Chapter 9: At Grade Intersection Capacity and Level of Service

9.1

Given: 2-lane intersection approach; CBD area
No cross street pedestrians during left turns
Lane width = 11 ft
+2% grade
No parking lanes; No bus stops
6% heavy vehicles
Protected phasing
$P_{LT} = 0.30$

$N = 2$
$f_w = 0.967$ (Table 9-5)
$f_{HV} = 0.943$ (Table 9-6)
$f_g = 0.990$ (Table 9-7)
$f_p = 1.0$ (Table 9-8)
$f_{bb} = 1.0$ (Table 9-9)
$f_a = 0.90$ (Table 9-10)
$f_{RT} = 1$ (Table 9-11a, no right turns)

$$f_{LT} = \frac{1.0}{1.0 + 0.05P_{LT}} = \frac{1.0}{1.0 + 0.05(0.30)} = 0.985 \text{ (Table 9-12)}$$

$s = s_0 N f_w f_{HV} f_g f_p f_{bb} f_a f_{RT} f_{LT}$

$s = 1900(2)(0.967)(0.943)(0.990)(1.0)(1.0)(0.90)(1.0)(0.985) = 3042$ vph green time

9.2

The following is the Highway Capacity Software (HCS) solution to the exercise. The specific answers requested in the problem statement are highlighted in bold.

```
HCS:  Signalized Intersection    Version 2.4a             08-08-1996  1
================================================================================
Streets: (E-W) Third Ave.              (N-S) Main St.
Analyst:                               File Name: Exerc_02.HC9
Area Type: CBD                         7-18-96 4-5 PM
================================================================================

                    Traffic and Roadway Conditions
--------------------------------------------------------------------------------
           |   Eastbound  |  Westbound   |  Northbound  |  Southbound
           | L    T    R  | L    T    R  | L    T    R  | L    T    R
           |---- ---- ----|---- ---- ----|---- ---- ----|---- ---- ----
No. Lanes  |    > 2  <    |    > 2  <    |    > 1  <    |    > 1  <
Volumes    |  60  700   50|  50  550   20|  40  500   30|  45  500   15
PHF or PK15|0.90 0.90 0.90|0.90 0.90 0.90|0.90 0.90 0.90|0.90 0.90 0.90
Lane Width |     11.0     |     11.0     |     15.0     |     15.0
Grade      |        0     |        0     |        0     |        0
% Heavy Veh|   5    5    5|   5    5    5|   5    5    5|   5    5    5
Parking    |(Y/N) N       |(Y/N) N       |(Y/N) N       |(Y/N) N
Bus Stops  |             0|             0|             0|             0
```

Con. Peds			100				100				100				100
Ped Button	(Y/N)	N			(Y/N)	N			(Y/N)	N			(Y/N)	N	
Arr Type		4				2				3				3	
RTOR Vols			15				10				20				10
Lost Time	3.00	3.00	3.00		3.00	3.00	3.00		3.00	3.00	3.00		3.00	3.00	3.00

Signal Operations

Phase Combination	1	2	3	4		5	6	7	8
EB Left	*				NB Left	*			
Thru	*				Thru	*			
Right	*				Right	*			
Peds					Peds				
WB Left	*				SB Left	*			
Thru	*				Thru	*			
Right	*				Right	*			
Peds					Peds				
NB Right					EB Right				
SB Right					WB Right				
Green	27.0P				Green	37.0P			
Yellow/AR	3.0				Yellow/AR	3.0			

Cycle Length: 70 sec Phase combination order: #1 #5

Volume Adjustment Worksheet

Direction/ Mvt	Mvt Vol	PHF	Adj Vol	Lane Grp	Lane Grp Vol	No. Ln	Lane Util Fact	Growth Fact	Adj Grp Vol	Prop LT	Prop RT
EB											
Left	60	0.90	67								
Thru	700	0.90	778	LTR	884	2	1.050	1.000	928	0.08	0.04
Right	50	0.90	39								
WB											
Left	50	0.90	56								
Thru	550	0.90	611	LTR	678	2	1.050	1.000	712	0.08	0.02
Right	20	0.90	11								
NB											
Left	40	0.90	44								
Thru	500	0.90	556	LTR	611	1	1.000	1.000	611	0.07	0.02
Right	30	0.90	11								
SB											
Left	45	0.90	50								
Thru	500	0.90	556	LTR	612	1	1.000	1.000	612	0.08	0.01
Right	15	0.90	6								

Saturation Flow Adjustment Worksheet

Direction	Ideal Sat	No.	f	f	f	f	f	f	f	f	Adj Sat

/LnGrp	Flow	Lns	W	HV	G	p	BB	A	RT	LT	Flow
EB											
LTR	1900	2	0.97	0.95	1.00	1.00	1.00	0.90	0.99	0.74	2326
WB											
LTR	1900	2	0.97	0.95	1.00	1.00	1.00	0.90	1.00	0.66	2078
NB											
LTR	1900	1	1.10	0.95	1.00	1.00	1.00	0.90	0.90	0.81	1302
SB											
LTR	1900	1	1.10	0.95	1.00	1.00	1.00	0.90	0.90	0.79	1263

Supplemental Permitted LT Worksheet

APPROACH	EB
Cycle Length, C	70
Actual Green Time for Lane Group, G	27
Effective Green Time for Lane Group, g	27
Opposing Effective Green Time, go	27
Number of Opposing Lanes, No	2
Number of Lanes in Lane Group, N	2
Adjusted Left-Turn Flow Rate, Vlt	67
Proportion of Left Turns in Lane Group, Plt	0.08
Left Turns per Cycle: LTC=Vlt*C/3600	1.30
Adjusted Opposing Flow Rate, Vo	712
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	6.92
Opposing Platoon Ratio, Rpo	0.67
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	6.30
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.74
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	8.83
gu=g-gq (or g-gf)	18.17
fs=(875-0.625Vo)/1000	0.43
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	0.24
El1	4.94
fmin	0.09
fm,(min=fmin;max=1.00)	0.58
flt=[fm+0.91(N-1)]/N	0.74

APPROACH	WB
Cycle Length, C	70
Actual Green Time for Lane Group, G	27
Effective Green Time for Lane Group, g	27
Opposing Effective Green Time, go	27
Number of Opposing Lanes, No	2
Number of Lanes in Lane Group, N	2
Adjusted Left-Turn Flow Rate, Vlt	56
Proportion of Left Turns in Lane Group, Plt	0.08
Left Turns per Cycle: LTC=Vlt*C/3600	1.09
Adjusted Opposing Flow Rate, Vo	928
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	9.02
Opposing Platoon Ratio, Rpo	1.33
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	7.57
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.49
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	10.37
gu=g-gq (or g-gf)	16.63

fs=(875-0.625Vo)/1000	0.29
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	0.32
El1	12.40
fmin	0.10
fm,(min=fmin;max=1.00)	0.41
flt=[fm+0.91(N-1)]/N	0.66

APPROACH	NB
Cycle Length, C	70
Actual Green Time for Lane Group, G	37
Effective Green Time for Lane Group, g	37
Opposing Effective Green Time, go	37
Number of Lanes in Lane Group, N	1
Proportion of Left Turns in Lane Group, Plt	0.07
Proportion of Left Turns in Opposing Flow, Plto	0.08
Adjusted Left-Turn Flow Rate, Vlt	44
Left Turns per Cycle: LTC=Vlt*C/3600	0.86
Adjusted Opposing Flow Rate, Vo	612
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	11.90
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.860*LTC^0.629)-tl	13.97
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.47
gq=4.943volc^0.762*qro^1.061-tl	11.69
gu=g-gq (or g-gf)	23.03
n=(gq-gf)/2	0.00
Ptho=1-Plto	0.92
El2	0.00
El1	7.07
fmin=2(1+Pl)/g	0.06
flt=fm,(min=fmin; max=1)	0.81

APPROACH	SB
Cycle Length, C	70
Actual Green Time for Lane Group, G	37
Effective Green Time for Lane Group, g	37
Opposing Effective Green Time, go	37
Number of Lanes in Lane Group, N	1
Proportion of Left Turns in Lane Group, Plt	0.08
Proportion of Left Turns in Opposing Flow, Plto	0.07
Adjusted Left-Turn Flow Rate, Vlt	50
Left Turns per Cycle: LTC=Vlt*C/3600	0.97
Adjusted Opposing Flow Rate, Vo	611
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	11.88
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.860*LTC^0.629)-tl	12.90
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.47
gq=4.943volc^0.762*qro^1.061-tl	11.67
gu=g-gq (or g-gf)	24.10
n=(gq-gf)/2	0.00
Ptho=1-Plto	0.93
El2	0.00
El1	7.02
fmin=2(1+Pl)/g	0.06
flt=fm,(min=fmin; max=1)	0.79

```
==========================================================================

                      Capacity Analysis Worksheet
--------------------------------------------------------------------------
             Adj     Adj  Sat   Flow               Lane Group
Direction Flow Rate  Flow Rate  Ratio  Green Ratio  Capacity   v/c
/LnGrp       (v)        (s)     (v/s)     (g/C)        (c)    Ratio
--------- ---------  ---------  -----  ----------- ---------- -----
EB
   LTR        928       2326    0.399     0.386        897    1.034 *
WB
   LTR        712       2078    0.343     0.386        802    0.888
NB
   LTR        611       1302    0.469     0.529        688    0.888
SB
   LTR        612       1263    0.485     0.529        668    0.917 *
                                 Sum (v/s) critical = 0.884
Lost Time/Cycle, L =   6.0 sec   Critical v/c(x)    = 0.966
--------------------------------------------------------------------------

                      Level of Service Worksheet
--------------------------------------------------------------------------
                       Delay Del   Lane  Calib Delay Lane Lane  Delay LOS
Direction  v/c   g/C    d    Adj   Group  d     d    Grp  Grp   By    By
/LnGrp    Ratio Ratio    1   Fact  Cap     2     2    Del  LOS   App   App
--------- ----- -----  ----- ----- ----- ----- ----- ---- ---- ----- ---
EB
   LTR     1.034 0.386  16.3 0.910   897   12   29.0  43.9  E   43.9  E
WB
   LTR     0.888 0.386  15.3 1.124   802   12    6.7  23.8  C   23.8  C
NB
   LTR     0.888 0.529  11.1 1.000   688   16    9.6  20.7  C   20.7  C
SB
   LTR     0.917 0.529  11.5 1.000   668   16   12.6  24.1  C   24.1  C
               Intersection Delay =  29.7 sec/veh Intersection LOS = D
--------------------------------------------------------------------------
```

