CEE 320 Final Examination (2 hours)

- Please write your name on this cover.
- Please write your last name on all other exam pages

- This examination is open-book, open-note.
- There is a group work evaluation on page 2, which you must fill out.
- There are 8 questions worth a total of 200 points.
- Each question lists the point value for that question.

- Please work quietly and respect other people’s space.
- Carefully read each question and ensure that you answer what is asked.
- If you need additional workspace, use the back of the page or the blank page included at the end of the examination.
- If you need to unstaple pages, I have a stapler to restaple them at the end of the examination.

Name (first, last): ___________________________________________
**Group Work Evaluation**

This is your opportunity to evaluate your group for Projects 1 and 2. You have 100 points to assign to the group. Please write the last name of each group member and distribute these 100 points to your group members, including yourself, in accordance with their contribution to the group. This will be used as a weighting factor in your project grades.

<table>
<thead>
<tr>
<th>Group Member Name</th>
<th>Points Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Becker, Jordan A</td>
<td></td>
</tr>
<tr>
<td>Poshusta, Catherine Ann</td>
<td></td>
</tr>
<tr>
<td>Hall</td>
<td></td>
</tr>
<tr>
<td>Simmons, Shellie Marie</td>
<td></td>
</tr>
<tr>
<td>Ahmed, Nawzad Saeed Sr</td>
<td></td>
</tr>
<tr>
<td>Anderson, Elysha Marie</td>
<td></td>
</tr>
<tr>
<td>Jain, Michele Lynn</td>
<td></td>
</tr>
<tr>
<td>Nevitt, Bethany Pershing</td>
<td></td>
</tr>
<tr>
<td>Murphy, Adrienne Elisa</td>
<td></td>
</tr>
<tr>
<td>Nguyen, Luan Kinh</td>
<td></td>
</tr>
<tr>
<td>Tan, Ming Ming</td>
<td></td>
</tr>
<tr>
<td>Tang, Yu Q</td>
<td></td>
</tr>
<tr>
<td>Zeng, Tingling</td>
<td></td>
</tr>
<tr>
<td>Lynum, Eric George</td>
<td></td>
</tr>
<tr>
<td>Monken, Clint Michael II</td>
<td></td>
</tr>
<tr>
<td>West, Brian Frederick</td>
<td></td>
</tr>
<tr>
<td>Scholer, Jesse Ian</td>
<td></td>
</tr>
<tr>
<td>Berde, Max Eric</td>
<td></td>
</tr>
<tr>
<td>Berg, Gunnar James</td>
<td></td>
</tr>
<tr>
<td>Lee, Kevin Lieng</td>
<td></td>
</tr>
<tr>
<td>Kinzig, Christopher Carl</td>
<td></td>
</tr>
</tbody>
</table>

**Group A**
Becker, Jordan A  
Poshusta, Catherine Ann  
Hall  
Simmons, Shellie Marie  
Ahmed, Nawzad Saeed Sr

**Group B**
Anderson, Elysha Marie  
Jain, Michele Lynn  
Nevitt, Bethany Pershing  
Murphy, Adrienne Elisa

**Group C**
Nguyen, Luan Kinh  
Tan, Ming Ming  
Tang, Yu Q  
Zeng, Tingling

**Group D**
Lynum, Eric George  
Monken, Clint Michael II  
West, Brian Frederick  
Scholer, Jesse Ian

**Group E**
Berde, Max Eric  
Berg, Gunnar James  
Lee, Kevin Lieng  
Kinzig, Christopher Carl

**Group F**
Haigh, Christopher Charles  
Koekemoer, Rocco De Villiers  
Nguyen, Vu-Hoang Trung  
Posten, Dustin Lee

**Group G (see note 1 at lower right)**
Grife, Mariah Dianna  
Mak, Ryan Chi-Chung  
Phok, Wendiara Month

**Group H**
Roberts, Christopher Michael  
Warner, Alexander Keith  
Yamamoto, Kelli Ann  
Peterson, Kathleen Noel

**Group I (see note 2 at lower right)**
Patterson, Aaron Leigh  
Stringer, Stuart Judson  
Maier, Marcelo Martin  
Woen, Billie  
Ignacio, Ronald Arcena

