UNIVERSITY OF JOHANNESBURG

PROGRAM	:	BACHELOR OF ENGINEERING TECHNOLOGY *CIVIL ENGINEERING*
SUBJECT	:	**TRANSPORTATION ENGINEERING 3A**
CODE	:	**TRACIA3**
DATE	:	WINTER EXAMINATION 31 MAY 2019
DURATION	:	SESSION 1 (08:30 – 11:30)
WEIGHT	:	40: 60
FULL MARKS	:	102
TOTAL MARKS	:	100

EXAMINER	:	Mrs M. A. Kasenge
MODERATOR	:	Ms. E Schmidt
NUMBER OF PAGES	:	4 PAGES AND 27 ANNEXURES

INSTRUCTIONS	:	**QUESTION PAPERS MUST BE HANDED IN.**
	:	CALCULATOR (ONE PER CANDIDATE)
	:	ANSWER ALL THE QUESTIONS

Programmable calculators will be allowed (one per candidate). Candidates are warned to erase from the memory of any calculator in their possession that can store alpha characters as text, notes or other information that could in any way assist in answering written ("theory") questions. If this instruction is not complied with it will be deemed that the candidate has in his possession under examination rules illegal material and will be disqualified.

QUESTION 1

1.1 A 15 kN passenger vehicle originally traveling on a straight and level road gets onto a section of the road with a horizontal curve of radius = 300 m. If the vehicle was originally traveling at 90 km/h, at sea level and has a front cross-sectional area of 3.2 m^2. Determine:

1.1.1. The additional horsepower on the curve the vehicle must produce to maintain the original speed. (12)

1.1.2. The total resistance force on the vehicle as it traverses the horizontal curve, and the total horsepower. (3)

1.2 The elevated section of the M1 highway goes through Johannesburg central business district (CBD) and crosses a local street as shown in Figure 1. The partial cloverleaf exit ramp is on a 3 percent downgrade, and all vehicles leaving the highway must stop at the intersection with the local street. Determine: (15)

1.2.1 Minimum ramp radius

1.2.2 Length of the ramp for the following conditions:

- Maximum speed on highway = 100 km/h
- Distance between exit sign and exit ramp = 81 m
- Letter height of road sign = 75 mm
- Perception-reaction time = 2.5 s
- Maximum superelevation = 0.08
- Expressway grade = +2 %

Assume that a driver can read a road sign within his or her area of vision at a distance of 15 m for each 25 mm of letter height, and the driver sees the stop sign immediately on entering the ramp.

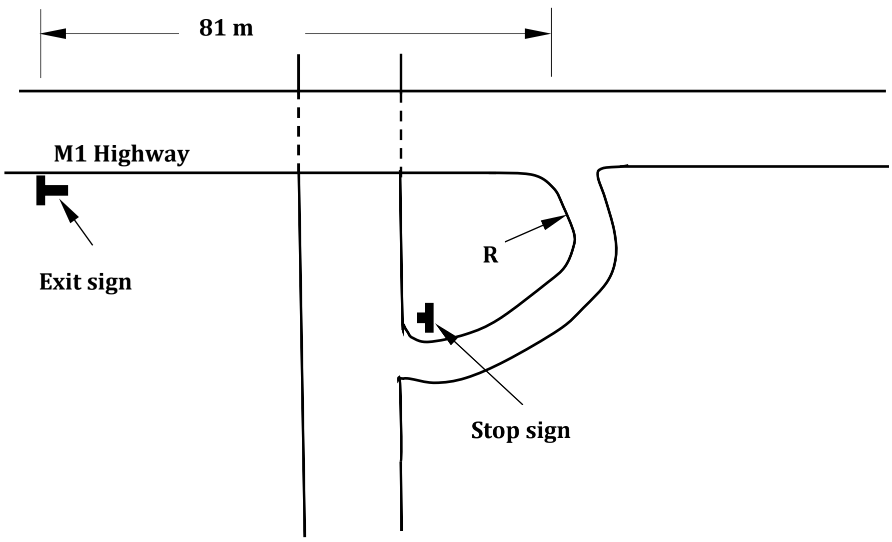


Fig. 1: Layout of M1 Highway Ramp and a Local Street

[30]

QUESTION 2

2.1. A traffic count taken between 7:00 a.m. and 2:00 p.m. on a rural highway found the following hourly volumes.

Time	Hourly volume
07:00 - 08:00	310
08:00 - 09:00	289
09:00 - 10:00	241
10:00 - 11:00	251
11:00 - 12:00	267
12:00 - 13:00	264
13:00 – 14:00	243

If these data were collected on a Tuesday in March, estimate the AADT on this section of highway.
Assume that the expansion factors given in Tables 4.6, 4.7, and 4.8 apply. (5)

2.2. The speeds of five vehicles were measured at the mid-point of one kilometre section of roadway. The speeds for vehicles 1, 2, 3, 4 and 5 were 75, 72, 86, 83 and 78 km/h respectively. Assuming all vehicles were travelling at constant speed over this roadway section, calculate the time-mean speed and space-mean speed. (5)

2.3. Vehicle time headways and spacing's were measured at a point along a highway, from a single lane, over the course of an hour. The average values were calculated as 2.5 s/veh for headway and 60 m/veh for spacing. Calculate the average speed of the traffic. (12)

[22]

QUESTION 3

A freeway has a capacity of 4,500 vehicles per hour and a constant traffic volume of 3,500 vehicles per hour at 8:00 a.m. on a particular day. At that time, a traffic accident happens and the freeway is closed for 15 minutes. At 8:15 a.m. the freeway is partially opened with a capacity of 2,500 vehicles per hour. At 8:30 a.m., the freeway is completely opened with the capacity of 4,500 vehicles per hour.
Draw the queuing diagram (time versus number of vehicles) and determine the time of queue dissipation, longest queue length, total delay, average delay per vehicle, and the longest wait of any vehicle.

[25]

QUESTION 4

4.1. Given: Urban six-lane freeway, 3.5 m wide lanes, 1.5 m wide shoulder on the right, 0.5 m shoulder on the left, Grade 3% 1.5 km long, 6% trucks, 3% intercity buses.