9.3

A complete operational analysis based on the Highway Capacity Software (HCS) is included here. Exercise 3 requests the left-turn adjustment factor only for the EB approach, in a case where there is an exclusive left-turn lane. The left-turn adjustment-factor computation is highlighted in bold.

```
HCS:  Signalized Intersection    Version 2.4a             08-02-1996  1
==========================================================================
Streets: (E-W) Ryder St.               (N-S) Moss Ave.
Analyst:                               File Name: Exerc_03.HC9
Area Type: Other                       8-1-96
==========================================================================

                     Traffic and Roadway Conditions
--------------------------------------------------------------------------
           |   Eastbound  |  Westbound   |  Northbound  |  Southbound
```

	L	T	R	L	T	R	L	T	R	L	T	R
No. Lanes	1	2	<	1	2	<		> 1	<		> 1	<
Volumes	80	870	50	80	756	53	35	425	25	15	500	30
PHF or PK15	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Lane Width	12.0	12.0		12.0	12.0			12.0			12.0	
Grade		3			-3			3			-3	
% Heavy Veh	5	5	5	5	5	5	5	5	5	5	5	5
Parking	(Y/N)	N		(Y/N)	N		(Y/N)	N		(Y/N)	N	
Bus Stops			0			0			0			0
Con. Peds			0			0			0			0
Ped Button	(Y/N)	N		(Y/N)	N		(Y/N)	N		(Y/N)	N	
Arr Type	3	3		3	3			3			3	
RTOR Vols			0			0			0			0
Lost Time	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Signal Operations

Phase Combination	1	2	3	4		5	6	7	8
EB Left	*				NB Left	*			
Thru	*				Thru	*			
Right	*				Right	*			
Peds					Peds				
WB Left	*				SB Left	*			
Thru	*				Thru	*			
Right	*				Right	*			
Peds					Peds				
NB Right					EB Right				
SB Right					WB Right				
Green	35.0P				Green	27.0P			
Yellow/AR	4.0				Yellow/AR	4.0			

Cycle Length: 70 sec Phase combination order: #1 #5

Volume Adjustment Worksheet

Direction/ Mvt	Mvt Vol	PHF	Adj Vol	Lane Grp	Lane Grp Vol	No. Ln	Lane Util Fact	Growth Fact	Adj Grp Vol	Prop LT	Prop RT
EB											
Left	80	0.95	84	L	84	1	1.000	1.000	84	1.00	0.00
Thru	870	0.95	916	TR	969	2	1.050	1.000	1017	0.00	0.05
Right	50	0.95	53								
WB											
Left	80	0.95	84	L	84	1	1.000	1.000	84	1.00	0.00

Thru	756	0.95	796	TR	852	2	1.050	1.000	895	0.00	0.07
Right	53	0.95	56								
NB											
Left	35	0.95	37								
Thru	425	0.95	447	LTR	510	1	1.000	1.000	510	0.07	0.05
Right	25	0.95	26								
SB											
Left	15	0.95	16								
Thru	500	0.95	526	LTR	574	1	1.000	1.000	574	0.03	0.06
Right	30	0.95	32								

Saturation Flow Adjustment Worksheet

Direction /LnGrp	Ideal Sat Flow	No. Lns	f W	f HV	f G	f p	f BB	f A	f RT	f LT	Adj Sat Flow
EB											
L	1900	1	1.00	0.95	0.99	1.00	1.00	1.00	1.00	0.15	270
TR	1900	2	1.00	0.95	0.99	1.00	1.00	1.00	0.99	1.00	3538
WB											
L	1900	1	1.00	0.95	1.01	1.00	1.00	1.00	1.00	0.11	204
TR	1900	2	1.00	0.95	1.01	1.00	1.00	1.00	0.99	1.00	3635
NB											
LTR	1900	1	1.00	0.95	0.99	1.00	1.00	1.00	0.89	0.86	1372
SB											
LTR	1900	1	1.00	0.95	1.01	1.00	1.00	1.00	0.89	0.95	1560

Supplemental Permitted LT Worksheet

APPROACH	**EB**
Cycle Length, C	**70**
Actual Green Time for Lane Group, G	**35**
Effective Green Time for Lane Group, g	**36**
Opposing Effective Green Time, go	**36**
Number of Opposing Lanes, No	**2**
Number of Lanes in Lane Group, N	**1**
Adjusted Left-Turn Flow Rate, Vlt	**84**
Proportion of Left Turns in Lane Group, Plt	**1.00**
Left Turns per Cycle: LTC=Vlt*C/3600	**1.63**
Adjusted Opposing Flow Rate, Vo	**895**
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	**8.70**
Opposing Platoon Ratio, Rpo	**1**
Lost time per phase, tl	**3**
gf=Gexp(-0.882*LTC^0.717)-tl	**0.00**
Opposing Queue Ratio: qro=1-Rpo(go/C)	**0.49**
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	**8.25**
gu=g-gq (or g-gf)	**27.75**
fs=(875-0.625Vo)/1000	**0.32**
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	**1.00**
El1	**5.10**
fmin	**0.11**
fm,(min=fmin;max=1.00)	**0.15**
flt=[fm+0.91(N-1)]/N	**0.15**

APPROACH	WB
Cycle Length, C	70
Actual Green Time for Lane Group, G	35
Effective Green Time for Lane Group, g	36
Opposing Effective Green Time, go	36
Number of Opposing Lanes, No	2
Number of Lanes in Lane Group, N	1
Adjusted Left-Turn Flow Rate, Vlt	84
Proportion of Left Turns in Lane Group, Plt	1.00
Left Turns per Cycle: LTC=Vlt*C/3600	1.63
Adjusted Opposing Flow Rate, Vo	1017
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	9.89
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	0.00
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.49
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	10.39
gu=g-gq (or g-gf)	25.61
fs=(875-0.625Vo)/1000	0.24
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	1.00
El1	6.56
fmin	0.11
fm,(min=fmin;max=1.00)	0.11
flt=[fm+0.91(N-1)]/N	0.11

APPROACH	NB
Cycle Length, C	70
Actual Green Time for Lane Group, G	27
Effective Green Time for Lane Group, g	28
Opposing Effective Green Time, go	28
Number of Lanes in Lane Group, N	1
Proportion of Left Turns in Lane Group, Plt	0.07
Proportion of Left Turns in Opposing Flow, Plto	0.03
Adjusted Left-Turn Flow Rate, Vlt	37
Left Turns per Cycle: LTC=Vlt*C/3600	0.72
Adjusted Opposing Flow Rate, Vo	574
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	11.16
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.860*LTC^0.629)-tl	10.42
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.60
gq=4.943volc^0.762*qro^1.061-tl	15.07
gu=g-gq (or g-gf)	12.93
n=(gq-gf)/2	2.33
Ptho=1-Plto	0.97
El2	2.28
El1	6.08
fmin=2(1+Pl)/g	0.08
flt=fm,(min=fmin; max=1)	0.86

APPROACH	SB
Cycle Length, C	70
Actual Green Time for Lane Group, G	27
Effective Green Time for Lane Group, g	28
Opposing Effective Green Time, go	28
Number of Lanes in Lane Group, N	1

Proportion of Left Turns in Lane Group, Plt	0.03
Proportion of Left Turns in Opposing Flow, Plto	0.07
Adjusted Left-Turn Flow Rate, Vlt	16
Left Turns per Cycle: LTC=Vlt*C/3600	0.31
Adjusted Opposing Flow Rate, Vo	510
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	9.92
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.860*LTC^0.629)-tl	14.87
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.60
gq=4.943volc^0.762*qro^1.061-tl	13.51
gu=g-gq (or g-gf)	13.13
n=(gq-gf)/2	0.00
Ptho=1-Plto	0.93
El2	0.00
El1	5.06
fmin=2(1+Pl)/g	0.07
flt=fm,(min=fmin; max=1)	0.95

Capacity Analysis Worksheet

Direction /LnGrp	Adj Flow Rate (v)	Adj Sat Flow Rate (s)	Flow Ratio (v/s)	Green Ratio (g/C)	Lane Group Capacity (c)	v/c Ratio	
EB							
L	84	270	0.311	0.514	139	0.605	
TR	1017	3538	0.287	0.514	1820	0.559	
WB							
L	84	204	0.412	0.514	105	0.801	*
TR	895	3635	0.246	0.514	1869	0.479	
NB							
LTR	510	1372	0.372	0.400	549	0.929	*
SB							
LTR	574	1560	0.368	0.400	624	0.920	

Sum (v/s) critical = 0.783

Lost Time/Cycle, L = 6.0 sec Critical v/c(x) = 0.857

Level of Service Worksheet

Direction /LnGrp	v/c Ratio	g/C Ratio	Delay d 1	Del Adj Fact	Lane Group Cap	Calib d 2	Delay d 2	Lane Grp Del	Lane Grp LOS	Delay By App	LOS By App
EB											
L	0.605	0.514	9.1	1.000	139	16	5.1	14.2	B	9.5	B
TR	0.559	0.514	8.8	1.000	1820	16	0.3	9.1	B		
WB											
L	0.801	0.514	10.7	1.000	105	16	22.5	33.2	D	10.6	B
TR	0.479	0.514	8.3	1.000	1869	16	0.2	8.5	B		
NB											
LTR	0.929	0.400	15.2	1.000	549	16	16.2	31.4	D	31.4	D
SB											
LTR	0.920	0.400	15.2	1.000	624	16	13.6	28.8	D	28.8	D

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              Intersection Delay =  16.9 sec/veh Intersection LOS = C
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9.4

The following is the Highway Capacity Software (HCS) solution to Exercise 9. Exercise 4 requests the left-turn adjustment factor only for the EB approach, in a case where the left turns are made from a shared lane. Computation of the left-turn adjustment factor is highlighted in bold.

```
HCS:  Signalized Intersection    Version 2.4a             08-02-1996  1
========================================================================
Streets: (E-W) Ryder St.               (N-S) Moss Ave.
Analyst:                               File Name: Exer_4&9.HC9
Area type: Other                       8-1-96
========================================================================

                    Traffic and Roadway Conditions
------------------------------------------------------------------------
           |   Eastbound  |  Westbound   |  Northbound  |  Southbound
           | L    T    R  | L    T    R  | L    T    R  | L    T    R
           |---- ---- ----|---- ---- ----|---- ---- ----|---- ---- ----
No. Lanes  |    > 2  <    |    > 2  <    |    > 1  <    |    > 1  <
Volumes    |  80  870   50|  80  756   53|  35  425   25|  15  500   30
PHF or PK15|0.95 0.95 0.95|0.95 0.95 0.95|0.95 0.95 0.95|0.95 0.95 0.95
Lane Width |     12.0     |     12.0     |     12.0     |     12.0
Grade      |        3     |       -3     |        3     |       -3
% Heavy Veh|   5    5    5|   5    5    5|   5    5    5|   5    5    5
Parking    |(Y/N) N       |(Y/N) N       |(Y/N) N       |(Y/N) N
Bus Stops  |             0|             0|             0|             0
Con. Peds  |             0|             0|             0|             0
Ped Button |(Y/N) N       |(Y/N) N       |(Y/N) N       |(Y/N) N
Arr Type   |        3     |        3     |        3     |        3
RTOR Vols  |             0|             0|             0|             0
Lost Time  |3.00 3.00 3.00|3.00 3.00 3.00|3.00 3.00 3.00|3.00 3.00 3.00
------------------------------------------------------------------------

                          Signal Operations
------------------------------------------------------------------------
Phase Combination 1     2     3     4 |           5     6     7     8
EB  Left          *                   |NB  Left    *
    Thru          *                   |    Thru    *
    Right         *                   |    Right   *
    Peds                              |    Peds
                                      |
WB  Left          *                   |SB  Left    *
    Thru          *                   |    Thru    *
    Right         *                   |    Right   *
    Peds                              |    Peds
                                      |
NB  Right                             |EB  Right
SB  Right                             |WB  Right
                                      |
Green          35.0P                  |Green    27.0P
Yellow/AR       4.0                   |Yellow/AR 4.0
```