**Group J**
Barthule, Wayne Robert  
Bigbee, Nathan Leigh  
Taylor, Matthew Allen  
Drescher, Jerome Raymond

**Group K**
Feskens, Ryan James  
Gothard, Matthew Otto  
McArdle, Carly Rose  
Pesicka, Benjamin Andrew

**Group L**
Fox, Trevor James  
Winter, Santtu Antti  
Oterson, Carol Lee Jr  
Goodall, Scott Ian

**Group M**
Jenkins, Joseph Allen  
Dove, David Jackson  
Prull, Joshua Lee  
Arflin, Anderson

**Group O**
Boyett, Jason William  
Gabelein, Timothy Wilson  
Riedy, Nathaniel Robert  
Jeevaratnam, Vamathan

---

**Note 1:** Group G, you lost a member for project 2. Please base your rating of group members on the 3 remaining members only.

**Note 2:** Group I, you gained a member for project 2. Do not penalize Ron for coming in on Project 2 only. I will fix that issue.
Question 1: Short Questions (5 points each)

What is the capacity (in terms of passenger cars per lane per hour) of a freeway whose measured free flow speed (FFS) is 65 mph?

2350 pc/ln/hr

3 points for the number, 2 points for the correct units

What is a peak hour factor (PHF) and what is it used to account for?

PHF is the ratio of the hourly volume in question to the maximum 15-minute flow rate expanded to an hourly volume. (if equation below is given at least some explanation of variables is needed to get full credit)

\[ PHF = \frac{V}{V_{15} \times 4} \]

It accounts for the varying or non-uniform vehicle arrival rate during the period of analysis

What large transportation system was analyzed by Daniel McFadden’s team as the original test of his discreet choice modeling system?

Bay Area Rapid Transit (BART)

Just “BART” is okay too.
For the SR 520 bridge, which situation is likely to have a lower peak hour factor (PHF)?

1. 1:00 a.m. on a Tuesday.
2. 5:00 p.m. on a Tuesday.

Remember that during times of high volume (peak hour) such as 5pm on a Tuesday, the volume is not likely to fluctuate much over the hour in question. This leads to a PHF near 1.0. In times of lower volume, it only takes a few vehicles to make the highest 15-minute flow (multiplied by 4) significantly higher than the hourly volume, which tends to drive PHF away from 1.0 and make it lower. This is evident on the traffic data from Project 2.

In terms of congestion, what does WSDOT feel is the most important metric to the public? (there are 2 items – either one is acceptable for full credit)

- Travel time predictability
- Travel time reliability

If they just say “travel time” then you get most credit (4 points) but not all.

Give 3 examples of intelligent transportation systems (ITS) used by the Washington State Department of Transportation.

- Traffic Systems Management Center
- Variable message signs
- Weather monitoring stations
- Traffic maps on web, PDA
- 511 traffic information service
- Trafficgauge devices
- Traffic cameras
- Ramp metering
- Weigh-in-motion stations
- There are many more

You must do more than just list ATMS, CVO, etc. You actually have to give examples.

If a highway performance function (HPF) assigns traffic to a route that results in LOS F, is the HPF travel time prediction still valid? Why or why not? (1 - 3 sentences should suffice).

Not valid. HPFs will give volumes no matter what the constraints. If you put a volume in, you get a travel time out. This needs to be tempered with knowledge of actual traffic flow. LOS F means that there is a breakdown in flow with stop-and-go situations. Flow rates vary greatly in LOS F conditions and will certainly be different than predicted by the HPF.

(Extra credit) Name a movie that who’s lead character is a transportation engineer.

Best answer I saw: Mission Impossible 3.
**Question 2 (30 points)**

At milepost 32.44, Aurora Avenue (SR 99) enters the Battery Street Tunnel in the southbound direction. There is a horizontal curve entering this tunnel with the dimensions shown below. Determine the design speed for this tunnel to the nearest 5 mph increment based on this horizontal curve (remember to round down).

