Question 1: Short Answers

a) When a bottleneck is activated, is the departure rate equal to capacity, or the arrival rate?

capacity

b) Using basic traffic stream models, if the jam density of a particular roadway is 500 vehicles/mile, what is the density at capacity?

Therefore, $k_{cap} = \frac{5o0}{2} = 250 \quad vehicles \ / \ mile$

c) What US President was most responsible for the development of the Interstate Highway System?

Eisenhower

d) Give an example of a common form of mathematical model used to estimate the volume of trips an individual or household makes in a given time period. Provide the name of the model, and an example equation.

poisson
Ln (lambda) = B+B1x+B2x2+…..

e) True or false: In User Equilibrium, travel times on all routes are equivalent.

true

f) True or false: In System Optimal Conditions, each travelers travel time is minimized.

false

Question 2: Short Calculation

If drivers arrive at a single toll booth at the average rate of 1 vehicle every 12 seconds, and the arrivals can be modeled as a poisson process. What is the probability of 2 vehicles arriving in 12 seconds?

18.4%

Write the highway performance function for a link 10 miles long with a free flow speed of 60 miles and hour, where for each 1000 vehicles travel time is increased by 30 seconds.

T=10+.5X – minutes and thousands of vehicles
T=600+30x – seconds and thousands of vehicles
T=600+.03x – seconds and vehicles

Estimate the ESALs for a 3 axle truck. The total weight of the truck is 18,000 lbs.

0.037 ESALs

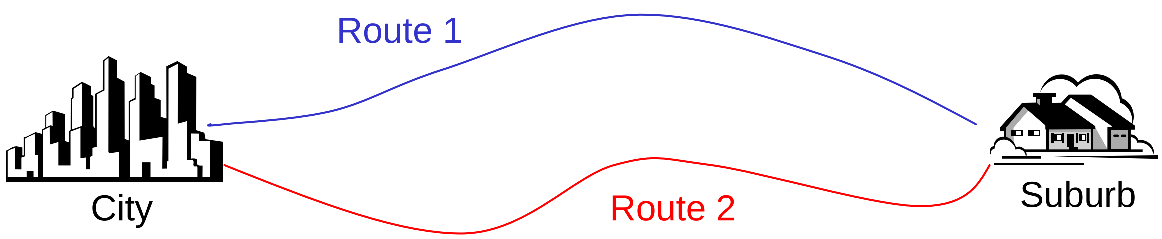
Question 3

As described in the schematic diagram below, imagine that during the morning peak hour there are 10,000 vehicles that travel from the suburbs to the city using route 1 or route 2. The highway performance functions for these routes are as follows:

$$\text{Route 1: } t_1 = 12 + 0.581x_1^2$$
$$\text{Route 2: } t_2 = 14 + 1.623x_2$$

Where t_i is the travel time on route i, and x_i is the volume on route i, in thousands of vehicles. Assuming these 10,000 vehicles can choose between these two routes, and these two routes only, find and report the following:

1. The user equilibrium (UE) distribution of traffic between the routes.
2. The system optimal (SO) distribution of traffic between the routes.
3. If the combined capacity of the two routes is 8,000 vehicles per hour is the HPF travel time prediction still valid? Why or why not? (1 - 3 sentences should suffice).



User Equilibrium
X_1=4.376
X_2=5.624

t_1,t_2=23.13 minutes

System Optimum
X_1=3.612
X_2=6.388

t_1=19.56
t_2=24.37

The HPF assumes a linear or quadratic relationship that doesn't replicate the dramatic increase in travel time experienced in over capacity conditions. These functions are only valid when volume is less than capacity (so no, the aren't).

Question 4

Just before I-5 intersects US 2 in Everett there is an automatic data counter (ADC) station (at mile post 193.29). I-5 characteristics at this station are:

- Urban freeway classification
- No HOV lanes
- 11 ft lane width
- 8 ft right-side shoulders
- 0.85 interchanges per mile
- Volume: 6,456 vehicles/hour
- PHF = 0.98
- 3 lanes in each direction
- 7% trucks and buses
- No recreational vehicles
- Level terrain
- Driver population adjustment factor = 1.0

Report the following:

1. Free flow speed for this section of freeway (to the nearest mile per hour).
2. The 15-minute passenger-car equivalent flow rate (v_p in pcplph).
3. The freeway section level of service (LOS). Assume you have access to the LOS figure and charts.

