UNIVERSITI SAINS MALAYSIA

KSCP Examination
2016/2017 Academic Session

August 2017

EAL335 – Traffic and Transportation Engineering
[*Kejuruteraan Pengangkutan dan Lalulintas*]

Duration : 3 hours
[*Masa : 3 jam*]

Please check that this examination paper consists of **SEVENTEEN (17)** pages of printed material including appendix before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **TUJUH BELAS (17)** muka surat yang bercetak termasuk lampiran sebelum anda memulakan peperiksaan ini.*]

Instructions : This paper consists of **SIX (6)** questions. Answer **FIVE (5)** questions.

[***Arahan** : Kertas ini mengandungi **ENAM (6)** soalan. Jawab **LIMA (5)** soalan.*]

In the event of any discrepancies, the English version shall be used.

[*Sekiranya terdapat percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.*]

1. Traffic congestion is high amongst the complaints of many road users in Malaysia. Not only in the big cities, now congestion as also a common problem in smaller cities, townships and even the expressway. As the traffic congestion in Malaysia is prevalent, it shows that our transport system is still not sustainable.

Kesesakan lalu lintas merupakan keluhan paling tinggi di kalangan pengguna jalan raya di Malaysia. Bukan sahaja di bandar-bandar besar, kini kesesakan lalu lintas juga merupakan masalah yang sering terjadi di bandar-bandar kecil, pekan-pekan dan lebuhraya. Memandangkan kesesakan lalu lintas berlaku secara berleluasa di Malaysia, ini menunjukkan bahawa sistem pengangkutan kita masih belum mapan.

[a] Explain **FIVE (5)** possible factors that may have contributed to the congestion problem.

*Terangkan **LIMA (5)** faktor yang mungkin menjadi penyebab kepada masalah kesesakan lalu lintas.*

[10 marks/*markah*]

[b] Explain **ONE (1)** example from traffic and transportation engineering perspective to solve the congestion problem.

*Terangkan **SATU (1)** contoh daripada perspektif kejuruteraan trafik dan pengangkutan untuk menyelesaikan masalah kesesakan lalu lintas.*

[5 marks/*markah*]

[c] Public transport is one alternative to reduce congestion problem. However, for Malaysia, there are signs that public transportation system still needs improvement. State **FIVE (5)** requirements of good public transport system and explain how each factor could increase the quality of the public transport service.

Pengangkutan awam adalah salah satu alternatif untuk mengurangkan masalah kesesakan. Walaubagaimanapun, bagi Malaysia, terdapat tanda-tanda bahawa sistem pengangkutan awam masih memerlukan penambahbaikan. Nyatakan ***LIMA (5)*** *keperluan sistem pengangkutan awam yang baik dan terangkan bagaimana setiap faktor boleh meningkatkan kualiti perkhidmatan pengangkutan awam.*

[5 marks/*markah*]

2. [a] Explain the meaning of "peak hour factor" and why is peak hour important in the analysis of traffic behaviour? What are the minimum and maximum values of peak hour factor? With the aid of bar charts, explain the conditions when the peak hour factor is at the minimum and when it is at the maximum.

Apakah itu "faktor waktu puncak" dan kenapa faktor waktu puncak ini penting dalam analisis kelakuan lalu lintas? Apakah nilai minimum dan maksimum faktor waktu puncak? Dengan berbantukan lakaran carta bar, terangkan keadaan apabila faktor waktu puncak adalah minimum and apabila ia adalah maksimum.

[6 marks/*markah*]

[b] A study was conducted at the mid-block section of a two-lane road with level terrain to determine the level-of-service of the road and the results obtained are shown in **Table 1**. Based on the values shown in **Table 1**,

Satu kajian telah dijalankan pada pertengahan blok seksyen jalan dua-lorong yang rata untuk menentukan aras-perkhidmatan jalan tersebut dan keputusan yang diperolehi adalah seperti yang ditunjukkan didalam ***Jadual 1****. Berdasarkan kepada nilai yang ditunjukkan dalam* ***Jadual 1****,*

[i] Compute the flow rate for northbound and southbound in pcu/h and subsequently compute the directional split.

Kira kadar aliran ke utara dan selatan dalam ukp/j dan seterusnya kira pecahan arah.