**Cross Section View**

<table>
<thead>
<tr>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>tunnel wall</td>
<td>tunnel wall</td>
</tr>
<tr>
<td>tunnel wall</td>
<td>tunnel wall</td>
</tr>
<tr>
<td>4 ft.</td>
<td>10 ft.</td>
</tr>
<tr>
<td>2 ft. wide</td>
<td>10 ft.</td>
</tr>
<tr>
<td>R = 409 ft.</td>
<td></td>
</tr>
</tbody>
</table>

**Plan View**

- R = 409 ft.
- Δ = 22.69º
- No superelevation

You need to check both the horizontal curve SSD and the superelevation. I realize you can get the right answer even if you ignore superelevation but doing so does not represent good engineering practice. You really have to look at it.

**First, check SSD**

\[
M_s = \frac{1}{2} \text{ inside lane + distance to wall} = 5 + 2 = 7
\]

\[
R_v = 409 - 4 - 10 - 5 = 390 \text{ ft}
\]

\[
SSD = \frac{\pi R_v}{90} \left[ \cos^{-1} \left( \frac{R_v - M_s}{R_v} \right) \right] = \frac{\pi (390)}{90} \left[ \cos^{-1} \left( \frac{390 - 7}{390} \right) \right] = 148 \text{ ft}
\]

From Table 3.1 in the text, 25 mph SSD = 155 ft and 20 mph SSD = 115 ft. Therefore, to the nearest 5 mph, the design speed based on SSD = 20 mph.

For full credit, you need to check superelevation for 20 mph:

\[
R_v = \frac{V^2}{g(f_s + e)} = \frac{(20 \times 1.47)^2}{32.2(0.27 + 0)} = 99.42 \text{ ft}
\]

The 0.27 is the \( f_s \) used in the Table 3.5 replacement for 20 mph. Therefore, you only need 99.42 ft but your actual \( R_v \) is 390 ft so the curve is okay for 20 mph in terms of superelevation (or lack of superelevation). The limiting factor is SSD and the design speed is 20 mph. These are the actual dimensions of this curve. The speed limit here is actually 40 mph. Is it safe according to AASHTO standards? Not really. My recommendation: drive on the outside lane here to increase your SSD.
Question 3 (25 points)

Assume the logit model shown below describes the choice of which of three parking lots people will choose when attending Mariners’ games at Safeco Field. If there is a total of 2,500 vehicles choosing between these lots for a Wednesday night game against the Detroit Tigers, answer the following questions:

1. What is the maximum amount Homeplate Parking could charge for parking and still expect to sell every space in its lot?
2. With a security guard on duty, Homeplate Parking can charge more per space and still sell out the lot. On average, is it cost effective (will they make more additional money than they spend on the guard) for Homeplate Parking to hire a security guard at $250 for the evening? Show calculations to support your answer.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Profile values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Safeco Field Garage (2,000 spaces)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>4.77</td>
<td>1</td>
</tr>
<tr>
<td>Distance to nearest ballpark entrance (feet)</td>
<td>-0.03</td>
<td>200</td>
</tr>
<tr>
<td>Parking fee (dollars)</td>
<td>-0.1</td>
<td>25</td>
</tr>
<tr>
<td>Covered parking available (1 if available, 0 if not)</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Number of kids in car attending game</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Homeplate Parking (400 spaces)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to nearest ballpark entrance (feet)</td>
<td>-0.01</td>
<td>300</td>
</tr>
<tr>
<td>Parking fee (dollars)</td>
<td>-0.1</td>
<td>??</td>
</tr>
<tr>
<td>Security guard on duty and visible (1 if yes, 0 if no)</td>
<td>0.09</td>
<td>0</td>
</tr>
<tr>
<td><strong>Qwest Field Garage (1,000 spaces)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-4.93</td>
<td>1</td>
</tr>
<tr>
<td>Parking fee (dollars)</td>
<td>-0.1</td>
<td>15</td>
</tr>
<tr>
<td>Arrival time (in minutes before first pitch)</td>
<td>0.11</td>
<td>15</td>
</tr>
</tbody>
</table>

