King Saud University
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Civil Engineering Department

CE 431: Highway Engineering
Tutorial Note 8: Chapter 6
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6-1 Three cars travel over a 200 ft section of highway at constant speeds of 35, 40, and 45 ft/sec. Compute the time-mean and space-mean speeds for this condition.

- Time-mean speed by equation 6-1

$$\overline{\mu_t} = \frac{\sum \mu_i}{n}$$

$$\overline{\mu_t} = \frac{35 + 40 + 45}{3} = 40\ ft/sec$$

- Space-mean speed by equation 6-2

$$\overline{\mu_s} = \frac{nd}{\sum t_i}$$

$$t_1 = \frac{200}{35} = 5.71\ sec$$

$$t_2 = \frac{200}{40} = 5.0\ sec$$

$$t_3 = \frac{200}{45} = 4.44\ sec$$

$$\overline{\mu_s} = \frac{3 \times 200}{5.71 + 5 + 4.44} = 39.6\ ft/sec$$

Alternatively,

$$\overline{\mu_s} = \frac{n}{\sum \frac{1}{\mu_i}}$$

$$\overline{\mu_s} = \frac{3}{\left(\frac{1}{35} + \frac{1}{40} + \frac{1}{45}\right)} = 39.6\ ft/sec$$

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6-2 Three cars travel over a 60 m section of highway at constant speeds of 19, 20, and 25 m/sec. Compute the time-mean and space-mean speeds for this condition.

- Time-mean speed by equation 6-1

$$\overline{\mu_t} = \frac{\sum \mu_i}{n}$$

$$\overline{\mu_t} = \frac{19 + 20 + 25}{3} = 21.33\ m/sec$$

- Space-mean speed by equation 6-2

$$\overline{\mu_s} = \frac{nd}{\sum t_i}$$

$$t_1 = \frac{60}{19} = 3.16\ sec$$

$$t_2 = \frac{60}{20} = 3.0\ sec$$

$$t_3 = \frac{60}{25} = 2.4\ sec$$

$$\overline{\mu_s} = \frac{3 \times 60}{3.16 + 3 + 2.4} = 21.03\ m/sec$$

Alternatively,

$$\overline{\mu_s} = \frac{n}{\sum \frac{1}{\mu_i}}$$

$$\overline{\mu_s} = \frac{3}{\left(\frac{1}{19} + \frac{1}{20} + \frac{1}{25}\right)} = 21.03\ m/sec$$

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6-3 For the conditions described in problem 6-1, estimate the variance about space-mean speed.

By equation 6-3

$$\overline{\mu_t} = \overline{\mu_s} + \frac{\sigma_s^2}{\overline{\mu_s}}$$

$$40 = 39.6 + \frac{\sigma_s^2}{\overline{39.6}}$$

$$\sigma_s^2 = 15.84$$

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6-4 For the conditions described in problem 6-2, estimate the variance about space-mean speed.