— Peak hour factor = 0.90

— Average highway speed = 100 km/h

— Determine service volumes at Levels of service A, B, C, D, and E. (10)

4.2. Given rural two-lane highway with 3.75 m wide lanes, 3 m shoulders, overall long section in level terrain, ideal alignment with an average highway speed of 120 km/h, 100% passing opportunity, 6% tucks. If the DHV is 1900 vehicles/hour, determine the level of service provided. (10)

[20]

QUESTION 5

An approach to a pre-timed signal has 25 seconds -of effective green in a 60-second cycle. The approach volume is 500 veh/h and the saturation flow rate is 1400 veh/h.

Calculate the average vehicle delay assuming D/D/I queuing,

[05]

BACHELOR OF ENGINEERING TECHNOLOGY

CIVIL ENGINEERING

TRANSPORTATION ENGINEERING 3A

TRACIA3

FORMULA SHEET

AND

ANNEXURES

WINTER EXAMINATIONS

31 MAY 2019

PREPARED BY MRS MA KASENGE

Visual acuity	— $\varphi = 2tan^{-1}\left(\frac{H}{2D}\right)$ — $VA = \frac{d}{D}$
Heavy vehicle Gross weight	— $W = 230\left[\frac{LN}{N-1} + 23N + 36\right]$
Acceleration as a Function of Velocity	— $\frac{du_t}{dt} = \alpha - \beta u_t$ — $t = \frac{1}{\beta}\ln\frac{(\alpha-\beta u_{0)}}{\alpha-\beta u_t}$ — $u_t = \frac{\alpha}{\beta}\left(1-e^{-\beta t}\right) + u_0 e^{-\beta t}$ — $x = \int_0^t u_t\,dt = \left(\frac{\alpha}{\beta}\right)t - \frac{\alpha}{\beta^2}\left(1-e^{-\beta t}\right) + \frac{u_0}{\beta}\left(1-e^{-\beta t}\right)$
Vehicle dynamic characteristics	— $F = ma + R_a + R_{rl} + R_g$ — $R_a = \frac{\rho}{2}\,C_D\,A_f v^2$ $\quad P_{R_a} = \frac{\rho}{2}\,C_D\,A_f v^3$ — $R_{rl} = f_{rl}W$ $\quad P_{R_{rl}} = f_{rl}Wv$ — $R_c = \frac{0.077v^2W}{2gR}v^2$ — $f_{rl} = 0.01\left(1+\frac{v}{44.73}\right)$ — $R_g = Wg$
Braking Distance	— $d_r = v_1 t_r$ — $d_s = d{+}d_r$ — $v_2^2 = v_1^2 \pm 2ad$ — $d_B = \frac{(v_1^2-v_2^2)}{2a}$ *if vehicle comes to a stop.......* $d_B = \frac{v_1^2}{2a}$ — $d_B = \frac{v_1^2}{2g\left(\frac{a}{g}\pm G\right)}$ $\quad d_B = \frac{V^2}{254\left[\left(\frac{a}{g}\right)\pm G\right]}$ — $u_u = \left(\frac{D_b}{D_t}u_t^2 + u_i^2\right)$
Stopping sight distance	— $SSD = \frac{Vt}{3.6} + \frac{V^2}{254\left[\left(\frac{a}{g}\right)\pm G\right]}$ — $SSD = 0.278ut + \frac{u_1^2-u_2^2}{254\left[\left(\frac{a}{g}\right)\pm G\right]}$

Passing Sight Distance	– $\mathrm{PSD} = \mathrm{d}_1 + \mathrm{d}_2 + \mathrm{d}_3 + \mathrm{d}_4$ – $\mathrm{d}_1 = \frac{\mathrm{t}_1(v_1 + v_2)}{2}$ – $\mathrm{d}_2 = v_2 \mathrm{t}_2$ – $\mathrm{d}_4 = \frac{2}{3}\mathrm{d}_2$
Spot Speed Studies	— $\bar{u} = \frac{\sum u_i}{N}$ $\quad\quad \bar{u} = \frac{\sum f_i u_i}{\sum f_i}$ — $S = \sqrt{\frac{\sum(u_i - \bar{u})^2}{N-1}}$ $\quad\quad S = \sqrt{\frac{\sum f_i(u_i - \bar{u})^2}{N-1}}$ — $f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^{2/2x\sigma^2}}$ — $N = \left(\frac{Z\sigma}{d}\right)^2$ $\quad\quad Z = (X - \mu)/\sigma$ — $S_d = \sqrt{\left(\frac{S_1^2}{n_1}\right) + \left(\frac{S_2^2}{n_2}\right)}$
t-Test Comparison	— $T = \frac{\bar{u}_1 - \bar{u}_2}{\left(S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}\right)}$ — $S_p{}^2 = \frac{(n_1 - 1)S_1{}^2 + (n_2 - 1)S_2{}^2}{n_1 + n_2 - 2}$
Number of Counts Stations	— $n = \frac{t^2_{\alpha/2,N-1}\left(\frac{s^2}{d^2}\right)}{1 + (1/N)\left(t^2_{\alpha/2,N-1}\right)\left(\frac{s^2}{d^2}\right)}$
Expansion Factors from Continuous Count Stations	— $HEF = \frac{total\ volume\ for\ 24\text{–}hr\ period}{volume\ for\ particular\ hour}$ — $DEF = \frac{average\ total\ volume\ for\ week}{Average\ volume\ for\ particular\ day}$ — $MEF = \frac{AADT}{ADT\ for\ particular\ month}$

Traffic Stream Parameters	— $q = \frac{n*3600}{T}$ $\quad q = \frac{n}{t}$ $\quad q = \frac{n}{\sum_{i=1}^{n} h_i}$ $\quad q = \frac{1}{\bar{h}}$ — $t = \sum_{i=1}^{n} h_i$ $\quad \bar{t} = \frac{1}{n}\sum_{i=1}^{n} t_i$ — $\bar{u}_t = \frac{\sum_{i=1}^{n} u_i}{n}$ — $\bar{u}_s = \frac{l}{\frac{1}{n}\sum_{i=1}^{n} t_i}$ $\quad \bar{u}_s = \frac{l}{\bar{t}}$ $\quad \bar{u}_s = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\left[\frac{1}{u_i}\right]}$ — $k = \frac{n}{l}$ $\quad k = \frac{n}{\sum_{i=1}^{n} S_i}$ $\quad k = \frac{1}{\bar{S}}$ — $l = \sum_{i=1}^{n} S_i$
Basic Traffic Stream Models	**Speed-Density Model** — $u = u_f\left(1 - \frac{k}{k_j}\right)$
	Flow-Density Model — $q = u_f\left(k - \frac{k^2}{k_j}\right)$ — $\frac{dq}{dk} = u_f\left(1 - \frac{2k}{k_j}\right) = 0$ — $k_{cap} = \frac{k_j}{2}$ — $u_{cap} = u_f\left(1 - \frac{k_j}{2k_j}\right) = \frac{u_f}{2}$ — $q_{cap} = u_{cap}\, k_{cap}$ $\quad q_{cap} = \frac{u_f k_j}{4}$
	Speed-Flow Model — $k = k_j\left(1 - \frac{u}{u_f}\right)$ — $q = k_j\left(u - \frac{u^2}{u_f}\right)$

