NCHRP 3-60: Capacity and Quality of Service of Interchange Ramp-Terminals



Research Team

Univ. of Florida: L. Elefteriadou

PSU: J. Mason, C. Fang

Polytechnic U: R. Roess, E. Prassas

Project Objectives:

- Develop improved methods for capacity and quality of service analysis of interchange ramp terminals.
- Revise Chapter 26 of the HCM 2000 to address a full range of interchange types.
- Consider planning, design and operational procedures.

Project Status and Next Steps

- Draft Final Report and Revised Chapter have been submitted to the NCHRP panel
- Panel comments will be addressed and the Final Report will be submitted by March 31st, 2005.
- Chapter to be reviewed by ICRT and HCQS.

Agenda Items:

- Chapter Review:
  - Final Design and Operational Analysis (Methodology, Applications, Examples)
  - Planning and Preliminary Design (Methodology, Applications, Examples)
- Software development plans by McTrans

Project Overview:

- Phase I – Started June 2001, completed February 2002
  - Tasks 1 – 4
- Phase II – Received notice to proceed April 2002, to be completed by September 2004
  - Tasks 5 – 9
- Quarterly reports submitted and feedback received from the panel.
- Presentations at each HCQS meeting to the HCQS/Interchange Subcommittee (starting July 2001), including two previous committee-wide workshops.

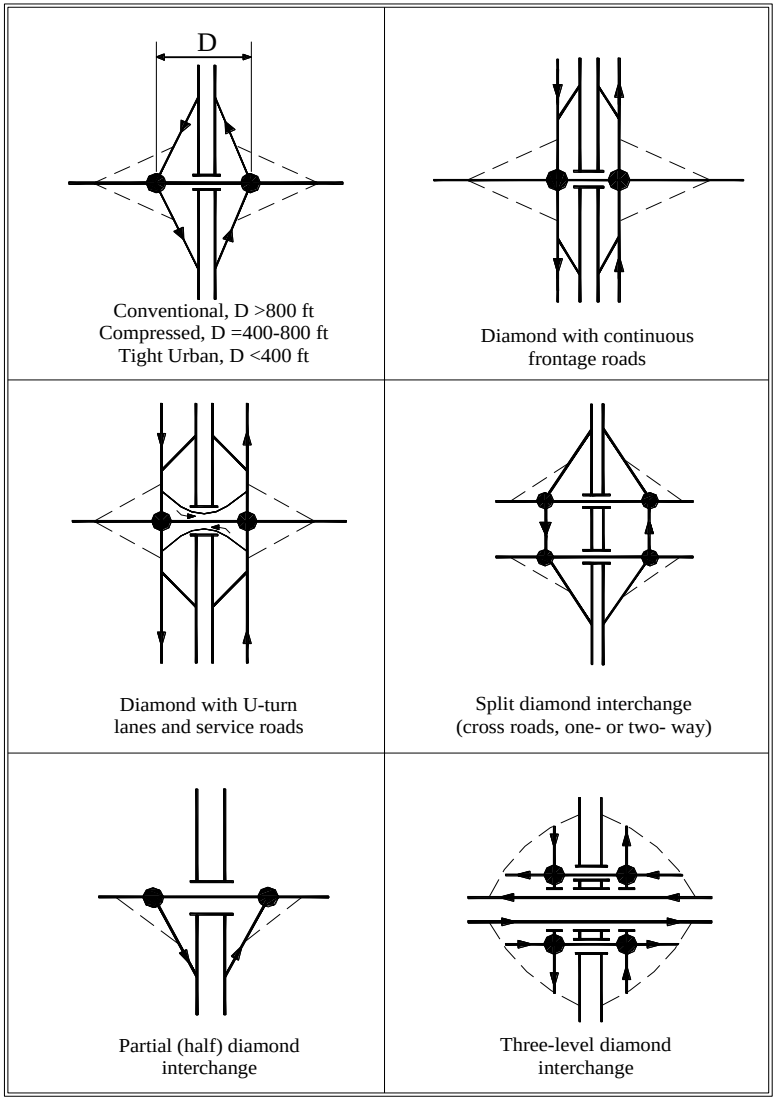
Chapter 26 Outline:

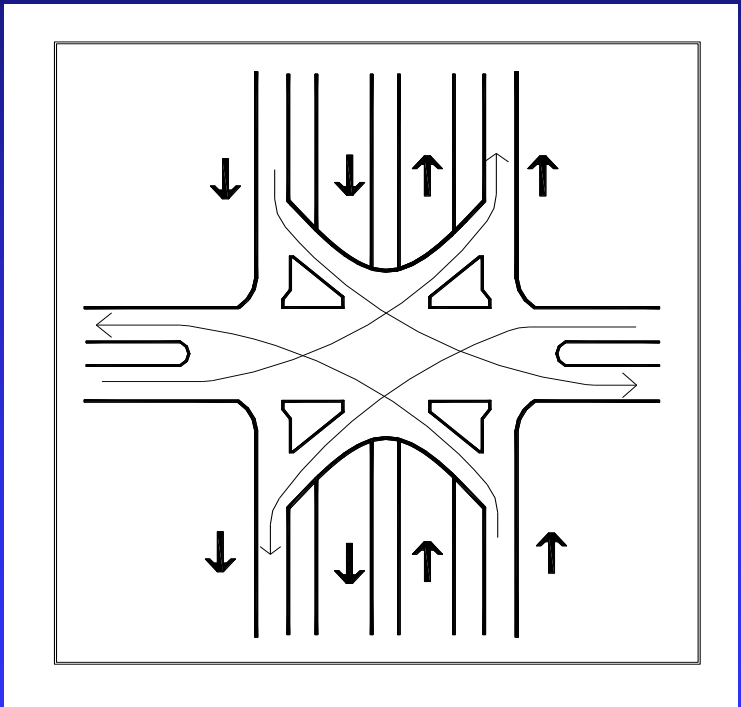
- Introduction
- Methodology
  - Final Design and Operational Analysis
  - Planning and Preliminary Engineering
- Applications
- Examples
- Appendix A – Timing Considerations for Signalized Two-Intersection Interchanges
- Appendix B – Traffic Simulation for the Analysis of Signalized Interchanges
- Appendix C - Worksheets

