CV4112 Traffic Engineering
Semester 1 Examination 2021-2022
Suggested Solutions by Lim Kai Jian

Q1(a)

Period	Sample Size	Sample Mean Speed	Sample s.d
Before	$n_1 = 28$	$\bar{x}_1 = 76.8$ km/h	$S_1 = 11.8$ km/h
After	$n_2 = 74$	$\bar{x}_2 = 68.2$ km/h	$S_2 = 15.2$ km/h

Check if variances are equal or not:

$H_0: \sigma_1^2 - \sigma_2^2 = 0$

$H_1: \sigma_1^2 - \sigma_2^2 \neq 0$

$f_{1-\alpha/2}(v_1, v_2)$ $f_{\alpha/2}(v_1, v_2)$

$= \left[f_{\alpha/2}(v_2, v_1)\right]^{-1}$

$$f_{obs} = \frac{S_1^2}{S_2^2} = \frac{11.8^2}{15.2^2} = 0.603$$

$v_1 = 28 - 1 = 27$, $v_2 = 74 - 1 = 73$

$f_{0.05}(27, 73) = 1.6389$

$$f_{1-0.05}(27, 73) = \frac{1}{f_{0.05}(73, 27)} = \frac{1}{1.766} = 0.566$$

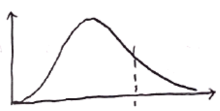
Since f_{obs} does not fall in the rejection zone, H_0 is not rejected and the population variances are equal.

Hypothesis Testing for Speed Reduction: (Pop ~ Normal, pop. variance unknown $n_1 < 30 \Rightarrow$ t - test w/ pooled variance)

1 sided testing

$H_0: \mu_1 - \mu_2 = 4$

$H_1: \mu_1 - \mu_2 > 4$



$t_{0.10}, v = n_1 + n_2 - 2$
$= 28 + 74 - 2 = 100$

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{(n_1 + n_2 - 2)}$$

$$= \frac{(28-1)(11.8)^2 + (74-1)(15.2)^2}{(28 + 74 - 2)}$$

$$= 206.254$$

$S_p = 14.362$

$$t_{obs} = \frac{(76.8 - 68.2) - 4}{14.3615\sqrt{\frac{1}{28} + \frac{1}{74}}} = 1.4436 > t_{critical} = 1.290$$

$\therefore$ H_0 is rejected and there is a speed reduction of more than 4km/h

Lower Bound of Confidence Interval:

$$P(\mu_1 - \mu_2 > t_\alpha) = 1 - \alpha = 0.90$$

$$\Rightarrow \text{Lower Bound} = (\bar{x}_1 - \bar{x}_2) - t_{0.10}\left(14.3615\sqrt{\frac{1}{28} + \frac{1}{74}}\right)$$

$$= (76.8 - 68.2) - 1.290 \times 3.186$$

$$= 4.49 \text{ km/h}$$

$\Rightarrow$ 90% chance the difference $(\mu_1 - \mu_2)$ will be greater than 4.49 km/h

Q1(b)

Perhaps the before-study will be better if the sample size is greater than 30 such that the study can be shorter as we can immediately use the z-test for the test statistic.

Q2(a)

Rank	Movement
1	2, 3, 5, 6 - slip road
2	1, 4, 9, 12 - slip road
3	8, 11
4	7, 10

Movement 1

$P_{0,1} = 0.90$

Movement 4

$P_{0,4} = 0.83$

Movement 11

$P_{0,11} = 0.527$

Movement 12

$P_{0,12} = 0$

Movement 9 (Rank 2)

$V_{c,9} = V_5/N = 340/2 = 170$ veh/h

$C_{m,9} = C_{p,9} = 831$ veh/h

Movement 8 (Rank 3)

$V_{c,8} = 2V_4 + V_5 + 2V_1 + V_2 + V_3 = 1044$ veh/h

$C_{p,8} = 242$ veh/h

$C_{m,8} = 242\ (0.83)(0.90) = 181$ veh/h

Movement 7 (Rank 4)