Models of Traffic Flow	$P(n) = \frac{(\lambda t)^n e^{-\lambda t}}{n!}$ $\lambda = \frac{q}{3600}$
Queuing Theory	D/D/1 — $\lambda = \frac{3600}{h} = veh/h$ — $\mu = \frac{3600}{h} = veh/h$
	M/D/1 $\rho = \frac{\lambda}{\mu}$ $\rho < 1.0$ — $\overline{Q} = \frac{\rho}{2(1-\rho)} = veh$ — $\overline{w} = \frac{1}{2\mu}\left(\frac{\rho}{1-\rho}\right) = min/veh$ — $\overline{t} = \frac{1}{2\mu}\left(\frac{2-\rho}{1-\rho}\right) = min/veh$
	M/M/1 $\rho = \frac{\lambda}{\mu}$ $\rho < 1.0$ — $\overline{Q} = \frac{\rho^2}{(1-\rho)} = veh$ — $\overline{w} = \frac{1}{\mu}\left(\frac{\lambda}{\mu-\lambda}\right) = min/veh$ — $\overline{t} = \frac{1}{\mu-\lambda} = min/veh$
	M/M/N $\rho = \frac{\lambda}{\mu}$ $\rho/N < 1.0$ — $\overline{Q} = \frac{P_0 \rho^{N+1}}{N!N}\left[\frac{1}{\left(1-\frac{\rho}{N}\right)^2}\right] = veh$ — $\overline{w} = \frac{\rho+\overline{Q}}{\lambda} - \frac{1}{\mu} = min/veh$ — $\overline{t} = \frac{\rho+\overline{Q}}{\lambda} = min/veh$
	M/M/N (Stuff) — Probability of having no vehicles

	$P_0 = \frac{1}{\sum_{nc=0}^{N-1} \frac{\rho^{n_c}}{n_c!} + \frac{\rho^N}{N!\left(1-\frac{\rho}{N}\right)}}$ — Probability of having *n* vehicles $P_n = \frac{\rho^n P_0}{n!}$ for n $\leq N$ $P_n = \frac{\rho^n P_0}{N^{n-N}\, N!}$ for n $\geq N$ — Probability of being in a queue $P_{n>N} = \frac{P_0\, \rho^{N+1}}{N!\, N\left(1-\frac{\rho}{N}\right)}$
Intersection Design	— $R_{min} = \frac{V^2}{127(e+f_s)}$ — $f_s = 0.21 - 0.001V$ — $d_{ISD} = 0.278V_{major} * t_g$ — $t_g = t_a + \frac{w + L_a}{0.167V_{minor}}$
LOS **Basic Freeway Segment**	— $PHF = \frac{V}{4*V_{15}}$ — $FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID}$ — $f_{HV} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)}$ — $v_p = \frac{V}{PFH*N*f_{HV}*fp}$ — $V = vp * PHF * N * f_{HV} * fp$ — $D = \frac{v_p}{S}$ — $DHV = AADT * K * D$
LOS **Multilane Highway**	— $V = v_p * PHF * N * f_{HV}$ — $FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A$ — $TLC = LC_R + LC_L$

LOS Two Lane Highway	— $FFS = S_{FM} + 0.0125 \frac{V_f}{f_{HV}}$ — $v_p = \frac{V}{PHF * f_G * f_{HV}}$ — $FFS = BFFS - f_{LS} - f_A$ — $ATS = FFS - 0.0125 v_p - f_{np}$ — $PTSF = BPTSF + f_{\frac{d}{np}}$ — $BPTSF = 100(1 - e^{-0.000879 v_p})$

BRAKE FORCE COEFFICIENTS FOR VARIOUS SPEEDS	
Speed (Km/h)	**Brake Force Coefficients**
40	0.37
60	0.32
80	0.30
100	0.29
120	0.28
140	0.27

Constant Corresponding to Level of Confidence	
Confidence Level (%)	***Constant Z***
68.3	1.00
86.6	1.50
90.0	1.64
95.0	1.96
95.5	2.00
98.8	2.50
99.0	2.58
99.7	3.00

HOURLY EXPANSION FACTORS FOR A RURAL PRIMARY ROAD					
Hour	**Volume**	**HEF**	**Hour**	**Volume**	**HEF**
6:00–7:00 a.m.	294	42.00	6:00–7:00 p.m.	743	16.62
7:00–8:00 a.m.	426	29.00	7:00–8:00 p.m.	706	17.49
8:00–9:00 a.m.	560	22.05	8:00–9:00 p.m.	606	20.38
9:00–10:00 a.m.	657	18.80	9:00–10:00 p.m.	489	25.26
10:00–11:00 a.m.	722	17.10	10:00–11:00 p.m.	396	31.19
11:00–12:00 p.m.	667	18.52	11:00–12:00 a.m.	360	34.31
12:00–1:00 p.m.	660	18.71	12:00–1:00 a.m.	241	51.24
1:00–2:00 p.m.	739	16.71	1:00–2:00 a.m.	150	82.33
2:00–3:00 p.m.	832	14.84	2:00–3:00 a.m.	100	123.50
3:00–4:00 p.m.	836	14.77	3:00–4:00 a.m.	90	137.22
4:00–5:00 p.m.	961	12.85	4:00–5:00 a.m.	86	143.60
5:00–6:00 p.m.	892	13.85	5:00–6:00 a.m.	137	90.14