Find utilities

\[ U_{\text{safeco}} = 4.77 - 0.03(200) - 0.1(25) + 0.1(1) + 0.2(1) = -3.43 \]
\[ U_{\text{HP}} = -0.01(300) - 0.1(x) + 0.09(0) = -3 - 0.1x \]
\[ U_{\text{qwest}} = -4.93 - 0.1(15) + 0.11(15) = -4.78 \]

Find exponentials

\[ e^{U_{\text{safeco}}} = e^{-3.43} = 0.0324 \]
\[ e^{U_{\text{qwest}}} = e^{-4.78} = 0.0084 \]
For Homeplate Parking to sell out they must sell 400 spaces. Find the probability of selecting Homeplate Parking such that exactly 400 of the 2500 potential customers will choose it.

\[ P_{HP} = \frac{400}{2500} = 0.16 \]

Now solve for x using the probability equation for Homeplate Parking

\[ P_{HP} = 0.16 = \frac{e^{U_{HP}}}{e^{U_{HP}} + 0.0084 + 0.0324} = \frac{e^{U_{HP}}}{e^{U_{HP}} + 0.0408} \]

\[ 0.0065 = 0.84e^{U_{HP}} \Rightarrow U_{HP} = -4.857 \]

Now solve for x:

\[ -4.857 = -3 - 0.1x \Rightarrow x = 18.57 \]

Now find out about the security guard. How much more could Homeplate Parking charge per space with a security guard present? The utility equation changes to:

\[ U_{HP} = -0.01(300) - 0.1(x) + 0.09(1) = -2.91 - 0.1x \]

Now solve for x:

\[ -4.857 = -2.91 - 0.1x \Rightarrow x = 19.47 \]

Therefore, you could charge $0.90 more per space and make 0.90 \times 400 = $360 more. This is less than the cost of the security guard ($250) so it is cost effective to hire a security guard.
**Question 4 (25 points)**

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**

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

\[
\ln \lambda = -1.5 + 0.1 + 0.0001 \times 55 + 0.1 \times 1 + 0.1 \times 4 - 1 \times 0.1 - 0.1 \times 0 + 0.15 \times 1.3 = -0.1995
\]

\[
e^{-0.1995} = 0.8191
\]

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

\[
P(n) = \frac{e^{-\lambda} \lambda^n}{n!} \quad P(0) = \frac{e^{-0.8191}(2)^0}{0!} = 0.1943
\]

Therefore, the probability of this household taking zero trips in 2 days is about 19.43%
Question 5 (25 points)

I-82 eastbound leaves Selah, WA and enters the U.S. Military Training Reservation before it reaches Umtanum Pass. At milepost 22.65, in the middle of this upgrade, the eastbound portion of the Interstate has the following characteristics:

- Rural freeway classification
- No HOV lanes
- 11 ft lane width
- 10 ft right-side shoulders
- 2 eastbound lanes (4 lanes total)
- 1 on-ramp between MP 19.65 and 25.65
- Peak hour factor = 0.91
- 23% trucks and buses
- 2% recreational vehicles
- 5% upgrade for 1 mile
- Driver population adjustment factor = 1.0

Using this data and the related WSDOT Peak Hour Report on the following page, report the following information related to LOS on the highest eastbound volume day of 2006:

1. Date, hour and day of the week for the highest eastbound volume.
2. Free flow speed for this section of freeway (to the nearest mile per hour).
3. The 15-minute passenger-car equivalent flow rate ($v_p$ in pcplph).
4. The freeway section level of service (LOS).
5. LOS if truck and bus traffic increased from the current 23% to 40%.