By equation 6-3

$$\overline{\mu_t} = \overline{\mu_s} + \frac{\sigma_s^2}{\overline{\mu_s}}$$

$$21.33 = 21.03 + \frac{\sigma_s^2}{\overline{21.03}}$$

$$\sigma_s^2 = 6.31$$

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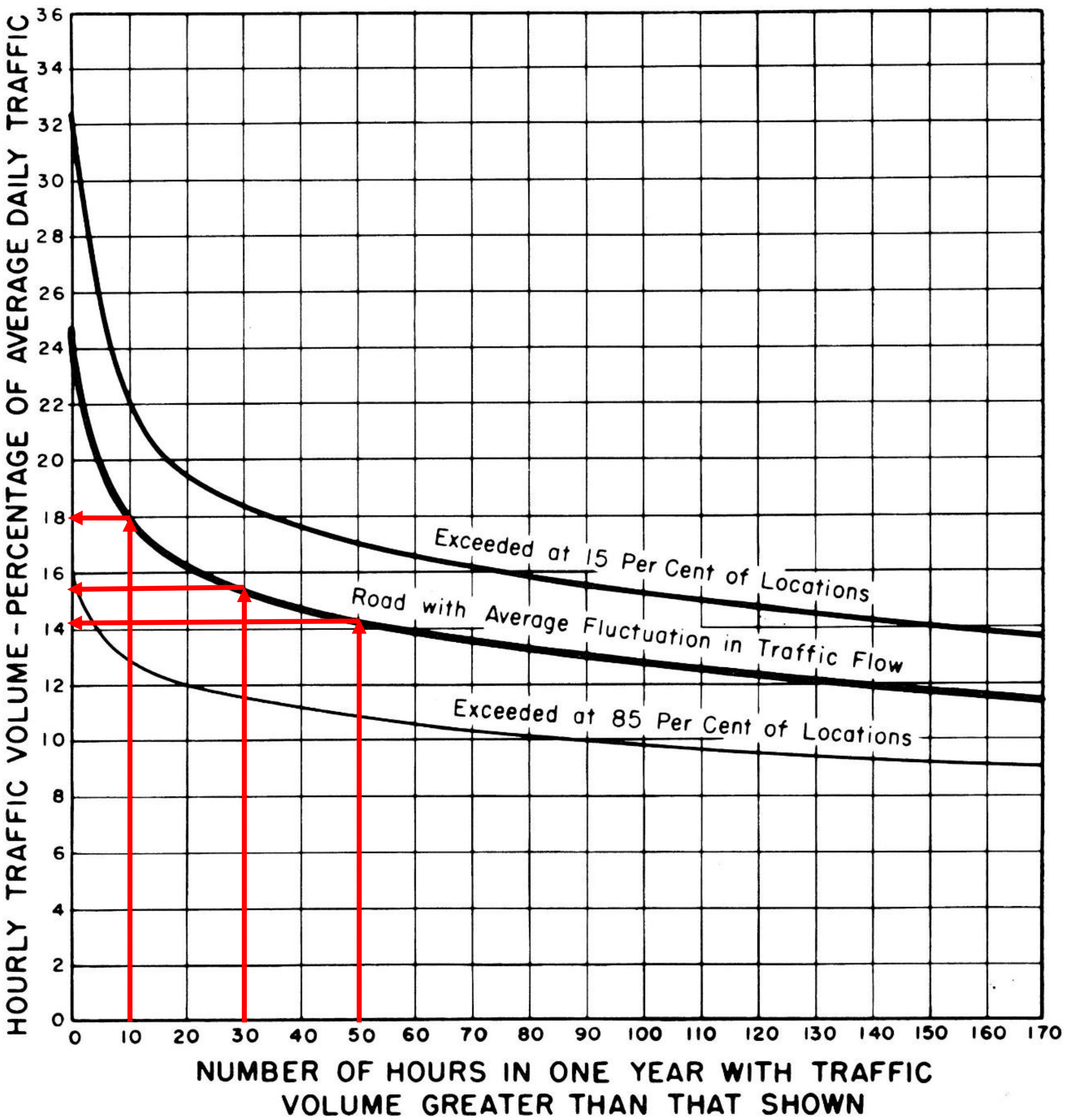
6-5 The estimated future average daily traffic for a rural highway is 8,000. Assume that the relationship between peak hourly flows and ADT is as shown in figure 6-1. Estimate the design hourly volume. What would be the effect of using the 10th highest hour for design purposes? The 50th highest hour?

By Figure 6-1



Road with average fluctuation in traffic flow is assumed.

For the 30th highest hour: DHV = 0.153 × 8000 = 1224 vph

For the 10th highest hour: DHV = 0.180 × 8000 = 1440 vph

For the 50th highest hour: DHV = 0.142 × 8000 = 1224 vph

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6-6 Arrivals at a parking lot are assumed to follow the Poisson distribution. The average arrival rate is 2.8 per minute. What is the probability that during a given minute no car will arrive? What percentage of the time will no car arrive?

The probability that during a given minute no car will arrive is given by equation 6-6

$$P(x) = \frac{m^x e^{-m}}{x!}$$

$$P(0) = \frac{2.8^0 e^{-2.8}}{0!} = 0.061$$

Percentage of the time will no car arrive = 0.061 × 100 = 6.1%

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6-7 A street has an hourly volume of 360 vehicles. A pedestrian requires a gap of at least 10 seconds to cross. Assuming headway can be described by a negative exponential distribution, what is the probability that the pedestrian will have to wait to cross?