DAILY EXPANSION FACTORS FOR A RURAL PRIMARY ROAD		
Day of Week	***Average Volume***	***DEF***
Monday	10,714	1.002
Tuesday	9722	1.104
Wednesday	11,413	0.940
Thursday	10,714	1.002
Friday	13,125	0.818
Saturday	11,539	0.930
Sunday	7895	1.359

MONTHLY EXPANSION FACTORS FOR A RURAL PRIMARY ROAD		
Month	***ADT***	***MEF***
January	1350	1.756
February	1200	1.975
March	1450	1.635
April	1600	1.481
May	1700	1.394
June	2500	0.948
July	4100	0.578
August	4550	0.521
September	3750	0.632
October	2500	0.948
November	2000	1.185
December	1750	1.354

Table 6.5: Recommended sight distances for intersections with no traffic control (Case A)

Design speed (km/h)	Sight distance (m)
20	20
30	25
40	30
50	40
60	50
70	65
80	80
90	95
100	120
110	140
120	165

Table 6.6: Adjustment factors for approach sight distances based on approach gradient										
Approach gradient (%)	Design speed (km/h)									
	30	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**
-6	1,1	1,1	1,1	1,1	1,1	1,2	1,2	1,2	1,2	1,2
-5	1,0	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,2	1,2
-4	1,0	1,0	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
-3 to +3	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
+4	1,0	1,0	1,0	0,9	0,9	0,9	0,9	0,9	0,9	0,9
+5	1,0	1,0	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9
+6	1,0	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9

Table 6.7: Travel Times Used to Determine the Leg of the Departure Sight Triangle along the Major Road for Right and Left Turns from Stop-Controlled Approaches (Cases B1 and B2).	
Design vehicle	**Travel time (s) at design speed of major road**
Passenger car	7,5
Single-unit truck	9,5
Semi-trailer	11,5
Adjustment for multilane highways: For right turns onto two-way highways with more than two lanes, add 0,5 seconds for passenger cars or 0,7 seconds for trucks for each additional lane, in excess of one, to be crossed by the turning vehicle. For left turns, no adjustment is necessary	
Adjustment for approach gradients: If the approach gradient on the minor road exceeds +3 per cent: ❑ Add 0,1 seconds per percent gradient for left turns ❑ Add 0,2 seconds per percent gradient for right turns	

Table 6.8: Travel times used to determine the leg of the departure sight triangle along the major road to accommodate crossing manoeuvres at stop-controlled intersections (Case B3)	
Design vehicle	**Travel time (s) at Design speed of major road**
Passenger car	6,5
Single-unit truck	8,5
Semi trailer	10,5
Adjustment for multilane highways: For crossing a major road with more than two lanes, add 0,5 seconds for passenger cars and 0,7 seconds for trucks for each additional lane to be crossed. In the case of dual carriageways with inadequate width of median for refuge, count the median as another lane to be crossed.	
Adjustment for approach grades: If the approach gradient of the minor road exceeds +3 %, add 0,2 seconds per percent gradient in excess of 3 %.	

Table 6.9: Leg of approach sight triangle along the minor road to accommodate crossing manoeuvres from yield-controlled approaches		
Design speed (km/h)	**Distance along minor road (m)**	**Travel time from decision point to major road (t_a)[a,b]**
30	30	3,4
40	40	3,7
50	50	4,1
60	65	4,7
70	85	5,3
80	110	6,1
90	140	6,8
100	165	7,3
110	190	7,8
120	230	8,6

a For minor-road approach gradients that exceed +3 per cent, multiply by the appropriate adjustment factor from Table 6.6.

b Travel time applies to a vehicle that slows before crossing the intersection but does not stop.

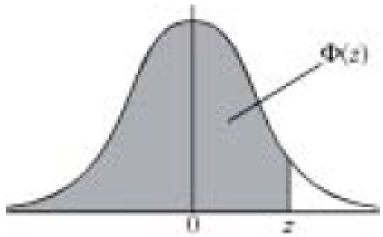
Table 6.10: Travel times used to determine the sight distance along the major road to accommodate right turns from the major road (Class F)	
Design vehicle	**Travel time (s) at design speed of major road**
Passenger car	5,5
Single-unit truck	6,5
Semi trailer	7,5
Adjustment for multilane highways: For right turns that have to cross more than one opposing lane, add 0,5 s for passenger cars and 0,7 s for trucks for each additional lane to be crossed. In the case of dual carriageways where the median is not sufficiently wide to provide refuge for the turning vehicle, the median should be regarded as an additional lane to be crossed.	

THE NORMAL DISTRIBUTION FUNCTION

If Z has a normal distribution with mean 0 and variance 1 then, for each value of z, the table gives the value of $\Phi(z)$, where

$$\Phi(z) = \mathrm{P}(Z \le z).$$

For negative values of z use $\Phi(-z) = 1 - \Phi(z)$.

