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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2015/2016

COURSE NAME	:	ADVANCED TRAFFIC ENGINEERING
COURSE CODE	:	BFT 40503
PROGRAMME	:	BACHELOR OF CIVIL ENGINEERING WITH HONOURS
DATE	:	DECEMBER 2015 / JANUARY 2016
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS

THIS QUESTION PAPER CONSISTS OF **ELEVEN (11)** PAGES

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Q1 (a) In 1959, Harold Greenberg concluded that traffic speed and density are related through the following model:

$$v = C \ln\left(\frac{k_j}{k}\right)$$

where v = speed (km/h), k = density (veh/km), k_j = jam density (veh/km) and C = constant.

Prove that the constant C is actually the value of the optimal speed (v_m).

(8 marks)

(b) **Table 1** shows speed and density data obtained from traffic surveillance along an exit ramp of an expressway.

(i) Develop a linear equation to show the relationship between speed and density on this exit ramp using regression analysis.

(12 marks)

(ii) Estimate the maximum flow along the exit ramp based on the equation that you have developed in **Q1(b)(i)**.

(5 marks)

Q2 Data on accepted and rejected gaps of vehicles turning left from the minor road of an unsignalised intersection is shown in **Table 2**. The peak hour volume is 1,200 veh/hr and the arrival of the major road vehicles is assumed to follow a Poisson distribution.

(a) Estimate the critical gap using Raff's calculation method.

(15 marks)

(b) Verify your answer in **Q2(a)** by using a graphical method.

(6 marks)

(c) Predict the number of acceptable gaps that will be available for minor road vehicles turning left onto the major road during the peak hour.

(4 marks)

Q3 The layout and traffic demand, in passenger car unit per hour (pcu/hr), of a four-leg intersection that is to be upgraded to a signalised intersection using a 4-phased signal system are shown in **Figure Q3**. The saturation flows and pedestrian volumes for the four approaches are provided in **Table 3**. The following information is also given:

All red interval (R)	= 2 sec
Yellow interval per phase (τ)	= 4 sec
Lost time per phase (l)	= 3 sec
Desired critical volume-capacity ratio (X_c)	= 0.85
Effective pedestrian crosswalk width (W_E)	= 2.5 m
Pedestrian crosswalk length (L)	= 14 m
Average pedestrian speed (S_P)	= 1.22 m/s

(a) Propose a suitable cycle time (C) using the methodology recommended by Highway Capacity Manual (HCM).

(13 marks)

(b) Determine the actual green time (G_a) for each phase.

(4 marks)

(c) Check if the minimum green times required for pedestrian crossing (G_p) are sufficient or not.

(8 marks)

Q4 The performance of a 1.2 km of divided four-lane principal arterial with two signalised intersections at spacings of 700 m and 500 m is analysed. The green times are 30 sec and 35 sec respectively. The following information is provided:

Speed limit	= 70 km/h
Traffic volume (v)	= 850 veh/h
Saturation flow (s)	= 1,850 pc/h/ln
Signal type	= Pretimed
Arrival type	= Type 3
Initial queue delay (d_3)	= 0 sec
Cycle length (C)	= 120 sec
Analysis period (T)	= 0.25 hours

(a) Determine the class and free flow speed of the arterial.

(3 marks)

(b) Calculate the capacity (c), degree of saturation (X) and running time (T_R) for each segment.

(10 marks)

(c) Evaluate the performance of each segment in terms of control delay (d) and travel speed (S_A).

(12 marks)

- END OF QUESTIONS -

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Table 1: Density and speed data obtained along the exit ramp of an expressway

Density (veh/km)	Speed (km/h)
12	80
22	72
23	65
26	66
31	54
30	59
37	47
42	41

Table 2: Accepted and rejected gaps

Gap, t (sec)	Number of Accepted Gaps < t	Number of Rejected Gaps > t
1	3	108
2	11	85
3	29	54
4	54	32
5	90	10
6	112	2

Table 3: Saturation flows and pedestrian volumes on the approaches

Phase	1		2		3		4	
Approach	West		East		North		South	
Movement	Through + Left	Right	Through + Left	Right	Through + Left	Right	Through + Left	Right
Saturation Flow [a]	1800	1000	1700	1000	1600	900	1700	900
Number of Pedestrians Crossing [b]	40		35		30		25	

Note: a The unit for saturation flow is passenger car unit/hour .
b The unit for number of pedestrians crossing is pedestrians/interval/direction.