The probability that the headway is more than 10 seconds is given by equation 6-7

$$P(g > T) = e^{-VT}$$

$$P(g > T) = e^{-360\times\frac{10}{3600}} = 0.37$$

Probability that the pedestrian will have to wait to cross = 1 – 0.37 = 0.63

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6-10 Estimate the service flow rate for the level of service B for a six-lane freeway (three lanes per direction) with 12 ft (3.6 m) lanes and obstructions 6 ft (1.8 m) from the edge of pavement on one side only. The section is to accommodate 12 percent heavy trucks and busses and 2 percent recreational vehicles. Assume the adjustment factor for the driver population, f_p, is 0.95. The design speed is 75 mph (120 km/h), and the section has a +3 percent grade that is 0.7 mile (1.1 km) long.

Using table 6-4,

Level of service B and FFS = 75 mph ➔ service flowrate v_p= 1350 passenger car per hour per lane.

- For one direction, the service flowrate v_p = 1350 x 3 = 4050 passenger car per hour.
- For one direction, the service flowrate v_p = 1350 x 6 = 8100 passenger car per hour.

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6-11 Estimate the capacity of the freeway segment described in Problem 6-10.

Capacity ➔ LOS E ➔ service flowrate v_p = 2400 passenger car per hour per lane

By equation 6-9

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p}$$

$$V = v_p \times PHF \times N \times f_{HV} \times f_p$$

PHF = 1, because of capacity conditions

N = 3, given (one direction)

f_p = 0.95, given

f_{HV} = by equation 6-10

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

E_T = 1.5, and E_R = 3, using tables 6-9 and 6-10 respectively.

$$f_{HV} = \frac{1}{1 + 0.12(1.5 - 1) + 0.02(3 - 1)} = 0.91$$

Substituting,

$$V = 2400 \times 1 \times 3 \times 0.91 \times 0.95 = 6225\ vph$$

For both directions = 6225 × 2 = 12450 vph

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6-12 Estimate the capacity of the approach lane of a signalized intersection located in the central business district given the following conditions:

- **Two approach lanes 10 ft wide.**
- **8% heavy vehicles.**
- **+4% grade along the approach.**
- **30 busses stopping per hour.**
- **20 parking maneuvers per hour.**
- **Through traffic only.**
- **Cycle length = 65 sec.**
- **Green ratio = 0.5**

Signalized intersection capacity, c_i, is given by equation 6-12

$$c_i = s_i \times \left(\frac{g_i}{C}\right)$$

Saturation flowrate, s, is given by equation 6-13

$$s = s_0 \times N \times f_W \times f_{HV} \times f_g \times f_p \times f_{bb} \times f_a \times f_{LU} \times f_{LT} \times f_{RT} \times f_{Lpb} \times f_{Rpb}$$

s_0 = 1900 vph, if not given, use 1900 vph

N = 2

f_{LU} = 1, no lane utilization

f_{LT} = 1, not left turn

f_{RT} = 1, no right turn

f_{Lpb} = 1, no pedestrian or bikes

f_{Rpb} = 1, no pedestrian or bikes

f_a = 0.9, located in the central business district

f_W is given by equation 6-14

$$f_W = 1 + \left(\frac{W - 12}{30}\right) = 1 + \left(\frac{10 - 12}{30}\right) = 0.933$$

f_{HV} is given by equation 6-15

$$f_{HV} = \frac{100}{100 + \%HV(E_T - 1)} = \frac{100}{100 + 8(2 - 1)} = 0.926$$

f_g is given by equation 6-16

$$f_g = 1 - \frac{\%G}{100} = 1 - \frac{4}{100} = 0.96$$

f_p is given by equation 6-17

$$f_p = \frac{N - 0.1 - \left(\frac{18N_m}{3600}\right)}{N} = \frac{2 - 0.1 - \left(\frac{18 \times 20}{3600}\right)}{2} = 0.9$$

f_{bb} is given by equation 6-18

$$f_p = \frac{N - \left(\frac{14.4N_b}{3600}\right)}{N} = \frac{2 - \left(\frac{14.4 \times 30}{3600}\right)}{2} = 0.94$$

Substituting in equation 6-13 to find s,

$$s = 1900 \times 2 \times 0.933 \times 0.926 \times 0.96 \times 0.9 \times 0.94 \times 0.9 \times 1 \times 1 \times 1 \times 1 \times 1 = 2400\ vph\ (green)$$

Substituting in equation 6-12 to find c_i,

$$c_i = 2400 \times 0.5 = 1200\ vph$$

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6-13 If the average stopped delay per vehicle for the intersection described in problem 6-12 is 20 sec, what is the level of service?

Using table 6-12 ➔ LOS is B

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