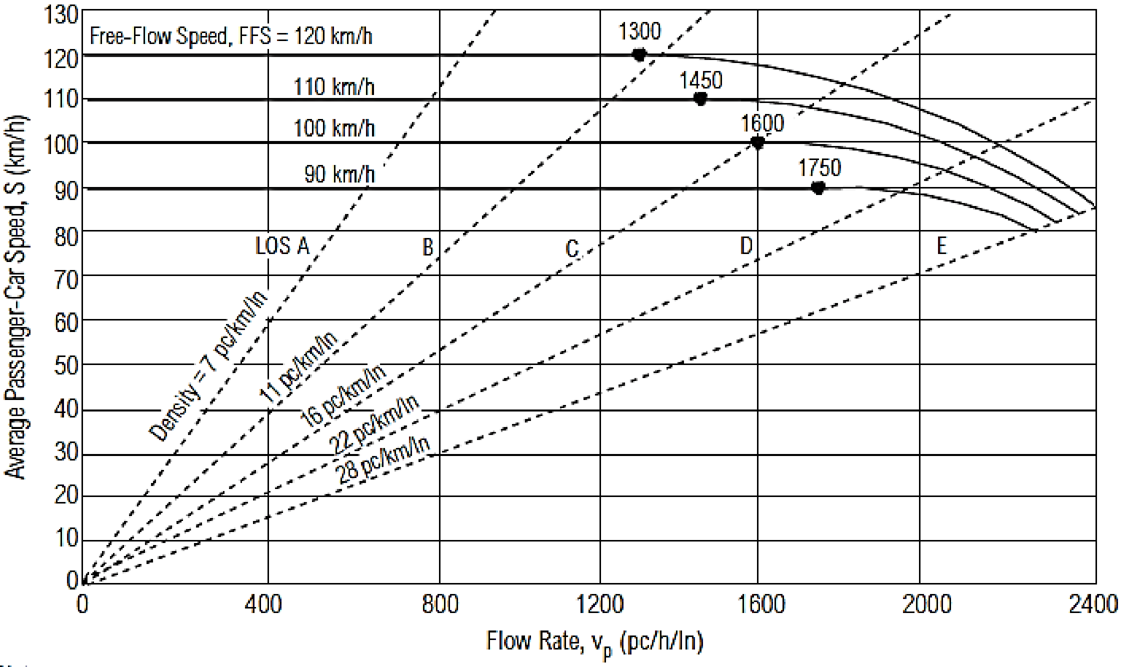


z	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5 (ADD)	6	7	8	9
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359	4	8	12	16	20	24	28	32	36
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753	4	8	12	16	20	24	28	32	36
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141	4	8	12	15	19	23	27	31	35
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517	4	7	11	15	19	22	26	30	34
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879	4	7	11	14	18	22	25	29	32
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224	3	7	10	14	17	20	24	27	31
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549	3	7	10	13	16	19	23	26	29
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852	3	6	9	12	15	18	21	24	27
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133	3	5	8	11	14	16	19	22	25
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389	3	5	8	10	13	15	18	20	23
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621	2	5	7	9	12	14	16	19	21
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830	2	4	6	8	10	12	14	16	18
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015	2	4	6	7	9	11	13	15	17
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177	2	3	5	6	8	10	11	13	14
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319	1	3	4	6	7	8	10	11	13
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441	1	2	4	5	6	7	8	10	11
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545	1	2	3	4	5	6	7	8	9
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633	1	2	3	4	4	5	6	7	8
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706	1	1	2	3	4	4	5	6	6
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767	1	1	2	2	3	4	4	5	5
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817	0	1	1	2	2	3	3	4	4
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857	0	1	1	2	2	2	3	3	4
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890	0	1	1	1	2	2	2	3	3
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916	0	1	1	1	1	2	2	2	2
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936	0	0	1	1	1	1	1	2	2
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952	0	0	0	1	1	1	1	1	1
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964	0	0	0	0	1	1	1	1	1
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974	0	0	0	0	0	1	1	1	1
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981	0	0	0	0	0	0	0	1	1
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986	0	0	0	0	0	0	0	0	0

LEVEL-OF-SERVICE THRESHOLDS FOR A BASIC FREEWAY SEGMENT	
LOS	Density Range (pc/km/ln)
A	0–7
B	> 7–11
C	> 11–16
D	> 16–22
E	> 22–28
F	> 28

EXHIBIT 23-2. LOS CRITERIA FOR BASIC FREEWAY SEGMENTS					
Criteria	LOS				
	A	B	C	D	E
FFS = 120 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	120.0	120.0	114.6	99.6	85.7
Maximum v/c	0.35	0.55	0.77	0.92	1.00
Maximum service flow rate (pc/h/ln)	840	1320	1840	2200	2400
FFS = 110 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	110.0	110.0	108.5	97.2	83.9
Maximum v/c	0.33	0.51	0.74	0.91	1.00
Maximum service flow rate (pc/h/ln)	770	1210	1740	2135	2350
FFS = 100 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	100.0	100.0	100.0	93.8	82.1
Maximum v/c	0.30	0.48	0.70	0.90	1.00
Maximum service flow rate (pc/h/ln)	700	1100	1600	2065	2300
FFS = 90 km/h					
Maximum density (pc/km/ln)	7	11	16	22	28
Minimum speed (km/h)	90.0	90.0	90.0	89.1	80.4
Maximum v/c	0.28	0.44	0.64	0.87	1.00
Maximum service flow rate (pc/h/ln)	630	990	1440	1955	2250

EXHIBIT 23-3. SPEED-FLOW CURVES AND LOS FOR BASIC FREEWAY SEGMENTS



Note:
Capacity varies by free-flow speed. Capacity is 2400, 2350, 2300, and 2250 pc/h/ln at free-flow speeds of 120, 110, 100, and 90 km/h, respectively.

For $90 \le FFS \le 120$ and for flow rate (v_p)
$(3100 - 15FFS) < v_p \le (1800 + 5FFS)$,

$$S = FFS - \left[\frac{1}{28}(23FFS - 1800)\left(\frac{v_p + 15FFS - 3100}{20FFS - 1300} \right)^{2.6} \right]$$

For $90 \le FFS \le 120$ and
$v_p \le (3100 - 15FFS)$,
$S = FFS$

EXHIBIT 23-4. ADJUSTMENTS FOR LANE WIDTH	
Lane Width (m)	Reduction in Free-Flow Speed, fLW (km/h)
3.6	0.0
3.5	1.0
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

EXHIBIT 23-5. ADJUSTMENTS FOR RIGHT-SHOULDER LATERAL CLEARANCE				
Right-Shoulder Lateral Clearance (m)	Reduction in Free-Flow Speed, f_{LC} (km/h)			
	Lanes in One Direction			
	2	3	4	≥ 5
≥ 1.8	0.0	0.0	0.0	0.0
1.5	1.0	0.7	0.3	0.2
1.2	1.9	1.3	0.7	0.4
0.9	2.9	1.9	1.0	0.6
0.6	3.9	2.6	1.3	0.8
0.3	4.8	3.2	1.6	1.1
0.0	5.8	3.9	1.9	1.3

EXHIBIT 23-6. ADJUSTMENTS FOR NUMBER OF LANE	
Number of Lanes (One Direction)	Reduction in Free-Flow Speed, fN (km/h)
≥ 5	0.0
4	2.4
3	4.8
2	7.3

EXHIBIT 23-7. ADJUSTMENTS FOR INTERCHANGE DENSITY	
Interchanges per Kilometre	Reduction in Free-Flow Speed, fID (km/h)
≤ 0.3	0.0
0.4	1.1
0.5	2.1
0.6	3.9
0.7	5.0
0.8	6.0
0.9	8.1
1.0	9.2
1.1	10.2
1.2	12.1