Find FFS

$$F F S = B F F S - f_{LW} - f_{LC} - f_N - f_{ID}$$

BFFS = 75 mph because it is a rural freeway and no other information is 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
- $f_N = 0$ from Table 6.5 because it is always 0 for rural freeway segments
- $f_{ID} = 0$ from Table 6.6

$$F F S = B F F S - f_{LW} - f_{LC} - f_N - f_{ID} = 75 - 1.9 - 0 - 0 - 0 = 73.1 = 73 \text{ mph}$$

Note, must say 73 mph for full credit (to nearest mph)

Calculate $f_{HV}$

Table 6.8 gives $E_T = 3.0$ for a 5% upgrade for 1 mile
Table 6.9 gives $E_R = 4.5$ for a 5% upgrade for 1 mile

$$f_{HV} = \frac{1}{1 + P_T (E_T - 1) + P_R (E_R - 1)} = \frac{1}{1 + (0.23)(3.0 - 1) + (0.02)(4.5 - 1)} = 0.6536$$
Find $v_p$

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

PHF = 0.91  
N = 2  
f_{HV} = 0.6536  
f_p = 1.0

Find $V$
Use the Peak Hour Report page for the highest volume in the EB direction. This is actually the second highest total volume and gives 1,327 veh/hr. This occurs on 11/22/06 during the 1700 or 5:00 p.m. hour (5-6 pm). Right before Thanksgiving.

$$v_p = \frac{1327}{0.91 \times 2 \times 0.6536 \times 1} = 1,116 \text{ pcplph}$$

Find LOS
From Figure 6.2, speed ($S$) = 73 mph

$$D = \frac{v_p}{S} = \frac{1116}{73} = 15.28 \text{ pcplpm}$$

From Table 6.1, LOS B

If the truck percentage increases to 40%

$$f_{HV} = \frac{1}{1 + P_T (E_T - 1) + P_R (E_R - 1)} = \frac{1}{1 + (0.40)(3.0 - 1) + (0.02)(4.5 - 1)} = 0.5348$$

$$v_p = \frac{1327}{0.91 \times 2 \times 0.5348 \times 1} = 1,363 \text{ pcplph}$$

From Figure 6.2, speed ($S$) = 72 or 73 mph (equations on slide 37 give 72.9 mph)