[ii] Subsequently, by using the calculated values from part (b) i) and referring to the graph and tables in the appendix, determine the level-of-service for the two-lane road based on the given design parameters. **Use the worksheet in the appendix for calculation and submit the worksheet together with the answer script.**

Seterusnya, dengan menggunakan nilai yang dikira dalam bahagian (b) i) dan berdasarkan kepada graf dan jadual dalam lampiran, tentukan aras perkhdimatan untuk jalan dua-lorong tersebut berdasarkan kepada parameter reka bentuk yang diberi. ***Gunakan borang kerja yang diberikan dalam lampiran untuk pengiraan dan hantar sekali borang kerja tersebut dengan skrip jawapan.***

Segment length/*Panjang segmen* = 5.0 km
Lane width/*Lebar lorong* = 3.6 m
Shoulder width/ *Lebar bahu jalan* = 1.6 m
Peak hour factor/*Faktor waktu puncak* = 0.95
Percentage of trucks and buses/*Peratusan trak dan bas* = 12%
Percentage of recreational vehicles/ *Peratusan kenderaan rekreasi* = 3%
Percentage of no-passing zone/*Peratusan zon larangan memotong* = 0%
Access point density/ *Kepadatan akses* = 6/km
Base free flow speed/*Kelajuan aliran bebas asas* = 90 km/h

[14 marks/*markah*]

Table 1: Time taken for each vehicle to cross the reference line
Jadual 1: Masa yang diambil oleh kenderaan untuk melintasi garis rujukan

Sequence of passenger car when crossing the reference line *Turutan kenderaan penumpang semasa melintasi garisan rujukan*	Time when the last axle of the passenger car crosses the stop line (s) *Masa ketika gandar belakang kenderaan penumpang melintasi garis henti (s)*	
	Northbound *Ke Utara*	Southbond *Ke Selatan*
1	0.0	2.5
2	4.1	5.2
3	8.4	7.9
4	12.6	11.1
5	17.0	13.5
6	21.2	16.5
7	25.8	19.2
8	29.8	21.7
9	34.5	24.5
10	38.9	27.8
11	43.1	31.3

3. [a] With the aid of sketches, discuss the meaning of free-flow speed and jam density in the speed-flow, speed-density and flow-density relationships.

Dengan berbantukan lakaran, bincangkan maksud kelajuan aliran-bebas dan ketumpatan sesak dalam hubungan kelajuan-aliran, kelajuan-ketumpatan dan aliran-ketumpatan.

[9 marks/*markah*]

[b] A speed study was conducted on a road section which is 800 meters in length. The data collected are as shown in the **Table 2**. Based on the travel time given in **Table 2**, calculate the speed of each vehicle in km/h and subsequently, calculate the space mean speed and time mean speed in km/h. Compare and explain on the values of space mean speed and time mean speed obtained.

Satu kajian kelajuan telah dijalankan pada satu segmen jalan dengan jarak yang berukuran 800 meter. Data yang dicerap adalah seperti yang ditunjukkan dalam ***Jadual 2****. Berdasarkan masa perjalanan dalam* ***Jadual 2****, kira kelajuan setiap kenderaan dalam km/j dan seterusnya kira kelajuan ruang purata dan kelajuan masa purata dalam km/j. Bandingkan dan terangkan nilai kelajuan ruang purata dan kelajuan masa purata yang diperolehi.*

[11 marks/*markah*]

Table 2: Travel time

Jadual 2: Masa perjalanan

No. *No.*	Time (seconds) *Masa (saat)*
1	31.5
2	32.6
3	33.5
4	32.1
5	30.2
6	32.2
7	34.1
8	31.9
9	29.9
10	28.7
11	27.8
12	32.5
13	30.5
14	29.0
15	28.4

4. [a] An intersection is an area whose main function is to provide for the change of route directions. With the aid of sketches, discuss on the different types of conflicts that occur at a two-lane two-way cross junction and a staggered T-junction. Subsequently, discuss on possible solutions to reduce conflict at a four-legged and three-legged intersections.

Persimpangan adalah kawasan yang fungsi utamanya adalah untuk memberi peruntukan bagi perubahan arah laluan. Dengan bantuan lakaran, bincangkan jenis-jenis konflik yang berlaku di persimpangan silang dua-lorong dua-hala dan persimpangan-T berperingkat. Selepas itu, bincangkan penyelesaian yang mungkin untuk mengurangkan konflik di persimpangan empat dan persimpangan tiga.