EXHIBIT 23-8. PASSENGER-CAR EQUIVALENTS ON EXTENDED FREEWAY SEGMENTS			
Factor	Type of Terrain		
	Level	Rolling	Mountainous
E_T (trucks and buses)	1.5	2.5	4.5
E_R (RVs)	1.2	2.0	4.0

EXHIBIT 23-9. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON UPGRADES										
Upgrade (%)	Length (km)	E_T								
		Percentage of Trucks and Buses								
		2	4	5	6	8	10	15	20	25
< 2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
≥ 2–3	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.8–1.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 1.2–1.6	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.6–2.4	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 2.4	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
> 3–4	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8–1.2	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	> 1.2–1.6	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 1.6–2.4	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	> 2.4	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
> 4–5	0.0–0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.8–1.2	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	> 1.2–1.6	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.6	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
> 5–6	0.0–0.4	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.5	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.5–0.8	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.8–1.2	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.2–1.6	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	> 1.6	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	0.0–0.4	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 0.4–0.5	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	> 0.5–0.8	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	> 0.8–1.2	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	> 1.2–1.6	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	> 1.6	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

EXHIBIT 23-10. PASSENGER-CAR EQUIVALENTS FOR RVs ON UPGRADES										
		E_R								
		Percentage of RVs								
Upgrade (%)	Length (km)	2	4	5	6	8	10	15	20	25
≤ 2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
> 2–3	0.0–0.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.8	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
> 3–4	0.0–0.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.4–0.8	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
> 4–5	0.0–0.4	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 0.4–0.8	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.8	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
> 5	0.0–0.4	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
	> 0.4–0.8	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	> 0.8	6.0	4.5	4.0	4.5	3.5	3.0	3.0	2.5	2.0

EXHIBIT 23-11. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND BUSES ON DOWNGRADES					
		E_T			
		Percentage of Trucks			
Downgrade (%)	Length (km)	5	10	15	20
< 4	All	1.5	1.5	1.5	1.5
4–5	≤ 6.4	1.5	1.5	1.5	1.5
4–5	> 6.4	2.0	2.0	2.0	1.5
> 5–6	≤ 6.4	1.5	1.5	1.5	1.5
> 5–6	> 6.4	5.5	4.0	4.0	3.0
> 6	≤ 6.4	1.5	1.5	1.5	1.5
> 6	> 6.4	7.5	6.0	5.5	4.5

EXHIBIT 23-12. URBAN FREEWAY FFS AND INTERCHANGE SPACING (SEE FOOTNOTE FOR ASSUMED VALUES)				
Number of Lanes	Free-Flow Speed (km/h)			
	Interchange Spacing (km)			
	1.00	1.25	2.00	3.00
2	94	97	101	103
3	96	99	103	105
4	98	102	106	108
5	99	104	108	110

EXHIBIT 20-2. LOS CRITERIA FOR TWO-LANE HIGHWAYS IN CLASS I		
LOS	Percent Time-Spent-Following	Average Travel Speed (km/h)
A	≤ 35	> 90
B	> 35–50	> 80–90
C	> 50–65	> 70–80
D	> 65–80	> 60–70
E	> 80	≤ 60

EXHIBIT 20-3. LOS CRITERIA (GRAPHICAL) FOR TWO-LANE HIGHWAYS IN CLASS I

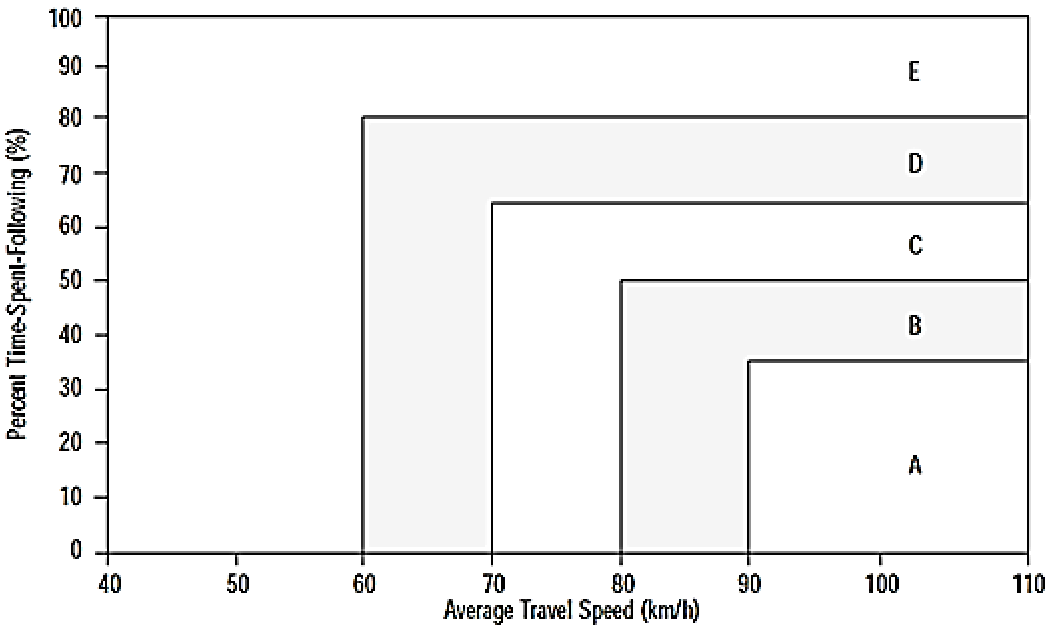


EXHIBIT 20-4. LOS CRITERIA FOR TWO-LANE HIGHWAYS IN CLASS II	
LOS	Percent Time-Spent-Following
A	≤ 40
B	> 40–55
C	> 55–70
D	> 70–85
E	> 85

EXHIBIT 20-5. ADJUSTMENT (fLS) FOR LANE WIDTH AND SHOULDER WIDTH				
Lane Width (m)	Reduction in FFS (km/h)			
	Shoulder 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

