NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2010-2011

CV3401 – TRANSPORTATION ENGINEERING

December 2010 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains FIVE (5) questions and comprises FIVE (5) pages.
2. Answer ALL questions.
3. This is an Open-Book Examination.
4. The questions do not carry equal marks.

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1. The speed-density relationship for a particular roadway can be represented by:

$$v = A\,ln(\frac{B}{k+C})$$

Speed v is in kilometres (km) per hour and density k is in vehicles per km. A, B and C are three parameters to be determined. If it is given that the jam density is 180 veh/km, the free flow speed is 80 km/h, and when speed is 40 km/h, the corresponding density is 40 veh/km.

(a) Determine the speed-density relationship. (9 Marks)

(b) Derive the capacity of the roadway. (You are not required to obtain the numerical value of the capacity) (4 Marks)

2. Zone A and Zone B are linked by a highway. The average hourly person-trips from A to B are 5,000 in total. Currently, two modes of transportation are available: car and bus. Their characteristics are summarised in the following table.

5000 ppl/h

Table Q2: Characteristics of Transportation Modes

Performance Categories	Bus	Car
Out-of-vehicle time (w)	20 minutes	5 minutes
In-vehicle time (t)	25 minutes	15 minutes
Out-of-pocket cost (c)	$10.0	$50.0

A consultant has established the following utility function for residents of these two zones.

$$U = -1.0 - 0.2w - 0.1t - 0.1c$$

where U is the utility associated with a particular mode, w (minutes) is the average out-of-vehicle waiting time, c ($) is the out-of-pocket cost, and t (minutes) is the in-vehicle time. Use the logit model for the following analyses.

(a) Determine the number of passengers per hour using car and bus from A to B. (5 Marks)

(b) Assume that each bus can hold 100 passengers, whereas each car on average carries 2 passengers (including the driver). Assume that the highway only carries traffic from A to B. Determine the hourly traffic volume (in veh/h) using the highway? (4 Marks)

(c) To contain congestion, the government plans to charge congestion pricing to cars so as to reduce the total car traffic volume to just below 1,000 vehicles/hour (the assumption that each car on average carries 2 passengers remains). Assume that buses are exempted from this congestion charge and the bus performance characteristics remain unchanged. How much should this congestion charge be? Give your answer to the nearest dollar. (7 Marks)

Note: Question No.2 continues on page 3.

(d) The government is also considering the use of a bus-only lane. That is, buses will maintain the same in-vehicle time of 25 minutes and follow the same characteristics as those in Table Q2. The in-vehicle time of car, however, now follows this travel time function:

$$t = 10 + \frac{x}{25}$$

where t is the in-vehicle time (minutes) and x is the car traffic volume per hour (the assumption that each car on average carries 2 passengers remains). The out-of-vehicle time (w) and out-of-pocket cost (c) of car remain the same as those in Table Q2. There is no congestion pricing.

Determine the number of car trips from A to B. Give your answer in a functional form, while the exact numerical answer is not required.

(8 Marks)

3. Figure Q3 shows the transportation network connecting node A to node B. The link travel time functions are as follows:

Link 1: $t_1 = 10 + 3x_1$
Link 2: $t_2 = 12 + 2x_2$
Link 3: $t_3 = 20 + x_3$

where x_i, t_i are, respectively, the traffic flow and travel time on link i.

Apply the user equilibrium principle (Wardrop's first principle) to the following traffic assignment problems.

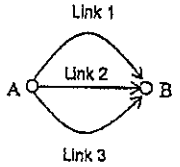

Figure Q3: Transportation Network

(a) If the total demand from A to B is 11 units, determine the traffic flows on all the three links. (Hint: at this equilibrium, all the three links will be used).

(5 Marks)

(b) If, at another equilibrium wherein the total demand is not 11 units any longer, the traffic flow on link 2 is 2 units, determine the traffic flow on link 1 and link 3, and also the total demand at this equilibrium.

