies

- OBJECTIVE: collect data on the number of vehicles and/or pedestrians that pass a point on a highway facility during a specified time period.
  - 15 minutes up to a year depending on the purpose of the analysis.
- Estimated traffic volume characteristics are:

1. **A**verage **A**nnual **D**aily **T**raffic (**AADT)**: the average of 24-hour counts collected every day of the year. Used for:
   - Estimation of highway user revenues
   - Computation of crash rates
   - Evaluation of the economic feasibility of highway projects

Volume Studies

② **A**verage **D**aily **T**raffic (**ADT)**: average of 24-hour counts collected over a number of days greater than one but less than a year. Used for:

- Planning of highway activities
- Measurement of current demand
- Evaluation of existing traffic flow

③ **P**eak **H**our **V**olume (**PHV)**: the maximum number of vehicles that pass a point on a highway during a period of 60 consecutive minutes. Used for:

- Functional classification of highways
- Geometric design (number of lanes, signalization…etc)
- Capacity analysis
- Development of parking regulations

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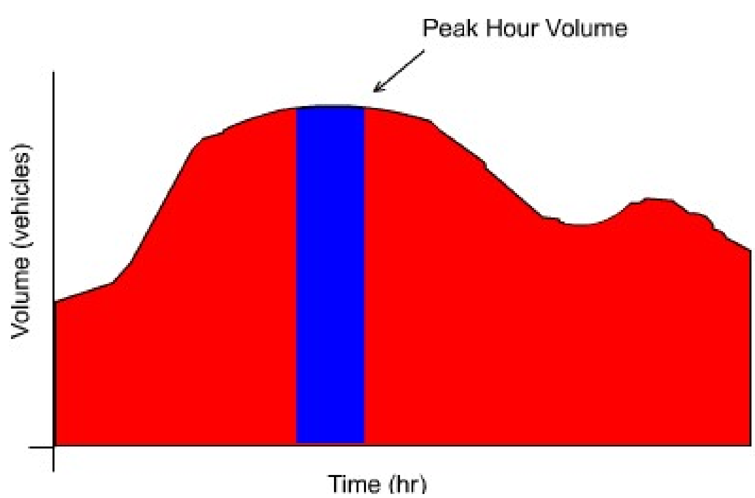
Volume Studies



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Designating Traffic Directions

- Northbound (NB): Traffic heading towards **North**
- Southbound (SB): Traffic heading towards **South**
- Eastbound (EB): Traffic heading towards **East**
- Westbound (WB): Traffic heading towards **West**

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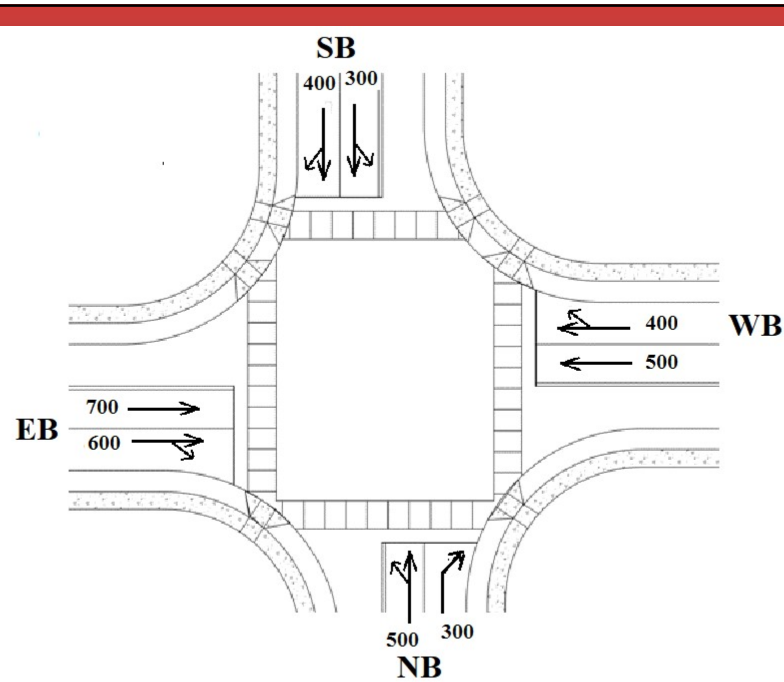

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Volume Studies

④ **Vehicle Classification (VC)**: recording volume with respect to the type of vehicles (PC, two-axle trucks, or three-axle trucks). Used for:

- Design of geometric characteristics (turning-radii requirements, maximum grades, lane widths, and so forth)
- Capacity analyses, passenger-car equivalents of trucks
- Adjustment of traffic counts obtained by machines
- Structural design of highway pavements, bridges, and so forth

⑤ **Vehicle Miles (Kilometer) of Travel (VMT / VKT)**: a measure of travel along a section of road.

- It is a base for allocating resources for maintenance and improvement of highway

$$\boxed{VMT = ADT * L}$$

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Methods of Conducting Volume Counts

- **Manual Method**: A person records each vehicle
  - Mechanical hand counter
  - Advanced electric manual counting devices

Figure 6.4 Electronic Manual Counter

Disadvantages:

- Labor intensive (expensive)
- Limitations of human factors
- Cannot be used for long periods of counting.

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Methods of Conducting Volume Counts

- **Automatic Method**: Classified into two categories
  - **Those that require the laying of detectors** (surface or subsurface)
    - such as pneumatic road tubes (surface) and magnetic or electric contact device (subsurface)
  - **Those that do not require the laying of detectors** it uses different technologies such as laser scanning and infrared.

