Problem 1
1. (5) Draw a typical queuing input-output diagram (Newell Curve) (for one lane) consistent with observed data on a freeway bottleneck with an uncongested capacity of 1800 vehicles per hour per lane and an arrival rate that starts at 1600 vehicles per hour for 15 minutes, rises to 2000 vehicles per hour for 30 minutes, and drops back to 1600 vehicles per hour for the final 15 minutes.
2. (5) Show how to compute delay on the graph.
3. (5) Show the delay for the 500\textsuperscript{th} vehicle
4. (5) How many vehicles are in the congested region at time the 500\textsuperscript{th} vehicle enters the congested region.
5. (5) How many vehicles are in the congested region at the time the 500\textsuperscript{th} vehicle leaves the front of the queue.

A. the queue starts at the end of the 15\textsuperscript{th} minute

B. The total delay is indicated by the shaded area; the delay of an individual vehicle is indicated by the horizontal difference between A(t) and D(t).
C. The delay = time when the vehicle left the queue – time when the vehicle enter the queue =
\[ \frac{(500 - 400)\text{veh}}{1800\text{veh/hr}} - \frac{(500 - 400)\text{veh}}{2000\text{veh/hr}} = \frac{1}{180}\text{hr} = 20\text{sec} \]

D. Time spent when 500th vehicle enters the queue since the queue forms =
\[ \frac{1}{20}\text{hr} \times \frac{1}{2000\text{veh/hr} - 1800\text{veh/hr}} = 10\text{veh} \]

E. Time spent when 500th vehicle leaves the queue since the queue forms =
\[ \frac{1}{18}\text{hr} \times (2000\text{veh/hr} - 1800\text{veh/hr}) = 11.1\text{veh} \approx 11\text{veh} \]
2. (25) You are asked to model a freeway ramp meter with one lane of SOV traffic and an HOV bypass lane. Assume vehicles arrive with a random Poisson distribution, and the service rate (the rate at which the light turns green) is stochastic (it is determined by freeway conditions, which from the point of view of travelers on the ramp is random, with a negative exponential distribution). In the peak hour, 800 vehicles arrive at the ramp, of which 100 are high occupancy vehicles with 2 passengers each. The traffic light is timed to turn green on average once every 4 seconds, and is only green long enough to let one vehicle through. Assume the ramp can hold as many vehicles as want to use it.

A. (5) Determine the percent of time the ramp is empty, not empty
B. (5) How much time will each HOV user save?
C. (5) How much time does each SOV user save because the HOV users don’t wait in the queue?
D. (5) Determine the average queue length
E. (5) How often does the queue exceed 15 cars?

\[ \lambda = 700 \text{ veh/hr} \]
\[ \mu = \text{one veh/4 sec} = 900 \text{ veh/hr} \]
\[ \lambda' = 100 \text{ veh/hr} \]
\[ \rho = \frac{\lambda}{\mu} = 0.78 \]
\[ P(n>0) = \rho^{n+1} = 0.78 = 78\% \]
\[ P(n=0) = 1 - 0.78 = 0.22 = 22\% \]

\[ t = \frac{1}{\mu - \lambda} = \frac{1}{(900 - 700)/\text{hr}} = 18 \text{ sec} \]

Each HOV user will save 18 seconds.
C. if all the 800 vehicles enter SOV,
Arrival Rate $\lambda = 800 \text{veh/hr}$

$$t = \frac{1}{\mu - \lambda} = \frac{1}{(900 - 800)/hr} = 36 \text{sec}$$

The time saved
$36\text{sec} - 18\text{sec} = 18\text{sec}$

D. Average queue length $= \frac{\rho^2}{1 - \rho} = 2.72 = 3$

E. $P(n > 15) = \rho^{15+1} = 0.018 = 1.8\%$
3. (25) The upstream traffic flow on a road with two lanes is $q_1 = 1800$ veh/hr with speed of $u_1 = 90$ km/hr. As the result of a crash, one lane is blocked and flow is reduced to $q_2 = 900$ veh/hr. The density in the queue is $k_2 = 70$ veh/km. The value of time is $10$/hour/vehicle

(A) (5) What is the shockwave speed ($u_w$)?

(B) (5) If this continues for 1 hour, before the lane is cleared, how many vehicles long will the queue be?

(C) (5) How much did this crash cost society in terms of delay?

(D) (5) If a freeway service patrol (tow truck service) could clear the crash in 30 minutes instead of an hour, how much should society be willing to pay for that service?

(E) (5) If a variable message sign placed 2 km upstream of the crash site instantly (at the moment of the crash) advises travelers to divert 1 km upstream of the crash site to a frontage road that maintains a freeflow speed of 75 km/hr (despite the crash), how much should society pay for the freeway service patrol?

Problem 3.

A.

\[
q_1 = 1800 \quad u_1 = 90 \quad k_1 = q_1 / u_1 = 20
\]

\[
q_2 = 900 \quad k_2 = 70 \quad u_2 = 900 / 70 = 12.86
\]

\[
u_w = \frac{900 - 1800}{70 - 20} = -18
\]

B.