(8 Marks)

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4. (a) A pair of vertical curves are to connect a series of tangent grades for which the slopes are shown in Figure Q4.

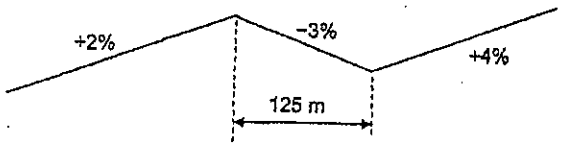

Figure Q4

(I) Perform applicable calculations using the following information to identify the constraints that would prevent the pair of vertical curves from being fully developed.

Driver reaction time: 2.5 s
Driver eye height: 1.050 m
Tyre-pavement friction coefficient: 0.30
Object height for stopping: 0.150 m
Road design speed: 70 km/h

(II) Briefly discuss two ways to deal with the constraints identified in part (I). (You do not need to perform any further calculation).

(17 Marks)

(b) A speed review exercise aimed at raising the speed limit of a highway network to 80 km/h revealed a tight horizontal curve which may not be able to accommodate the speed increase. Field investigations revealed the following conditions at this curve:

- curve radius: 250 m
- super-elevation: 5%
- set-back distance to obstruction on inside of curve: 8.5 m
- tyre-pavement friction coefficient (f): 0.30
- sideway force coefficient (f_s): 0.14
- 85th percentile traffic speed: 77 km/h
- minimum stopping sight distance (for 80 km/h): 130 m

(i) Check whether the horizontal curve is adequate for vehicles to navigate this curve at 80 km/h speed. Support your answer with applicable calculations.

(ii) If there are inadequacies in the horizontal curve, propose suitable remedial measures that you can apply.

(13 Marks)

5. A 2-lane 2-way road link is to be constructed to connect a coastal village to a nearby highway. The proposed design is a 3-layer flexible pavement on roadbed soil, using materials having properties given in Table Q5.The SN values for the pavement above each respective layer have been determined using the AASHTO procedures.

Table Q5

Material	Drainage coefficient	Layer coefficient	SN value above layer
Roadbed soil	0.60	0.05	3.3
Sandy gravel	1.10	0.12	2.5
Crushed stone	1.25	0.18	1.7
Asphalt concrete	impermeable	0.45	not applicable

(a) Compute the thickness of each layer in the flexible pavement.

(6 Marks)

(b) A rigid concrete pavement design can also be considered. What conclusions can you draw from replacing the flexible pavement with a rigid pavement?

(8 Marks)

(c) The AASHTO design procedures make use of probabilistic concept in designing structural thickness of pavement. Briefly discuss how probabilistic features are incorporated into the AASHTO design procedures.

(6 Marks)

END OF PAPER

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1. a>. $V = A\ln(\frac{B}{k+C})$

$k = k_j = 180$ veh/km $V = 0$

$\Rightarrow A\ln(\frac{B}{k+C}) = 0 \quad \Rightarrow \quad B = 180 + C$

$V = 40$km/h $k = 120$ veh/km

$\Rightarrow A\ln(\frac{B}{120+C}) = 40$

$V_f = 80$km/h $k = 0$

$\Rightarrow A\ln(\frac{B}{C}) = 80$

$\Rightarrow C = 16 \quad B = 196 \quad A = 31.93$

$\Rightarrow V = 31.93\ln(\frac{196}{k+16})$ ✱

b>. $q = vk = 31.93k\ln(\frac{196}{k+16})$ ← ✓

$\frac{dq}{dk} = 31.93(\ln(\frac{196}{k+16}) - \frac{k}{k+16}) = 0$

$\Rightarrow k = 70.72 \quad q_c = 1841.3$ veh/h ✱

2. a>. $U_b = -1.0 - 0.2\times 20 - 0.1\times 25 - 0.1\times 10 = -8.5$

$U_c = -1.0 - 0.2\times 5 - 0.1\times 15 - 0.1\times 30 = -8.5$

$P_b = P_c = \frac{e^{-8.5}}{e^{-8.5}\times 2} = 50\% \quad \Rightarrow q_b = 2500$ | $q_c = 2500$ passenger/hr. ✱

b>. $q = 2500 \div 100 + 2500 \div 2 = 1275$ veh/hr ✱

c>. $q_c = 1000$ veh/hr $\Rightarrow$ No. of car passengers $= 2\times q_c = 2000$