Traffic Eye Universal System

Remote Traffic Microwave Sensor RTMS

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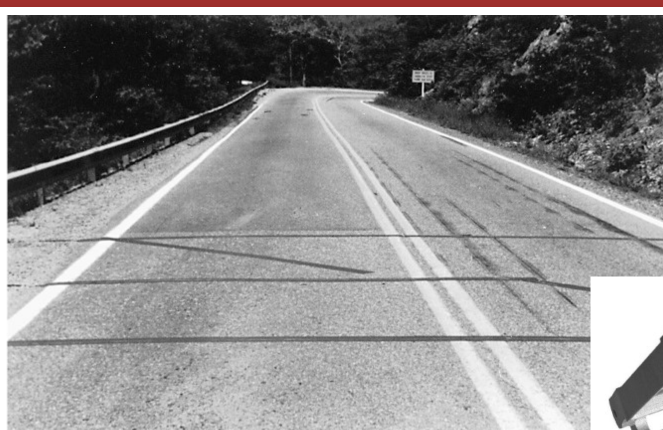

Figure 4.8 An Example of a Sensor Setup of a Surface Detector Using Pneuma

SOURCE: Photograph by Lewis Woodson, Virginia Transportation Research Council, Char

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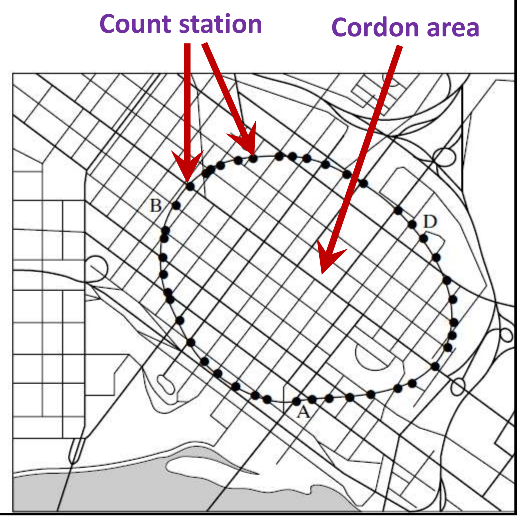
Types of Volume Counts

① **Cordon Counts:** When information is required within an area such as the central business district (CBD).

Useful for:

- Planning of parking facilities
- Updating and evaluating traffic operational techniques,
- Making long-range plans for freeway and arterial street systems.



Types of Volume Counts

② **Screen Line Counts**: the study area is divided into large sections by running imaginary lines (screen lines) across the study area. Used for:

- Screen lines might be natural and man-made barriers (rivers railway tracks)
- Screen lines are usually not crossed more than once by the same street.
- It facilitates the detection of variations in the traffic volume and traffic flow direction, due to changes in the land-use pattern of the area.

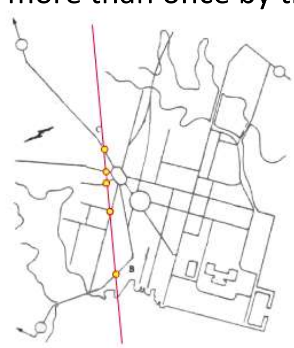
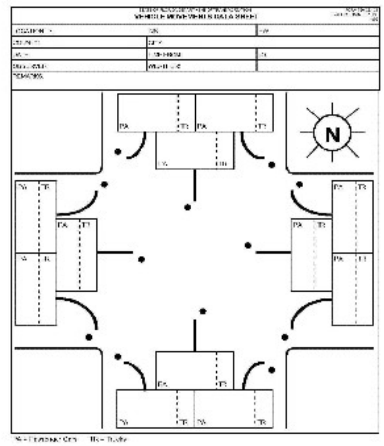


Figure 6.6 Station Locations for a Screen Line Count

Types of Volume Counts

③ **Intersection Counts**: to determine vehicle classification, through movements, and turning movements at intersections.

- Determining phase lengths and cycle times
- Design of channelization at intersections
- Design of general improvements to intersections.



Intersection Count Data Sheet

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Types of Volume Counts

④ **Pedestrian Volume Counts**: CBD sidewalk, mid-blocks, and cross walks.

- To evaluate existing or proposed pedestrian facilities are to be undertaken

⑤ **Periodic Volume Counts:** for duration ranging from <u>15 min to continuous</u>.

- It is not feasible to collect continuous data on all roads because of the cost involved.

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Types of Volume Counts

⑤ **Periodic Volume Counts:**

– ***Continuous Counts***: taken continuously using mechanical or electronic counters

✓**Permanent count stations**

✓Road classification is necessary for stations selection

✓A highway link is defined as a homogeneous section that has the same traffic characteristics, such as AADT and daily, weekly, and seasonal variations in traffic volumes.

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Types of Volume Counts

⑤ **Periodic Volume Counts:**

– ***Control Counts***: taken at stations known as **control-count stations**

✓Stations are strategically located so representative samples can be taken in an area-wide traffic counting program.

✓Used to determine seasonal and monthly variations of traffic characteristics so that expansion factors can be determined to estimate year-round average values.

✓Major control count: monthly, with 24-hour directional counts taken on at least three days a week on major roads

✓Minor control count: five-day weekday counts taken every other month

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Types of Volume Counts

⑤ **Periodic Volume Counts:**

– ***Coverage Counts***: used to estimate ADT, using expansion factors

✓Study area is usually divided into zones that have similar traffic characteristics.

✓At least one coverage station is located in each zone.

✓A 24-hour non-directional weekday count is taken at least once every four years at each coverage station.

✓The data indicate changes in area-wide traffic characteristics.

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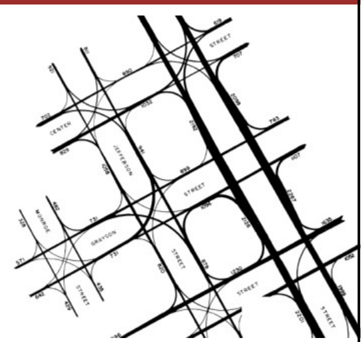
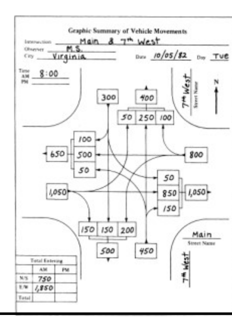
Traffic Volume Data Representation

- **Traffic Flow Map**
  - Traffic volumes on individual routes
  - Width of a band, which is drawn in proportion to the traffic volume



- **Intersection Summary Sheet**
  - Graphic representations of the volume and direction of all traffic movements.
  - These volumes can be either ADTs or PHVs.