$V_{c,7} = 2V_4 + V_5 + 2V_1 + V_2/N + 0.5V_{11} = 859$ veh/h

$C_{p,7} = 276$ veh/h

$p'' = (0.90)(0.83)(0.527) = 0.39367$

$p' = 0.65(0.39367) - (0.39367)/(0.039367 + 3) + 0.6(0.39367)^{0.5} = 0.5163$

$C_{m,7} = 276\ (0.5163) = 143$ veh/h

Shared Lane Capacity, $C_{SH} = \frac{66+78+86}{\frac{66}{143}+\frac{78}{181}+\frac{86}{831}} = 231$ veh/h

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Q2(b)

Delay of N-B approach = 103.2 s

(Using the control delay formula for unsignalized intersection, where $C_{m,x}$ = 231, T = 0.25, V_x = 230)

LOS = F

The performance of LOS F means that the junction is operating beyond its capacity. Perhaps, converting the intersection to a signalised intersection can help to direct traffic better.

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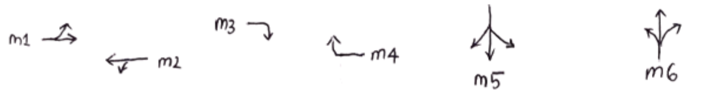
Q3

$C = \sum_i (I+G)_i \qquad L = nl + \sum_{j=1}^{n} R_j$

×1.25 (excess of 10%) , ×1.75 RT

Phase A Phase B Phase C Phase D



$S = 525w, \quad S = \dfrac{1800}{1 + \frac{1.52}{r}}$

A → B → C → D → A

Compute Traffic Flow

$V_1 = 1077 + (211 - 1584 \times 0.1)(1.25) + 1584(0.1)$
$= 1301$ pcu/h

$V_2 = 993 + (169 - 1479 \times 0.1)(1.25) + 1479(0.1)$
$= 1167$ pcu/h

$V_3 = 296$ pcu/h

$V_4 = 317$ pcu/h

$V_5 = 243 + (264 - 592 \times 0.1)(1.25) + 592 \times 0.1 + 85(1.75)$
$= 707$ pcu/h

$V_6 = 422 + (106 - 760 \times 0.1)(1.25) + 760 \times 0.1 + 232(1.75)$
$= 942$ pcu/h

Compute Saturation Flow

$S_1 = S_2 = 525(3 \times 3.6) = 5670$ pcu/h

$S_3 = S_4 = \dfrac{1800}{1 + \frac{1.52}{16}} = 1643$ pcu/h

$S_5 = S_6 = 525(2 \times 3.6) = 3780$ pcu/h

V/s ratio

$y_1 = 1301/5670 = \underline{0.229}$ } Phase A
$y_2 = 1167/5670 = 0.205$

$y_3 = 296/1643 = 0.180$ } Phase B
$y_4 = 317/1643 = \underline{0.192}$

$y_5 = 707/3780 = \underline{0.187}$ Phase C

$y_6 = 942/3780 = \underline{0.249}$ Phase D

$\sum_{i=1}^{n} y_i = 0.857$

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$$L = 4(2) + 4(1) = 12\,s \quad , \quad C_o = \frac{1.5(12) + 5}{1 - 0.857} \approx 165\,s$$

$$\text{Green Time} = 165 - 4(4) = 149\,s$$

Phase A : $\frac{0.229}{0.857} \times 149 = 39.8\,s \quad > G_{min} = 25\,s$

Phase B : $\frac{0.192}{0.857} \times 149 = 33.4\,s$

Phase C : $\frac{0.187}{0.857} \times 149 = 32.5\,s \quad > G_{min} = 32\,s$

Phase D : $\frac{0.249}{0.857} \times 149 = 43.3\,s \quad > G_{min} = 32\,s$

Discuss: The right turning traffic for the minor approaches is not significant and if a phase is assigned specifically for this movement, it may not be the most optimal.