Cycle Length: 70 sec Phase combination order: #1 #5

Volume Adjustment Worksheet

Direction/ Mvt	Mvt Vol	PHF	Adj Vol	Lane Grp	Lane Grp Vol	No. Ln	Lane Util Fact	Growth Fact	Adj Grp Vol	Prop LT	Prop RT
EB											
Left	80	0.95	84								
Thru	870	0.95	916	LTR	1053	2	1.050	1.000	1106	0.08	0.05
Right	50	0.95	53								
WB											
Left	80	0.95	84								
Thru	756	0.95	796	LTR	936	2	1.050	1.000	983	0.09	0.06
Right	53	0.95	56								
NB											
Left	35	0.95	37								
Thru	425	0.95	447	LTR	510	1	1.000	1.000	510	0.07	0.05
Right	25	0.95	26								
SB											
Left	15	0.95	16								
Thru	500	0.95	526	LTR	574	1	1.000	1.000	574	0.03	0.06
Right	30	0.95	32								

Saturation Flow Adjustment Worksheet

Direction /LnGrp	Ideal Sat Flow	No. Lns	f W	f HV	f G	f p	f BB	f A	f RT	f LT	Adj Sat Flow
EB											
LTR	1900	2	1.00	0.95	0.99	1.00	1.00	1.00	0.99	0.62	2179
WB											
LTR	1900	2	1.00	0.95	1.01	1.00	1.00	1.00	0.99	0.59	2165
NB											
LTR	1900	1	1.00	0.95	0.99	1.00	1.00	1.00	0.89	0.86	1372
SB											
LTR	1900	1	1.00	0.95	1.01	1.00	1.00	1.00	0.89	0.95	1560

Supplemental Permitted LT Worksheet

APPROACH	**EB**
Cycle Length, C	**70**
Actual Green Time for Lane Group, G	**35**
Effective Green Time for Lane Group, g	**36**
Opposing Effective Green Time, go	**36**

Number of Opposing Lanes, No	**2**
Number of Lanes in Lane Group, N	**2**
Adjusted Left-Turn Flow Rate, Vlt	**84**
Proportion of Left Turns in Lane Group, Plt	**0.08**
Left Turns per Cycle: LTC=Vlt*C/3600	**1.63**
Adjusted Opposing Flow Rate, Vo	**983**
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	**9.56**
Opposing Platoon Ratio, Rpo	**1**
Lost time per phase, tl	**3**
gf=Gexp(-0.882*LTC^0.717)-tl	**6.99**
Opposing Queue Ratio: qro=1-Rpo(go/C)	**0.49**
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	**9.77**
gu=g-gq (or g-gf)	**26.23**
fs=(875-0.625Vo)/1000	**0.26**
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	**0.33**
El1	**15.15**
fmin	**0.07**
fm,(min=fmin;max=1.00)	**0.32**
flt=[fm+0.91(N-1)]/N	**0.62**

APPROACH	WB
Cycle Length, C	70
Actual Green Time for Lane Group, G	35
Effective Green Time for Lane Group, g	36
Opposing Effective Green Time, go	36
Number of Opposing Lanes, No	2
Number of Lanes in Lane Group, N	2
Adjusted Left-Turn Flow Rate, Vlt	84
Proportion of Left Turns in Lane Group, Plt	0.09
Left Turns per Cycle: LTC=Vlt*C/3600	1.63
Adjusted Opposing Flow Rate, Vo	1106
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	10.75
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	6.99
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.49
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	12.08
gu=g-gq (or g-gf)	23.92
fs=(875-0.625Vo)/1000	0.18
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	0.45
El1	16.00
fmin	0.08
fm,(min=fmin;max=1.00)	0.28
flt=[fm+0.91(N-1)]/N	0.59

APPROACH	NB
Cycle Length, C	70
Actual Green Time for Lane Group, G	27
Effective Green Time for Lane Group, g	28
Opposing Effective Green Time, go	28
Number of Lanes in Lane Group, N	1
Proportion of Left Turns in Lane Group, Plt	0.07
Proportion of Left Turns in Opposing Flow, Plto	0.03
Adjusted Left-Turn Flow Rate, Vlt	37
Left Turns per Cycle: LTC=Vlt*C/3600	0.72
Adjusted Opposing Flow Rate, Vo	574

Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	11.16
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.860*LTC^0.629)-tl	10.42
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.60
gq=4.943volc^0.762*qro^1.061-tl	15.07
gu=g-gq (or g-gf)	12.93
n=(gq-gf)/2	2.33
Ptho=1-Plto	0.97
El2	2.28
El1	6.08
fmin=2(1+Pl)/g	0.08
flt=fm,(min=fmin; max=1)	0.86

APPROACH	SB
Cycle Length, C	70
Actual Green Time for Lane Group, G	27
Effective Green Time for Lane Group, g	28
Opposing Effective Green Time, go	28
Number of Lanes in Lane Group, N	1
Proportion of Left Turns in Lane Group, Plt	0.03
Proportion of Left Turns in Opposing Flow, Plto	0.07
Adjusted Left-Turn Flow Rate, Vlt	16
Left Turns per Cycle: LTC=Vlt*C/3600	0.31
Adjusted Opposing Flow Rate, Vo	510
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	9.92
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.860*LTC^0.629)-tl	14.87
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.60
gq=4.943volc^0.762*qro^1.061-tl	13.51
gu=g-gq (or g-gf)	13.13
n=(gq-gf)/2	0.00
Ptho=1-Plto	0.93
El2	0.00
El1	5.06
fmin=2(1+Pl)/g	0.07
flt=fm,(min=fmin; max=1)	0.95

Capacity Analysis Worksheet

Direction /LnGrp	Adj Flow Rate (v)	Adj Sat Flow Rate (s)	Flow Ratio (v/s)	Green Ratio (g/C)	Lane Group Capacity (c)	v/c Ratio	
EB							
LTR	1106	2179	0.508	0.514	1121	0.987	*
WB							
LTR	983	2165	0.454	0.514	1113	0.883	
NB							
LTR	510	1372	0.372	0.400	549	0.929	*
SB							
LTR	574	1560	0.368	0.400	624	0.920	

Sum (v/s) critical = 0.879

Lost Time/Cycle, L = 6.0 sec **Critical v/c(x) = 0.962**

Level of Service Worksheet

Direction /LnGrp	v/c Ratio	g/C Ratio	Delay d 1	Del Adj Fact	Lane Group Cap	Calib d 2	Delay d 2	Lane Grp Del	Lane Grp LOS	Delay By App	LOS By App
EB											
LTR	0.987	0.514	12.7	1.000	1121	16	17.9	30.7	D	30.7	D
WB											
LTR	0.883	0.514	11.5	1.000	1113	16	6.1	17.6	C	17.6	C
NB											
LTR	0.929	0.400	15.2	1.000	549	16	16.2	31.4	D	31.4	D
SB											
LTR	0.920	0.400	15.2	1.000	624	16	13.6	28.8	D	28.8	D

Intersection Delay = 26.4 sec/veh **Intersection LOS = D**

9.5

The following is the Highway Capacity Software (HCS) solution to the exercise. The specific answers requested in the problem statement are highlighted in bold.

HCS: Signalized Intersection Version 2.4a 08-08-1996 1

Streets: (E-W) Grand Ave. (N-S) 4th St.
Analyst: File Name: Exerc_05.HC9
Area Type: CBD 7-30-96

Traffic and Roadway Conditions

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
No. Lanes		> 2 <			> 2 <			> 1 <			> 1 <	
Volumes	60	570	30	25	635	18	27	330	20	35	450	45
PHF or PK15	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Lane Width		12.0			12.0			14.0			14.0	
Grade		0			0			0			0	
% Heavy Veh	5	5	5	5	5	5	5	5	5	5	5	5
Parking	(Y/N)	N		(Y/N)	N		(Y/N)	N		(Y/N)	N	
Bus Stops			0			0			0			0
Con. Peds			80			80			80			80
Ped Button	(Y/N)	N		(Y/N)	N		(Y/N)	N		(Y/N)	N	
Arr Type		4			2			3			3	
RTOR Vols			0			0			0			0

Lost Time	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Signal Operations

Phase Combination	1	2	3	4	5	6	7	8
EB Left	*				NB Left	*		
Thru	*				Thru	*		
Right	*				Right	*		
Peds					Peds			
WB Left	*				SB Left	*		
Thru	*				Thru	*		
Right	*				Right	*		
Peds					Peds			
NB Right					EB Right			
SB Right					WB Right			
Green	30.0P				Green	27.0P		
Yellow/AR	4.0				Yellow/AR	4.0		

Cycle Length: 65 sec Phase combination order: #1 #5

Volume Adjustment Worksheet

Direction/ Mvt	Mvt Vol	PHF	Adj Vol	Lane Grp	Lane Grp Vol	No. Ln	Lane Util Fact	Growth Fact	Adj Grp Vol	Prop LT	Prop RT
EB											
Left	60	0.85	71								
Thru	570	0.85	671	LTR	777	2	1.050	1.000	816	0.09	0.05
Right	30	0.85	35								
WB											
Left	25	0.85	29								
Thru	635	0.85	747	LTR	797	2	1.050	1.000	837	0.04	0.03
Right	18	0.85	21								
NB											
Left	27	0.85	32								
Thru	330	0.85	388	LTR	444	1	1.000	1.000	444	0.07	0.05
Right	20	0.85	24								
SB											
Left	35	0.85	41								
Thru	450	0.85	529	LTR	623	1	1.000	1.000	623	0.07	0.09
Right	45	0.85	53								

Saturation Flow Adjustment Worksheet

Direction /LnGrp	Ideal Sat Flow	No. Lns	f W	f HV	f G	f p	f BB	f A	f RT	f LT	Adj Sat Flow
EB											