Chapter 26, Part I: Introduction

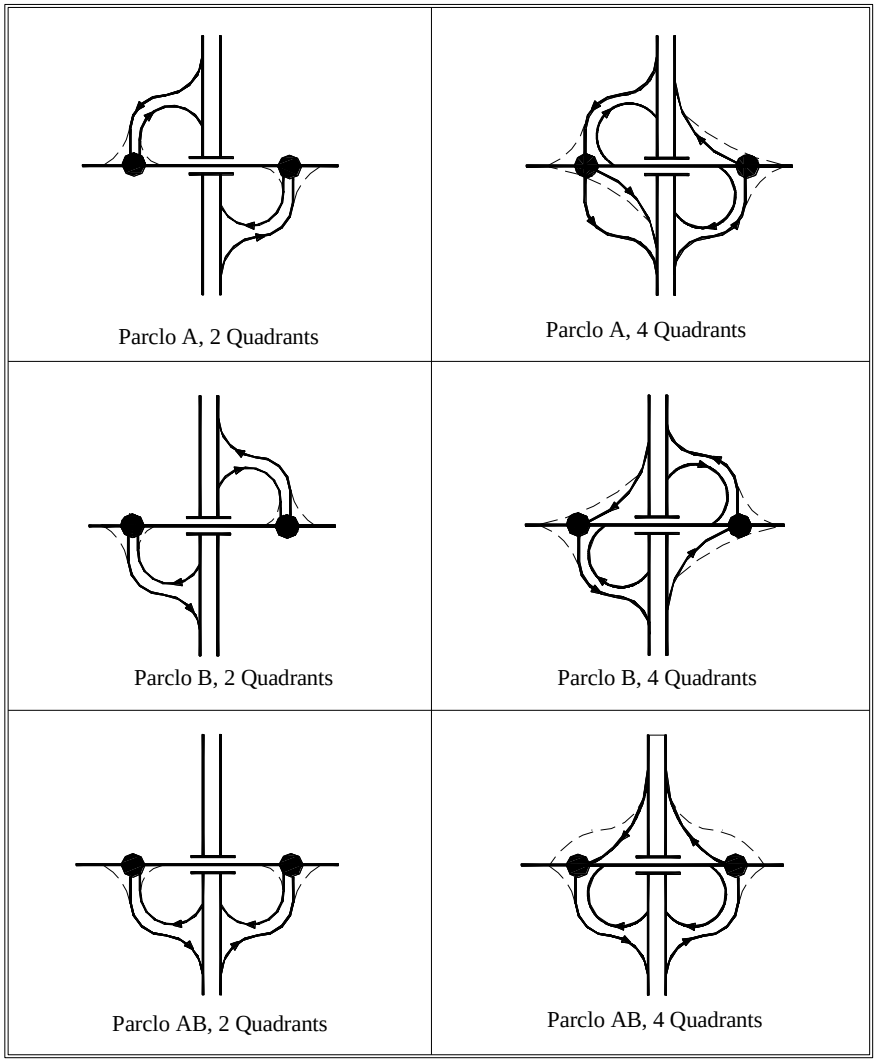
- Scope of the Chapter
- Limitations of the Methodology
- Types of Interchanges
  - Two Intersection Interchanges
  - SPUIs
- Unique Operational Characteristics of Interchanges
- Types of Analysis
  - Final Design and Operational Analysis
  - Planning and Preliminary Design
- Level of Service Framework

Types of Interchanges





Types of Interchanges (cont'd)



Unique Operational Characteristics of Interchanges

EXHIBIT 26-4. ILLUSTRATION AND NOTATION OF ORIGIN-DESTINATION DEMANDS AT AN INTERCHANGE

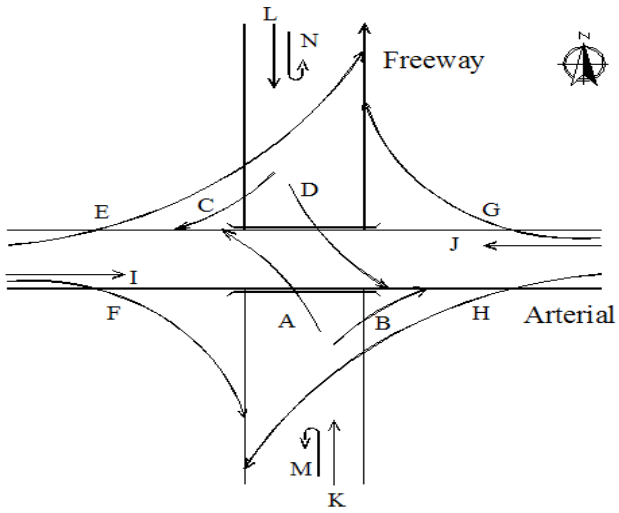
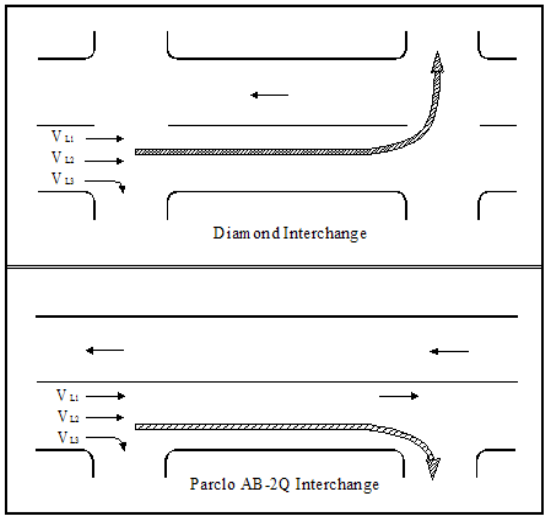


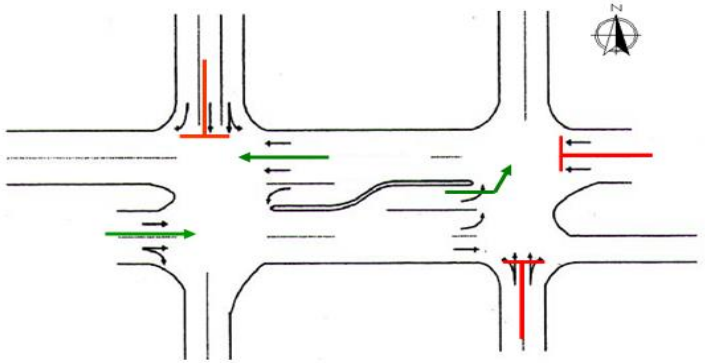
EXHIBIT 26- 7. LANE UTILIZATION FOR THE EXTERNAL THROUGH MOVEMENT



Unique Operational Characteristics of Interchanges (cont'd)

- Queue presence in the internal link, and the effects of distance between the two intersections.
- Demand starvation potential.