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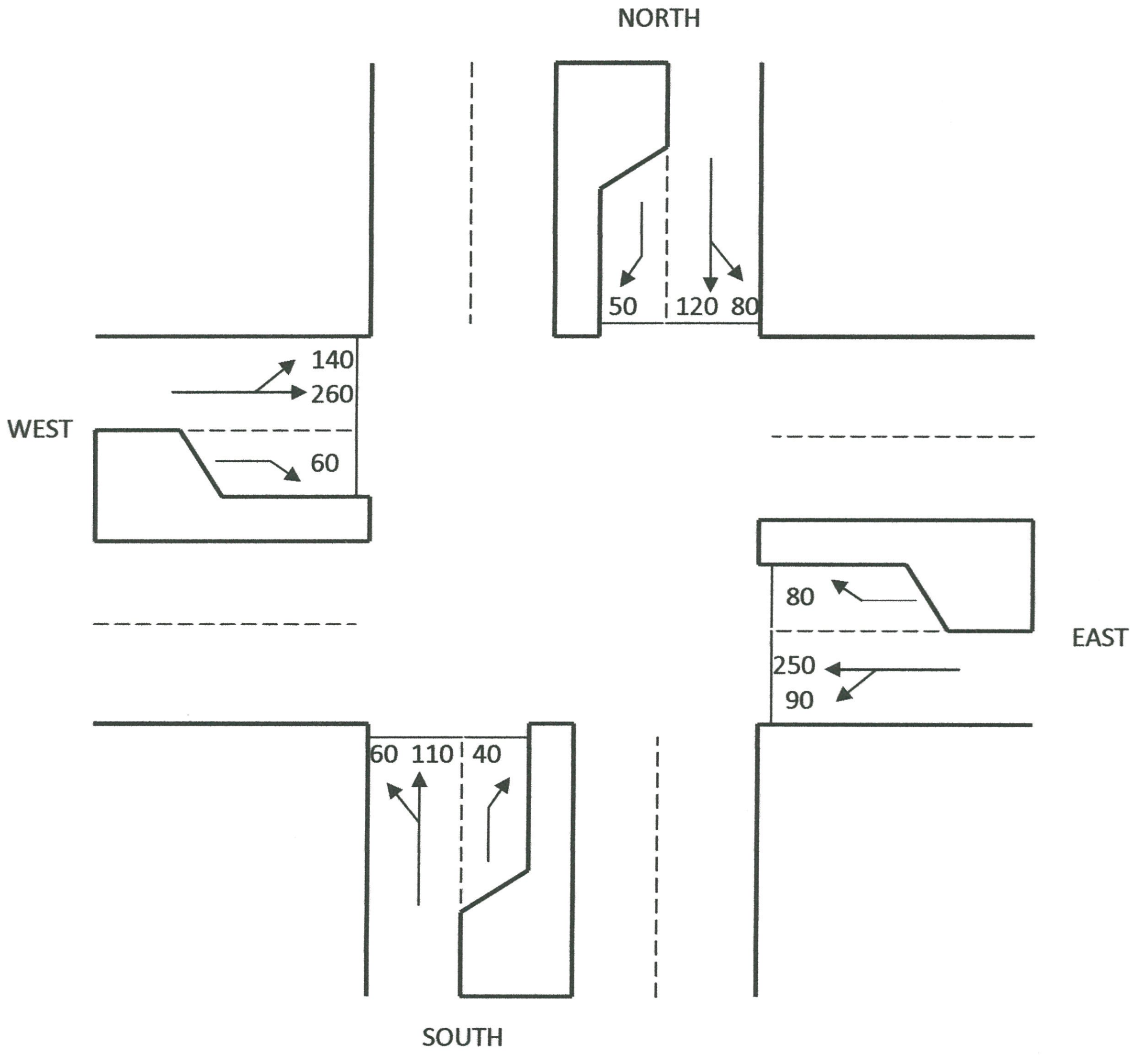

FIGURE Q3: Layout and traffic demand (pcu/hr) of the four-leg intersection

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Table 4: Urban street class based on functional and design categories (HCM, 2000)

Design Category	Functional Category	
	Principal Arterial	Minor Arterial
High-Speed	I	N/A
Suburban	II	II
Intermediate	II	III or IV
Urban	III or IV	IV

Table 5: Functional and design categories (HCM, 2000)

Criterion	Functional Category	
	Principal Arterial	Minor Arterial
Mobility function	Very important	Important
Access function	Very minor	Substantial
Points connected	Freeways, important activity centers, major traffic generators	Principal arterials
Predominant trips served	Relatively long trips between major points and through-trips entering, leaving, and passing through the city	Trips of moderate length within relatively small geographical areas