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Intersection Summary Table

LOCATION:	Rafidia	CITY:	Nablus
Governorate	Nablus	DAY:	Tuesday
OBSERVER:	Traffic	DATE:	18/2/2024

TIME		NORTHBOUND				SOUTHBOUND				EASTBOUND				WESTBOUND				GRAND
FROM	TO	L	T	R	Total	L	T	R	Total	L	T	R	Total	L	T	R	Total	TOTAL
7:15 AM	7:30 AM	11	61	3	75	5	111	15	131	22	6	22	50	3	8	2	13	269
7:30 AM	7:45 AM	7	58	1	66	3	110	35	148	15	2	19	36	4	7	1	12	262
7:45 AM	8:00 AM	11	60	0	71	1	109	29	139	18	3	16	37	5	3	2	10	257
8:00 AM	8:15 AM	7	74	3	84	1	114	29	144	21	11	17	49	3	5	1	9	286
8:15 AM	8:30 AM	7	69	3	79	2	107	18	127	11	4	20	35	7	17	8	32	273
8:30 AM	8:45 AM	9	85	5	99	4	105	26	135	23	8	20	51	7	9	5	21	306
8:45 AM	9:00 AM	14	78	3	95	3	91	21	115	22	1	26	49	4	6	0	10	269
9:00 AM	9:15 AM	9	79	2	90	6	104	21	131	21	5	33	59	4	9	2	15	295

			NB	SB	EB	WB	Intersection
Peak Hour	8:15 – 9:15	PHF =	0.92	0.94	0.82	0.61	0.93
		PHV =	363	508	194	78	1143

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$$\text{PHF} = \frac{\text{Volume during peak hour}}{4 \times \text{volume during peak 15 min within peak hour}}$$

TIME		NORTHBOUND				SOUTHBOUND				EASTBOUND				WESTBOUND				GRAND
FROM	TO	L	T	R	Total	L	T	R	Total	L	T	R	Total	L	T	R	Total	TOTAL
8:15 AM	8:30 AM	7	69	3	79	2	107	18	127	11	4	20	35	7	17	8	32	273
8:30 AM	8:45 AM	9	85	5	99	4	105	26	135	23	8	20	51	7	9	5	21	306
8:45 AM	9:00 AM	14	78	3	95	3	91	21	115	22	1	26	49	4	6	0	10	269
9:00 AM	9:15 AM	9	79	2	90	6	104	21	131	21	5	33	59	4	9	2	15	295

	NB	SB	EB	WB	Intersection
PHF=	0.92	0.94	0.82	0.61	0.93
PHV=	363	508	194	78	1143
Peak 15 min=	99	135	59	32	306

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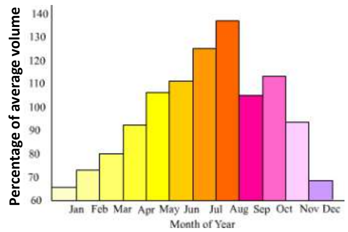
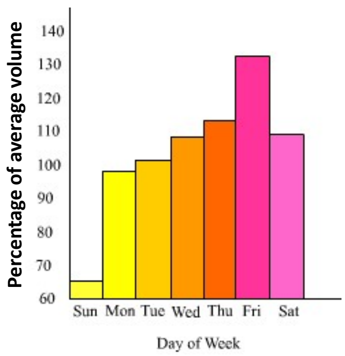
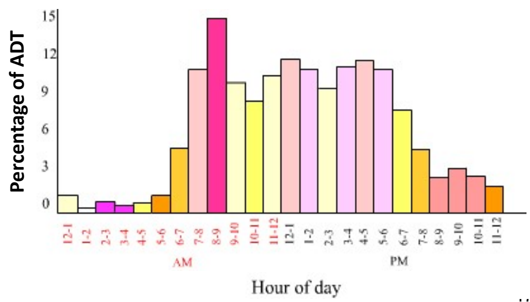
Traffic Volume Data Representation

- **Time-Based Distribution Charts**
  - Show the hourly, daily, monthly, or annual variations in traffic volume
  - Volumes are usually given as a percentage of the average volume.







Traffic Volume Data Representation

- **Summary Tables**
  - Summary of traffic volume data such as PHV, VC, and ADT

Table 4.4 Summary of Traffic Volume Data for a Highway Section

PHV	430
ADT	5375
Vehicle Classification (VC)	
Passenger cars	70%
Two-axle trucks	20%
Three-axle trucks	8%
Other trucks	2%

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Traffic Volume Characteristics:

Monthly variations | Daily variations | Hourly variations

- They are taken into consideration:
  - When traffic counts are being planned, so that volumes collected at a particular time or place can be related to volumes collected at other times and places.
  - A knowledge of these characteristics can also be used to estimate the accuracy of traffic counts.

Although traffic volume at a section of a road varies from time to time, this variation is repetitive and rhythmic.

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Sample Size and Adjustment of Periodic Counts

- Impracticality of collecting data continuously every day,
  - It is necessary to collect sample data
  - It is necessary to estimate annual volumes from periodic counts, this involves the determination of:

a) Minimum Sample Size (Number of count stations)

b) Daily, monthly, and/or seasonal expansion factors for each class of highway

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Sample Size and Adjustment of Periodic Counts

a. Determination of Number of Count Stations:

– It depends on **the precision level** desired **(95%-5%)**

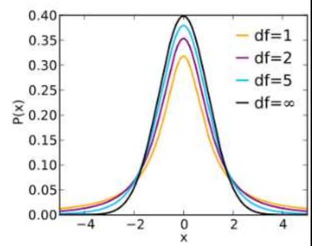
– When the sample size is less than 30 and the selection of counting stations is random,

a distribution known as the student's t distribution may be used to determine the sample size

– Student *t* distribution

- Unbounded (with a mean of zero)
- A variance that depends on the scale parameter, commonly referred to as the **degrees of freedom v = N-1**

$$\boxed{\text{variance} = v/(v\text{-}2)}$$



Sample Size and Adjustment of Periodic Counts

a. Determination of Number of Count Stations:

– Assuming that the sampling locations are randomly selected, the minimum sample number is given as:

$$n = \frac{t^2_{\alpha/2,N-1}(S^2/d^2)}{1+(1/N)(t^2_{\alpha/2,N-1})(S^2/d^2)}$$

Where

n =minimum number of count locations required

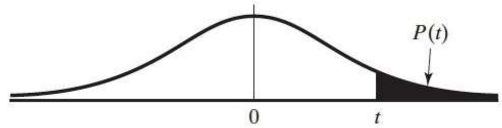
t = value of the student's t distribution with (1-α/2) confidence level (N-1 degrees of freedom)

N = total number of links (population) from which a sample is to be selected

α = significance level

S = estimate of the spatial standard deviation of the link volumes

d = the allowable range of error



$$P(t) = \int_t^{\infty} \frac{(f-1/2)\,!}{(f-2/2)\,!\sqrt{\pi f}}\,(1+t^2/f)^{+\,(f+1)/2}\,dt$$