LTR	1900	2	1.00	0.95	1.00	1.00	1.00	0.90	0.99	0.68	2215
WB											
LTR	1900	2	1.00	0.95	1.00	1.00	1.00	0.90	1.00	0.83	2701
NB											
LTR	1900	1	1.07	0.95	1.00	1.00	1.00	0.90	0.89	0.84	1299
SB											
LTR	1900	1	1.07	0.95	1.00	1.00	1.00	0.90	0.89	0.90	1377

Supplemental Permitted LT Worksheet

APPROACH	EB
Cycle Length, C	65
Actual Green Time for Lane Group, G	30
Effective Green Time for Lane Group, g	31
Opposing Effective Green Time, go	31
Number of Opposing Lanes, No	2
Number of Lanes in Lane Group, N	2
Adjusted Left-Turn Flow Rate, Vlt	71
Proportion of Left Turns in Lane Group, Plt	0.09
Left Turns per Cycle: LTC=Vlt*C/3600	1.28
Adjusted Opposing Flow Rate, Vo	837
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	7.56
Opposing Platoon Ratio, Rpo	0.67
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	7.46
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.68
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	9.18
gu=g-gq (or g-gf)	21.82
fs=(875-0.625Vo)/1000	0.35
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	0.32
El1	7.85
fmin	0.09
fm,(min=fmin;max=1.00)	0.46
flt=[fm+0.91(N-1)]/N	0.68

APPROACH	WB
Cycle Length, C	65
Actual Green Time for Lane Group, G	30
Effective Green Time for Lane Group, g	31
Opposing Effective Green Time, go	31
Number of Opposing Lanes, No	2
Number of Lanes in Lane Group, N	2
Adjusted Left-Turn Flow Rate, Vlt	29
Proportion of Left Turns in Lane Group, Plt	0.04
Left Turns per Cycle: LTC=Vlt*C/3600	0.52
Adjusted Opposing Flow Rate, Vo	816
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	7.37
Opposing Platoon Ratio, Rpo	1.33
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	14.23
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.37
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	4.71
gu=g-gq (or g-gf)	16.77
fs=(875-0.625Vo)/1000	0.37
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	0.14
El1	6.80

fmin	0.07
fm,(min=fmin;max=1.00)	0.76
flt=[fm+0.91(N-1)]/N	0.83

APPROACH	NB
Cycle Length, C	65
Actual Green Time for Lane Group, G	27
Effective Green Time for Lane Group, g	28
Opposing Effective Green Time, go	28
Number of Lanes in Lane Group, N	1
Proportion of Left Turns in Lane Group, Plt	0.07
Proportion of Left Turns in Opposing Flow, Plto	0.07
Adjusted Left-Turn Flow Rate, Vlt	32
Left Turns per Cycle: LTC=Vlt*C/3600	0.58
Adjusted Opposing Flow Rate, Vo	623
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	11.25
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.860*LTC^0.629)-tl	11.68
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.57
gq=4.943volc^0.762*qro^1.061-tl	14.19
gu=g-gq (or g-gf)	13.81
n=(gq-gf)/2	1.25
Ptho=1-Plto	0.93
El2	1.24
El1	7.59
fmin=2(1+Pl)/g	0.08
flt=fm,(min=fmin; max=1)	0.84

APPROACH	SB
Cycle Length, C	65
Actual Green Time for Lane Group, G	27
Effective Green Time for Lane Group, g	28
Opposing Effective Green Time, go	28
Number of Lanes in Lane Group, N	1
Proportion of Left Turns in Lane Group, Plt	0.07
Proportion of Left Turns in Opposing Flow, Plto	0.07
Adjusted Left-Turn Flow Rate, Vlt	41
Left Turns per Cycle: LTC=Vlt*C/3600	0.74
Adjusted Opposing Flow Rate, Vo	444
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	8.02
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.860*LTC^0.629)-tl	10.25
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.57
gq=4.943volc^0.762*qro^1.061-tl	10.28
gu=g-gq (or g-gf)	17.72
n=(gq-gf)/2	0.01
Ptho=1-Plto	0.93
El2	0.02
El1	4.00
fmin=2(1+Pl)/g	0.08
flt=fm,(min=fmin; max=1)	0.90

==========

Capacity Analysis Worksheet

Direction /LnGrp	Adj Flow Rate (v)	Adj Sat Flow Rate (s)	Flow Ratio (v/s)	Green Ratio (g/C)	Lane Group Capacity (c)	v/c Ratio
EB						
LTR	816	2215	0.368	0.477	1056	**0.772 ***
WB						
LTR	837	2701	0.310	0.477	1288	**0.650**
NB						
LTR	444	1299	0.342	0.431	560	**0.793**
SB						
LTR	623	1377	0.452	0.431	593	**1.050 ***

Sum (v/s) critical = 0.821

Lost Time/Cycle, L = 6.0 sec **Critical v/c(x) = 0.904**

Level of Service Worksheet

Direction /LnGrp	v/c Ratio	g/C Ratio	Delay d 1	Del Adj Fact	Lane Group Cap	Calib d 2	Delay d 2	Lane Grp Del	Lane Grp LOS	Delay By App	**LOS By App**
EB											
LTR	0.772	0.477	10.7	0.801	1056	12	1.9	10.5	B	10.5	**B**
WB											
LTR	0.650	0.477	9.8	1.212	1288	12	0.6	12.5	B	12.5	**B**
NB											
LTR	0.793	0.431	12.2	1.000	560	16	5.3	17.5	C	17.5	**C**
SB											
LTR	1.050	0.431	14.1	1.000	593	16	43.1	57.2	E	57.2	**E**

Intersection Delay = 22.9 sec/veh **Intersection LOS = C**

Even though the SB approach is at capacity, the overall intersection level of service is C. Therefore, the existing design is acceptable.

9.6

The following is the Highway Capacity Software (HCS) solution to the exercise. This is one suitable three-phase signal plan. This plan is acceptable without any improvements to the given geometry.

```
HCS:  Signalized Intersection    Version 2.4a             08-08-1996  1
================================================================================
Streets: (E-W) Pine Blvd.              (N-S) Oak St.
Analyst:                               File Name: Exerc_06.HC9
Area Type: Other                       7-30-96
================================================================================

                    Traffic and Roadway Conditions
--------------------------------------------------------------------------------
```

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
No. Lanes	1	2			2 <			> 2 <				
Volumes	100	900			650	100	35	700	25			
PHF or PK15	0.95	0.95			0.95	0.95	0.95	0.95	0.95			
Lane Width	12.0	12.0			12.0			12.0				
Grade		-1			1			0				
% Heavy Veh	10	10			10	10	5	5	5			
Parking	(Y/N)	N		(Y/N)	N		(Y/N)	Y	10			
Bus Stops			10			10			0			
Con. Peds			0			30			30			0
Ped Button	(Y/N)	N		(Y/N)	N		(Y/N)	N				
Arr Type	3	3			3			3				
RTOR Vols			0			0			0			
Lost Time	3.00	3.00			3.00	3.00	3.00	3.00	3.00			

Signal Operations

Phase Combination	1	2	3	4		5	6	7	8
EB Left	*	*			NB Left	*			
Thru	*	*			Thru	*			
Right					Right	*			
Peds					Peds				
WB Left					SB Left				
Thru		*			Thru				
Right		*			Right				
Peds					Peds				
NB Right					EB Right				
SB Right					WB Right				
Green	10.0P	30.0P			Green	26.0P			
Yellow/AR	4.0	4.0			Yellow/AR	4.0			

Cycle Length: 78 sec Phase combination order: #1 #2 #5

Volume Adjustment Worksheet

Direction/ Mvt	Mvt Vol	PHF	Adj Vol	Lane Grp	Lane Grp Vol	No. Ln	Lane Util Fact	Growth Fact	Adj Grp Vol	Prop LT	Prop RT
EB											
Left	100	0.95	105	L	105	1	1.000	1.000	105	1.00	0.00
Thru	900	0.95	947	T	947	2	1.050	1.000	994	0.00	0.00
WB											
Thru	650	0.95	684	TR	789	2	1.050	1.000	828	0.00	0.13
Right	100	0.95	105								
NB											
Left	35	0.95	37								
Thru	700	0.95	737	LTR	800	2	1.050	1.000	840	0.05	0.03
Right	25	0.95	26								

SB

Saturation Flow Adjustment Worksheet

Direction /LnGrp	Ideal Sat Flow	No. Lns	f W	f HV	f G	f p	f BB	f A	f RT	f LT	Adj Sat Flow
EB										0.12	204
L	1900	1	1.00	0.91	1.00	1.00	1.00	1.00	1.00	0.95	1649
T	1900	2	1.00	0.91	1.00	1.00	0.98	1.00	1.00	1.00	3402
WB											
TR	1900	2	1.00	0.91	1.00	1.00	0.98	1.00	0.98	1.00	3301
NB											
LTR	1900	2	1.00	0.95	1.00	0.93	1.00	1.00	1.00	1.00	3324

SB

Supplemental Permitted LT Worksheet

APPROACH	EB
Cycle Length, C	78
Actual Green Time for Lane Group, G	44
Effective Green Time for Lane Group, g	34
Opposing Effective Green Time, go	31
Number of Opposing Lanes, No	2
Number of Lanes in Lane Group, N	1
Adjusted Left-Turn Flow Rate, Vlt	105
Proportion of Left Turns in Lane Group, Plt	1.00
Left Turns per Cycle: LTC=Vlt*C/3600	2.27
Adjusted Opposing Flow Rate, Vo	828
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	8.97
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	0
gf=Gexp(-0.882*LTC^0.717)-tl	0.00
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.60
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	14.04
gu=g-gq (or g-gf)	19.96
fs=(875-0.625Vo)/1000	0.36
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	1.00
El1	6.22
fmin	0.12
fm,(min=fmin;max=1.00)	0.12
flt=[fm+0.91(N-1)]/N	0.12