[8 marks/*markah*]

[b] A raindrop shaped roundabout with level gradient is as shown in **Figure 1** and the design hourly volume for year 2017 is given in **Table 3**. Determine the maximum weaving volume of the roundabout for year 2032 and determine if the capacity of the roundabout is sufficient to cater for future traffic demand for year 2032 if annual growth rate is 5.5%. If the capacity of a roundabout is insufficient and not possible to widen the roundabout by adding more lanes, please provide suggestions as how to increase the capacity of the roundabout.

*Satu bulatan berbentuk titisan hujan yang rata adalah seperti yang ditunjukkan dalam **Rajah 1** dan isipadu reka bentuk jaman untuk tahun 2017 adalah diberikan dalam **Jadual 3**. Tentukan isipadu jalinan yang maksimum untuk bulatan tersebut pada tahun 2032 dan tentukan sama ada kapasiti bulatan tersebut mencukupi untuk menampung permintaan lalu lintas pada tahun 2032 jika kadar pertumbuhan tahunan adalah 5.5%. Sekiranya kapasiti bulatan tidak mencukupi dan tidak dapat memperluaskan bulatan dengan menambah lebih banyak lorong, sila berikan cadangan bagaimana untuk meningkatkan kapasiti bulatan.*

[12 marks/*markah*]

Given:
Diberi:

$$Q_p = \frac{160W\left(1+\frac{e}{W}\right)}{1+\left(\frac{W}{L}\right)}$$

Where:
Dimana :

Q_p = Capacity of weaving section (vph)
Q_p = *Kapasiti bahagian jalinan* (kend/j)

W = Width of weaving section (m) = 10.0 m
W = *Lebar bahagian jalinan* (m) = 10.0 m

e = 0.5(e_1 + e_2), average entry width (m) = 6.5 m
e = 0.5(e_1 + e_2), *lebar kemasukan purata* (m) = 6.5 m

L = Length of weaving section (m) = 30.0 m
L = *Panjang bahagian jalinan* (m) = 30.0 m

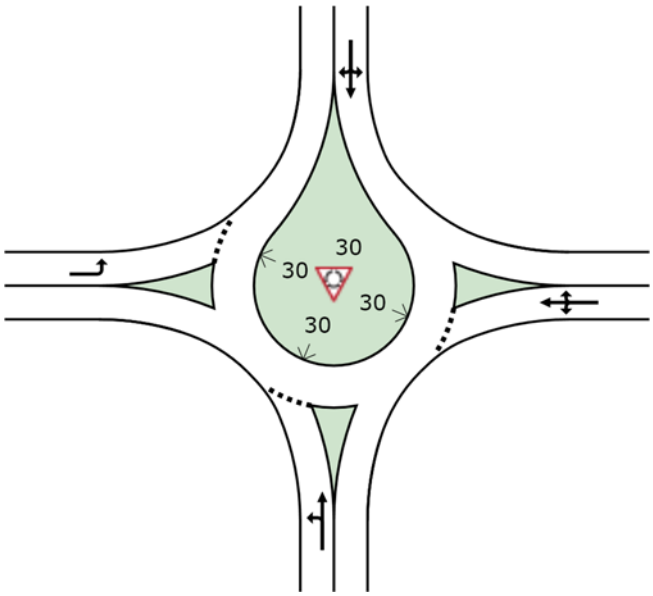


Figure 1: Raindrop shaped roundabout

Rajah 1: Bulatan berbentuk titisan hujan

Table 3: Design hourly volume (2017)

Jadual 3: Isipadu reka bentuk jaman (2017)

Approach	Direction	Volume (vph)
South	Left-turn	108
	Straight through	253
East	Left-turn	96
	Straight through	215
	Right-turn	105
North	Left-turn	94
	Straight through	164
	Right-turn	133
West	Left-turn	214

5. [a] Travel demand model aims to identify the effects of future developments in the transport networks towards the road users' trips and route choices. In the transportation planning, the classical travel demand model is popularly known as four-stage demand model (FSDM). With the aid of the flow chart of FSDM in the transportation planning, **explain the function and the relationship of the four basic models in the travel demand model**.