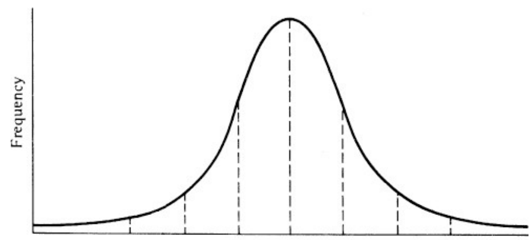


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Table A.1 Level of Significance for One-Tailed Test

	.250	*.100*	*.050*	*.025*	*.010*	*.005*	*.0025*	*.0005*
	Level of Significance for a Two-Tailed Test							
Degrees of Freedom	*.500*	*.200*	*.100*	*.050*	*.020*	*.010*	*.005*	*.001*
1.	1.000	3.078	6.314	12.706	31.821	63.657	27.321	536.627
2.	.816	1.886	2.920	4.303	6.965	9.925	14.089	31.599
3.	.765	1.638	2.353	3.182	4.541	5.841	7.453	12.924
4.	.741	1.533	2.132	2.776	3.747	4.604	5.598	8.610
5.	.727	1.476	2.015	2.571	3.365	4.032	4.773	6.869
6.	.718	1.440	1.943	2.447	3.143	3.707	4.317	5.959
7.	.711	1.415	1.895	2.365	2.998	3.499	4.029	5.408
8.	.706	1.397	1.860	2.306	2.896	3.355	3.833	5.041
9.	.703	1.383	1.833	2.262	2.821	3.250	3.690	4.781
10.	.700	1.372	1.812	2.228	2.764	3.169	3.581	4.587
11.	.697	1.363	1.796	2.201	2.718	3.106	3.497	4.437
12.	.695	1.356	1.782	2.179	2.681	3.055	3.428	4.318
13.	.694	1.350	1.771	2.160	2.650	3.012	3.372	4.221
14.	.692	1.345	1.761	2.145	2.624	2.977	3.326	4.140
15.	.691	1.341	1.753	2.131	2.602	2.947	3.286	4.073
16.	.690	1.337	1.746	2.120	2.583	2.921	3.252	4.015
17.	.689	1.333	1.740	2.110	2.567	2.898	3.222	3.965
18.	.688	1.330	1.734	2.101	2.552	2.878	3.197	3.922
19.	.688	1.328	1.729	2.093	2.539	2.861	3.174	3.883
20.	.687	1.325	1.725	2.086	2.528	2.845	3.153	3.850
21.	.686	1.323	1.721	2.080	2.518	2.831	3.135	3.819

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(Continued)

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Table A.1 Level of Significance for One-Tailed Test (*continued*)

	.250	.100	.050	.025	.010	.005	.0025	.0005
	Level of Significance for a Two-Tailed Test							
Degrees of Freedom	.500	.200	.100	.050	.020	.010	.005	.001
22.	.686	1.321	1.717	2.074	2.508	2.819	3.119	3.792
23.	.685	1.319	1.714	2.069	2.500	2.807	3.104	3.768
24.	.685	1.318	1.711	2.064	2.492	2.797	3.091	3.745
25.	.684	1.316	1.708	2.062	2.485	2.787	3.078	3.725
26.	.684	1.315	1.706	2.056	2.479	2.779	3.067	3.707
27.	.684	1.314	1.703	2.052	2.473	2.771	3.057	3.690
28.	.683	1.313	1.701	2.048	2.467	2.763	3.047	3.674
29.	.683	1.311	1.699	2.045	2.462	2.756	3.038	3.659
30.	.683	1.310	1.697	2.042	2.457	2.750	3.030	3.646
35.	.682	1.306	1.690	2.030	2.438	2.724	2.996	3.591
40.	.681	1.303	1.684	2.021	2.423	2.704	2.971	3.551
45.	.680	1.301	1.679	2.014	2.412	2.690	2.952	3.520
50.	.679	1.299	1.676	2.009	2.403	2.678	2.937	3.496
55.	.679	1.297	1.673	2.004	2.396	2.668	2.925	3.476
60.	.679	1.296	1.671	2.000	2.390	2.660	2.915	3.460
65.	.678	1.295	1.669	1.997	2.385	2.654	2.906	3.447
70.	.678	1.294	1.667	1.994	2.381	2.648	2.899	3.435
80.	.678	1.292	1.664	1.990	2.374	2.639	2.887	3.416
90.	.677	1.291	1.662	1.987	2.368	2.632	2.878	3.402
100.	.677	1.290	1.660	1.984	2.364	2.626	2.871	3.390
125.	.676	1.288	1.657	1.979	2.357	2.616	2.858	3.370
150.	.676	1.287	1.655	1.976	2.351	2.609	2.849	3.357
200.	.676	1.286	1.653	1.972	2.345	2.601	2.839	3.340
∞	.6745	1.2816	1.6448	1.9600	2.3267	2.5758	2.8070	3.2905

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Sample Size and Adjustment of Periodic Counts

Example 4.4 Minimum Number of Count Stations

To determine a representative value for the ADT on 100 highway links that have similar volume characteristics, it was decided to collect 24-hour volume counts on a sample of these links. Estimates of mean and standard deviation of the link volumes for the type of highways in which these links are located are 32,500 and 5500, respectively. Determine the minimum number of stations at which volume counts should be taken if a 95–5 precision level is required with a 10 percent allowable error.

Solution:

- Establish the data.

$\alpha = (100-95) = 5$ percent
$S = 5500$
$m = 32{,}500$
$d = 0.1 \times 32{,}500 = 3250$ (allowable range of error)
$v = 100 - 1 = 99$
$t_{\alpha/2,99} \approx 1.984$ (from Appendix A)

- Use Eq. 4.7 to solve for n.

$$n = \frac{t^2_{\alpha/2,N-1}(S^2/d^2)}{1 + (1/N)(t^2_{\alpha/2,N-1})(S^2/d^2)}$$

$$= \frac{(1.984^2 \times 5500^2)/3250^2}{1 + (1/100)(1.984^2 \times 5500^2)/3250^2} = \frac{11.27}{1.11} = 10.1$$

Counts should be taken at a minimum of 11 stations. When sample sizes are greater than 30, the normal distribution is used instead of the student's t distribution.