Capacity Analysis Worksheet

Direction /LnGrp	Adj Flow Rate (v)	Adj Sat Flow Rate (s)	Flow Ratio (v/s)	Green Ratio (g/C)	Lane Group Capacity (c)	v/c Ratio	
EB Lsec.	0	204	0.000	0.436	92	0.000	
Lpri.	105	1649	0.064	0.141	233	0.451	*
Ltot.	105				325	0.323	

```
   T          994       3402    0.292     0.577       1963    0.506
WB
   TR         828       3301    0.251     0.397       1312    0.631 *
NB
   LTR        840       3324    0.253     0.346       1151    0.730 *
SB
                                  Sum (v/s) critical = 0.567
Lost Time/Cycle, L =   9.0 sec   Critical v/c(x)    = 0.641
------------------------------------------------------------------------
```

```
                       Level of Service Worksheet
------------------------------------------------------------------------
                        Delay Del   Lane  Calib Delay Lane Lane Delay LOS
Direction  v/c   g/C    d    Adj   Group  d     d    Grp  Grp  By    By
/LnGrp    Ratio Ratio   1    Fact  Cap    2     2    Del  LOS  App   App
--------- ----- -----  ----- ----- ----- ----- ----- ---- ---- ----- ---
EB
   L       0.323 0.321   7.0 1.000   325   16    0.2   7.3  B   7.6  B
   T       0.506 0.577   7.5 1.000  1963   16    0.2   7.7  B
WB
   TR      0.631 0.397  14.4 1.000  1312   16    0.7  15.1  C  15.1  C
NB
   LTR     0.730 0.346  17.0 1.000  1151   16    1.7  18.6  C  18.6  C
SB
               Intersection Delay =  13.2 sec/veh Intersection LOS = B
========================================================================
Supplemental Uniform Delay Worksheet

Approach                                                    Eastbound
Adj. LT Vol  (v)                                            105
v/c ratio  (x)                                               0.32
Primary phase effective green                               11.00
gq from Supplemental LT Worksheet                           14.04
gu from Supplemental LT Worksheet                           19.96
Red time  (r)                                               33.00
Arrivals qa = v/(3600(max(x,1)                               0.03
Primary Ph. Departures Sp=s/3600                             0.46
Secondary Ph. Departures Ss=S(Gq+Gu)/(Gu*3600)               0.10
Xperm                                                        0.51
Xprot                                                        0.25
Case                                                         1
Queue at beginning of green arrow (Qa)                       0.96
Queue at beginning of unsaturated green (Qu)                 0.41
Residual queue (Qr)                                          0.00
Uniform Delay                                                7.04
```

9.7

The following is the Highway Capacity Software (HCS) solution to the exercise.

```
HCS:  Signalized Intersection    Version 2.4a             08-16-1996  1
========================================================================
```

Streets: (E-W) Main St. (N-S) Johnson St.
Analyst: File Name: Exerc_07.HC9
Area Type: Other 8-5-96
Comment: Problem 7

Traffic and Roadway Conditions

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
No. Lanes	1	2	<	1	2	<	1	2	<	1	2	<
Volumes	50	250	75	75	500	25	100	1250	50	125	750	50
PHF or PK15	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Lane Width	11.0	11.0		11.0	11.0		11.0	11.0		11.0	11.0	
Grade		0			0			0			0	
% Heavy Veh	5	5	5	5	5	5	5	5	5	5	5	5
Parking	(Y/N)	N		(Y/N)	N		(Y/N)	N		(Y/N)	N	
Bus Stops			0			0			0			0
Con. Peds			100			100			100			100
Ped Button	(Y/N)	Y	20.0 s	(Y/N)	Y	20.0 s	(Y/N)	Y	20.0 s	(Y/N)	Y	20.0
Arr Type	3	3		3	3		3	3		3	3	
RTOR Vols			0			0			0			0
Lost Time	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Signal Operations

Phase Combination	1	2	3	4		5	6	7	8
EB Left	*				NB Left	*			
Thru		*			Thru		*		
Right		*			Right		*		
Peds		*			Peds	*			
WB Left	*				SB Left	*			
Thru		*			Thru		*		
Right		*			Right		*		
Peds		*			Peds	*			
NB Right					EB Right				
SB Right					WB Right				
Green	7.0P	19.0P			Green	18.0P	45.0P		
Yellow/AR	4.0	4.0			Yellow/AR	4.0	4.0		

Cycle Length: 105 sec Phase combination order: #1 #2 #5 #6

Volume Adjustment Worksheet

Direc-	Lane	Lane	Adj

tion/ Mvt	Mvt Vol	PHF	Adj Vol	Lane Grp	Grp Vol	No. Ln	Util Fact	Growth Fact	Grp Vol	Prop LT	Prop RT
EB											
Left	50	0.85	59	L	59	1	1.000	1.000	59	1.00	0.00
Thru	250	0.85	294	TR	382	2	1.050	1.000	401	0.00	0.23
Right	75	0.85	88								
WB											
Left	75	0.85	88	L	88	1	1.000	1.000	88	1.00	0.00
Thru	500	0.85	588	TR	617	2	1.050	1.000	648	0.00	0.05
Right	25	0.85	29								
NB											
Left	100	0.85	118	L	118	1	1.000	1.000	118	1.00	0.00
Thru	1250	0.85	1471	TR	1530	2	1.050	1.000	1606	0.00	0.04
Right	50	0.85	59								
SB											
Left	125	0.85	147	L	147	1	1.000	1.000	147	1.00	0.00
Thru	750	0.85	882	TR	941	2	1.050	1.000	988	0.00	0.06
Right	50	0.85	59								

Saturation Flow Adjustment Worksheet

Direction /LnGrp	Ideal Sat Flow	No. Lns	f W	f HV	f G	f p	f BB	f A	f RT	f LT	Adj Sat Flow
EB											
L	1900	1	0.97	0.95	1.00	1.00	1.00	1.00	1.00	0.95	1662
TR	1900	2	0.97	0.95	1.00	1.00	1.00	1.00	0.95	1.00	3339
WB											
L	1900	1	0.97	0.95	1.00	1.00	1.00	1.00	1.00	0.95	1662
TR	1900	2	0.97	0.95	1.00	1.00	1.00	1.00	0.99	1.00	3466
NB											
L	1900	1	0.97	0.95	1.00	1.00	1.00	1.00	1.00	0.95	1662
TR	1900	2	0.97	0.95	1.00	1.00	1.00	1.00	0.99	1.00	3478
SB											
L	1900	1	0.97	0.95	1.00	1.00	1.00	1.00	1.00	0.95	1662
TR	1900	2	0.97	0.95	1.00	1.00	1.00	1.00	0.99	1.00	3466

Capacity Analysis Worksheet

Direction /LnGrp	Adj Flow Rate (v)	Adj Sat Flow Rate (s)	Flow Ratio (v/s)	Green Ratio (g/C)	Lane Group Capacity (c)	v/c Ratio	
EB							
L	59	1662	0.035	0.076	127	0.466	
TR	401	3339	0.120	0.190	636	0.631	
WB							
L	88	1662	0.053	0.076	127	0.695	*
TR	648	3466	0.187	0.190	660	0.982	*
NB							
L	118	1662	0.071	0.181	301	0.392	
TR	1606	3478	0.462	0.438	1524	1.054	*

```
SB
   L          147       1662    0.088     0.181        301    0.489 *
   TR         988       3466    0.285     0.438       1518    0.651
                                Sum (v/s) critical = 0.790
Lost Time/Cycle, L =  12.0 sec   Critical v/c(x)    = 0.892
------------------------------------------------------------------------
```

Level of Service Worksheet

Direction /LnGrp	v/c Ratio	g/C Ratio	Delay d 1	Del Adj Fact	Lane Group Cap	Calib d 2	Delay d 2	Lane Grp Del	Lane Grp LOS	Delay By App	**LOS By App**
EB											
L	0.466	0.076	35.3	1.000	127	16	2.0	37.3	D	31.9	**D**
TR	0.631	0.190	29.7	1.000	636	16	1.4	31.2	D		
WB											
L	0.695	0.076	36.0	1.000	127	16	10.0	46.0	E	53.9	**E**
TR	0.982	0.190	32.2	1.000	660	16	22.8	55.0	E		
NB											
L	0.392	0.181	28.8	1.000	301	16	0.5	29.3	D	53.7	**E**
TR	1.054	0.438	22.4	1.000	1524	16	33.1	55.5	E		
SB											
L	0.489	0.181	29.4	1.000	301	16	1.0	30.4	D	19.9	**C**
TR	0.651	0.438	17.6	1.000	1518	16	0.7	18.3	C		

Intersection Delay = 41.8 sec/veh **Intersection LOS = E**

9.8

The following is the Highway Capacity Software (HCS) solution to the exercise. This is one suitable intersection layout and phasing sequence that provides a condition of under capacity.

HIGHWAY CAPACITY MANUAL SIGNALIZED INTERSECTION PLANNING METHOD
LANE VOLUME WORKSHEET

File name: Date: 8 - 2 - 19 96 Time Period:

(E/W): (N/S): Analyst :

Peak hour factor: .9 Comment: Exercise 08

	EAST BOUND	WEST BOUND	NORTH BOUND	SOUTH BOUND
LEFT TURN MOVEMENT				
1. LT volume	100	125	150	200
2. Opposing mainline volume	645	700	1200	1150
3. Number of exclusive LT lanes	0	0	1	1
Cross Product [2] * [1]	64500	87500	180000	230000
Left Lane Configuration (E=Excl, S=Shrd):	S	S	E	E
Left Turn Treatment Type:	Perm	Perm	Perm	Perm
4. LT adjustment factor	N/A	N/A	1.0	1.0
5. LT lane vol	N/A	N/A	N/A	N/A

RIGHT TURN MOVEMENT

Right Lane Configuration (E=Excl, S=Shrd)	S	S	S	S
6. RT volume	100	120	250	200
7. Exclusive lanes	N/A	N/A	N/A	N/A
8. RT adjustment factor	.85	.85	.85	.85
9. Exclusive RT lane volume	0	0	0	0
10. Shared lane vol	118	141	294	235

THROUGH MOVEMENT

11. Thru volume	500	400	900	1000
12. Parking adjustment factor	1	1	1	1
13. No. of thru lanes including shared	2	2	2	2
14. Total approach volume	618	541	1194	1235
15. Prop. of left turns in lane group	N/A	N/A	0	0
16. Left turn equivalence	4.14	4.8	10.4	9.35
17. LT adj. factor:	.63	.57	N/A	N/A
18. Through lane volume	494	477	597	618
19. Critical lane volume	494	477	597	618

Left Turn Check (if [16] > 8)

20. Permitted left turn sneaker capacity: 7200/Cmax	N/A	N/A	60	60

HIGHWAY CAPACITY MANUAL SIGNALIZED INTERSECTION PLANNING METHOD
SIGNAL OPERATIONS WORKSHEET

File name: Date: 8 - 2 - 19 96 Time Period:

(E/W): (N/S): Analyst :

	EAST BOUND	WEST BOUND	NORTH BOUND	SOUTH BOUND
Phase Plan Selection from Lane Volume Worksheet				
Critical through-RT vol: [19]	494	477	597	618
LT lane vol: [5]	N/A	N/A	N/A	N/A
Left turn protection: (P/U/N)	U	U	U	U
Dominant left turn: (Indicate by '*')		*		*

Selection Criteria based on the specified left turn protection

* Indicates the dominant left turn for each opposing pair

Plan 1:	U	U	U	U
Plan 2a:	U	P	U	P
Plan 2b:	P	U	P	U
Plan 3a:	*P	P	*P	P
Plan 3b:	P	*P	P	*P
Plan 4:	N	N	N	N

```
Min. cycle (Cmin)    60           Max. cycle (Cmax)    120

Timing Plan                          --- EAST-WEST ----    -- NORTH-SOUTH ---
                           Value     Ph 1   Ph 2   Ph 3    Ph 1   Ph 2   Ph 3

Movement codes                       EWG                   NSG
Critical phase vol [CV]              494    0      0       618    0      0
Critical sum [CS]          1112
CBD adjustment [CBD]       .9
Reference sum [RS]         1385
Lost time/phase [PL]                 3      0      0       3      0      0
Lost time/cycle [TL]       6
Cycle length [CYC]         60
Green time                           27     0      0       33     0      0
Critical v/c ratio [Xcm]   0.76
Status                     Under capacity.
```

9.9

Refer to the solution to Exercise 4. A critical *V/c* ratio of 0.90 or lower is not achieved. The overall intersection LOS is D.