$p_c' = \frac{2000}{5000} = 40\%$

$p_c' = \frac{e^{U_c'}}{e^{U_c'} + e^{U_b}} = \frac{e^{U_c'}}{e^{U_c'} + e^{-8.5}} = 40\% \quad \Rightarrow U_c' = -8.91$

$U_c' = -1.0 - 0.2\times 5 - 0.1\times 15 - 0.1\times C = -8.91$

$\Rightarrow C = 54.0$

$\Rightarrow$ Congestion charge $= 54 - 30 = 24$ dollars

2.

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a) $U_b = -1.0 - 0.2\times 20 - 0.1\times 25 - 0.1\times 10 = -8.5$

$U_c'' = -1.0 - 0.2\times 5 - 0.1\times(10+\frac{x}{25}) - 0.1\times 50 = -8 - \frac{x}{250}$

$x = \frac{5000 \times \frac{e^{(-8-\frac{x}{250})}}{e^{-8.5}+e^{(-8-\frac{x}{250})}}}{2} \Rightarrow 2500\, e^{(-8-\frac{x}{250})} = x\left[e^{-8.5} + e^{(-8-\frac{x}{250})}\right]$

$\Rightarrow x = 482.6$

No. of car trips = 241.3 veh/hr

$\frac{e^{-8-0.004x}}{e^{-8.5}+e^{-8-0.004x}} = \frac{2x}{5000}$

3. a) $t_1 = 10 + 3x_1 \quad t_2 = 12 + 2x_2 \quad t_3 = 20 + x_3$

All 3 links are used

$\Rightarrow \begin{cases} 10+3x_1 = 12+2x_2 = 20+x_3 \\ x_1 + x_2 + x_3 = 11 \end{cases}$

$\Rightarrow \begin{cases} x_1 = 4 \\ x_2 = 5 \\ x_3 = 2 \end{cases}$

b) $x_2 = 2 \Rightarrow t_2 = 12 + 2\times 2 = 16$

Link 3 is not used

$t_1 = 10 + 3x_1 = 16$

$x_1 = 2$

$\Rightarrow \begin{cases} x_1 = 2 \\ x_2 = 2 \\ x_3 = 0 \end{cases}$ total demand $= 2+2+0 = 4$

4.

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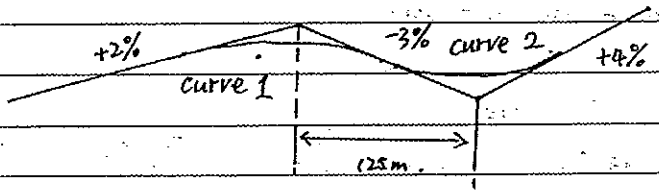
4. a)

ii)



$t_r = 2.5s$ $h_1 = 1.050m$ $h_2 = 0.150m$ $f = 0.30$ $V = 70km/h$

Assume the pair of vertical curves can be fully developed

For curve 1, the max $SSD_1 = 2.5 \times \frac{70}{3.6} + \frac{(70/3.6)^2}{2g(0.30 - 0.03)} = 120.0m$.