Criterion	Design Category			
	High-Speed	Suburban	Intermediate	Urban
Driveway/access density	Very low density	Low density	Moderate density	High density
Arterial type	Multilane divided; undivided or two-lane with shoulders	Multilane divided; undivided or two-lane with shoulders	Multilane divided or undivided; one-way, two-lane	Undivided one-way, two-way, two or more lanes
Parking	No	No	Some	Significant
Separate left-turn lanes	Yes	Yes	Usually	Some
Signals/km	0.3–1.2	0.6–3.0	2–6	4–8
Speed limit	75–90 km/h	65–75 km/h	50–65 km/h	40–55 km/h
Pedestrian activity	Very little	Little	Some	Usually
Roadside development	Low density	Low to medium density	Medium to moderate density	High density

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Table 6: Urban street LOS by class (HCM, 2000)

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	90 to 70 km/h	70 to 55 km/h	55 to 50 km/h	55 to 40 km/h
Typical FFS	80 km/h	65 km/h	55 km/h	45 km/h
LOS	Average Travel Speed (km/h)			
A	> 72	> 59	> 50	> 41
B	> 56–72	> 46–59	> 39–50	> 32–41
C	> 40–56	> 33–46	> 28–39	> 23–32
D	> 32–40	> 26–33	> 22–28	> 18–23
E	> 26–32	> 21–26	> 17–22	> 14–18
F	≤ 26	≤ 21	≤ 17	≤ 14

Table 7: Relationship between arrival type and platoon ratio (HCM, 2000)

Arrival Type	Range of Platoon Ratio (R_p)	Default Value (R_p)	Progression Quality
1	≤ 0.50	0.333	Very poor
2	> 0.50–0.85	0.667	Unfavorable
3	> 0.85–1.15	1.000	Random arrivals
4	> 1.15–1.50	1.333	Favorable
5	> 1.50–2.00	1.667	Highly favorable
6	> 2.00	2.000	Exceptional

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Table 8: Segment running time per kilometer (HCM, 2000)

Urban Street Class	I			II			III		IV		
FFS (km/h)	90[a]	80[a]	70[a]	70[a]	65[a]	55[a]	55[a]	50[a]	55[a]	50[a]	40[a]
Average Segment Length (m)	Running Time per Kilometer (s/km)										
100	b	b	b	b	b	b	-	-	-	129	159
200	b	b	b	b	b	b	88	91	97	99	125
400	59	63	67	66	68	75	75	78	77	81	96
600	52	55	61	60	61	67	d	d	d	d	d
800	45	49	57	56	58	65	d	d	d	d	d
1000	44	48	56	55	57	65	d	d	d	d	d
1200	43	47	54	54	57	65	d	d	d	d	d
1400	41	46	53	53	56	65	d	d	d	d	d
1600	40[c]	45[c]	51[c]	51[c]	55[c]	65[c]	d	d	d	d	d

Notes:

a. It is best to have an estimate of FFS. If there is none, use the table above, assuming the following default values:

For Class	FFS (km/h)
I	80
II	65
III	55
IV	45

b. If a Class I or II urban street has a segment length less than 400 m, (a) reevaluate the class and (b) if it remains a distinct segment, use the values for 400 m.

c. For long segment lengths on Class I or II urban streets (1600 m or longer), FFS may be used to compute running time per kilometer. These times are shown in the entries for a 1600-m segment.

d. Likewise, Class III or IV urban streets with segment lengths greater than 400 m should first be reevaluated (i.e., the classification should be confirmed). If necessary, the values above 400 m can be extrapolated.

Although this table does not show it, segment running time depends on traffic flow rates; however, the dependence of intersection delay on traffic flow rate is greater and dominates in the computation of travel speed.

Table 9: Recommended upstream filtering / metering adjustment factor for lane groups with upstream signals (HCM, 2000)

	Degree of Saturation at Upstream Intersection, X_u						
	0.40	0.50	0.60	0.70	0.80	0.90	≥ 1.0
I	0.922	0.858	0.769	0.650	0.500	0.314	0.090

Note: $I = 1.0 - 0.91 X_u^{2.68}$ and $X_u \leq 1.0$.