$$D = \frac{v_p}{S} = \frac{1363}{73} = 18.67 \text{ pcplpm}$$

From Table 6.1, LOS C
### SR 82 MP 24.83 SELAH ADC SITE R048
**K FOR PEAK 200 HOURS OF 2006**

**AADT= **15596  
**K 30 FACTOR= **11.25  
**K 100 FACTOR= **10.58  
**K 200 FACTOR= **9.92  
**D FACTOR= **54.84

### SR 82 MP 24.83 SELAH ADC SITE R048
**D% IN THE PEAK 200 HOURS OF 2006**

<table>
<thead>
<tr>
<th>MO</th>
<th>DY</th>
<th>YR</th>
<th>WK</th>
<th>HR</th>
<th>HR VOL</th>
<th>PERCENT OF AADT</th>
<th>HOUR NUMBER</th>
<th>AADT</th>
<th>EAST VOLUME</th>
<th>WEST VOLUME</th>
<th>EAST % OF TOTAL VOLUME</th>
<th>WEST % OF TOTAL VOLUME</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>22</td>
<td>6</td>
<td>4</td>
<td>18</td>
<td>2150</td>
<td>13.79</td>
<td>1</td>
<td>18596</td>
<td>1292</td>
<td>158</td>
<td>60.09</td>
<td>39.91</td>
</tr>
<tr>
<td>11</td>
<td>22</td>
<td>6</td>
<td>4</td>
<td>17</td>
<td>2036</td>
<td>13.07</td>
<td>2</td>
<td>1545</td>
<td>1327</td>
<td>158</td>
<td>65.08</td>
<td>34.92</td>
</tr>
<tr>
<td>11</td>
<td>22</td>
<td>6</td>
<td>4</td>
<td>15</td>
<td>2030</td>
<td>13.32</td>
<td>3</td>
<td>1101</td>
<td>926</td>
<td>158</td>
<td>64.24</td>
<td>35.76</td>
</tr>
<tr>
<td>5</td>
<td>26</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>2045</td>
<td>13.23</td>
<td>4</td>
<td>1064</td>
<td>952</td>
<td>158</td>
<td>62.78</td>
<td>37.22</td>
</tr>
<tr>
<td>5</td>
<td>26</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>1937</td>
<td>12.68</td>
<td>5</td>
<td>961</td>
<td>1303</td>
<td>158</td>
<td>33.90</td>
<td>66.10</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>17</td>
<td>1833</td>
<td>12.14</td>
<td>5</td>
<td>788</td>
<td>1097</td>
<td>158</td>
<td>42.05</td>
<td>57.95</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>18</td>
<td>1961</td>
<td>11.93</td>
<td>7</td>
<td>791</td>
<td>1070</td>
<td>158</td>
<td>42.5</td>
<td>57.5</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>6</td>
<td>6</td>
<td>19</td>
<td>1945</td>
<td>11.83</td>
<td>8</td>
<td>1118</td>
<td>727</td>
<td>158</td>
<td>60.9</td>
<td>39.1</td>
</tr>
<tr>
<td>5</td>
<td>26</td>
<td>6</td>
<td>6</td>
<td>18</td>
<td>1844</td>
<td>11.82</td>
<td>9</td>
<td>1067</td>
<td>837</td>
<td>158</td>
<td>54.61</td>
<td>45.39</td>
</tr>
<tr>
<td>11</td>
<td>22</td>
<td>6</td>
<td>4</td>
<td>14</td>
<td>1940</td>
<td>11.18</td>
<td>10</td>
<td>938</td>
<td>984</td>
<td>158</td>
<td>51.90</td>
<td>48.10</td>
</tr>
</tbody>
</table>
Problem 6 (20 points)

A new freeway ramp meter will be installed on the Medina onramp to westbound SR 520. There is 70 ft from the ramp meter stop line back to the nearest intersection, and each stopped vehicle takes up an average of 20 ft. The desired meter rate is one vehicle every 10 seconds, while the arrival rate averages one vehicle arrival every 11 seconds.

Using M/D/1 queue analysis answer the following questions:

- What is the average queue length?
- Will the average queue length extend into the intersection?
- What is the average time spent in the system (in seconds)?
- What meter rate (in terms of time between vehicles), calculated to the nearest whole second, will result in an average queue length of less than 1 vehicle?

\[
\rho = \frac{\lambda}{\mu} = \frac{5.45 \text{ vehicles}}{6 \text{ vehicles/min}} = 0.9083
\]

\[
\overline{Q} = \frac{\rho^2}{2(1 - \rho)} = \frac{(0.9083)^2}{2(1 - 0.9083)} = 4.5 \text{ vehicles} \quad \text{(using } \rho = 0.9 \text{ gives 4.05 vehicles, OK)}
\]

Therefore, at 20 ft/vehicle your queue length (on average) is:

\[
4.5 \times 20 = 90 \text{ ft} \quad \text{Realistically, this means the queue on average is either 4 or 5 vehicles long (80 or 100 ft) – both lengths are over the 70 ft provided and thus the queue would extend into the intersection.}
\]

\[
\overline{w} = \frac{1}{2\mu} \left( \frac{\rho}{1 - \rho} \right) = \frac{1}{2(6)} \left( \frac{0.9083}{1 - 0.9083} \right) = 0.825 \text{ min} = 49.5 \text{ sec}
\]

\[
\overline{t} = \frac{1}{2\mu} \left( \frac{2 - \rho}{1 - \rho} \right) = \frac{1}{2(6)} \left( \frac{2 - 0.9083}{1 - 0.9083} \right) = 1.0 \text{ min}
\]

About 1 minute = average time spent in the system.