Model permintaan perjalanan bertujuan untuk mengenalpasti kesan pembangunan di dalam jaringan pengangkutan terhadap perjalanan and pemilihan laluan oleh pengguna jalan raya. Di dalam perancangan pengangkutan, model permintaan perjalanan klasik yang terkenal ialah Model Permintaan Empat Peringkat. Dengan berbantukan carta alir Model Permintaan Empat Peringkat di dalam perancangan pengangkutan, ***terangkan fungsi dan perkaitan empat model asas di dalam model permintaan perjalanan tersebut.***

[10 marks/*markah*]

[b] Bandar Baru Kulim Hi-Tech is now facing a rapid development before reaching the year of 2025. **Table 4** shows the land use developments at Bandar Baru Kulim Hi-Tech for Phase 1 and Phase 2. The development for Phase 1 was completed in July 2017 and the development for Phase 2 will be completed in September 2019. Calculate the trip generation for land use developments at Bandar Baru Kulim Hi-Tech for morning peak and evening peak for both phases by referring to the **Table 5**.

Bandar Baru Kulim Hi-Tech sedang rancak mengalami pembangunan sebelum tahun 2025. ***Jadual 4*** *menunjukkan pembangunan tanah di Bandar Baru Kulim Hi Tech bagi Fasa 1 dan Fasa 2. Pembangunan bagi Fasa 1 telah siap pada Julai 2017 dan pembangunan bagi Fasa 2 akan siap pada September 2019. Kirakan permintaan perjalanan bagi pembangunan tanah Bandar Baru Kulim Hi-Tech bagi waktu puncak pagi dan petang untuk kedua – dua fasa dengan merujuk kepada* ***Jadual 5****.*

[10 marks/*markah*]

Table 4: Land use developments at Bandar Baru Kulm Hi-Tech for Phase 1 and Phase 2

Jadual 4: Pembanguan tanah di Bandar Baru Kulim Hi- Tech untuk Fasa 1 dan Fasa 2.

Development/ *Pembangunan*	Phase 1/ *Fasa 1(2017)*	Phase 2 / *Fasa 2(2019)*
Terrace Houses/ *Rumah teres*	450 units/*unit*	140 units/*unit*
Semi - Detached houses/ *Rumah Berkembar*	140 units/*unit*	145 units/*unit*
Shop houses/ *Rumah Kedai*	15 units/*unit*	10 units/*unit*

Table 5: Trip generation equations
Jadual 5: Persamaan Penjanaan Perjalanan

Land Use / *Guna Tanah*	**Peak/ *Waktu puncak***	**Equations/ *Persamaan***	**Var**	**In %**	**Out %**	**pcu/ veh**
Terrace house/ *Rumah Teres*	AM	y = 0.6529x + 33.5021	Units/*unit*	29	71	0.90
	PM	y = 0.7008x + 31.5582	Units/*unit*	61	39	0.87
Shop house/ *Rumah Kedai*	AM	y= 8.06 x + 11.9	Units/*unit*	59	41	0.90
	PM	y= 10.68 x + 34.7	Units/*unit*	52	48	0.87
Detached/Semi-detached/ *Rumah Berkembar*	AM	y =1.51x	Units/*unit*	42	58	0.88
	PM	y = 1.54x	Units/*unit*	56	44	0.91

6. [a] Elasticity of demand in transportation measures the responsiveness of demand for a transport mode to change in one of its determinants. With the aid of diagrams give **THREE (3)** examples of elasticity of demand.

*Keanjalan permintaan dalam pengangkutan mengukur tindak balas permintaan bagi mod pengangkutan terhadap perubahan salah satu penentu-penentunya. Dengan bantuan rajah berikan **TIGA (3)** contoh keanjalan permintaan.*

[9 marks/*markah*]

[b] In 2014 the ferry fare to Pulau Sentosa is RM8.00 with the average 100 passengers per day. However in 2015 the ferry service indicated that 8% rose in fares which resulted in a 2.25% drop in the number of passengers. In order to accommodate the cost for services and infrastructures, in 2016 the fare rose again by 7.3% from the fare of the previous year. Based on your understanding in elasticity concept, determine the elasticity effect in this situation.