EXHIBIT 26-8. DEMAND STARVATION AT THE INTERNAL LINK OF A DIAMOND INTERCHANGE



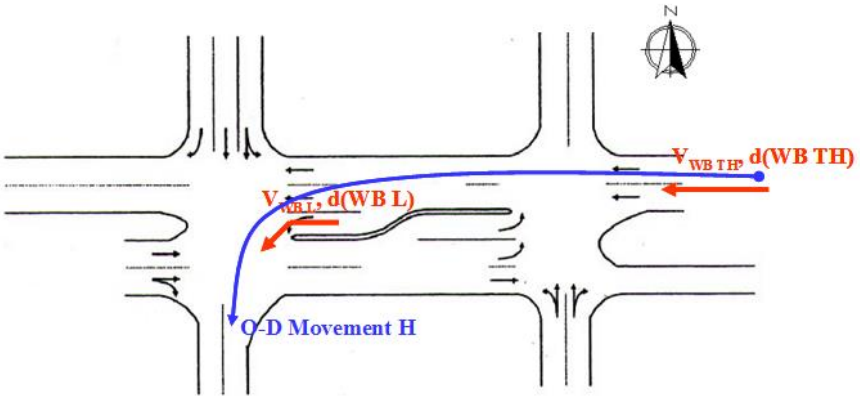
Level of Service Framework

EXHIBIT 26-10. LOS CRITERIA FOR EACH OD OF AN INTERCHANGE

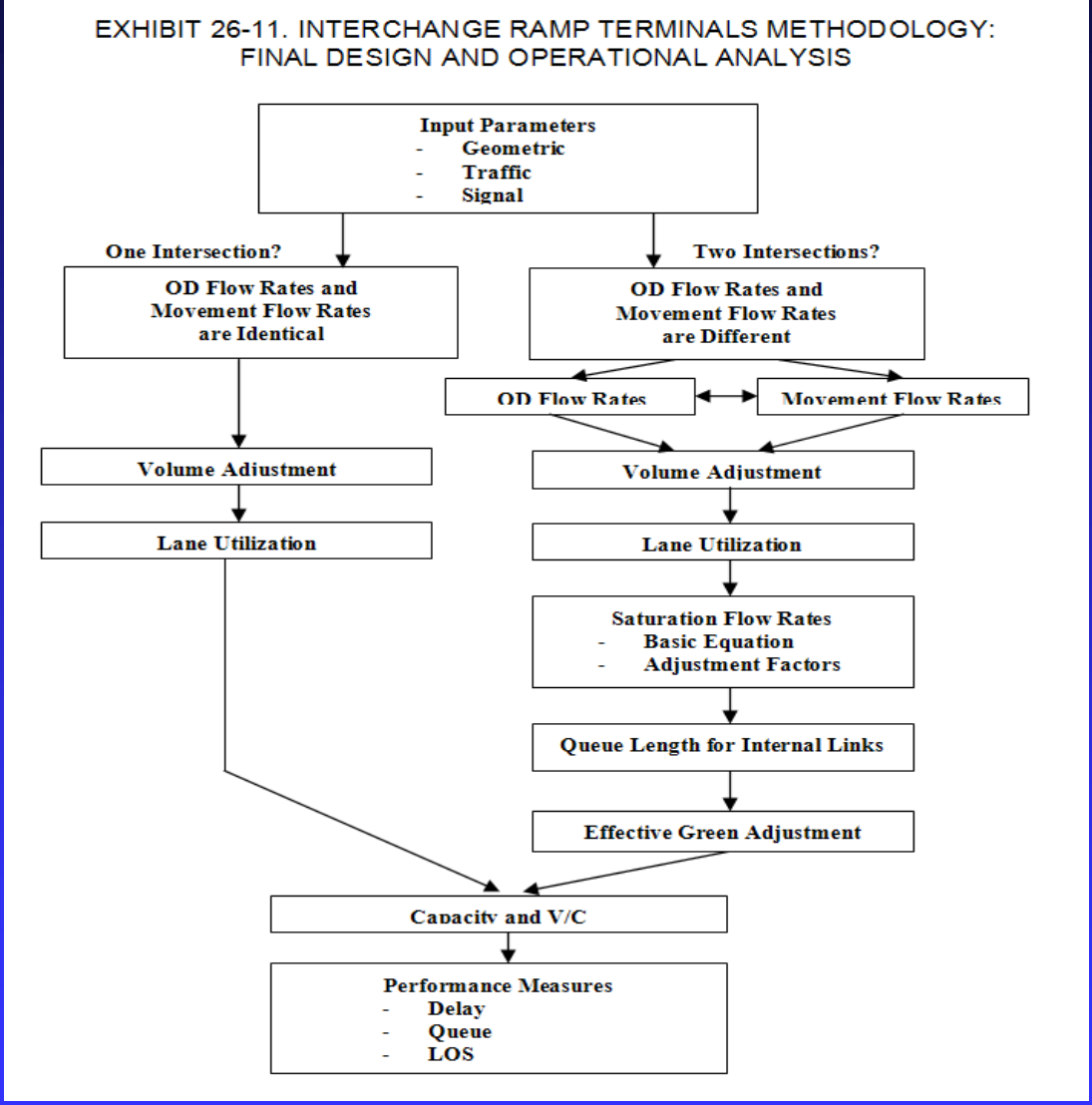
Level of Service	Delay (s/veh)
A	≤ 10
B	>10-20
C	>20-35
D	>35-55
E	>55
F	If for any of the lane groups within the OD: v/c >1.0 OR R_Q>1.0

$$\text{Delay for OD H} = \frac{(v_{WBTH} \times d_{WBTH} + v_{WBL} \times d_{WBL})}{v_{WBTH} + v_{WBL}}$$

EXHIBIT 26-9. ILLUSTRATION OF THE LOS CONCEPT AT A DIAMOND INTERCHANGE



Chapter 26 – Methodology: Final Design and Operational Analysis

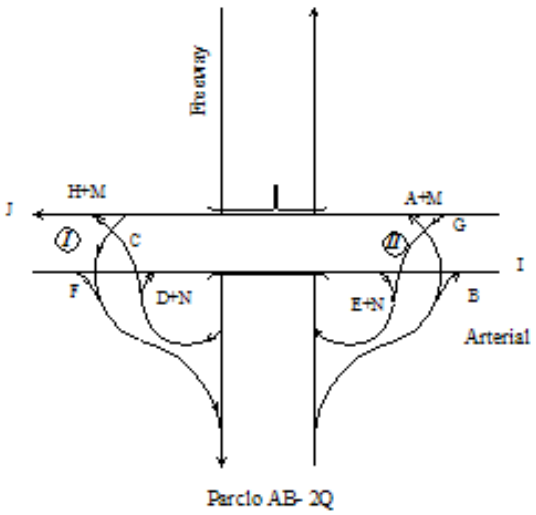


Workshop on Interchange Ramp Terminals, HCQS, January 2005

Adjustments Due to Lane Utilization

EXHIBIT 26-17. LANE UTILIZATION MODELS FOR THE EXTERNAL ARTERIAL APPROACHES OF PARCLO AB-2Q (WB ONLY) INTERCHANGES

2-LANE ARTERIAL	
WESTBOUND Leftmost lane ($\%V_{L1}$)	$\%V_{L1} = \frac{1}{2} + 0.468 \times (\frac{V_H}{V_H + V_J})$
WESTBOUND Right lane ($\%V_{L2}$)	$\%V_{L2} = 1 - \%V_{L1}$
3-LANE ARTERIAL	
WESTBOUND Leftmost lane ($\%V_{L1}$)	$\%V_{L1} = \frac{1}{3} + 0.735 \times (\frac{V_H}{V_H + V_J})$
WESTBOUND Middle lane ($\%V_{L2}$)	$\%V_{L2} = 1 - \%V_{L1} - \%V_{L3}$
WESTBOUND Right lane ($\%V_{L3}$)	$\%V_{L3} = \frac{1}{3} - 0.308 \times (\frac{V_H}{V_H + V_J})$
4-LANE ARTERIAL	
WESTBOUND Leftmost lane ($\%V_{L1}$)	$\%V_{L1} = \frac{1}{4} + 0.768 \times (\frac{V_H}{V_H + V_J})$
WESTBOUND Middle lanes ($\%V_{L2}$, $\%V_{L3}$)	$\%V_{L2} = (1 - \%V_{L1} - \%V_{L4})/2$ $\%V_{L3} = (1 - \%V_{L1} - \%V_{L4})/2$
WESTBOUND Right lane ($\%V_{L4}$)	$\%V_{L4} = \frac{1}{4} - 0.202 \times (\frac{V_H}{V_H + V_J})$



Parclo AB- 2Q

EXHIBIT 26-18 (G). PARCLO AB-2Q

EXHIBIT 26-18. ORIGIN-DESTINATION FLOWS FOR EACH INTERCHANGE CONFIGURATION (CONT'D)

Saturation Flow Rate Estimation

EXHIBIT 26-19. ADJUSTMENT FACTOR FOR TURN RADIUS (f_R)

Radius of the Travel Path (ft)	Movement Type	
	Left & Right-Turn	Through
25	0.817	1.00
50	0.899	1.00
100	0.947	1.00
150	0.964	1.00
200	0.973	1.00
250	0.978	1.00
300	0.982	1.00
350	0.984	1.00

EXHIBIT 26-20. ADJUSTMENT FACTOR FOR TRAFFIC PRESSURE (f_V)

Traffic volume, Vpcpl	Movement Type	
	Left-Turn	Through & Right-Turn
3.0	0.953	0.947
6.0	0.971	0.961
9.0	0.991	0.974
12.0	1.011	0.988
15.0	1.032	1.003
18.0	1.054	1.018
21.0	1.077	1.033
24.0	1.100	1.049