For the adjusted meter rate, you want to solve the “average length of queue” equation so Q-bar \( \leq 1.0 \)

\[
\overline{Q} = \frac{\rho^2}{2(1 - \rho)} = \frac{(\rho)^2}{2(1 - \rho)} = 1 \text{ vehicle}
\]
\[ 2 - 2\rho = \rho^2 \quad \Rightarrow \quad \rho^2 + 2\rho - 2 = 0 \quad \Rightarrow \quad \rho = 0.7321 \text{ or } -2.7321 \]

Obviously, you can’t have a negative number for \(\rho\) so choose 0.7321. Now, enter this into the equation for \(\rho\) to get arrival rate:

\[
\rho = \frac{\lambda}{\mu} = \frac{5.45 \text{ vehicles}}{\mu \text{ min}} = 0.7321 \quad \Rightarrow \quad \mu = 7.44 \text{ vehicles/ min} = 8.06 \text{ sec/ vehicle} 
\]

Depending upon your rounding you could have gotten answers a bit different than this.
Question 7 (15 points)

A semi-tractor trailer crosses a set of dual loop detectors with the geometry shown below. The on-time for loop 1 is 0.83 seconds and the on-time for loop 2 is 0.91 seconds. The truck triggers loop 2 at 0.33 seconds after loop 1. How long is the truck and trailer combination?

Use the dual loop equations for determining speed and length on slide 31 of the traffic detection lecture notes.

\[
\text{Speed} = \frac{I_{\text{dist}}}{t_2 - t_1} = \frac{(20 + 6)}{0.33} = 78.79 \text{ ft sec} \\
L_{\text{truck}} = \frac{\text{Speed}(ot_1 + ot_2)}{2} = \frac{78.79(0.83 + 0.91)}{2} = 68.55 \text{ ft}
\]
Question 8 (25 points)
You are designing a vertical alignment for a portion of SR 9 near Marysville. An equal
tangent crest vertical curve must go align with an existing intersection. At the center of
the intersection SR 9 must be flat and at the existing intersection’s elevation. Known
grades, stationing and elevations are given in the drawing below.

Report the following:

- PVC and PVT stations
- PVC and PVT elevations
- Design speed rounded down to the nearest 5 mph.

Profile View

At PVC, \( y = c \). Therefore, \( c = 255 \) (elevation of PVI) – \( L/2(G_1) = 255 – L \) (L in stations)
At PVC, \( b = G_1 = 2.0 \)

Anywhere, \( a = \frac{G_2 - G_1}{2L} = \frac{-4.0 - 2.0}{2L} = \frac{-6.0}{2L} = \frac{-3.0}{L} \)

The high point of the curve is when the derivative = 0. Working in percent and stations,
\[ \frac{dy}{dx} = 2ax + b = 0 = 2 \left( \frac{-3.0}{L} \right) x + 2 \quad \Rightarrow \quad x = 0.33L \]

Put everything into the equation of the curve with the only unknown being \( L \).
\[ y = ax^2 + bx + c \quad \Rightarrow \quad 250 = -\frac{3.0}{L} \left(0.33L\right)^2 + 2.0(0.33L) + \left(255 - L\right) \]
\[ 250 = -0.327L + 0.67L + 25 - L \]
0.657L = 5 \quad \Rightarrow \quad L = 7.61 \text{ stations } = 761 \text{ ft}

Find PVC and PVT stations

\[
STA_{PVC} = 1900 - x = 1900 - 0.33(761) = 1648.9 = 16 + 48.9
\]

\[
STA_{PVT} = STA_{PVC} + L = 1648.9 + 761 = 2409.9 = 24 + 09.9
\]

Find the PVC and PVT elevations

\[
elev_{PVC} = 255 - L = 255 - 7.61 = 247.39 \text{ ft}
\]

\[
elev_{PVT} = elev_{PVT} + G_2 \left( \frac{L}{2} \right) = 255 - 0.04 \left( \frac{761}{2} \right) = 239.8 \text{ ft}
\]

Design Speed

\[
K = \frac{L}{A} = \frac{761}{6} = 126.8
\]

From Table 3.2 in the text, K = 114 for 55 mph and K = 151 for 60 mph. Therefore, the design speed rounded down to the nearest 5 mph is 55 mph.

There are other ways to do it using things like:

- High point = K|G_i|
- Other brute force methods – there actually were a couple of real good ones – I am impressed