Pada 2014 tambang feri ke Pulau Sentosa adalah RM8.00 dengan purata 100 penumpang sehari. Walau bagaimanapun, pada tahun 2015 perkhidmatan feri menunjukkan peningkatan 8% bagi tambang lalu mengakibatkan penurunan 2.25% kepada bilangan penumpang. Untuk menampung kos perkhidmatan dan prasarana, pada tahun 2016 tambang naik sebanyak 7.3% daripada tambang tahun sebelumnya. Berdasarkan pemahaman anda di dalam konsep keanjalan, tentukan kesan keanjalan dalam keadaan ini.

[11 marks/*markah*]

APPENDIX / *LAMPIRAN*

The following graph, tables and worksheet are extracted from U.S. Highway Capacity Manual 2000.

Graf, jadual dan borang kerja yang berikut diambil daripada U.S. Highway Capacity Manual 2000.

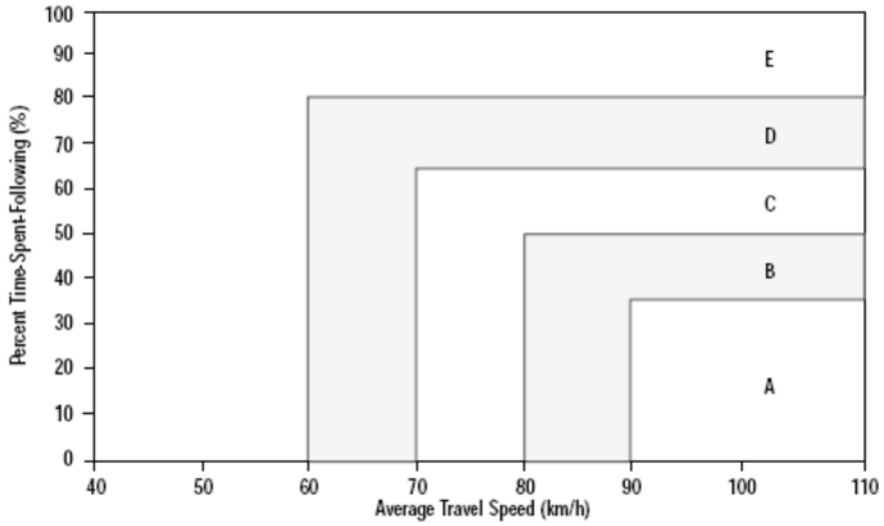


Exhibit 20-3: LOS Criteria for Two-Lane Highway for Class I

Exhibit 20-5: Adjustment (f_{LS}) for Lane Width and Shoulder Width

	Reduction in FFS (km/h)			
	Shoulder Width (m)			
Lane Width (m)	≥ 0.0 < 0.6	≥ 0.6 < 1.2	≥ 1.2 < 1.8	≥ 1.8
2.7 < 3.0	10.3	7.7	5.6	3.5
≥ 3.0 < 3.3	8.5	5.9	3.8	1.7
≥ 3.3 < 3.6	7.5	4.9	2.8	0.7
≥ 3.6	6.8	4.2	2.1	0.0

Exhibit 20-6: Adjustment (f_A) for Access-Point Density

Access Points per km	Reduction in FFS (km/h)
0	0.0
6	4.0
12	8.0
18	12.0
≥ 24	16.0

…14/-

Exhibit 20-7: Grade Adjustment Factor (f_G) to determine speeds on Two-Way and Directional Segments

Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
		Level	Rolling
0–600	0–300	1.00	0.71
> 600–1200	> 300–600	1.00	0.93
> 1200	> 600	1.00	0.99

Exhibit 20-8: Grade Adjustment Factor (f_G) to Determine Percent Time-Spent-Following on Two-Way and Directional Segments

Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
		Level	Rolling
0–600	0–300	1.00	0.77
> 600–1200	> 300–600	1.00	0.94
> 1200	> 600	1.00	1.00

Exhibit 20-9: Passenger-Car Equivalents for Trucks and RVs to Determine Speeds on Two-Way and Directional Segments

Vehicle Type	Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
			Level	Rolling
Trucks, E_T	0–600	0–300	1.7	2.5
	> 600–1,200	> 300–600	1.2	1.9
	> 1,200	> 600	1.1	1.5
RVs, E_R	0–600	0–300	1.0	1.1
	> 600–1,200	> 300–600	1.0	1.1
	> 1,200	> 600	1.0	1.1

Exhibit 20-10: Passenger-Car Equivalents for Trucks and Rvs to Determine Percent Time-Spent-Following on Two-Way and Directional Segments