Additional Lost Time for the Upstream Approaches due to Downstream Queue

Additional Lost Time on the External Arterial Approach:

$$L_{D\text{-}A} = G_A - 0.106 * DQ_A - 5.39 * \frac{OL_{up}}{C} \qquad (26\text{-}5)$$

Additional Lost Time on the Ramp Approach:

$$L_{D\text{-}R} = G_R - 0.106 * DQ_R - 5.39 * \frac{OL_{up}}{C} \qquad (26\text{-}6)$$

Queue Length for Internal Links

Queue at the beginning of the upstream arterial phase A:

$$Q_A = 0.017 \frac{V_R}{N_R} - 7.93 \times \frac{G_D}{C} - 0.082 OL_{UD} + 0.194 G_R \qquad (26\text{-}9)$$

Queue at the beginning of the upstream ramp phase R:

$$Q_R = 0.017 \frac{V_A}{N_A} - 7.93 \times \frac{G_D}{C} - 0.082 OL_{RD} + 0.194 G_A \qquad (26\text{-}10)$$

These are multiplied by the average vehicle length, in ft, (default value recommended is 25 ft) to obtain the distance from the stop line to the end of the queue

Additional Lost Time for the Internal Link due to Demand Starvation

$$L_{DS} = OL_{DS} - Q_{INITIAL} * h_I$$

$$Q_{INITIAL} = \left(\frac{v_{Ramp-L} \times C}{N_{Ramp-L} \times 3600} - \frac{(OL_{RD} - t_L)}{h_I} \right) + \left(\frac{v_{Arterial} \times C}{N_{Arterial} \times 3600} - \frac{(OL_{UD} - t_L)}{h_I} \right)$$

Total Lost Time:

Arterial approaches: $t_L' = l_1 + L_{D-A} + Y - e$ (26-14)

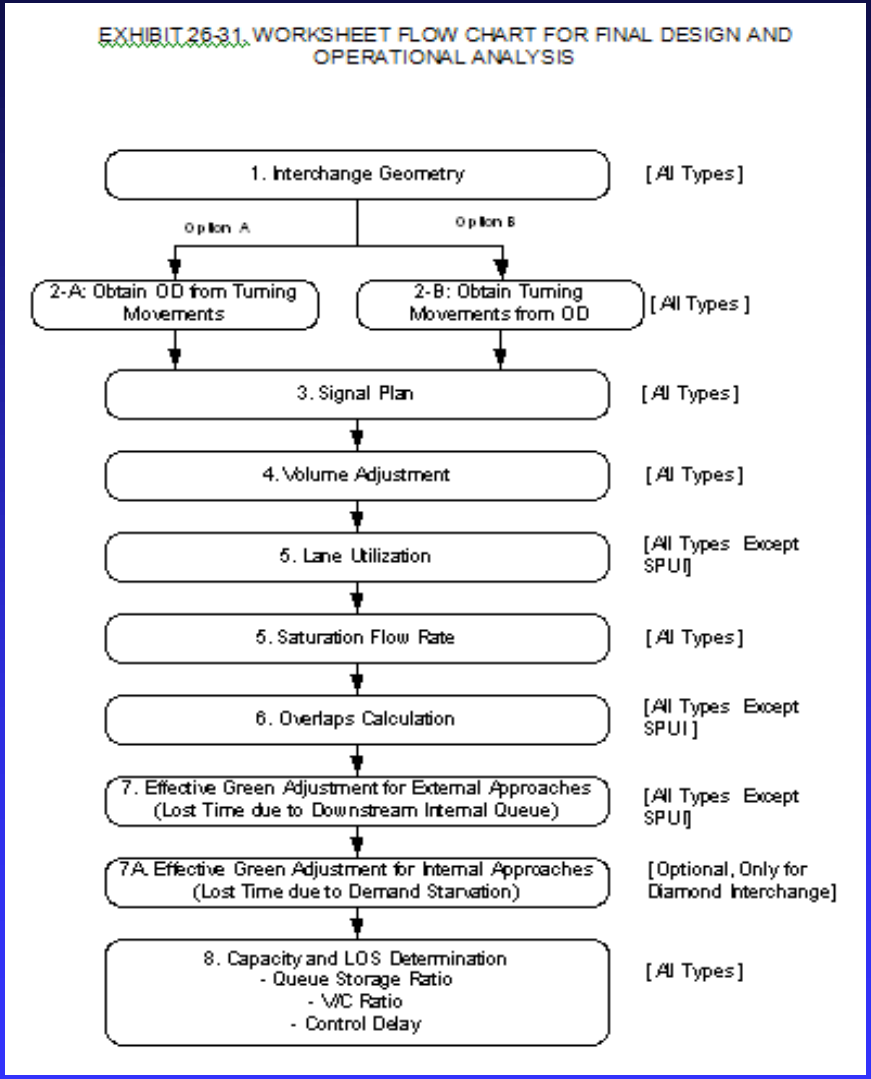
Ramp approaches: $t_L' = l_1 + L_{D-R} + Y - e$ (26-15)

Internal Approaches: $t_L' = l_1 + L_{DS} + Y - e$ (26-16)

Performance Measures and LOS

- Average Queue Storage Ratio for each lane group
- v/c for each lane group
- Average Control Delay for each lane group, and for each Origin-Destination (the weighted average of lane group delays)
- LOS determination based on Origin-Destinations

Chapter 26 - Applications



Types of Interchanges Analyzed Using the Final Design and Operational Analysis Method:

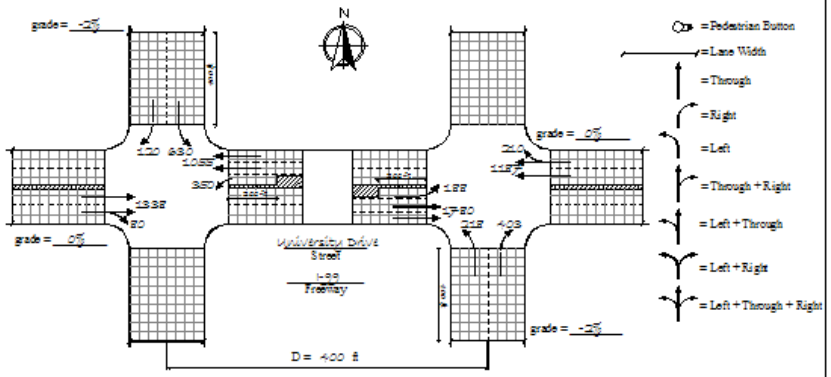
- **Single-Point Urban Interchange (SPUI)**
- **Diamond Interchange (TUDI)**
- **Partial Cloverleaf A - 4 Quadrants (Parclo A 4Q)**
- **Partial Cloverleaf A – 2 Quadrants (Parclo A 2Q)**
- **Partial Cloverleaf B – 4 Quadrants (Parclo B 4Q)**
- **Partial Cloverleaf B – 2 Quadrants (Parclo B 2Q)**
- **Partial Cloverleaf AB-2 Quadrants (Parclo AB 2Q)**
- **Partial Cloverleaf AB-4 Quadrants (Parclo AB 4Q)**

Chapter 26 – Example 1

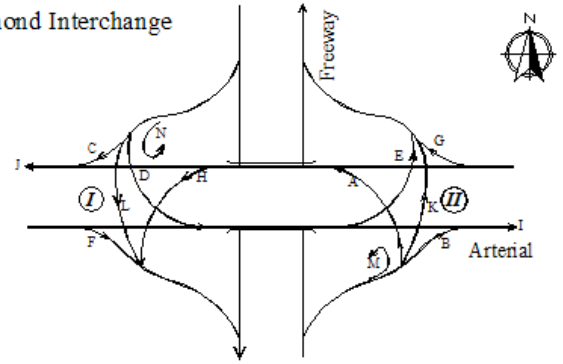
DIAMOND INTERCHANGE INPUT WORK SHEET (1)

General Information		***Site Information***	
Analyst	Alexandra, Clara	Interchange	University Drive / I-99
Agency or Company	Pennsylvania State University	Area Type	■ CBD ☐ Other
Date Performed	12/06/2004	Jurisdiction	State College
Analysis Time Period	15 min	Analysis Year	2004

Interchange Geometry



OD and Turning Movement Figure



Example 1 (Cont'd)

The Question

What are the control delay, queue-storage ratio and LOS for each O-D movement?