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Sample Size and Adjustment of Periodic Counts

b. <u>Adjustment of Periodic Counts:</u> They are determined either from continuous count stations or from control count stations

Expansion Factors from Continuous Count Stations

Hourly Expansion Factor $$\text{HEF} = \frac{\text{total volume for 24-hr period}}{\text{volume for particular hour}}$$

Daily Expansion Factor $$\text{DEF} = \frac{\text{average total volume for week}}{\text{average volume for particular day}}$$

Monthly Expansion Factor $$\text{MEF} = \frac{\text{AADT}}{\text{ADT for particular month}}$$

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Table 4.5 Hourly Expansion Factors for a Rural Primary Road

Hour	*Volume*	*HEF*	*Hour*	*Volume*	*HEF*
6:00–7:00 a.m.	294	42.00	6:00–7:00 p.m.	743	16.62
7:00–8:00 a.m.	426	29.00	7:00–8:00 p.m.	706	17.49
8:00–9:00 a.m.	560	22.05	8:00–9:00 p.m.	606	20.38
9:00–10:00 a.m.	657	18.80	9:00–10:00 p.m.	489	25.26
10:00–11:00 a.m.	722	17.10	10:00–11:00 p.m.	396	31.19
11:00–12:00 p.m.	667	18.52	11:00–12:00 a.m.	360	34.31
12:00–1:00 p.m.	660	18.71	12:00–1:00 a.m.	241	51.24
1:00–2:00 p.m.	739	16.71	1:00–2:00 a.m.	150	82.33
2:00–3:00 p.m.	832	14.84	2:00–3:00 a.m.	100	123.50
3:00–4:00 p.m.	836	14.77	3:00–4:00 a.m.	90	137.22
4:00–5:00 p.m.	961	12.85	4:00–5:00 a.m.	86	143.60
5:00–6:00 p.m.	892	13.85	5:00–6:00 a.m.	137	90.14

Total daily volume = 12,350.

$$\text{HEF} = \frac{\text{total volume for 24-hr period}}{\text{volume for particular hour}}$$

- See 8:00 – 9:00 a.m.
- HEF = 12,350 / 560 = 22.05
- Or the 24-hr volume = 560 x 22.05 = 12,350

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Table 4.6 Daily Expansion Factors for a Rural Primary Road

Day of Week	Volume	DEF
Sunday	7895	9.515
Monday	10,714	7.012
Tuesday	9722	7.727
Wednesday	11,413	6.582
Thursday	10,714	7.012
Friday	13,125	5.724
Saturday	11,539	6.510

Total weekly volume = 75,122.

- See Friday
- DEF = 75,122 / 13,125 = 5.724
- Or the 7-day volume =
13,125 x 5.724 = 75,122

Table 4.7 Monthly Expansion Factors for a Rural Primary Road

Month	ADT	MEF
January	1350	1.756
February	1200	1.975
March	1450	1.635
April	1600	1.481
May	1700	1.394
June	2500	0.948
July	4100	0.578
August	4550	0.521
September	3750	0.632
October	2500	0.948
November	2000	1.185
December	1750	1.354

Total yearly volume = 28,450.
Mean average daily volume = 2370.

- See June
- MEF = 2370 / 2500 = 0.948
- Or the AADT =
2500 x 0.948 = 2370

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Sample Size and Adjustment of Periodic Counts

Example 4.5 Calculating AADT Using Expansion Factors

A traffic engineer urgently needs to determine the AADT on a rural primary road that has the volume distribution characteristics shown in Tables 4.5, 4.6, and 4.7. She collected the data shown below on a Tuesday during the month of May. Determine the AADT of the road.

7:00–8:00 a.m.	400
8:00–9:00 a.m.	535
9:00–10:00 a.m.	650
10:00–11:00 a.m.	710
11:00–12 noon	650

Solution:

- Estimate the 24-hr volume for Tuesday using the factors given in Table 4.5.

$$\frac{(400 \times 29.0 + 535 \times 22.05 + 650 \times 18.80 + 710 \times 17.10 + 650 \times 18.52)}{5} = 11{,}959$$

- Adjust the 24-hr volume for Tuesday to an average volume for the week using the factors given in Table 4.6.

$$\text{Total 7-day volume} = 11{,}959 \times 7.727$$

$$\text{Average 24-hr volume} = \frac{11{,}959 \times 7.727}{7} = 13{,}201$$

- Since the data were collected in May, use the factor shown for May in Table 4.7 to obtain the AADT.

$$\text{AADT} = 13{,}201 \times 1.394 = 18{,}402$$

Homework

- Homework – on Moodle
- There will be a quiz next Sunday
- Be prepared with all the material you need: textbook, slides, pen, calculator, etc.

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2.3 Travel Time and Delay Studies

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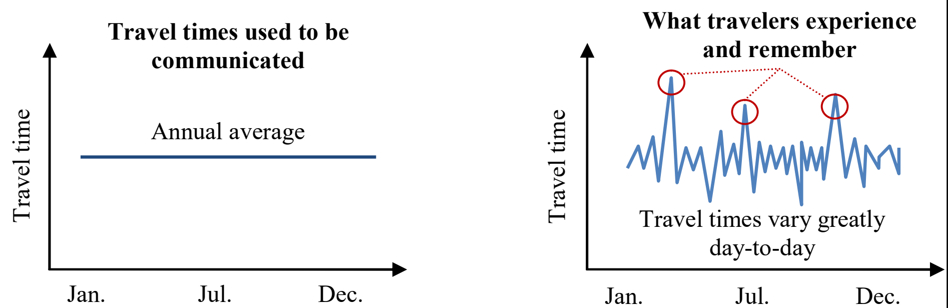
Travel Time and Delay Studies



Average travel times do not represent the real experience of road users

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Travel Time and Delay Studies

- **A travel time study** determines the amount of time required to travel from one point to another on a given route.
- Applications:
  - Efficiency of a route with respect to its ability to carry traffic
  - Identification of locations with relatively high delays and the causes
  - evaluate the effectiveness of traffic operation improvements through before-and-after studies
  - Determination of relative efficiency of a route by developing sufficiency ratings or congestion indices
  - Determination of travel times for trip assignment models
  - Compilation of travel time data for trend studies to evaluate the changes in efficiency and level of service with time
  - Performance of economic studies in the evaluation of traffic operation alternatives that reduce travel time

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Travel Time and Delay Studies