Find FFS

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID}$$

BFFS = 70 mph because it is an urban freeway (no other information given)
f_{LW} = -1.9 from Table 6.3 because lane width = 11 ft
f_{LC} = 0 from Table 6.4 because right-shoulder clearance > 6 ft
f_N = 3.0 from Table 6.5 there are 3 lanes in an urban freeway
f_{ID} = 1.78 interpolating from Table 6.6 – NOTE: must interpolate for credit

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID} = 75 - 0 - 0 - 0 - 1.54 = 63.32 = 63 \ mph$$

Note: must be to the nearest mph and not 63.32 to get full credit

Calculate f_{HV}
Table 6.8 gives E_T = 1.5 for flat terrain
Table 6.9 gives E_R = 1.2 for flat terrain

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} = \frac{1}{1 + (0.07)(1.5 - 1) + (0)(1.2 - 1)} = 0.9662$$

Find the 15-minute passenger-car equivalent flow rate

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

- PHF = 0.98
- N = 3
- f_{HV} = 0.9662
- f_p = 1.0

$$v_p = \frac{6,456}{0.98 \times 3 \times 0.9662 \times 1} = 2,273 \quad pcplph$$

Find LOS
From Figure 6.2, speed (S) = 54 mph
Or, by exact equation, S = 53.69 mph

$$D = \frac{v_p}{S} = \frac{2273}{54} = 42.09 \quad pcplpm$$

From Table 6.1, **LOS E**

Question 5

It is proposed to make SR 522 between Woodinville and Monroe into a 4-lane divided highway. A Poisson regression trip generation model was developed to determine the number of additional morning peak hour person-trips per day anticipated on this new expanded highway. The table below shows this model and the variable values for one particular household in Monroe.

Based on the Poisson regression model below, report the following:

1. The average number of additional morning peak hour person-trips per day that this household would generate.
2. The probability that the time between these additional morning peak hour person-trips is greater than 2 days.

Poisson Regression Model: Number of additional morning peak hour trips/day

Variable	Coefficient	Household Profile
Constant	-1.5	0
Education (undergraduate degree or higher)	0.1	1
Income	0.0001	55
Household wants to work in Seattle	0.1	1
Number of autos owned in the last ten years	0.1	4
Number of non-workers	-1	1
Senior household (age>60 for all members)	-0.1	0
Number of kids	0.15	1.3

$$\ln \lambda = -1.5(0) + 0.1(1) + 0.0001(55) + 0.1(1) + 0.1(4) - 1(1) - 0.1(0) + 0.15(1.3) = -0.1995$$

$$e^{-0.1995} = 0.8191$$

Therefore, this household will average about 0.82 person-trips/day.

$$P(n) = \frac{e^{-\lambda}\lambda^n}{n!} \qquad P(0) = \frac{e^{-0.8191(2)}\left(0.8191(2)\right)^0}{0!} = 0.1943$$

Therefore, the probability of this household taking zero trips in 2 days is about 19.43%

Question 6

Assume the logit model shown below describes route choice for 10,000 vehicles in the SR 520 and I-90 bridges if a toll system were to be installed on the SR 520 bridge.

What toll should WSDOT charge (to the nearest cent) so that the resulting traffic distribution from these 10,000 vehicles results in 3,500 vehicles selecting the SR 520 route?