The Facts

√ All lane widths are 12 ft

√ Percent of heavy vehicles is 5 % for all external and internal through movements. All other movements have 0% heavy vehicles

√ Both freeway ramps (I-99) have two-lane approaches

√ NB and SB grade = - 2 %, EB and WB grade = 0%

√ The distance between the two intersections is D=400 ft

√ Left turning radius from the arterial is 75 ft, from the ramp is 50 ft

√ Right turning radius is 50 ft for all approaches

√ PHF = 0.97 for all approaches

√ Arrival Type 4 for coordinated lane groups (EB/WB internal through approaches)

√ Arrival Type 3 for all other approaches

√ Platoon Ratio R_p = 1.333 for the coordinated lane groups

√ Lost time is 2 sec for each phase

√ Cycle length is 80 sec

√ Offset is 0 sec

√ Pre-timed control at both intersections

√ No pedestrians or bicycles at the interchange

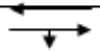
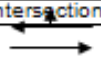
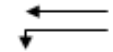
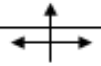
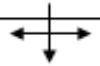
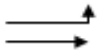
Example 1 (Cont'd)

DIAMOND INTERCHANGE OD AND TURNING MOVEMENTS WORKSHEET (2-B) OPTION B – OBTAIN TURNING MOVEMENTS FROM OD									
Input		Output							
OD Movement	Volume (veh/h)	Intersection I				Intersection II			
		Turning Movement		OD Movement	Volume (veh/h)	Turning Movement		OD Movement	Volume (veh/h)
A	218	EB	L	-	-	EB	L	E+N	188
B	403		EXT - R	F	80		R	-	-
C	120		EXT - TH	I+E	1338		TH	I+D	1780
D	630	WB	INT - L	H+M	350	WB	L	-	-
E	188		R	-			R	G	210
F	80		INT - TH	J+A	1055		TH	J+H	1187
G	210	NB	L	-	-	NB	L	A+M	218
H	350		R	-	-		R	B	403
I	1150		TH	-	-		TH	K	0
J	837		U Turn	-	-		U Turn	M	0
K	0	SB	L	D+N	630	SB	L	-	-
L	0		R	C	120		R	-	-
M	0		TH	L	0		TH	-	-
N	0		U Turn	N	0		U Turn	-	-

Example 1 (Cont'd)

DIAMOND INTERCHANGE SIGNAL PLAN WORKSHEET (3)

Signal Timing Plan

Phase Sequence	Intersection I	Timing	Intersection II	Timing
Φ1		G = *30 s* Y = *4 s*		G = *31 s* Y = *4 s*
Φ2		G = *20 s* Y = *4 s*		G = *20 s* Y = *4 s*
Φ3		G = *18 s* Y = *4 s*		G = *17 s* Y = *4 s*
Φ4		G = Y =		G = Y =
Φ5		G = Y =		G = Y =
Φ6		G = Y =		G = Y =

Cycle Length = *80* s Offset = *0* s

Signal Information

	EB				WB				NB			SB		
	EXT-TH	EXT-R	INT-L	INT-TH	EXT-TH	EXT-R	INT-L	INT-TH	L	TH	R	L	TH	R
Pretimed (P) or actuated (A)	P	P	P	P	P	P	P	P	P		P	P		P
Start-up lost time, l_1 (s)	2	2	2	2	2	2	2	2	2		2	2		2
Extension of effective green time, e (s)	2	2	2	2	2	2	2	2	2		2	2		2
Green time G(s)	30	30	17	48	31	31	20	50	20		20	18		18
Effective green time g(s), g=G-l_1+e	30	30	17	48	31	31	20	50	20		20	18		18
Min. timing for pedestrians G_p (s)	-				-				-			-		

Example 1 (Cont'd)

DIAMOND INTERCHANGE VOLUME ADJUSTMENT WORKSHEET (4)

Turning Movement Adjustment

	EB				WB				NB			SB		
	EXT-TH	EXT-R	INT-L	INT-TH	EXT-TH	EXT-R	INT-L	INT-TH	L	TH	R	L	TH	R
Volume, V (veh/h)	1338	80	188	1780	1187	210	350	1055	218		403	630		120
Peak-hour factor, PHF	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97		0.97	0.97		0.97
Adjusted flow rate, v_{ij} =V/PHF (veh/h)	1379	82	194	1835	1224	216	361	1088	225		415	649		124
Lane group														
Adjusted flow rate in lane group, v (veh/h)	1462		194	1835	1440		361	1088	225		415	649		124
Proportion of LT or RT (P_{LT} or P_{RT})	0.94	0.06	1.0	-	0.85	0.15	1.0	-	1.0	-	1.0	1.0	-	1.0
% heavy vehicles, % HV	5	0	0	5	5	0	0	5	0		0	0		0
Arrival type, AT	3	3	3	4	3	3	3	4	3		3	3		3
Lane width, (ft)	12	12	12	12	12	12	12	12	12		12	12		12
Grade, (%)	0	0	0	0	0	0	0	0	-2		-2	-2		-2
Approach pedestrian volume, $v_{ped,i}$ (p/h)	0				0				0			0		
Approach bicycle volume, v_{bic} (bicycles/h)	0				0				0			0		
Parking (Y or N)	N				N				N			N		
Parking maneuvers, N_m (maneuvers/h)	0				0				0			0		
Bus stopping, NB (buses/h)	0				0				0			0		

	NB – U turn	SB – U turn
Adjusted flow rate for U turns, v =V/PHF (veh/h)	0	0

OD Adjustment

OD Movement	Turning Movement	O-D Adjustment Flow Rate v_{O-D} (veh/h)
A	(NB – L) – (NB –U turn)	225
B	NB – R	415
C	SB – R	124
D	(SB – L) – (SB – U turn)	649
E	(EB – INT – L) – (SB – U turn)	194
F	EB EXT – R	82
G	WB EXT – R	216
H	(WB INT – L) – (NB – U turn)	361
I	(EB INT – TH) – (SB- L) + (SB – U turn)	1186
J	(WB INT –TH) – (NB – L) + (NB – U turn)	863
K	NB – TH	0
L	SB – TH	0
M	NB – U turn	0
N	SB – U turn	0

Example 1 (Cont'd)

DIAMOND INTERCHANGE LANE UTILIZATION AND SATURATION FLOW RATE WORKSHEET (5)

***Lane Utilization Adjustment** (use Exhibit 26-13)*

	EB EXT - TH	WB EXT – TH
	■ For 2-Lane Arterial ❑ For 3-lane Arterial ❑ For 4-lane Arterial	■ For 2-Lane Arterial ❑ For 3-lane Arterial ❑ For 4-lane Arterial
v_E (veh/h)	194	-
v_F (veh/h)	82	-
v_I (veh/h)	1186	-
v_G (veh/h)	-	216
v_H (veh/h)	-	361
v_J (veh/h)	-	863
Distance between two intersections, D (ft)	400	400
% V_{L1} (left most)	0.515	0.521
% V_{L2} (2nd from left)	0.485	0.479
% V_{L3} (3rd from left)	-	-
% V_{L4} (4th from left)	-	-
Maximum single lane %	0.515	0.521
Lane Utilization adjustment, f_{LU}	0.971	0.960

* For 1-lane Arterial: f_{LU} =1

Note: v_E is the flow for OD movement E, etc.