9.10

a.) 2-phase signal, pretimed

E-W flow ratio, $V/s = 0.50$

N-S flow ratio, $V/s = 0.25$

Lost time = change interval = 4 sec/phase (8 sec/cycle)

The minimum cycle length is computed using $X_c = 1.00$

$$C_{\min} = \frac{LX_c}{X_c - \Sigma(V/s)_{ci}} = \frac{8(1.0)}{1.0 - (0.5 + 0.25)} = 32 \text{ sec}$$

If a V/c of no more than 0.8 were desired, then $X = 0.8$

$$C = \frac{8(0.8)}{0.8 - (0.5 + 0.25)} = 128 \text{ sec (cycle too long)}$$

Try $X = 0.85$

$$C = \frac{8(0.85)}{0.85 - (0.5 + 0.25)} = 68 \text{ sec} \approx 70 \text{ sec (rounding to nearest 5 sec)}$$

The actual *V/c* ratio provided by the 70-sec cycle is

$$X_c = \sum_i \left(\frac{V}{s}\right)_{ci} \frac{C}{C - L} = (0.5 + 0.25)\left(\frac{70}{70 - 8}\right) = 0.85$$

1.) If the greens are allocated so that the *V/c* ratios for critical movements in each phase are equal, then

$$g_i = \left(\frac{V}{s}\right)_i \left(\frac{C}{X_i}\right)$$

$$g_1 = 0.5\left(\frac{70}{0.85}\right) = 41 \text{ sec}$$

$$g_2 = 0.25\left(\frac{70}{0.85}\right) = 21 \text{ sec}$$

Total = 62 sec

2.) If the minimum green time is assigned to the minor approach, and the balance to the major approach, then

$$g_2 = 0.25\left(\frac{70}{1.0}\right) = 17.5 \text{ sec}$$

g_1 = 70 - 8 - 17.5 = 44.5 sec

Total = 62 sec

b.) 2-phase semi-actuated signal

E-W flow ratio, *V/s* = 0.65

N-S flow ratio, *V/s* = 0.10

Designed to operate at critical *V/c* = 0.85

Lost time = 9 sec/cycle

$$C = \frac{9(0.85)}{0.85 - (0.65 + 0.1)} = 76.5 \text{ sec}$$

Because the signal is semi-actuated, the cycle length is not rounded off.

The green time for the side street is estimated using *V/c* = 1.0

$$g_2 = 0.1\left(\frac{76.5}{1.0}\right) = 7.65 \text{ sec}$$

g_1 = 76.5 - 9 - 7.65 = 59.85 sec

9.11

The following is the Highway Capacity Software (HCS) solution to the exercise. The specific answers requested in the problem statement are highlighted in bold.

```
            Center For Microcomputers In Transportation
HCS: Unsignalized Intersection   Release 2.1              Page 1
*****************************************************************
File Name ................ Exerc_11.HC0
Streets: (N-S) Molalla Ave.              (E-W) Main St.
Analyst...................
Date of Analysis.......... 7/19/96
Other Information.........
All-way Stop-controlled Intersection
```

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
No. Lanes	0>	2<	0	0>	2<	0	0>	1<	0	0>	1<	0
Volumes	50	325	75	50	225	75	45	245	60	35	225	50
PHF	.95	.95	.95	.95	.95	.95	.95	.95	.95	.95	.95	.95
Grade		0			0			0			0	
MC's*(%)	0	0	0	0	0	0	0	0	0	0	0	0
SU/RV's (%)	0	0	0	0	0	0	0	0	0	0	0	0
CV's*(%)	0	0	0	0	0	0	0	0	0	0	0	0
PCE's	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1

```
*MC's Motor Cycles      CV's Combination Vehicles
        Volume Summary and Capacity Analysis Worksheet
-----------------------------------------------------------------------
                                              EB      WB      NB      SB
```

LT Flow Rate	53	53	47	37
RT Flow Rate	79	79	63	53
Approach Flow Rate	474	369	368	327
Proportion LT	0.11	0.14	0.13	0.11
Proportion RT	0.17	0.21	0.17	0.16
Opposing Approach Flow Rate	369	474	327	368
Conflicting Approaches Flow Rate	695	695	843	843
Proportion, Subject Approach Flow Rate	0.31	0.24	0.24	0.21
Proportion, Opposing Approach Flow Rate	0.24	0.31	0.21	0.24
Lanes on Subject Approach	2	2	1	1
Lanes on Opposing Approach	2	2	1	1
LT, Opposing Approach	53	53	37	47
RT, Opposing Approach	79	79	53	63
LT, Conflicting Approaches	84	84	106	106
RT, Conflicting Approaches	116	116	158	158
Proportion LT, Opposing Approach	0.14	0.11	0.11	0.13
Proportion RT, Opposing Approach	0.21	0.17	0.16	0.17
Proportion LT, Conflicting Approaches	0.12	0.12	0.13	0.13
Proportion RT, Conflicting Approaches	0.17	0.17	0.19	0.19
Approach Capacity	690	669	505	495

****

Intersection Performance Summary

Movement	Approach Flow Rate	Approach Capacity	V/C Ratio	**Average Total Delay**	**LOS**
EB	474	690	0.69	**13.6**	**C**
WB	369	669	0.55	**8.1**	**B**
NB	368	505	0.73	**15.9**	**C**
SB	327	495	0.66	**12.3**	**C**

Intersection Delay = 12.58
Level of Service (Intersection) = C

9.12

The following is the Highway Capacity Software (HCS) solution to the exercise. The specific answers requested in the problem statement are highlighted in bold.

```
HCS:  Signalized Intersection    Version 2.4a             08-07-1996  1
================================================================================
Streets: (E-W) Moss Avenue             (N-S) Ryder Street
Analyst:                               File Name: Exerc_12.HC9
Area Type: Other                       8-7-96
================================================================================
```

Traffic and Roadway Conditions

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R

No. Lanes	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Volumes	105	450	105	125	500	80	100	560	90	95	525	40			
PHF or PK15	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90			
Lane Width	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0			
Grade		0			0			0			0				
% Heavy Veh	3	3	3	3	3	3	5	5	5	5	5	5			
Parking	(Y/N)	N		(Y/N)	N		(Y/N)	N		(Y/N)	N				
Bus Stops			0			0			0			0			
Con. Peds			0			0			0			0			
Ped Button	(Y/N)	N		(Y/N)	N		(Y/N)	N		(Y/N)	N				
Arr Type	3	3	3	3	3	3	5	5	5	5	5	5			
RTOR Vols			0			0			0			0			
Lost Time	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00			

Signal Operations

Phase Combination	1	2	3	4		5	6	7	8
EB Left	*				NB Left	*			
Thru	*				Thru	*			
Right	*				Right	*			
Peds					Peds				
WB Left	*				SB Left	*			
Thru	*				Thru	*			
Right	*				Right	*			
Peds					Peds				
NB Right					EB Right				
SB Right					WB Right				
Green	46.0P				Green	46.0P			
Yellow/AR	4.0				Yellow/AR	4.0			

Cycle Length: 100 sec Phase combination order: #1 #5

Volume Adjustment Worksheet

Direction/ Mvt	Mvt Vol	PHF	Adj Vol	Lane Grp	Lane Grp Vol	No. Ln	Lane Util Fact	Growth Fact	Adj Grp Vol	Prop LT	Prop RT
EB											
Left	105	0.90	117	L	117	1	1.000	1.000	117	1.00	0.00
Thru	450	0.90	500	T	500	1	1.000	1.000	500	0.00	0.00
Right	105	0.90	117	R	117	1	1.000	1.000	117	0.00	1.00
WB											
Left	125	0.90	139	L	139	1	1.000	1.000	139	1.00	0.00
Thru	500	0.90	556	T	556	1	1.000	1.000	556	0.00	0.00
Right	80	0.90	89	R	89	1	1.000	1.000	89	0.00	1.00
NB											
Left	100	0.90	111	L	111	1	1.000	1.000	111	1.00	0.00
Thru	560	0.90	622	T	622	1	1.000	1.000	622	0.00	0.00
Right	90	0.90	100	R	100	1	1.000	1.000	100	0.00	1.00
SB											

Left	95	0.90	106	L	106	1	1.000	1.000	106	1.00	0.00
Thru	525	0.90	583	T	583	1	1.000	1.000	583	0.00	0.00
Right	40	0.90	44	R	44	1	1.000	1.000	44	0.00	1.00

Saturation Flow Adjustment Worksheet

Direction /LnGrp	Ideal Sat Flow	No. Lns	f W	f HV	f G	f p	f BB	f A	f RT	f LT	Adj Sat Flow
EB											
L	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	1.00	0.13	244
T	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1845
R	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	0.85	1.00	1568
WB											
L	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	1.00	0.17	318
T	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1845
R	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	0.85	1.00	1568
NB											
L	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	1.00	0.16	297
T	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1810
R	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	0.85	1.00	1538
SB											
L	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	1.00	0.13	234
T	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1810
R	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	0.85	1.00	1538

Supplemental Permitted LT Worksheet

APPROACH	EB
Cycle Length, C	100
Actual Green Time for Lane Group, G	46
Effective Green Time for Lane Group, g	47
Opposing Effective Green Time, go	47
Number of Opposing Lanes, No	1
Number of Lanes in Lane Group, N	1
Adjusted Left-Turn Flow Rate, Vlt	117
Proportion of Left Turns in Lane Group, Plt	1.00
Left Turns per Cycle: LTC=Vlt*C/3600	3.25
Adjusted Opposing Flow Rate, Vo	556
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	15.44
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	0.00
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.53
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	20.69
gu=g-gq (or g-gf)	26.31
fs=(875-0.625Vo)/1000	0.53
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	1.00
El1	4.24
fmin	0.09
fm,(min=fmin;max=1.00)	0.13
flt=[fm+0.91(N-1)]/N	0.13