Vehicle Type	Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
			Level	Rolling
Trucks, E_T	0–600	0–300	1.1	1.8
	> 600–1,200	> 300–600	1.1	1.5
	> 1,200	> 600	1.0	1.0
RVs, E_R	0–600	0–300	1.0	1.0
	> 600–1,200	> 300–600	1.0	1.0
	> 1,200	> 600	1.0	1.0

Exhibit 20-11: Adjustment (f_{np}) for Effect of No-Passing Zones on Average Travel Speed on Two-Way Segments

Two-Way Demand Flow Rate, v_p (pc/h)	Reduction in Average Travel Speed (km/h)					
	No-Passing Zones (%)					
	0	20	40	60	80	100
0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.0	1.0	2.3	3.8	4.2	5.6
400	0.0	2.7	4.3	5.7	6.3	7.3
600	0.0	2.5	3.8	4.9	5.5	6.2
800	0.0	2.2	3.1	3.9	4.3	4.9
1000	0.0	1.8	2.5	3.2	3.6	4.2
1200	0.0	1.3	2.0	2.6	3.0	3.4
1400	0.0	0.9	1.4	1.9	2.3	2.7
1600	0.0	0.9	1.3	1.7	2.1	2.4
1800	0.0	0.8	1.1	1.6	1.8	2.1
2000	0.0	0.8	1.0	1.4	1.6	1.8
2200	0.0	0.8	1.0	1.4	1.5	1.7
2400	0.0	0.8	1.0	1.3	1.5	1.7
2600	0.0	0.8	1.0	1.3	1.4	1.6
2800	0.0	0.8	1.0	1.2	1.3	1.4
3000	0.0	0.8	0.9	1.1	1.1	1.3
3200	0.0	0.8	0.9	1.0	1.0	1.1

Exhibit 20-12: Adjustment ($f_{d/np}$) for Combined Effect of Directional Distribution of Traffic and Percentage of No-Passing Zones on Percent Time-Spent-Following on Two-Way Segments

Two-Way Flow Rate, v_p (pc/h)	Increase in Percent Time-Spent-Following (%)					
	No-Passing Zones (%)					
	0	20	40	60	80	100
Directional Split = 50/50						
≤ 200	0.0	10.1	17.2	20.2	21.0	21.8
400	0.0	12.4	19.0	22.7	23.8	24.8
600	0.0	11.2	16.0	18.7	19.7	20.5
800	0.0	9.0	12.3	14.1	14.5	15.4
1400	0.0	3.6	5.5	6.7	7.3	7.9
2000	0.0	1.8	2.9	3.7	4.1	4.4
2600	0.0	1.1	1.6	2.0	2.3	2.4
3200	0.0	0.7	0.9	1.1	1.2	1.4
Directional Split = 60/40						
≤ 200	1.6	11.8	17.2	22.5	23.1	23.7
400	0.5	11.7	16.2	20.7	21.5	22.2
600	0.0	11.5	15.2	18.9	19.8	20.7
800	0.0	7.6	10.3	13.0	13.7	14.4
1400	0.0	3.7	5.4	7.1	7.6	8.1
2000	0.0	2.3	3.4	3.6	4.0	4.3
≥ 2600	0.0	0.9	1.4	1.9	2.1	2.2
Directional Split = 70/30						
≤ 200	2.8	13.4	19.1	24.8	25.2	25.5
400	1.1	12.5	17.3	22.0	22.6	23.2
600	0.0	11.6	15.4	19.1	20.0	20.9
800	0.0	7.7	10.5	13.3	14.0	14.6
1400	0.0	3.8	5.6	7.4	7.9	8.3
≥ 2000	0.0	1.4	4.9	3.5	3.9	4.2
Directional Split = 80/20						
≤ 200	5.1	17.5	24.3	31.0	31.3	31.6
400	2.5	15.8	21.5	27.1	27.6	28.0
600	0.0	14.0	18.6	23.2	23.9	24.5
800	0.0	9.3	12.7	16.0	16.5	17.0
1400	0.0	4.6	6.7	8.7	9.1	9.5
≥ 2000	0.0	2.4	3.4	4.5	4.7	4.9
Directional Split = 90/10						
≤ 200	5.6	21.6	29.4	37.2	37.4	37.6
400	2.4	19.0	25.6	32.2	32.5	32.8
600	0.0	16.3	21.8	27.2	27.6	28.0
800	0.0	10.9	14.8	18.6	19.0	19.4
≥1400	0.0	5.5	7.8	10.0	10.4	10.7