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Table 10: Progression adjustment factors for uniform delay calculation (HCM, 2000)

Green Ratio (g/C)	Arrival Type (AT)					
	AT 1	AT 2	AT 3	AT 4	AT 5	AT 6
0.20	1.167	1.007	1.000	1.000	0.833	0.750
0.30	1.286	1.063	1.000	0.986	0.714	0.571
0.40	1.445	1.136	1.000	0.895	0.555	0.333
0.50	1.667	1.240	1.000	0.767	0.333	0.000
0.60	2.001	1.395	1.000	0.576	0.000	0.000
0.70	2.556	1.653	1.000	0.256	0.000	0.000
f_{PA}	1.00	0.93	1.00	1.15	1.00	1.00
Default, R_p	0.333	0.667	1.000	1.333	1.667	2.000

Notes:
$PF = (1 - P)f_{PA}/(1 - g/C)$.
Tabulation is based on default values of f_p and R_p.
$P = R_p \cdot g/C$ (may not exceed 1.0).
PF may not exceed 1.0 for AT 3 through AT 6.

Table 11: Signal control adjustment factor for controller type (HCM, 2000)

Unit Extension (s)	Degree of Saturation (X)					
	≤ 0.50	0.60	0.70	0.80	0.90	≥ 1.0
≤ 2.0	0.04	0.13	0.22	0.32	0.41	0.50
2.5	0.08	0.16	0.25	0.33	0.42	0.50
3.0	0.11	0.19	0.27	0.34	0.42	0.50
3.5	0.13	0.20	0.28	0.35	0.43	0.50
4.0	0.15	0.22	0.29	0.36	0.43	0.50
4.5	0.19	0.25	0.31	0.38	0.44	0.50
5.0[a]	0.23	0.28	0.34	0.39	0.45	0.50
Pretimed or Nonactuated Movement	0.50	0.50	0.50	0.50	0.50	0.50

Notes:
For a unit extension and its k_{min} value at X = 0.5: $k = (1 - 2k_{min})(X - 0.5) + k_{min}$, where $k \geq k_{min}$, and $k \leq 0.5$.
a. For a unit extension more than > 5.0, extrapolate to find k, keeping $k \leq 0.5$.

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The following equations may be useful to you:

$$v = v_f - \frac{v_f}{k_j}k \qquad v = v_f e^{\left(\frac{-k}{k_j}\right)} \qquad v = C\ln\left(\frac{k_j}{k}\right) \qquad Y = a - bX \qquad a = \frac{\sum Y}{n} - b\frac{\sum X}{n}$$

$$b = \frac{n(\sum XY) - (\sum X)(\sum Y)}{n(\sum X^2) - (\sum X)^2} \qquad r = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{\left(n(\sum X^2) - (\sum X)^2\right)\left(n(\sum Y^2) - (\sum Y)^2\right)}}$$

$$S_A = \frac{3600L}{T_R + d} \qquad d = d_1 * PF + d_2 + d_3 \qquad d_1 = \frac{0.5C\left(1 - \frac{g}{C}\right)^2}{1 - \left(\frac{g}{C}\right)min(X,1.0)}$$

$$d_2 = 900T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8kIX}{cT}}\right] \qquad I = 1.0 - 0.91X_u^{2.68} \qquad d_3 = \frac{1800Q_b(1+u)t}{cT}$$

$$t = 0 \ if \ Q_b = 0, \quad else \quad t = min\left(T, \frac{Q_b}{c[1 - min(1,X)]}\right)$$

$$u = 0 \ if \ t < T, \quad else \quad u = 1 - \frac{cT}{Q_b[1 - min(1,X)]} \qquad v_w = \frac{q_2 - q_1}{k_2 - k_1} \qquad X = \frac{v}{c}$$

$$c = s \times N \times \left(\frac{g}{C}\right) \qquad \tau_{min} = \delta + \frac{W+L}{v_o} + \frac{v_o}{2a} \qquad C_o = \frac{1.5L+5}{1-Y}$$

$$L = \sum l + R \qquad G_e = \frac{y}{Y}(C - L) \qquad G_a = G_e + l - \tau$$

$$If \ W_E > 3, \quad G_p = 3.2 + \frac{L}{S_p} + \left(2.7\frac{N_{ped}}{W_E}\right) \qquad If \ W_E \le 3, \quad G_p = 3.2 + \frac{L}{S_p} + \left(0.27N_{ped}\right)$$

$$X_c = \sum\left(\frac{v}{s}\right)_c * \frac{C}{C-L} \qquad t_c = t_1 + \frac{(t_2 - t_1)(p-q)}{(r-s)+(p-q)} \qquad \lambda = \frac{V}{T} \qquad \mu = \lambda t$$

$$P(h \ge t) = e^{-\lambda t} \qquad P(h < t) = 1 - e^{-\lambda t}$$

$$Freq.(h \ge t) = (V-1)e^{-\lambda t} \qquad Freq.(h < t) = (V-1)(1 - e^{-\lambda t})$$

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