For curve 2, the max $SSD_2 = 2.5 \times \frac{70}{3.6} + \frac{(70/3.6)^2}{2g(0.30 - 0.04)} = 122.7m$

If $L_1 \geq S_1$ $L_{min_1} = \frac{12 + 3.1 \times 120.0^2}{200(\sqrt{1.050} + \sqrt{0.150})} = 253.0\ m > S_1$

If $L_2 \geq S_2$ $L_{min_2} = \frac{14 + 3.1 \times 122.7^2}{120 + 3.5 \times 122.7} = 191.8\ m > S_2$

$\frac{L_1}{2} + \frac{L_2}{2} = 223.4m > 125m$.

⇒ The pair of curves cannot be fully developed

iii). ① Increase the friction between the tyre and pavement, thus reducing the required SSD.

② Limit the driving speed

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b> $R = 250m$ $e = 8\%$ $m = 6.5m$ $f = 0.30$ $f_s = 0.14$

$V_{85} = 77 km/h$ SSD_{85} (80km/h) = 130m.

ii> $V = 80 km/h \Rightarrow SSD = 130m$

SSD can be provided $= \frac{R}{28.65}\left[\cos^{-1}\left(\frac{R-m}{R}\right)\right] = \frac{250}{28.65}\left[\cos^{-1}\left(\frac{250-6.5}{250}\right)\right] = 114.3m < SSD$

∴ adequate SSD can be provided.

Criteria established by superelevation

e required $= \frac{V^2}{gR} - f_s = \frac{(80/3.6)^2}{9.81 \times 250} - 0.14 = 16.1\% > 8\%$

∴ The curve is not adequate for vehicles to navigate at 80 km/h speed.

ii> Increase the sideway force coefficient by reducing the speed limit. lower speed.

5. a> The pavement is layed as: A.C $SN_1 = 1.7$ $a_1 = 0.45$

Crushed stone $SN_2 = 2.5$ $a_2 = 0.18$ $m_2 = 1.$

Sandy Gravel $SN_3 = 3.3$ $a_3 = 0.12$ $m_3 = 1.$

Roadbed soil $a_4 = 0.05$ $m_3 = 1$

$D_1^* = \frac{SN_1}{a_1} = \frac{1.7 \times 25.4}{0.45} = 96.0 mm \Rightarrow D_1^* = 100 mm$ *

$SN_1^* = a_1 D_1^* = 0.45 \times 100 = 45.$

$D_2^* = \frac{2.5 \times 25.4 - 45}{0.18 \times 1.25} = 92.2 mm \Rightarrow D_2 = 90 mm$ *

$SN_2^* = m_2 a_2 D_2^* = 0.18 \times 1.25 \times 90 = 20.25$

$D_3^* = \frac{3.3 \times 25.4 - 20.25 - 45}{0.12 \times 1.10} = 170.2 mm \Rightarrow D_3 = 180 mm$ * 150mm

$SN_3^* = 0.12 \times 1.10 \times 180 = 23.76$

b> There are some advantages if the flexible pavement is replaced by the rigid pav

① Since the road is constructed near a coastal village, the soil could highly possibly be soft marine clay which may undergo settlement after constru Rigid pavement can readily span over poorly consolidated soils

② The economy in the village is still in development stage where technical organizations for effective and sustained road maintenance are we The lesser maintenance of rigid pavement is an advantage

③ The weathering near the coastal village is relatively severe. Rigid paveme do not suffer deterioration from weathering

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④ Rigid pavements are better than flexible pavement to cope with overloading. The disadvantages of rigid pavements over flexible pavements are

① Traffic forecast in less developed economies, say, this coastal village is less reliable while growth may be erratic over design period. Rigid pavements which are designed and constructed for a longer service life may cause a large initial capital outlay sunken for a long period.

② Quality assurance in less developed ~~in~~ region is often problematic, causing concrete pavements to become problematic.

c) In AASHTO method, ~~the inputs to determine~~ the thickness of each layer is related to soil conditions, traffic characteristics, and pavement ~~procedure~~ design characteristics to a performance index value expected at the end of the pavement's design life. All the inputs such as reliability, ESAL are based on the mean values.

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