APPROACH	WB

Cycle Length, C	100
Actual Green Time for Lane Group, G	46
Effective Green Time for Lane Group, g	47
Opposing Effective Green Time, go	47
Number of Opposing Lanes, No	1
Number of Lanes in Lane Group, N	1
Adjusted Left-Turn Flow Rate, Vlt	139
Proportion of Left Turns in Lane Group, Plt	1.00
Left Turns per Cycle: LTC=Vlt*C/3600	3.86
Adjusted Opposing Flow Rate, Vo	500
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	13.89
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	0.00
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.53
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	17.38
gu=g-gq (or g-gf)	29.62
fs=(875-0.625Vo)/1000	0.56
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	1.00
El1	3.65
fmin	0.09
fm,(min=fmin;max=1.00)	0.17
flt=[fm+0.91(N-1)]/N	0.17

APPROACH	NB
Cycle Length, C	100
Actual Green Time for Lane Group, G	46
Effective Green Time for Lane Group, g	47
Opposing Effective Green Time, go	47
Number of Opposing Lanes, No	1
Number of Lanes in Lane Group, N	1
Adjusted Left-Turn Flow Rate, Vlt	111
Proportion of Left Turns in Lane Group, Plt	1.00
Left Turns per Cycle: LTC=Vlt*C/3600	3.08
Adjusted Opposing Flow Rate, Vo	583
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	16.19
Opposing Platoon Ratio, Rpo	1.67
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	0.00
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.22
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	12.17
gu=g-gq (or g-gf)	34.83
fs=(875-0.625Vo)/1000	0.51
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	1.00
El1	4.52
fmin	0.09
fm,(min=fmin;max=1.00)	0.16
flt=[fm+0.91(N-1)]/N	0.16

APPROACH	SB
Cycle Length, C	100
Actual Green Time for Lane Group, G	46
Effective Green Time for Lane Group, g	47
Opposing Effective Green Time, go	47
Number of Opposing Lanes, No	1
Number of Lanes in Lane Group, N	1

Adjusted Left-Turn Flow Rate, Vlt	106
Proportion of Left Turns in Lane Group, Plt	1.00
Left Turns per Cycle: LTC=Vlt*C/3600	2.94
Adjusted Opposing Flow Rate, Vo	622
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	17.28
Opposing Platoon Ratio, Rpo	1.67
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	0.00
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.22
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	14.58
gu=g-gq (or g-gf)	32.42
fs=(875-0.625Vo)/1000	0.49
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	1.00
El1	5.33
fmin	0.09
fm,(min=fmin;max=1.00)	0.13
flt=[fm+0.91(N-1)]/N	0.13

Capacity Analysis Worksheet

Direction /LnGrp	Adj Flow Rate (v)	Adj Sat Flow Rate (s)	Flow Ratio (v/s)	Green Ratio (g/C)	Lane Group Capacity (c)	v/c Ratio
EB						
L	117	244	0.480	0.470	115	**1.020 ***
T	500	1845	0.271	0.470	867	**0.577**
R	117	1568	0.075	0.470	737	**0.159**
WB						
L	139	318	0.437	0.470	149	**0.930**
T	556	1845	0.301	0.470	867	**0.641**
R	89	1568	0.057	0.470	737	**0.121**
NB						
L	111	297	0.374	0.470	140	**0.795**
T	622	1810	0.344	0.470	851	**0.731**
R	100	1538	0.065	0.470	723	**0.138**
SB						
L	106	234	0.453	0.470	110	**0.964 ***
T	583	1810	0.322	0.470	851	**0.685**
R	44	1538	0.029	0.470	723	**0.061**

Sum (v/s) critical = 0.932

Lost Time/Cycle, L = 6.0 sec **Critical v/c(x) = 0.992**

Level of Service Worksheet

Direction /LnGrp	v/c Ratio	g/C Ratio	Delay d 1	Del Adj Fact	Lane Group Cap	Calib d 2	Delay d 2	Lane Grp Del	Lane Grp LOS	Delay By App	LOS By App
EB											
L	1.020	0.470	20.1	1.000	115	16	71.7	91.8	F	26.9	**D**
T	0.577	0.470	14.6	1.000	867	16	0.7	15.4	C		
R	0.159	0.470	11.5	1.000	737	16	0.0	11.5	B		
WB											
L	0.930	0.470	19.0	1.000	149	16	37.9	56.9	E	23.0	**C**
T	0.641	0.470	15.3	1.000	867	16	1.1	16.4	C		

```
   R       0.121 0.470  11.3 1.000   737   16    0.0  11.3  B
NB
   L       0.795 0.470  17.0 0.409   140    8   10.0  16.9  C   8.6  B
   T       0.731 0.470  16.3 0.409   851    8    1.2   7.8  B
   R       0.138 0.470  11.4 0.409   723    8    0.0   4.7  A
SB
   L       0.964 0.470  19.5 0.409   110    8   37.1  45.1  E  12.6  B
   T       0.685 0.470  15.7 0.409   851    8    0.8   7.3  B
   R       0.061 0.470  11.0 0.409   723    8    0.0   4.5  A
               Intersection Delay =  17.6 sec/veh Intersection LOS = C
------------------------------------------------------------------------
```

9.13

The following is the Highway Capacity Software (HCS) solution to the exercise. The specific answers requested in the problem statement are highlighted in bold.

```
HCS:  Signalized Intersection    Version 2.4a             08-07-1996  1
========================================================================
Streets: (E-W) Moss Avenue             (N-S) Ryder Street
Analyst:                               File Name: Exerc_13.HC9
Area Type: Other                       8-7-96
========================================================================

                    Traffic and Roadway Conditions
------------------------------------------------------------------------
           |   Eastbound  |  Westbound   |  Northbound  |  Southbound
           | L    T    R  | L    T    R  | L    T    R  | L    T    R
           |---- ---- ----|---- ---- ----|---- ---- ----|---- ---- ----
No. Lanes  | 1    1    1  | 1    1    1  | 1    1    1  | 1    1    1
Volumes    | 105  450  105| 125  500   80| 100  560   90|  95  525   40
PHF or PK15|0.90 0.90 0.90|0.90 0.90 0.90|0.90 0.90 0.90|0.90 0.90 0.90
Lane Width |12.0 12.0 12.0|12.0 12.0 12.0|12.0 12.0 12.0|12.0 12.0 12.0
Grade      |        0     |        0     |        0     |        0
% Heavy Veh|   3    3    3|   3    3    3|   5    5    5|   5    5    5
Parking    |(Y/N) N       |(Y/N) N       |(Y/N) N       |(Y/N) N
Bus Stops  |             0|              0|              0|              0
Con. Peds  |             0|              0|              0|              0
Ped Button |(Y/N) N       |(Y/N) N       |(Y/N) N       |(Y/N) N
Arr Type   |   3    3    3|   3    3    3|   5    5    5|   5    5    5
RTOR Vols  |             0|              0|              0|              0
Lost Time  |3.00 3.00 3.00|3.00 3.00 3.00|3.00 3.00 3.00|3.00 3.00 3.00
------------------------------------------------------------------------

                          Signal Operations
------------------------------------------------------------------------
Phase Combination 1     2     3     4 |            5     6     7     8
EB  Left          *                   |NB  Left    *
    Thru                *             |    Thru          *
    Right               *             |    Right         *
    Peds                              |    Peds
                                      |
WB  Left          *                   |SB  Left    *
    Thru                *             |    Thru          *
    Right               *             |    Right         *
```

	Peds					Peds			
NB	Right	*			EB	Right	*		
SB	Right	*			WB	Right	*		
Green		7.0P	32.0P		Green		7.0P	38.0P	
Yellow/AR		4.0	4.0		Yellow/AR		4.0	4.0	

Cycle Length: 100 sec Phase combination order: #1 #2 #5 #6

Volume Adjustment Worksheet

Direction/ Mvt	Mvt Vol	PHF	Adj Vol	Lane Grp	Lane Grp Vol	No. Ln	Lane Util Fact	Growth Fact	Adj Grp Vol	Prop LT	Prop RT
EB											
Left	105	0.90	117	L	117	1	1.000	1.000	117	1.00	0.00
Thru	450	0.90	500	T	500	1	1.000	1.000	500	0.00	0.00
Right	105	0.90	117	R	117	1	1.000	1.000	117	0.00	1.00
WB											
Left	125	0.90	139	L	139	1	1.000	1.000	139	1.00	0.00
Thru	500	0.90	556	T	556	1	1.000	1.000	556	0.00	0.00
Right	80	0.90	89	R	89	1	1.000	1.000	89	0.00	1.00
NB											
Left	100	0.90	111	L	111	1	1.000	1.000	111	1.00	0.00
Thru	560	0.90	622	T	622	1	1.000	1.000	622	0.00	0.00
Right	90	0.90	100	R	100	1	1.000	1.000	100	0.00	1.00
SB											
Left	95	0.90	106	L	106	1	1.000	1.000	106	1.00	0.00
Thru	525	0.90	583	T	583	1	1.000	1.000	583	0.00	0.00
Right	40	0.90	44	R	44	1	1.000	1.000	44	0.00	1.00

Saturation Flow Adjustment Worksheet

Direction /LnGrp	Ideal Sat Flow	No. Lns	f W	f HV	f G	f p	f BB	f A	f RT	f LT	Adj Sat Flow
EB											
L	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	1.00	0.95	1752
T	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1845
R	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	0.85	1.00	1568
WB											
L	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	1.00	0.95	1752
T	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1845
R	1900	1	1.00	0.97	1.00	1.00	1.00	1.00	0.85	1.00	1568
NB											
L	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	1.00	0.95	1719
T	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1810

	R	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	0.85	1.00	1538
SB												
	L	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	1.00	0.95	1719
	T	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1810
	R	1900	1	1.00	0.95	1.00	1.00	1.00	1.00	0.85	1.00	1538

Capacity Analysis Worksheet

Direction /LnGrp	Adj Flow Rate (v)	Adj Sat Flow Rate (s)	Flow Ratio (v/s)	Green Ratio (g/C)	Lane Group Capacity (c)	**v/c Ratio**	
EB							
L	117	1752	0.067	0.080	140	**0.835**	
T	500	1845	0.271	0.330	609	**0.821**	
R	117	1568	0.075	0.440	690	**0.170**	
WB							
L	139	1752	0.079	0.080	140	**0.992**	*
T	556	1845	0.301	0.330	609	**0.913**	*
R	89	1568	0.057	0.440	690	**0.129**	
NB							
L	111	1719	0.065	0.080	138	**0.807**	*
T	622	1810	0.344	0.390	706	**0.881**	*
R	100	1538	0.065	0.500	769	**0.130**	
SB							
L	106	1719	0.062	0.080	138	**0.771**	
T	583	1810	0.322	0.390	706	**0.826**	
R	44	1538	0.029	0.500	769	**0.057**	