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 (fG) 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 > 600–1,200 > 1,200	0–300 > 300–600 > 600	1.7 1.2 1.1	2.5 1.9 1.5
RVs, E_R	0–600 > 600–1,200 > 1,200	0–300 > 300–600 > 600	1.0 1.0 1.0	1.1 1.1 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 > 600–1,200 > 1,200	0–300 > 300–600 > 600	1.1 1.1 1.0	1.8 1.5 1.0
RVs, E_R	0–600 > 600–1,200 > 1,200	0–300 > 300–600 > 600	1.0 1.0 1.0	1.0 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	10.1	17.2	20.2	21	21.8
400	0	12.4	19	22.7	23.8	24.8
600	0	11.2	16	18.7	19.7	20.5
800	0	9	12.3	14.1	14.5	15.4
1400	0	3.6	5.5	6.7	7.3	7.9
2000	0	1.8	2.9	3.7	4.1	4.4
2600	0	1.1	1.6	2	2.3	2.4
3200	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	11.5	15.2	18.9	19.8	20.7
800	0	7.6	10.3	13	13.7	14.4
1400	0	3.7	5.4	7.1	7.6	8.1
2000	0	2.3	3.4	3.6	4	4.3
≥ 2600	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	22.6	23.2
600	0	11.6	15.4	19.1	20	20.9
800	0	7.7	10.5	13.3	14	14.6
1400	0	3.8	5.6	7.4	7.9	8.3
≥ 2000	0	1.4	4.9	3.5	3.9	4.2
Directional Split = 80/20						
≤ 200	5.1	17.5	24.3	31	31.3	31.6
400	2.5	15.8	21.5	27.1	27.6	28
600	0	14	18.6	23.2	23.9	24.5
800	0	9.3	12.7	16	16.5	17
1400	0	4.6	6.7	8.7	9.1	9.5
≥ 2000	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	25.6	32.2	32.5	32.8
600	0	16.3	21.8	27.2	27.6	28
800	0	10.9	14.8	18.6	19	19.4
≥1400	0	5.5	7.8	10	10.4	10.7

EXHIBIT 20-13. GRADE ADJUSTMENT FACTOR (fG) FOR ESTIMATING AVERAGE TRAVEL SPEED ON SPECIFIC UPGRADES				
		Grade Adjustment Factor, f_G		
		Range of Directional Flow Rates v_d (pc/h)		
Grade (%)	Length of Grade (km)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	0.81	1.00	1.00
	0.8	0.79	1.00	1.00
	1.2	0.77	1.00	1.00
	1.6	0.76	1.00	1.00
	2.4	0.75	0.99	1.00
	3.2	0.75	0.97	1.00
	4.8	0.75	0.95	0.97
	≥ 6.4	0.75	0.94	0.95
≥ 3.5 < 4.5	0.4	0.79	1.00	1.00
	0.8	0.76	1.00	1.00
	1.2	0.72	1.00	1.00
	1.6	0.69	0.93	1.00
	2.4	0.68	0.92	1.00
	3.2	0.66	0.91	1.00
	4.8	0.65	0.91	0.96
	≥ 6.4	0.65	0.90	0.96
≥ 4.5 < 5.5	0.4	0.75	1.00	1.00
	0.8	0.65	0.93	1.00
	1.2	0.60	0.89	1.00
	1.6	0.59	0.89	1.00
	2.4	0.57	0.86	0.99
	3.2	0.56	0.85	0.98
	4.8	0.56	0.84	0.97
	≥ 6.4	0.55	0.82	0.93
≥ 5.5 < 6.5	0.4	0.63	0.91	1.00
	0.8	0.57	0.85	0.99
	1.2	0.52	0.83	0.97
	1.6	0.51	0.79	0.97
	2.4	0.49	0.78	0.95
	3.2	0.48	0.78	0.94
	4.8	0.46	0.76	0.93
	≥ 6.4	0.45	0.76	0.93
≥ 6.5	0.4	0.59	0.86	0.98
	0.8	0.48	0.76	0.94
	1.2	0.44	0.74	0.91
	1.6	0.41	0.70	0.91
	2.4	0.40	0.67	0.91
	3.2	0.39	0.67	0.89
	4.8	0.39	0.66	0.88
	≥ 6.4	0.38	0.66	0.87

EXHIBIT 20-14. GRADE ADJUSTMENT FACTOR (fG) FOR ESTIMATING PERCENT TIME-SPENTFOLLOWING ON SPECIFIC UPGRADES				
		Grade Adjustment Factor, f_G		
		Range of Directional Flow Rates, v_d (pc/h)		
Grade (%)	Length of Grade (km)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	1.00	0.92	0.92
	0.8	1.00	0.93	0.93
	1.2	1.00	0.93	0.93
	1.6	1.00	0.93	0.93
	2.4	1.00	0.94	0.94
	3.2	1.00	0.95	0.95
	4.8	1.00	0.97	0.96
	≥ 6.4	1.00	1.00	0.97
≥ 3.5 < 4.5	0.4	1.00	0.94	0.92
	0.8	1.00	0.97	0.96
	1.2	1.00	0.97	0.96
	1.6	1.00	0.97	0.97
	2.4	1.00	0.97	0.97
	3.2	1.00	0.98	0.98
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 4.5 < 5.5	0.4	1.00	1.00	0.97
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 5.5 < 6.5	0.4	1.00	1.00	1.00
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00
≥ 6.5	0.4	1.00	1.00	1.00
	0.8	1.00	1.00	1.00
	1.2	1.00	1.00	1.00
	1.6	1.00	1.00	1.00
	2.4	1.00	1.00	1.00
	3.2	1.00	1.00	1.00
	4.8	1.00	1.00	1.00
	≥ 6.4	1.00	1.00	1.00