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Q4(a)

- 3 lanes each direction
- 3.6m wide lanes
- 3%, 3 km long upgrade
- 8% trucks, no RV
- Interchange 1.3km apart
- No lateral obstructions
- PHF = 0.90
- $f_p = 1.0$

Rural Highway · 3%, 3 km long upgrade

Speed Limit = 100 km/h ⇒ BFFS = 110 km/h

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID}$$
$$= 110 - 0 - 0 - 0 - 5.69$$
$$= 104.3$$

$$f_{HV} = \frac{1}{1+0.08(2.0-1)} = 0.926$$

At LOS E, $V_p\ max = 2300 + 50\left(\frac{4.3}{10}\right)$

$$V_p = \frac{V}{PHF \times f_p \times N \times f_{HV}} < 2321.5$$

$$V < 2321.5\ (0.926)(1.0)(3)(0.90)$$
$$= 5804 \text{ veh/h}$$

Q4(b)

Urban Expressway

$$FFS = 110 - 5.6 - 0 - 2.4 - 5.69$$
$$= 96.3 \text{ km/h}$$

Assumptions:

Posted speed limit unchanged. f_p unchanged

Interchange density unchanged. PHF unchanged

Percentage of trucks & RV & upgrade unchanged

At LOS E, $V_p\ max = 2250 + 50\left(\frac{6.3}{10}\right) = 2281.5$ pc/h/ln

$$V_p = \frac{V}{PHF \times f_p \times N \times f_{HV}} < 2281.5 \Rightarrow V < 2281.5\,(0.90)(1.0)(4)(0.926) = 7605 \text{ veh/h}$$

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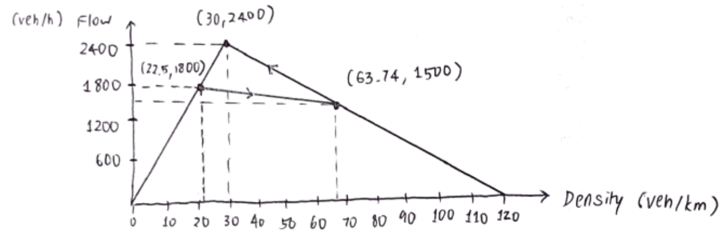
Q5

Q5. Flow - Density



$$3200 - 26.67k = 1500$$

$$k = \frac{1500 - 3200}{-26.67} = 63.74$$

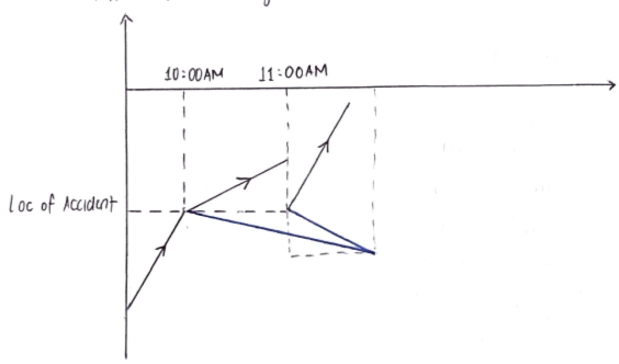
(a) Speed of Forming Shockwave

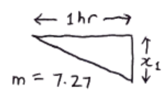
$$= \frac{q_2 - q_1}{k_2 - k_1} = \frac{1500 - 1800}{63.74 - 22.5} = -7.27 \text{ km/h} \quad \text{(backwards)}$$

Speed of Clearing Shockwave

$$= \frac{q_3 - q_2}{k_3 - k_2} = \frac{2400 - 1500}{30 - 63.74} = -26.67 \text{ km/h} \quad \text{(backwards)}$$