Travel Time Field Sheet

Site________________ Run___________ Time Start______ A.M/P.M

Recorder _______________ Comments _________________________

Note: Record Checkpoints must be submitted

			Per Section			
checkpoint Number	Cumulative Section Length (ft,mi)	Cumulative Travel Time (min:sec)	Delay (sec,min)	Stops (#)	Special Notes	Section Travel Time (sec,min)

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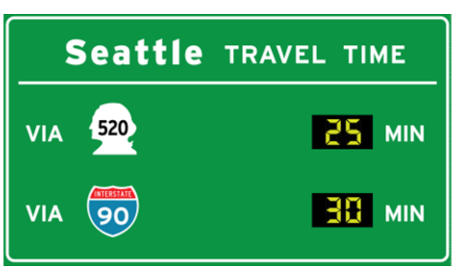
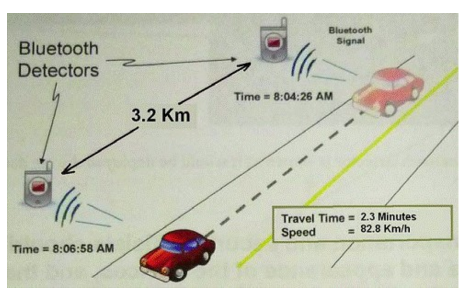
Definition of Terms Related to Time/Delay Studies

1. **Travel time:** the time taken by a vehicle to traverse a given section of a highway.
2. **Running time:** the time a vehicle is actually in motion while traversing a given section of a highway





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Definition of Terms Related to Time/Delay Studies

3. **Delay:** the time lost by a vehicle due to causes beyond the control of the driver
   a. **Operational delay:** that part of the delay caused by the impedance of other traffic, which can occur as:
      - ✓ Side friction: where the stream flow is interfered with by other traffic (Ex.: parking)
      - ✓ Internal friction: where the interference is within the traffic stream (Ex.: reduction in capacity of the highway).
   b. **Stopped-time delay**: that part of the delay during which the vehicle is not moving

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Definition of Terms Related to Time/Delay Studies

3. **Delay:**
   c. **Fixed delay**: that part of the delay caused by control devices such as traffic signals.
      - ✓ Occurs regardless of the traffic volume or the impedance that may exist.
4. **Travel-time Delay:**

= Actual travel time − travel time assuming the vehicle traverses with an average speed equal to that for an uncongested traffic flow

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Methods for Conducting Travel Time/Delay Studies

- These methods can be grouped into:
  - **A) Those using a test vehicle**
  - **B) Those not requiring a test vehicles**

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Methods for Conducting Travel Time/Delay Studies

A) Those using a test vehicle

1. ***Floating-Car Technique***: the test car is driven along the test section so that the test car "floats" with the traffic.
   - Driver of the test vehicle attempts to pass as many vehicles as those that pass his test vehicle
   - Minimum number of test runs can be determined using

$$N = \left(\frac{t_\alpha \times \sigma}{d}\right)^2$$

where

N = sample size (minimum number of test runs)
σ = standard deviation (mi/h)
d = limit of acceptable error in the speed estimate (mi/h)
t_α = value of the student's t distribution with $(1 - \alpha/2)$ confidence level and $(N - 1)$ degrees of freedom
α = significance level

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Methods for Conducting Travel Time/Delay Studies

A) Those using a test vehicle

$$N = \left(\frac{t_\alpha \times \sigma}{d}\right)^2$$

1. *Floating-Car Technique*:

- The limit of acceptable error used depends on the purpose of the study.
  - ✓ Before-and-after studies: 1.0 to 3.0 mi/h
  - ✓ Traffic operation, economic evaluations, and trend analyses: 2.0 to 4.0 mi/h
  - ✓ Highway needs and transportation planning studies: 3.0 to 5.0 mi/h

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Methods for Conducting Travel Time/Delay Studies

A) Those using a test vehicle

1. *Floating-Car Technique*:

Table 6.8 Approximate Minimum Sample Size Requirements for Travel Time and Delay Studies with Confidence Level of 95.0 Percent

Average Range in Travel Speed (kph)	Minimum Number of Runs for Specified Permitted Error				
	± 2.0 kph	±3.5 kph	± 5.0 kph	± 6.5 kph	± 8.0 kph
5	4	3	2	2	2
10	8	4	3	3	2
15	14	7	5	3	3
20	21	9	6	5	4
25	28	13	8	6	5
30	38	16	10	7	6

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Methods for Conducting Travel Time/Delay Studies

A) Those using a test vehicle

2. ***Average-Speed Technique***: driving the test car at a speed that, in the opinion of the driver, is the average speed of the traffic stream.
   - The travel time is recorded.
   - The test run is repeated for the minimum number of times as calculated by Equation 4.8

Alternatively, the driver alone can collect the data by using a laptop computer with internal clock and distance functions.

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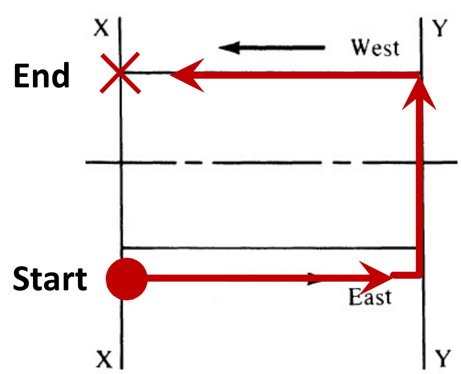
Methods for Conducting Travel Time/Delay Studies

A) Those using a test vehicle

3. ***Moving-Vehicle Technique***: the observer makes a round trip on a test section like the one shown below:



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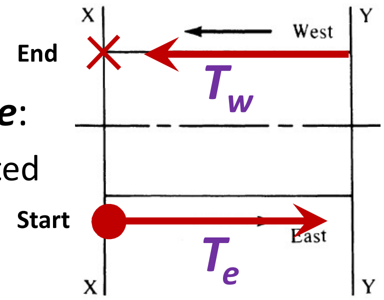
Methods for Conducting Travel Time/Delay Studies

A) Those using a test vehicle



3. *Moving-Vehicle Technique*:

The following data are collected

- T_e (***in minutes***)
- T_w (***in minutes***)
- N_e : number of vehicles **traveling west** in the opposite lane while the test car is traveling east
- O_w: number of vehicles that overtake the test car while the test car is traveling west
- P_w : number of vehicles that the test car passes while the test car is traveling west