Saturation Flow Rate

	EB				WB				NB			SB		
	EXT-TH	EXT-R	INT-L	INT-TH	EXT-TH	EXT-R	INT-L	INT-TH	L	TH	R	L	TH	R
Lane group														
Base saturation flow, s_o (pc/h/ln)	1900		1900	1900	1900		1900	1900	1900		1900	1900		1900
Number of lanes, N	2		1	2	2		1	2	1		1	1		1
Lane width adjustment, f_w	1		1	1	1		1	1	1		1	1		1
Heavy-vehicle adjustment, f_{hv}	0.952		1	0.952	0.952		1	0.952	1		1	1		1
Grade adjustment, f_g	1		1	1	1		1	1	1.01		1.01	1.01		1.01
Parking adjustment, f_p	1		1	1	1		1	1	1		1	1		1
Bus Blockage adjustment, f_{bb}	1		1	1	1		1	1	1		1	1		1
Area type adjustment, f_a	1		1	1	1		1	1	1		1	1		1
Lane Utilization adjustment, f_{LU}	0.971		1	1	0.960		1	1	1		1	1		1
Left-turn adjustment, f_{LT}	1		0.950	1	1		0.950	1	0.95		1	0.95		1
Right-turn adjustment, f_{RT}	0.992		1	1	0.977		1	1	1		0.85	1		0.85
Left-turn ped/bike adjustment, f_{Lpb}	1		1	1	1		1	1	1		1	1		1
Right-turn ped/bike adjustment, f_{Rpb}	1		1	1	1		1	1	1		1	1		1
Turn radius adjustment, f_R	0.899		0.930	1	0.899		0.930	1	0.899		0.899	0.899		0.899
Traffic pressure adjustment, f_t	1.009		0.961	1.030	1.008		0.984	0.989	0.965		0.975	1.028		0.946
Adjusted saturation flow, s (veh/h)	3163		1613	3727	3076		1653	3579	1582		1431	1685		1388

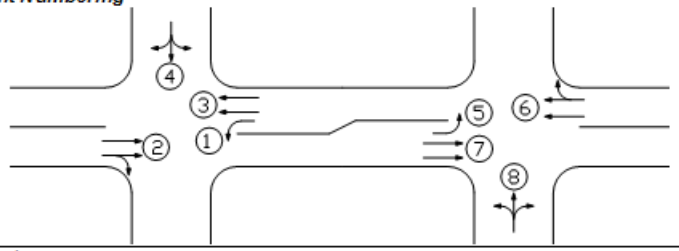
Note: For permitted left turns, the left-turn adjustment factor f_{LT} is calculated according to the respective supplemental worksheets (Chapter 16).

Example 1 (Cont'd)

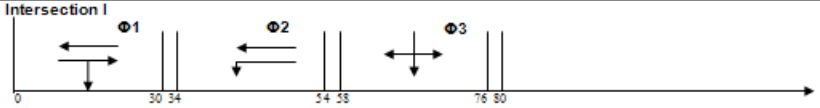
DIAMOND INTERCHANGE OVERLAPS CALCULATION WORKSHEET (6)

Plot of Signal Phasing Plan

Movement Numbering

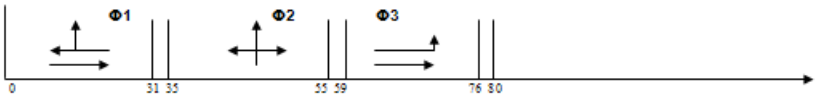


Intersection I



G= 30s Y= 4s | G= 20s Y= 4s | G= 18s Y= 4s

Intersection II



G= 31s Y= 4s | G= 20s Y= 4s | G= 17s Y= 4s

Calculation Of Overlaps

Overlap between the upstream through and downstream through green interval	OL_{UD}	OL_{UD} at EB	G2: 0 to 30s G7: 0 to 31s & 59 to 76s	Overlap between G2 and G7 = 30 - 0 = 30s
		OL_{UD} at WB	G6: 0 to 31s G3:0 to 54s	Overlap between G6 and G3 = 31 – 0 = 31 s
Overlap between the upstream ramp and downstream through green interval	OL_{RD}	OL_{RD} at EB/SB	G4: 58 to 76s G7:0 to 31s & 59 to 76s	Overlap between G4 and G7 = 76 – 59 = 17 s
		OL_{RD} at WB/NB	G8: 35 to 55s G3:0 to 54s	Overlap between G8 and G3 = 54 – 35 = 19 s
Green time overlap with demand starvation potential	OL_{DS}	OL_{DS} on EB	G1: 34 to 54s G7: 0 to 31s & 59 to 76s	Overlap between G1 and G7 = 0 s
		OL_{DS} on WB	G5: 59 to 76s G3: 0 to 54s	Overlap between G5 and G3 = 0 s

Note:
Gi: green phase for movement i (sec)
If OL_{DS} is not equal to zero, then use the worksheet (7A -Optional).

Example 1 (Cont'd)

DIAMOND INTERCHANGE EFFECTIVE GREEN ADJUSTMENT FOR EXTERNAL APPROACHES WORKSHEET (7)

Internal Queue Length at the Beginning of Each Upstream Phase

	EB - Internal Queue Length		WB - Internal Queue Length	
	EB EXT – TH Phase	SB – L Phase	WB EXT – TH Phase	NB – L Phase
Arterial through flow divided by the respective number of lanes, v_{Across}/N_{Across}	-	690	-	612
Ramp left turning flow divided by the respective number of lanes, v_{Across}/N_{Across}	649	-	225	-
Green for the downstream arterial through movement, G_B	48	48	50	50
Green for the upstream arterial (EB EXT –TH) or (WB EXT –TH) movement, G_A	-	30	-	31
Green for the upstream left ramp (SB- L) or (NB-L) movement, G_R	18	-	20	-
Overlap between the upstream through and downstream through green interval, OL_{AB}	30	-	31	-
Overlap between the upstream ramp and downstream through green interval, OL_{RB}	-	17	-	19
Cycle Length, C	80	80	80	80
Internal queue length at the beginning of upstream arterial phase A, Q_A $Q_A = \left[0.017\frac{v_{Across-L}}{N_{Across-L}} - 7.93\times\frac{G_R}{C} - 0.082DL_{AB} + 0.194G_A\right]\times L_A$	182.88	-	5.06	-
Internal queue length at the beginning of upstream ramp phase R, Q_R $Q_R = \left[0.017\frac{v_{Across-L}}{N_{Across-L}} - 7.93\times\frac{G_B}{C} - 0.082DL_{RB} + 0.194G_A\right]\times L_R$	-	284.82	-	9.90