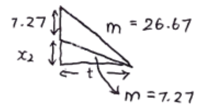
Time - Space Diagram





$$\frac{x_1}{1} = 7.27$$

$$x_1 = 7.27 \text{ km}$$



$$\frac{7.27 + x_2}{t} = 26.67$$

$$7.27 + x_2 = 26.67t$$

$$\frac{x_2}{t} = 7.27$$

$$x_2 = 7.27t$$

$$7.27 + 7.27t = 26.67t$$

$$t = \frac{7.27}{26.67 - 7.27} = 0.3747 \text{ hr}$$

$$x_2 = 7.27(0.3747) = 2.73 \text{ km}$$

Time that it intersects = 11.23 AM

Distance of intersection = $-7.27 - 2.73 = -10$ km (upstream)

Note: m refers to the gradient of the slope, which is also the magnitude of the speed

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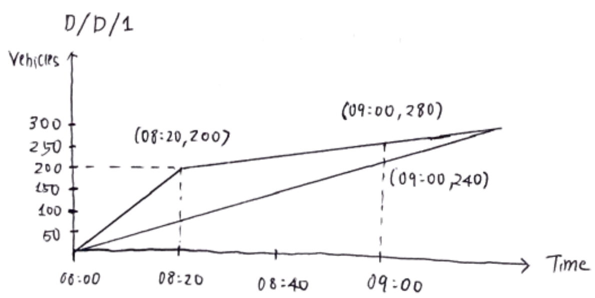
Q6(a)



λ - 600 veh/h for $t \leq 20$ mins
120 veh/h

μ - 1 veh / 15s
4 veh/min
240 veh/hr

Longest Queue $= 200 - 240\left(\frac{2}{6}\right) = 120$

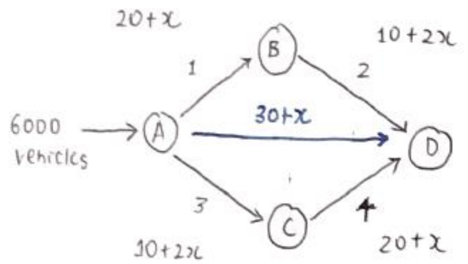
Time of Occurrence = 08:20AM

Queue Dissipate when:

$280 + 120\left(\frac{x}{60}\right) = 240 + 240\left(\frac{x}{60}\right)$

$x = 20 \Rightarrow$ at 09:20 AM

Q6(b)



Initially:

Path 1: A → B → D

Path 2: A → C → D

Travel time for both paths
@ Nash Equilibrium:

$x_1 = x_2 = 3$

$20 + x_1 + 10 + 2x_1 = 10 + 2x_2 + 20 + x_2$

$= 39$ mins

Adding a new link:

		Timing
Path 1 :	A → B → D	$20 + x_1 + 10 + 2x_1 = 33.6$ mins
Path 2 :	A → C → D	$10 + 2x_2 + 20 + x_2 = 33.6$ mins
Path 3 :	A → D	$30 + x_3 = 33.6$ mins

① = ② : $30 + 3x_1 = 30 + 3x_2$

$x_1 = x_2$

① = ③ : $30 + 3x_1 = 30 + x_3$

$3x_1 - x_3 = 0$

$x_3 = 3x_1$

② = ③ : $30 + 3x_2 = 30 + x_3$

$x_3 = 3x_2$

$x_1 + x_2 + x_3 = 6$

$x_1 + x_1 + 3x_1 = 6$

$x_1 = 1.2$

$x_3 = 3(1.2)$

$= 3.6$

Braess' paradox will not be observed since the duration of travel has reduced for all 3 paths after the addition of the new link.

Q6(c)

Congestion Pricing works on the principle that road users pay in proportion to the congestion that they are causing to other road users. In economic terms, it is equivalent to the marginal external congestion cost, and considers the societal optimum point

Toll Collection works on the principle that the road users pay according to what they will be using, such as a section of the highway. It does not consider the Marginal cost, in terms of the economics perspective.

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