EXHIBIT 20-15. PASSENGER-CAR EQUIVALENTS FOR TRUCKS FOR ESTIMATING AVERAGE SPEED ON SPECIFIC UPGRADES				
		Passenger-Car Equivalent for Trucks, E_T		
		Range of Directional Flow Rates, v_d (pc/h)		
Grade (%)	Length of Grade (km)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	2.5	1.9	1.5
	0.8	3.5	2.8	2.3
	1.2	4.5	3.9	2.9
	1.6	5.1	4.6	3.5
	2.4	6.1	5.5	4.1
	3.2	7.1	5.9	4.7
	4.8	8.2	6.7	5.3
	≥ 6.4	9.1	7.5	5.7
≥ 3.5 < 4.5	0.4	3.6	2.4	1.9
	0.8	5.4	4.6	3.4
	1.2	6.4	6.6	4.6
	1.6	7.7	6.9	5.9
	2.4	9.4	8.3	7.1
	3.2	10.2	9.6	8.1
	4.8	11.3	11.0	8.9
	≥ 6.4	12.3	11.9	9.7
≥ 4.5 < 5.5	0.4	4.2	3.7	2.6
	0.8	6.0	6.0	5.1
	1.2	7.5	7.5	7.5
	1.6	9.2	9.0	8.9
	2.4	10.6	10.5	10.3
	3.2	11.8	11.7	11.3
	4.8	13.7	13.5	12.4
	≥ 6.4	15.3	15.0	12.5
≥ 5.5 < 6.5	0.4	4.7	4.1	3.5
	0.8	7.2	7.2	7.2
	1.2	9.1	9.1	9.1
	1.6	10.3	10.3	10.2
	2.4	11.9	11.8	11.7
	3.2	12.8	12.7	12.6
	4.8	14.4	14.3	14.2
	≥ 6.4	15.4	15.2	15.0
≥ 6.5	0.4	5.1	4.8	4.6
	0.8	7.8	7.8	7.8
	1.2	9.8	9.8	9.8
	1.6	10.4	10.4	10.3
	2.4	12.0	11.9	11.8
	3.2	12.9	12.8	12.7
	4.8	14.5	14.4	14.3
	≥ 6.4	15.4	15.3	15.2

EXHIBIT 20-16. PASSENGER-CAR EQUIVALENTS FOR TRUCKS AND RVS FOR ESTIMATING PERCENT TIME-SPENT-FOLLOWING ON SPECIFIC UPGRADES					
		Passenger-Car Equivalent for Trucks, E_T			
		Range of Directional Flow Rates, v_d (pc/h)			
Grade (%)	Length of Grade (km)	0–300	> 300–600	> 600	RVs, E_R
≥ 3.0 < 3.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.0	1.0	1.0
	2.4	1.0	1.0	1.0	1.0
	3.2	1.0	1.0	1.0	1.0
	4.8	1.4	1.0	1.0	1.0
	≥ 6.4	1.5	1.0	1.0	1.0
≥ 3.5 < 4.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.0	1.0	1.0
	2.4	1.1	1.0	1.0	1.0
	3.2	1.4	1.0	1.0	1.0
	4.8	1.7	1.1	1.2	1.0
	≥ 6.4	2.0	1.5	1.4	1.0
≥ 4.5 < 5.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.0	1.0	1.0
	2.4	1.1	1.2	1.2	1.0
	3.2	1.6	1.3	1.5	1.0
	4.8	2.3	1.9	1.7	1.0
	≥ 6.4	3.3	2.1	1.8	1.0
≥ 5.5 < 6.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.0	1.0
	1.6	1.0	1.2	1.2	1.0
	2.4	1.5	1.6	1.6	1.0
	3.2	1.9	1.9	1.8	1.0
	4.8	3.3	2.5	2.0	1.0
	≥ 6.4	4.3	3.1	2.0	1.0
≥ 6.5	0.4	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.2	1.0	1.0	1.3	1.0
	1.6	1.3	1.4	1.6	1.0
	2.4	2.1	2.0	2.0	1.0
	3.2	2.8	2.5	2.1	1.0
	4.8	4.0	3.1	2.2	1.0
	≥ 6.4	4.8	3.5	2.3	1.0

EXHIBIT 20-17. PASSENGER-CAR EQUIVALENTS FOR RVS FOR ESTIMATING AVERAGE TRAVEL SPEED ON SPECIFIC UPGRADES				
		Passenger-Car Equivalent for RVs, E_R		
		Range of Directional Flow Rates, v_d(pc/h)		
Grade (%)	Length of Grade (km)	0–300	> 300–600	> 600
≥ 3.0 < 3.5	0.4	1.1	1.0	1.0
	0.8	1.2	1.0	1.0
	1.2	1.2	1.0	1.0
	1.6	1.3	1.0	1.0
	2.4	1.4	1.0	1.0
	3.2	1.4	1.0	1.0
	4.8	1.5	1.0	1.0
	≥ 6.4	1.5	1.0	1.0
≥ 3.5 < 4.5	0.4	1.3	1.0	1.0
	0.8	1.3	1.0	1.0
	1.2	1.3	1.0	1.0
	1.6	1.4	1.0	1.0
	2.4	1.4	1.0	1.0
	3.2	1.4	1.0	1.0
	4.8	1.4	1.0	1.0
	≥ 6.4	1.5	1.0	1.0
≥ 4.5 < 5.5	0.4	1.5	1.0	1.0
	0.8	1.5	1.0	1.0
	1.2	1.5	1.0	1.0
	1.6	1.5	1.0	1.0
	2.4	1.5	1.0	1.0
	3.2	1.5	1.0	1.0
	4.8	1.6	1.0	1.0
	≥ 6.4	1.6	1.0	1.0
≥ 5.5 < 6.5	0.4	1.5	1.0	1.0
	0.8	1.5	1.0	1.0
	1.2	1.5	1.0	1.0
	1.6	1.6	1.0	1.0
	2.4	1.6	1.0	1.0
	3.2	1.6	1.0	1.0
	4.8	1.6	1.2	1.0
	≥ 6.4	1.6	1.5	1.2
≥ 6.5	0.4	1.6	1.0	1.0
	0.8	1.6	1.0	1.0
	1.2	1.6	1.0	1.0
	1.6	1.6	1.0	1.0
	2.4	1.6	1.0	1.0
	3.2	1.6	1.0	1.0
	4.8	1.6	1.3	1.3
	≥ 6.4	1.6	1.5	1.4

EXHIBIT 20-18. PASSENGER-CAR EQUIVALENTS FOR ESTIMATING THE EFFECT ON AVERAGE TRAVEL SPEED OF TRUCKS THAT OPERATE AT CRAWL SPEEDS ON LONG STEEP DOWNGRADES			
Difference Between FFS and Truck Crawl Speed (km/h)	Passenger-Car Equivalent for Trucks at Crawl Speeds, E_{TC}		
	Range of Directional Flow Rates, v_d (pc/h)		
	0–300	> 300–600	> 600
≤ 20	4.4	2.8	1.4
40	14.3	9.6	5.7
≥ 60	34.1	23.1	13.0