Lost Time due to Downstream Internal Queue

	EB EXT – TH Phase	SB – L Phase	WB EXT – TH Phase	NB – L Phase
Green for the upstream arterial (EB EXT –TH) or (WB EXT –TH) movement, G_A	30	-	31	-
Green for the upstream left ramp (SB- L) or (NB-L) movement, G_R	-	18	-	20
Distance of the two intersections, D	400	400	400	400
Distance to the downstream queue at the beginning of upstream arterial green A, $DQ_A = D - Q_A$	217	-	395	-
Distance to the downstream queue at the beginning of upstream ramp green R, $DQ_R = D - Q_R$	-	115	-	152
Overlap between the upstream through and downstream through green interval, OL_{AB}	30	-	31	-
Overlap between the upstream ramp and downstream through green interval, OL_{RB}	-	17	-	19
Cycle length, C	80	80	80	80
Lost time for the external arterial approach, L_{D-A} $L_{D-A} = G_A - 0.106^* DQ_A - 5.39^*\frac{OL_{AB}}{C}$	4.96	-	-12.95~0	-
Lost time for the external ramp approach due to the presence of a downstream queue, L_{D-R} $L_{D-R} = G_R - 0.106^* DQ_R - 5.39^*\frac{OL_{RB}}{C}$	-	4.65	-	2.56
Notes: If L_{D-A}, L_{D-R} < 0 then use zero. If DQ_A, DQ_R < 0 then use zero.				

Effective Green

Lost time, t_A' (s), $t_A' = l_1 + L_{D-A} + Y - e$	8.96	-	4	-
Lost time, t_R' (s), $t_R' = l_1 + L_{D-R} + Y - e$	-	8.65	-	6.56
Effective green time adjusted due to downstream queue, g'(s), $g' = G+Y-t_A'$	25.04	13.35	31	17.44

Example 1 (Cont'd)

DIAMOND INTERCHANGE CAPACITY AND LOS DETERMINATION WORKSHEET (8)

Queue Storage Ratio (R_Q) for Lane Groups

	EB				WB				NB			SB		
	EXT-TH	EXT-R	INT-L	INT-TH	EXT-TH	EXT-R	INT-L	INT-TH	L	TH	R	L	TH	R
Lane Group														
Initial queue per lane at the start of analysis, $Q_{b,i}$	0		0	0	0		0	0	0		0	0		0
Number of lanes, N	2		1	2	2		1	2	1		1	1		1
Adjusted flow rate, v (veh/h)	1462		194	1835	1440		361	1088	225		415	649		124
Flow rate per lane, v_i (veh/h/ln)	731		194	918	720		361	544	225		415	649		124
Saturation flow rate, s (veh/h)	3163		1613	3727	3076		1653	3579	1582		1431	1685		1388
Saturation flow rate per lane, s_i (veh/h/ln)	1581		1613	1864	1538		1653	1789	1582		1431	1685		1388
Flow ratio, v_i / s_i	0.46		0.12	0.49	0.47		0.22	0.30	0.14		0.29	0.39		0.09
Effective green time, g (s) or g' (s)	25.04		17	48	31		20	50	17.44		20	13.35		18
Green ratio, g/C or g'/C	0.31		0.21	0.60	0.39		0.25	0.63	0.22		0.25	0.17		0.23
Capacity per lane, c_i (veh/h/ln) $c_i = s_i$ (g/C) or $c_i = s_i$ (g'/C)	495		343	1118	596		413	1118	345		358	281		312
v/c ratio, $X_i = v_i / c_i$	1.48		0.57	0.82	1.21		0.87	0.49	0.65		1.16	2.31		0.40
Upstream filtering factor, I	1		0.09	0.09	1		0.09	0.09	1		1	1		1
Platoon ratio, R_p	1		1	1.333	1		1	1.333	1		1	1		1
Effects of progression adjustment factor, PF	1		1	0.739	1		1	0.521	1		1	1		1
First-term queued vehicles, Q_1	16.24		3.85	11.87	16.00		7.69	3.39	4.55		9.23	14.43		2.34
Second-term adjustment factor, k_2	0.64		0.04	0.10	0.73		0.05	0.10	0.50		0.51	0.43		0.47
Second-term adjustment vehicles, Q_2	31.38		0.06	0.46	18.99		0.33	0.10	0.88		9.91	46.78		0.30
Average number of queued vehicles, $Q = Q_1 + Q_2$	47.62		3.91	12.33	34.99		8.03	3.49	5.43		19.14	61.22		2.64
Average queue spacing, L_q (ft)	25		25	25	25		25	25	25		25	25		25
Available queue storage, L_a (ft)	600		200	400	600		200	400	400		400	400		400
Average queue storage ratio, $R_Q = (L_q Q) / L_a$	1.98		0.49	0.77	1.46		1.00	0.22	0.34		1.20	3.83		0.17
Check storage ratio R_Q: If $R_Q > 1$, LOS of entire OD is F	F				F		F				F	F		

Note: For protected-plus-permitted left turns, the average queue storage ratio is calculated as the volume-weighted average of each phase:

$$R_Q = \frac{R_{Q\text{-}prot} \times v_{i\text{-}prot} + R_{Q\text{-}perm} \times v_{i\text{-}perm}}{v_i}$$

Example 1 (Cont'd)

DIAMOND INTERCHANGE CAPACITY AND LOS DETERMINATION WORKSHEET (9)

V/C for Lane Group

	EB				WB				NB			SB		
	EXT-TH	EXT-R	INT.-L	INT.-TH	EXT-TH	EXT-R	INT.-L	INT.-TH	L	TH	R	L	TH	R
Lane Group														
Adjusted flow rate, v (veh/h)	1462		194	1835	1440		361	1088	225		415	649		124
Saturation flow rate, s (veh/h)	3163		1613	3727	3076		1653	3579	1582		1431	1685		1388
Adjusted effective green time g'(s)	25.04		-	-	31		-	-	17.44		-	13.35		-
Effective green time g(s) or adjusted g''(s)	-	-	17	48	-	-	20	50	-		20	-		18
Green ratio, g'/C or g/C or g''/C	0.31		0.21	0.60	0.39		0.25	0.63	0.22		0.25	0.17		0.23
Capacity, c(veh/h), c= s (g'/C) or c= s (g/C) or c= s (g''/C)	990		343	2236	1192		413	2237	345		358	281		312
v/c ratio, X = v/c	1.48		0.57	0.82	1.21		0.87	0.49	0.65		1.16	2.31		0.40
Check V/C: If V/C > 1, LOS of entire OD is F	F				F						F	F		

Control Delay for Lane Group

Adjusted effective green time g'(s)	25.04		-	-	31		-	-	17.44			13.35		
Effective green time g(s)	-	-	17	48	-	-	20	50	-		20	-		18
Green ratio, g'/C or g/C	0.31		0.21	0.60	0.39		0.25	0.63	0.22		0.25	0.17		0.23
Capacity, c(veh/h), c= s (g/C) or c= s (g'/C)	990		343	2236	1192		413	2237	345		358	281		312
v/c ratio, X = v/c	1.48		0.57	0.82	1.21		0.87	0.49	0.65		1.16	2.31		0.40
Uniform Delay, d1 (sec/veh)	27.48		28.19	12.61	24.50		28.78	8.08	28.51		30.00	33.32		26.38
Incremental delay calibration, k	0.5		0.5	0.5	0.5		0.5	0.5	0.5		0.5	0.5		0.5
Incremental delay, d2 (sec/veh)	220.16		0.61	0.33	101.83		2.58	0.07	9.23		99.24	600.38		3.73
Initial queue delay, d3 (sec/veh)	0		0	0	0		0	0	0		0	0		0
Proportion of vehicles arriving on green, P	0.31		0.21	0.80	0.39		0.25	0.83	0.22		0.25	0.17		0.23
Progression adjustment factor, PF	1		1	0.576	1		1	0.512	1		1	1		1
Control delay, d (sec/veh) d=d1(PF)+d2+ d3	247.65		28.81	7.59	126.33		31.37	4.20	37.74		129.24	633.71		30.11