Methods for Conducting Travel Time/Delay Studies

A) Those using a test vehicle

3. *Moving-Vehicle Technique*:

	Volume	Average Travel time
Westbound	$V_w = \frac{(N_e + O_w - P_w)60}{T_e + T_w}$	$\bar{T}_w = T_w - \frac{(O_w - P_w)60}{V_w}$
Eastbound	$V_e = \frac{(N_w + O_e - P_e)60}{T_e + T_w}$	$\bar{T}_e = T_e - \frac{(O_e - P_e)60}{V_e}$

Example 4.6

Table 4.9 Data from Travel Time Study Using the Moving-Vehicle Technique

Run Direction/ Number	*Travel Time (min)*	*No. of Vehicles Traveling in Opposite Direction*	*No. of Vehicles That Overtook Test Vehicle*	*No. of Vehicles Overtaken by Test Vehicle*
Eastward				
1	2.75	80	1	1
2	2.55	75	2	1
3	2.85	83	0	3
4	3.00	78	0	1
5	3.05	81	1	1
6	2.70	79	3	2
7	2.82	82	1	1
8	3.08	78	0	2
Average	2.85	79.50	1.00	1.50
Westward				
1	2.95	78	2	0
2	3.15	83	1	1
3	3.20	89	1	1
4	2.83	86	1	0
5	3.30	80	2	1
6	3.00	79	1	2
7	3.22	82	2	1
8	2.91	81	0	1
Average	3.07	82.25	1.25	0.875

Example 4.6 Volume and Travel Time Using Moving-Vehicle Technique

The data in Table 4.9 were obtained in a travel time study on a section of highway using the moving-vehicle technique. Determine the travel time and volume in each direction at this section of the highway.

Mean time it takes to travel eastward (T_e) = 2.85 min

Mean time it takes to travel westbound (T_w) = 3.07 min

Average number of vehicles traveling westward when test vehicle is traveling eastward (N_e) = 79.50

Average number of vehicles traveling eastward when test vehicle is traveling westward (N_w) = 82.25

Average number of vehicles that overtake test vehicle while it is traveling westward (O_w) = 1.25

Average number of vehicles that overtake test vehicle while it is traveling eastward (O_e) = 1.00

Average number of vehicles the test vehicle passes while traveling westward (P_w) = 0.875

Average number of vehicles the test vehicle passes while traveling eastward (P_e) = 1.5

Solution:

- From Eq. 4.9, find the volume in the westbound direction.

$$V_w = \frac{(N_e + O_w - P_w)60}{T_e + T_w}$$

$$= \frac{(79.50 + 1.25 - 0.875)60}{2.85 + 3.07} = 809.5 \quad \text{(or 810 veh/h)}$$

- Similarly, calculate the volume in the eastbound direction.

$$V_e = \frac{(82.25 + 1.00 - 1.50)60}{2.85 + 3.07} = 828.5 \quad \text{(or 829 veh/h)}$$

- Find the average travel time in the westbound direction.

$$\overline{T}_w = 3.07 - \frac{(1.25 - 0.875)}{810}60 = 3.0 \text{ min}$$

- Find the average travel time in the eastbound direction.

$$\overline{T}_e = 2.85 - \frac{(1.00 - 1.50)}{829}60 = 2.9 \text{ min}$$

interchange

Methods for Conducting Travel Time/Delay Studies

B) Those not requiring a test vehicles

1. ***License-Plate Observations***: requires that observers be positioned at the beginning and end of the test section.
   - Each observer records the last three or four digits of the license plate of each car that passes together with the time at which the car passes.
     - ✓ It has been suggested that a sample size of 50 matched license plates will give reasonably accurate results.

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Methods for Conducting Travel Time/Delay Studies

B) Those not requiring a test vehicles

2. ***Interviews***: It is carried out by obtaining information from individuals who drive on the study site regarding their travel times and experience of delays.
   - It facilitates the collection of a large amount of data in a relatively short time
   - Results depends on the information given by the contacted people
3. ***ITS Advanced Technologies (TELEMATICS):*** The integrated use of telecommunications and informatics.

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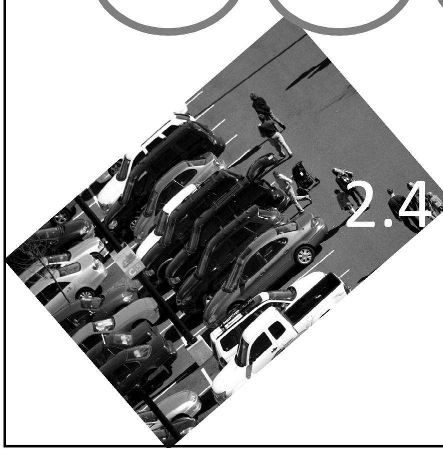

2.4 Parking Studies

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Parking Studies

- Any traveling vehicle will at one time or another be parked for short time or a much longer time.
- Great need for parking spaces in areas where land uses include business, residential, or commercial activities.
- "park-and-ride" increased the demand for parking spaces at transit stations.
- Providing adequate parking space in the CBD may necessitate the need for
  - parking bays along curbs which reduces the capacity of the streets and may affect the level of service

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Parking Studies

- Parking studies are used to:
  - Determine the demand for and the supply of parking facilities in an area,
  - Projection of the demand,
  - Views of various interest groups on how best to solve the parking problems.
- Types of parking facilities:
  1. **On-Street Parking Facilities**: Parking bays are provided alongside the curb on one or both sides of the street
     - unrestricted parking or restricted parking facilities
  2. **Off-Street Parking Facilities**: privately or publicly owned; surface lots and garages

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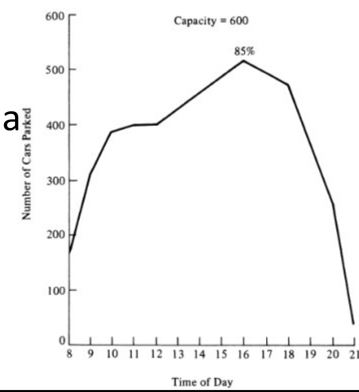
Definitions of Parking Terms

1. **Space-hour**: a unit of parking that defines the use of a single parking space for a period of 1 hour
2. **Parking Volume**: total number of vehicles that park in a study area during a specific length of time, usually a day
3. **Parking Accumulation**: number of parked vehicles in a study area at any specified time
   - curve of parking accumulation against time, which shows the variation of the **parking accumulation** during the day