The rate the queue is growing
\[
N = u_{q1} \cdot k_i = (90 - (-18)) \cdot 20 = 2160 \text{ veh/hr}
\]
vehicles that leave the queue
\[
N' = q_2 = 900 \text{ veh/hr}
\]
the queue size
\[
(2160-900) \cdot 1 = 1260 \text{ veh}
\]
When the queue begins to dissipate, a new wave emerges. Now

\[ q_1 = 900 \quad k_1 = 70 \quad u_1 = 900/70 = 12.86 \]
\[ q_2 = 1800 \quad u_2 = 90 \quad k_2 = 20 \]

\[ u_w = \frac{1800 - 900}{20 - 70} = -18 \]

The dissipating rate

\[ N = u_1 * k_1 = (u_1 - u_w) * k_1 = (12.86 - (-18)) * 70 = 2160 \text{ veh/hr} \]

the time to clear the queue

\[ 1260 \text{ (veh/hr)} + 1800 \text{ (veh/hr)} * t = 2160 \text{ (veh/hr)} * t \]
\[ t = 3.5 \text{ hrs} \]

Total Delay

As an alterative of the sample problem solution which uses integration to calculate the shaded area, we can also calculate it by adding up the areas of two shaded triangles in the graph:

\[ D = (2160 - 900) * 1/2 + (2160 - 900) * (4.5 - 1)/2 = 2835 \text{ veh.hrs} \]
The social cost of the crash
\[ C = 2835 \times 10 = 28,350 \text{ dollars} \]

D.
If the crash can be cleared in half an hour (0.5)

The queue size
\[ (2160 - 900) \times 0.5 = 630 \text{ veh} \]

the dissipation time
\[ 630 + 1800t = 2160t \]
\[ t = 1.75 \text{ hrs} \]

the queue will be clear 2.25 hours after the crash

repeat the above calculation in part C)

\[ D' = (2160 - 900) \times 0.5/2 + (2160 - 900) \times (2.25 - 0.5)/2 = 708.75 \text{ veh.hrs} \]

\[ C' = 7,087.5 \text{ dollars} \]

\[ C - C' = 28350 - 7087.5 = 21262.5 \]

The society is willing to pay $21,262.5 for this service

E.
If the Variable Message Sign (VMS) is installed, when the crash occurs, the upstream vehicles that are 2 km beyond the crash site will be informed and take the diversion. One hour later when the crash is cleared, the arriving vehicles will be informed by VMS and return to the faster main road.

If we also have patrol service, the crash will be cleared in half an hour. Then all the vehicles will return to the main road.

The time that a vehicle saves to traverse the distance between diversion entry and crash by taking the main road (with crash cleared) instead of taking the diversion:
Without the patrol service, the crash won’t be cleared until one hour after the crash. So the vehicles that pass VMS between 0.5 and 1 hour after the crash will choose to take the diversion instead of the main road.
Number of vehicles that won’t take the main road without the patrol service=1800veh/hr*(1-0.5)hr=900veh

Time saved because of the patrol service=
900 veh*1/450 hr=2veh.hr

Money the society is paying for the patrol service with VMS already installed=10 dollars/veh/hr *2veh.hr=20 dollars
4. (25) Determine the number of lanes in the Northbound direction required to maintain level of service C (or better) on a rural freeway section connecting two major cities. (Assume for this section there are no interchanges, so the interchange density is 0) (Identify which tables you used to get your constants and show which equations you used.) Is Level of Service C reasonable?

You have been given the following information:

- 15 minute traffic flows in Northbound direction = 900, 1000, 1050, 1125
- Trucks and Buses = 5%
- Recreational Vehicles (RVs) = 1%
- Lane width = 3.65 m
- Lateral clearance = 2 m
- $f_p = 0.95$
- Level terrain
- Estimated freeflow speed for base conditions is 115 km/h

$q_{60} = 400 + 1000 + 1050 + 1125 = 4075$
$q_{15} = 1125$
$PHF = \frac{q_{60}}{4 \times q_{15}} = 0.906$

$P_t = 0.05 \quad P_r = 0.01$

Using Table C.7 $E_t = 1.5 \quad E_r = 1.2$

$$f_{HV} = \frac{1}{1 + (0.05) \times (1.5 - 1) + (0.01) \times (1.2 - 1)} = 0.974$$

Table C.3 $f_{LW} = 0$
Table C.4 $f_{LC} = 0$
Table C.5 $f_N = 0$
Table C.6 $f_{ID} = 0$
BFFS = 115 km/hr
FFS = BFFS - $f_{LW}$ - $f_{LC}$ - $f_N$ - $f_{ID}$ = 115 - 0 - 0 - 0 - 0 = 115 km/hr

Using Table C.2 and interpolating
For LOS C:
$Q_p = (1840 + 1740)/2 = 1790$

For freeways,
\[ q_p = \frac{q_{60}}{(PHF)(l)(f_{HV})(f_p)} \]

so, \[ 1790 = \frac{4075}{0.906 \cdot l \cdot 0.974 \cdot 0.95} \]

\[ l = 2.7, \text{ 3 lanes needed} \]
SOLUTIONS:

1. 

(Covered in the lab)

2. Differences:
Pre-timed traffic signals: operate on a clock with fixed cycle length and fixed split for each phase. They can’t respond to short-term fluctuations in traffic demand. They usually don’t use detectors.
Traffic-actuated signals: can alter cycle and phase lengths in response to the change in traffic demand as detected by detectors.
There are different timing design methods for pre-timed and traffic-actuated signals.
(Covered in the lab)
since traffic-actuated signals tend to function under heavy traffic loads as if they were pretimed, we can use a fixed-time timing plan for an intersection under near-saturated conditions to determine its maximum green extensions.

3. (covered in the lab)
We can come up with an optimal timing plan to minimize average vehicle delay, average number of stops, the variance of delay, the variance of number of stops, or a combination of these. Simulation can be used to obtain these measures under a specific design. We can go through a guess-and-check process to find the best split of cycle under a specific criteria.