Sum (v/s) critical = 0.789

Lost Time/Cycle, L = 12.0 sec **Critical v/c(x) = 0.896**

Level of Service Worksheet

Direction /LnGrp	v/c Ratio	g/C Ratio	Delay d 1	Del Adj Fact	Lane Group Cap	Calib d 2	Delay d 2	Lane Grp Del	Lane Grp LOS	Delay By App	LOS By App
EB											
L	0.835	0.080	34.5	1.000	140	16	22.3	56.8	E	31.2	**D**
T	0.821	0.330	23.4	1.000	609	16	6.1	29.5	D		
R	0.170	0.440	12.9	1.000	690	16	0.0	12.9	B		
WB											
L	0.992	0.080	34.9	1.000	140	16	55.9	90.8	F	44.1	**E**
T	0.913	0.330	24.4	1.000	609	16	13.1	37.5	D		
R	0.129	0.440	12.6	1.000	690	16	0.0	12.6	B		
NB											
L	0.807	0.080	34.4	0.942	138	8	11.0	43.3	E	19.1	**C**
T	0.881	0.390	21.5	0.574	706	8	4.9	17.2	C		
R	0.130	0.500	10.2	0.333	769	8	0.0	3.4	A		
SB											
L	0.771	0.080	34.3	0.942	138	8	8.5	40.8	E	18.0	**C**

```
   T       0.826 0.390  20.9 0.574   706    8    3.0  14.9  B
   R       0.057 0.500   9.8 0.333   769    8    0.0   3.3  A
               Intersection Delay =  28.1 sec/veh Intersection LOS = D
------------------------------------------------------------------------
```

9.14

The following is the Highway Capacity Software (HCS) solution to the exercise. The specific answers requested in the problem statement are highlighted in bold.

```
HCS:  Signalized Intersection    Version 2.4a             08-07-1996  1
========================================================================
Streets: (E-W) 5th Avenue              (N-S) James Street
Analyst:                               File Name: Exerc_14.HC9
Area Type: Other                       8-7-96
========================================================================

                    Traffic and Roadway Conditions
------------------------------------------------------------------------
           |   Eastbound  |  Westbound   |  Northbound  |  Southbound
           | L    T    R  | L    T    R  | L    T    R  | L    T    R
           |---- ---- ----|---- ---- ----|---- ---- ----|---- ---- ----
No. Lanes  | 1    2  <    | 1    2    1  | 1    1  <    | 1    1    1
Volumes    | 175  980   75| 140 1020  205|  75  245   25|  50  160   95
PHF or PK15|0.95 0.95 0.95|0.95 0.95 0.95|0.95 0.95 0.95|0.95 0.95 0.95
Lane Width |11.0 11.0     |11.0 11.0 11.0|11.0 11.0     |10.0 10.0 10.0
Grade      |        2     |       -2     |        0     |         0
% Heavy Veh|   2    2    2|   2    2    2|   5    5    5|   5    5    5
Parking    |(Y/N) N       |(Y/N) N       |(Y/N) Y    40 |(Y/N) Y    25
Bus Stops  |             4|             2|             0|             0
Con. Peds  |            50|            50|            50|            50
Ped Button |(Y/N) Y 15.0 s|(Y/N) Y 15.0 s|(Y/N) Y 20.0 s|(Y/N) Y 20.0
Arr Type   |   4    4     |   4    4    4|   3    3     |   3    3    3
RTOR Vols  |             0|             0|             0|             0
Lost Time  |3.00 3.00 3.00|3.00 3.00 3.00|3.00 3.00 3.00|3.00 3.00 3.00
------------------------------------------------------------------------

                          Signal Operations
------------------------------------------------------------------------
Phase Combination 1     2     3     4 |            5     6     7     8
EB  Left          *                     |NB  Left    *
    Thru                *               |    Thru    *
    Right               *               |    Right   *
    Peds                *               |    Peds    *
                                        |
WB  Left          *                     |SB  Left    *
    Thru                *               |    Thru    *
    Right               *               |    Right   *
    Peds                *               |    Peds    *
                                        |
NB  Right                               |EB  Right
SB  Right                               |WB  Right
                                        |
Green          10.0P 44.0P              |Green    24.0P
Yellow/AR       4.0   4.0               |Yellow/AR 4.0
```

Cycle Length: 90 sec Phase combination order: #1 #2 #5

Volume Adjustment Worksheet

Direction/ Mvt	Mvt Vol	PHF	Adj Vol	Lane Grp	Lane Grp Vol	No. Ln	Lane Util Fact	Growth Fact	Adj Grp Vol	Prop LT	Prop RT
EB											
Left	175	0.95	184	L	184	1	1.000	1.000	184	1.00	0.00
Thru	980	0.95	1032	TR	1111	2	1.050	1.000	1167	0.00	0.07
Right	75	0.95	79								
WB											
Left	140	0.95	147	L	147	1	1.000	1.000	147	1.00	0.00
Thru	1020	0.95	1074	T	1074	2	1.050	1.000	1128	0.00	0.00
Right	205	0.95	216	R	216	1	1.000	1.000	216	0.00	1.00
NB											
Left	75	0.95	79	L	79	1	1.000	1.000	79	1.00	0.00
Thru	245	0.95	258	TR	284	1	1.000	1.000	284	0.00	0.09
Right	25	0.95	26								
SB											
Left	50	0.95	53	L	53	1	1.000	1.000	53	1.00	0.00
Thru	160	0.95	168	T	168	1	1.000	1.000	168	0.00	0.00
Right	95	0.95	100	R	100	1	1.000	1.000	100	0.00	1.00

Saturation Flow Adjustment Worksheet

Direction /LnGrp	Ideal Sat Flow	No. Lns	f W	f HV	f G	f p	f BB	f A	f RT	f LT	Adj Sat Flow
EB											
L	1900	1	0.97	0.98	0.99	1.00	1.00	1.00	1.00	0.95	1694
TR	1900	2	0.97	0.98	0.99	1.00	0.99	1.00	0.99	1.00	3494
WB											
L	1900	1	0.97	0.98	1.01	1.00	1.00	1.00	1.00	0.95	1728
T	1900	2	0.97	0.98	1.01	1.00	1.00	1.00	1.00	1.00	3637
R	1900	1	0.97	0.98	1.01	1.00	1.00	1.00	0.83	1.00	1497
NB											
L	1900	1	0.97	0.95	1.00	1.00	1.00	1.00	1.00	0.51	887
TR	1900	1	0.97	0.95	1.00	0.70	1.00	1.00	0.98	1.00	1205
SB											
L	1900	1	0.93	0.95	1.00	1.00	1.00	1.00	1.00	0.26	440
T	1900	1	0.93	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1689
R	1900	1	0.93	0.95	1.00	0.77	1.00	1.00	0.83	1.00	1081

Supplemental Permitted LT Worksheet

APPROACH NB

Cycle Length, C	90
Actual Green Time for Lane Group, G	24
Effective Green Time for Lane Group, g	25
Opposing Effective Green Time, go	25
Number of Opposing Lanes, No	1
Number of Lanes in Lane Group, N	1
Adjusted Left-Turn Flow Rate, Vlt	79
Proportion of Left Turns in Lane Group, Plt	1.00
Left Turns per Cycle: LTC=Vlt*C/3600	1.98
Adjusted Opposing Flow Rate, Vo	168
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	4.20
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	0.00
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.72
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	3.69
gu=g-gq (or g-gf)	21.31
fs=(875-0.625Vo)/1000	0.77
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	1.00
El1	1.68
fmin	0.16
fm,(min=fmin;max=1.00)	0.51
flt=[fm+0.91(N-1)]/N	0.51

APPROACH	SB
Cycle Length, C	90
Actual Green Time for Lane Group, G	24
Effective Green Time for Lane Group, g	25
Opposing Effective Green Time, go	25
Number of Opposing Lanes, No	1
Number of Lanes in Lane Group, N	1
Adjusted Left-Turn Flow Rate, Vlt	53
Proportion of Left Turns in Lane Group, Plt	1.00
Left Turns per Cycle: LTC=Vlt*C/3600	1.33
Adjusted Opposing Flow Rate, Vo	284
Opposing Flow per Lane, Per Cycle: Volc=VoC/3600No	7.10
Opposing Platoon Ratio, Rpo	1
Lost time per phase, tl	3
gf=Gexp(-0.882*LTC^0.717)-tl	0.00
Opposing Queue Ratio: qro=1-Rpo(go/C)	0.72
gq = Volc * qro / (.5 - Volc * (1 - qro) / go)-tl	9.18
gu=g-gq (or g-gf)	15.82
fs=(875-0.625Vo)/1000	0.70
Pl=Plt[1+{(N-1)g/(fsgu+4.5)}]	1.00
El1	2.43
fmin	0.16
fm,(min=fmin;max=1.00)	0.26
flt=[fm+0.91(N-1)]/N	0.26

==========

Capacity Analysis Worksheet

Direction /LnGrp	Adj Flow Rate (v)	Adj Sat Flow Rate (s)	Flow Ratio (v/s)	Green Ratio (g/C)	Lane Group Capacity (c)	**v/c Ratio**
EB						
L	184	1694	0.109	0.122	207	**0.889 ***
TR	1167	3494	0.334	0.500	1747	**0.668 ***
WB						
L	147	1728	0.085	0.122	211	**0.696**
T	1128	3637	0.310	0.500	1818	**0.620**
R	216	1497	0.144	0.500	748	**0.289**
NB						
L	79	887	0.089	0.278	246	**0.321**
TR	284	1205	0.236	0.278	335	**0.848 ***
SB						
L	53	440	0.120	0.278	122	**0.434**
T	168	1689	0.099	0.278	469	**0.358**
R	100	1081	0.093	0.278	300	**0.333**

Sum (v/s) critical = 0.678

Lost Time/Cycle, L = 9.0 sec **Critical v/c(x) = 0.754**

Level of Service Worksheet

Direction /LnGrp	v/c Ratio	g/C Ratio	Delay d 1	Del Adj Fact	Lane Group Cap	Calib d 2	Delay d 2	Lane Grp Del	Lane Grp LOS	Delay By App	**LOS By App**
EB											
L	0.889	0.122	29.6	1.000	207	12	19.3	48.9	E	15.6	**C**
TR	0.668	0.500	12.8	0.767	1747	12	0.5	10.4	B		
WB											
L	0.696	0.122	28.8	1.000	211	12	5.0	33.8	D	11.9	**B**
T	0.620	0.500	12.4	0.767	1818	12	0.4	9.9	B		
R	0.289	0.500	10.0	0.767	748	12	0.0	7.7	B		
NB											
L	0.321	0.278	19.6	1.000	246	16	0.3	19.9	C	32.4	**D**
TR	0.848	0.278	23.3	1.000	335	16	12.5	35.9	D		
SB											
L	0.434	0.278	20.3	1.000	122	16	1.6	21.8	C	20.3	**C**
T	0.358	0.278	19.8	1.000	469	16	0.2	20.0	C		
R	0.333	0.278	19.7	1.000	300	16	0.3	19.9	C		

Intersection Delay = 16.2 sec/veh **Intersection LOS = C**