Definitions of Parking Terms

4. **Parking Load**: the **area** under the accumulation curve between two specific times
   - Given as the number of space-hours used during the specified period of time
5. **Parking Duration**: length of time a vehicle is parked at a parking bay.
   - Average parking duration gives an indication of how frequently a parking space becomes available.
6. **Parking Turnover**: rate of use of a parking space

$$\boxed{\text{Parling Turnover} = \frac{\text{Parking Volume for a specific period}}{\text{Number of parking spaces}}}$$

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Methodology of Parking Studies

- A comprehensive parking study usually involves:
  1. **Inventory of existing parking facilities**: A detailed listing of the location and all other relevant characteristics of each legal parking facility, private and public, in the study area
     - ✓ Type and number of parking spaces at each parking facility
     - ✓ Times of operation and limit on duration of parking, if any
     - ✓ Type of ownership (private or public)
     - ✓ Parking fees, if any, and method of collection
     - ✓ Restrictions on use (open or closed to the public)
     - ✓ Other restrictions, if any (loading and unloading zones)
     - ✓ Probable degree of permanency

Updated at regular intervals of about four to five years

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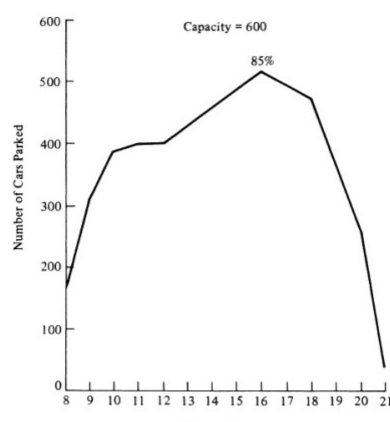
Methodology of Parking Studies

- A comprehensive parking study usually involves:
  2. **Collection of parking data:**
     - ***Accumulation***: It is obtained by checking the amount of parking during regular intervals on different days of the week

Obtained information is used to determine:
✓ Hourly variations of parking
✓ Peak periods of parking demand



Methodology of Parking Studies

- A comprehensive parking study usually involves:
  2. **Collection of parking data:**
     - ***Turnover and Duration***: usually obtained by collecting data on a sample of parking spaces in a given block.
       - It is done by recording the license plate of the vehicle parked on each parking space in the sample at the ends of fixed intervals during the study period.
       - The length of the fixed intervals depends on the maximum permissible duration

Turnover $$T = \frac{\text{number of different vehicles parked}}{\text{number of parking spaces}}$$

Electronic systems use wireless sensors detect the arrival and departure of a vehicle at a parking space

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Methodology of Parking Studies

- A comprehensive parking study usually involves:
  3. **Identification of parking generators:** It involves
     - Identifying parking generators (for example, shopping centers or transit terminals)
     - Locating these on a well-Prepared map or the study area

  4. **Parking demand:** It is obtained by interviewing drivers at the various parking facilities listed during the inventory

Information Sought for Parking Demand Interview

(1) trip origin
(2) purpose of trip
(3) driver's destination reached on foot after parking.

The interview must also note the location of the parking facility, the times of arrival and departure, and the vehicle type.

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Analysis Parking Data

- It includes summarizing, coding, and interpreting the data. The final relevant information includes:
  - Number and duration for vehicles legally parked
  - Number and duration for vehicles illegally parked
  - Space-hours of demand for parking
  - Supply of parking facilities

It is straightforward involving simple arithmetical and statistical calculations

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Analysis Parking Data

- **Space-hours of demand for parking**

$$D = \sum_{i=1}^{N} (n_i t_i)$$

D = space vehicle-hours demand for a specific period of time
N = number of classes of parking duration ranges
t_i = midparking duration of the ith class
n_i = number of vehicles parked for the ith duration range

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Analysis Parking Data

- **Space-hours of supply**

$$S = f\sum_{i=1}^{N}(t_i)$$

S = practical number of space-hours of supply for a specific period of time
N = number of parking spaces available
t_i = total length of time in hours when the ith space can be legally parked on during the specific period
f = efficiency factor

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Analysis Parking Data

- The efficiency factor f is used to correct for time lost in each turnover.
  - It is determined on the basis of the best performance a parking facility is expected to produce.
  - Efficiency factors is determined for different types of parking facilities
    - Curb parking (during highest demand) → 78% - 96%
    - Surface lots and garages → 75% - 92%
  - Average values for the efficiency factor
    - 90% for curb parking,
    - 80% for garages
    - 85% for surface lots.

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Example 4-7

- The owner of a parking garage located in a CBD has observed that **20%** of those wishing to park are turned back every day during the open hours of 8 a.m. to 6 p.m. (10 hours) because of lack of parking spaces.
- An analysis of data collected at the garage indicates that 60% of those who park are commuters, with an average parking duration of 9 hr, and the remaining are shoppers, whose average parking duration is 2 hr.
- If 20% of those who cannot park are commuters and the rest are shoppers, and a total of 200 vehicles currently park daily in the garage, **determine the number of additional spaces required to meet the excess demand**. Assume parking efficiency is 0.90.

Solution:

- Calculate the space-hours of demand using Eq. 4.12.

$$D = \sum_{i=1}^{N}(n_i t_i)$$

Commuters now being served $= 0.6 \times 200 \times 9 = 1080$ space-hr

Shoppers now being served $= 0.4 \times 200 \times 2 = 160$ space-hr

Total number of vehicles turned away $= \frac{200}{0.8} - 200 = 50$

Commuters not being served = 0.2 × 50 × 9 = 90 space-hr
Shoppers not being served = 0.8 × 50 × 2 = 80 space-hr
Total space-hours of demand = (1080 + 160 + 90 + 80) = 1410
Total space-hours served = 1080 + 160 = 1240
Number of space-hours required = 1410 − 1240 = 170

- Determine the number of parking spaces required from Eq. 4.13.

$$S = f \sum_{i=1}^{N} t_i = 170 \text{ space-hr}$$

- Use the length of time each space can be legally parked on (8 a.m. through 6 p.m. = 10 hr) to determine the number of additional spaces.

$$0.9 \times 10 \times N = 170$$
$$N = 18.89$$

At least 19 additional spaces will be required, since a fraction of a space cannot be used.

Homework

- 4-14
- 4-15
- 4-18
- 4-19
- 4-20

Chapter 2
Traffic Engineering Studies