Variable	**Coefficient**	**Profile values**
SR 520 Route		
Constant	0.2	1
Distance from residence to nearest on ramp (miles)	-0.07	3
Toll (in dollars)	-0.3	???
Flexibility of work arrival time (1 if flexible, 0 if not)	-0.022	1
Income (in thousands of dollars)	0.0034	50
I-90 Route		
Distance from residence to nearest on ramp (miles)	-0.1	6
Income (in thousands of dollars)	0.0011	50
Work on the south end of Seattle (1 if yes, 0 if no)	0.4	1

Find utilities

$$U_{520} = 0.2 - 0.07(3) - 0.3(x) - 0.022(1) + 0.0034(50) = 0.138 - 0.3x$$

$$U_{90} = -0.1(6) + 0.0011(50) + 0.4(1) = -0.145$$

Find exponential for I-90

$$e^{U_{I-90}} = e^{-0.145} = 0.865$$

For SR 520 to attract 3,500 out of 10,000 vehicles, you need the probability of selection SR 520 to equal:

$$P_{520} = \frac{3500}{10000} = 0.35$$

Now solve for x using the probability equation for Homeplate Parking

$$P_{520} = 0.35 = \frac{e^{U_{520}}}{e^{U_{520}} + e^{U_{90}}} = \frac{e^{U_{HP}}}{e^{U_{HP}} + 0.865}$$

$$0.303 = 0.65 e^{U_{520}} \quad \Rightarrow \quad U_{520} = -0.764$$

Now solve for x:

$$-0.764 = 0.138 - 0.3x \quad \Rightarrow \quad x = \$3.01$$

Question 7

A toll booth on a turnpike is open from 8:00 am to 12:00 midnight. Vehicles start arriving at 7:45 am at a uniform deterministic rate of 6 per minute until 8:15 am and from then on at two per minute. If vehicles are processed at a uniform deterministic rate of six per minute, determine when the queue will dissipate, the total delay, the maximum queue length (in vehicles), and the longest vehicle delay under FIFO.

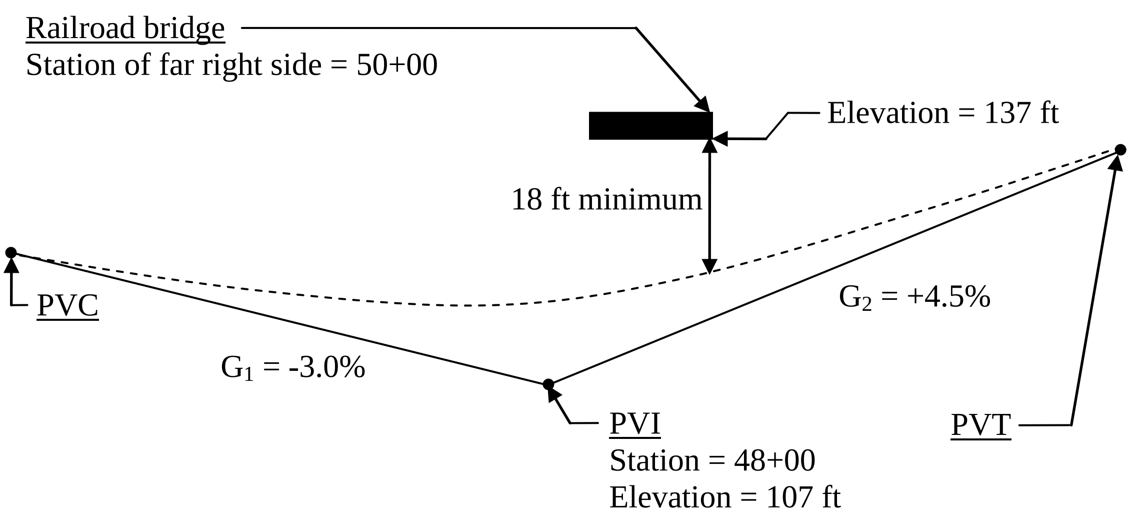
Time queue dissipates: 8:37:30
Total delay: 3037.5 vehicle minutes
Maximum queue length: 90 vehicles
Longest vehicle delay under FIFO: 15 minutes

Question 8

You are designing the vertical alignment of Strander Blvd. extension in the Renton-Tukwila area. An equal tangent sag vertical curve must go under an existing north-south rail line. The centerline roadway surface must be at least 18 ft below the proposed rail bridge. Known grades, stationing and elevations are given in the drawing below. Design the curve for the highest possible design speed without violating the 18 ft clearance requirement.