- oooOooo –

NO ANGKA GILIRAN : _____

TWO-WAY TWO-LANE HIGHWAY SEGMENT WORKSHEET

General Information

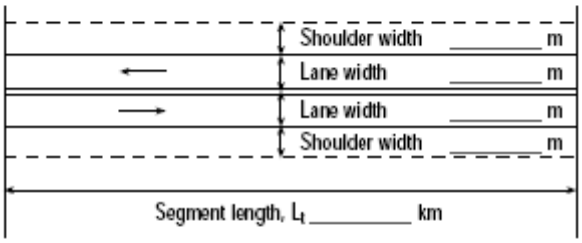
Analyst _____
Agency or Company _____
Date Performed _____
Analysis Time Period _____

Site Information

Highway _____
From/To _____
Jurisdiction _____
Analysis Year _____

❑ Operational (LOS) ❑ Design (v_p) ❑ Planning (LOS) ❑ Planning (v_p)

Input Data



❑ Class I highway ❑ Class II highway
Terrain ❑ Level ❑ Rolling
Two-way hourly volume _____ veh/h
Directional split _____ / _____
Peak-hour factor, PHF _____
% Trucks and buses, P_T _____ %
% Recreational vehicles, P_R _____ %
% No-passing zone _____ %
Access points/km _____ /km

Average Travel Speed

Grade adjustment factor, f_G (Exhibit 20-7)	
Passenger-car equivalents for trucks, E_T (Exhibit 20-9)	
Passenger-car equivalents for RVs, E_R (Exhibit 20-9)	
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	
v_p * highest directional split proportion[2] (pc/h)	

Free-Flow Speed from Field Measurement	Estimated Free-Flow Speed
Field measured speed, S_{FM} _____ km/h Observed volume, V_f _____ veh/h Free-flow speed, FFS _____ km/h $FFS = S_{FM} + 0.0125(\frac{V_f}{f_{HV}})$	Base free-flow speed, BFFS _____ km/h Adj. for lane width and shoulder width, f_{LS} (Exhibit 20-5) _____ km/h Adj. for access points, f_A (Exhibit 20-6) _____ km/h Free-flow speed, FFS _____ km/h $FFS = BFFS - f_{LS} - f_A$

Adj. for no-passing zones, f_{np} (km/h) (Exhibit 20-11)	
Average travel speed, ATS (km/h) $ATS = FFS - 0.0125v_p - f_{np}$	

Percent Time-Spent-Following

Grade adjustment factor, f_G (Exhibit 20-8)	
Passenger-car equivalents for trucks, E_T (Exhibit 20-10)	
Passenger-car equivalents for RVs, E_R (Exhibit 20-10)	
Heavy-vehicle adjustment factor, f_{HV} $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$	
Two-way flow rate,[1] v_p (pc/h) $v_p = \frac{V}{PHF * f_G * f_{HV}}$	
v_p * highest directional split proportion[2] (pc/h)	
Base percent time-spent-following, BPTSF (%) $BPTSF = 100(1 - e^{-0.000879v_p})$	
Adj. for directional distribution and no-passing zone, $f_{d/np}$ (%) (Exhibit 20-12)	
Percent time-spent-following, PTSF (%) $PTSF = BPTSF + f_{d/np}$	

Level of Service and Other Performance Measures

Level of service, LOS (Exhibit 20-3 for Class I or 20-4 for Class II)	
Volume to capacity ratio, v/c $v/c = \frac{v_p}{3,200}$	
Peak 15-min vehicle-kilometers of travel, $VkmT_{15}$ (veh-km) $VkmT_{15} = 0.25L_t(\frac{V}{PHF})$	
Peak-hour vehicle-kilometers of travel, $VkmT_{60}$ (veh-km) $VkmT_{60} = V * L_t$	
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \frac{VkmT_{15}}{ATS}$	

Notes

1. If $v_p \geq 3,200$ pc/h, terminate analysis—the LOS is F.
2. If highest directional split $v_p \geq 1,700$ pc/h, terminate analysis—the LOS is F.