Report the longest possible curve length and the associated design speed rounded down to the nearest 5 mph. (now where do I remember seeing a problem like this before?)

Profile View Not to scale



This is essentially the same problem as the last one on the midterm. There are two principal ways you can solve this problem. Either one is fine, although the first way is shorter and perhaps less prone to math errors.

Method 1: Determine L using vertical curve offsets

$A = |G_1 - G_2| = |-3 - 4.5| = 7.5$

At station 50+00, the elevation of the roadway can be no more than:

Elevation of bridge bottom (137 ft) – 18 ft = 119 ft

Also realize that the PVI is at the half-way point on the vertical curve, or L/2. This makes station 50+00 = PVI station + 200 ft. OR… L/2 + 200.

Use the offset equation: $Y = \frac{A}{200L}x^2$

Note that the offset is the elevation of G_1 at station 50+00 minus the roadway elevation and that the elevation of G_1 at station 50+00 is the PVI elevation + 200(G_1):

$$Y = 119 - (107 + 200(-0.03)) = 18 \quad ft$$

$$Y = \frac{A}{200L}x^2 = 18 = \frac{7.5}{200L}\left(\frac{L}{2} + 200\right)^2$$

$$18 = \frac{0.0375}{L}\left(0.25L^2 + 200L + 40{,}000\right) \Rightarrow 480L = \left(0.25L^2 + 200L + 40{,}000\right)$$

$0 = 0.25L^2 - 280L + 40{,}000$ ← solve quadratic and get L = 951.9 or 168.1 ft.

Since 168.1 ft is too short (the curve would not even extend to station 50+00 and it would also not be the LONGEST curve one could design), choose L = 951.9 ft.

Method 2: Determine L using the equation for a vertical curve
(working in stations and percent grade)
At PVC, y = c. Therefore, c = 107 (elevation of PVI) – L/2(G_1) = 107 +1.5L
At PVC, b = G_1 = -3.0

Anywhere, $a = \frac{G_2 - G_1}{2L} = \frac{4.5 - -3.0}{2L} = \frac{7.5}{2L} = \frac{3.75}{L}$

You know the elevation of the point on the curve below the bridge: station 50+00, elevation 134 ft (see method 1 for a determination of the elevation). The station (50+00) is actually L/2 + 2.

Use the point and the equation for the curve to solve for L:

$$y = ax^2 + bx + c \Rightarrow 134 = \frac{3.75}{L}\left(\frac{L}{2} + 2\right)^2 - 3.0\left(\frac{L}{2} + 2\right) + 107 + 1.5L$$

$$119 = \frac{3.75}{L}\left(\frac{L^2}{4} + 2L + 4\right) - 1.5L - 6 + 107 + 1.5L$$

$$0 = \frac{3.75}{L}\left(0.25L^2 + 2L + 4\right) - 18$$

$$0 = 3.75\left(0.25L^2 + 2L + 4\right) - 18L$$

$0 = 0.9375L^2 - 10.5L + 15$ ← solve quadratic and get L = 9.512 or 1.681 stations

Since 1.681 stations is too short (the curve would not even extend to station 50+00 and it would also not be the LONGEST curve one could design), choose L = 9.512 stations or 951.2 ft.

Determine the design speed

Using the K-value and Table 3.3 in the textbook:

$$K = \frac{L}{A} = \frac{951.9}{7} = 126.9$$

From Table 3.3, the minimum K-value for a 55 mph design speed is 115, while the minimum K-value for a 60 mph design speed is 136. Since we have a K-value of 126.9 to work with, this is greater than 115, but less than 136. Therefore, the maximum design speed is 55 mph.

You could also just begin choosing random design speeds from Table 3.3 and then calculate the elevation of the resulting curve at station 19+00. Once you find the speed where the elevation is too low, you know you have exceeded the design speed. If you did it this way, you got most credit but the curve length you found would not be the “longest possible”.