Example 1 (Cont'd)

DIAMOND INTERCHANGE LOS DETERMINATION WORKSHEET (10)			
Control Delay for OD Movements and LOS Determination			
OD Movement	Corresponding turning movements for delay calculation	Delay Calculation	LOS
A	(NB – L) and (WB INT – TH)	9.95	A
B	(NB – R)	129.24	F
C	(SB – R)	30.11	B
D	(SB – L) and (EB INT – TH)	171.26	F
E	(EB EXT – TH) and (EB INT – L)	220.69	F
F	(EB EXT – R)	247.65	F
G	(WB EXT – R)	126.33	F
H	(WB EXT – TH) and (WB INT – L)	104.71	F
I	(EB EXT – TH) and (EB INT – TH)	110.60	F
J	(WB EXT – TH) and (WB INT – TH)	68.86	F
K	(NB – TH)	-	-
L	(SB – TH)	-	-
M	(NB – L) and (WB INT – L)	-	-
N	(SB – L) and (EB INT – L)	-	-

Chapter 26 – Methodology: Planning and Preliminary Design Analysis

Methodology based upon:

Bonneson, J., Zimmerman, K., Jacobson, M.,
Review and Evaluation of Interchange Ramp Design Considerations for Facilities Without Frontage Roads
Texas Transportation Institute, Texas A&M University System, College Station TX, September 2003.
Sponsored by the Texas Department of Transportation in cooperation with the Federal Highway Administration.

The methodology allows:

1. For a given set of O-D movements, eight basic types of signalized interchange configurations may may be compared on the basis of estimated interchange delay.

2. For a given type of interchange, the impact of intersection spacing on delay can be examined (within the range of applicability for each interchange model).

3. For a given type of interchange, the impact of the number and assignment of lanes on ramps and the arterial roadway can be assessed, also on the basis of interchange delay.

Types of Interchanges Included in the Planning and Preliminary Design Methodology:

Single-Point Urban Interchange (SPUI)
Tight Urban Diamond Interchange (TUDI)
Compressed Urban Diamond Interchange (CUDI)
Conventional Diamond Interchange (CDI)
Partial Cloverleaf A - 4 Quadrants (Parclo A 4Q)
Partial Cloverleaf A – 2 Quadrants (Parclo A 2Q)
Partial Cloverleaf B – 4 Quadrants (Parclo B 4Q)
Partial Cloverleaf B – 2 Quadrants (Parclo B 2Q)

Thus, the methodology does not cover the same interchange types covered by the operational analysis methodology.

Some Caveats:

1. **TTI methodology also covers unsignalized interchanges – not included in Chapter 26.**

2. **Definition of interchange delay is similar to operational methodology, but models are different; compatibility is not assured.**

3. **Methodology assumes good signalization:**
   - **SPUI, TUDI, and CUDI are assumed to operate with one controller;**
   - **All other types assume two controllers.**
   - **Signal phasing and timing are assumed to be optimal.**

Default Values for Saturation Flow Rates

Type of Interchange	Default Saturation Flow Rate (veh/hg/ln)		
	Left Turns	Through	Right Turns
SPUI	1800	1800	1800
TUDI	1700	1800	1800
CUDI	1700	1800	1800
CDI	1700	1800	1800
Parclo A 4Q & 2Q	1700	1800	1800
Parclo B 4Q & 2Q	1700	1800	1800

Step 1: Mapping of Interchange O-D's to Phase-Movements

EXHIBIT 26-24 MAPPING OF INTERCHANGE ORIGINS AND DESTINATIONS INTO PHASE MOVEMENTS FOR PLANNING AND PRELIMINARY DESIGN ANALYSIS

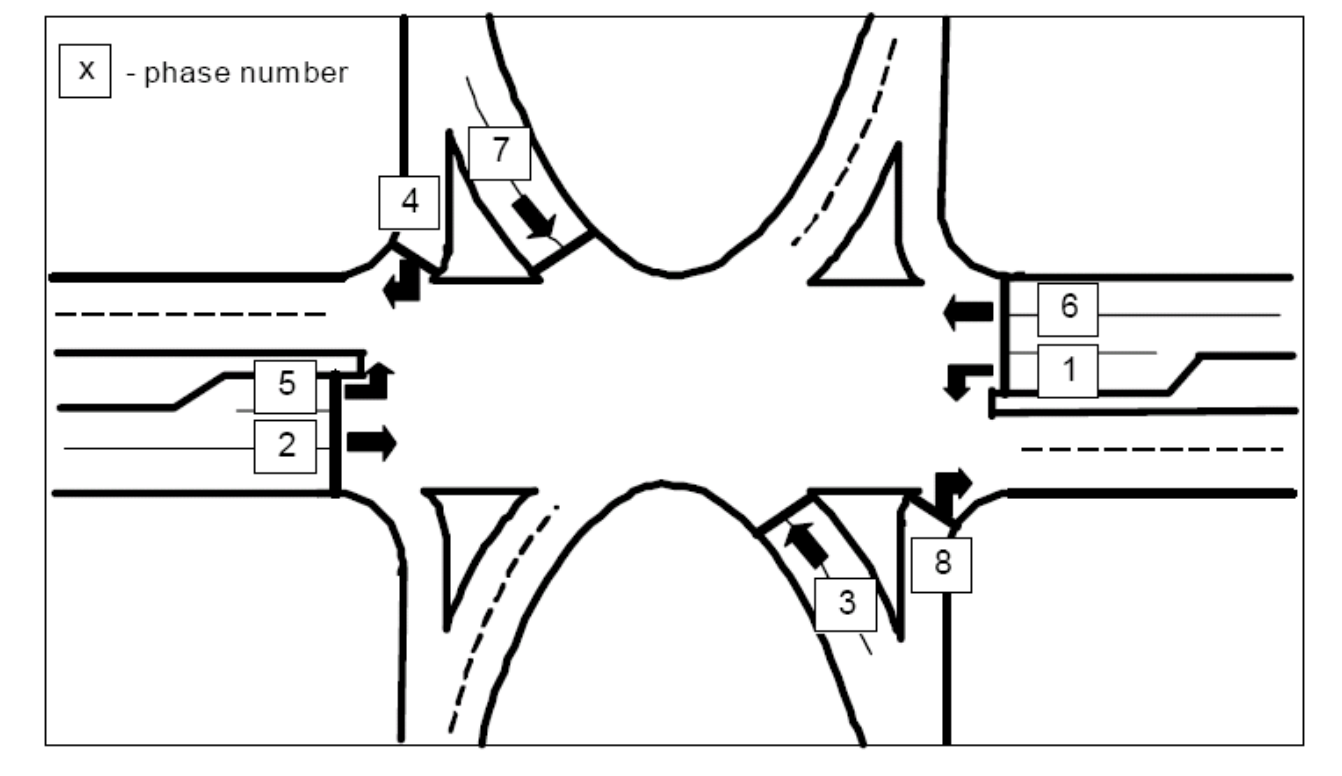
Type of Interchange	NEMA Phase Movement Number							
	1	2	3	4	5	6	7	8
SPUI	WBL	EBT+*EBR*	NBL+NBU	*SBR*	EBL	WBT+*WBR*	SBL+SBU	*NBR*
TUDI/CUDI	WBL+NBU	EBL+EBT +*EBR*	***	SBL+*SBR* +SBU	EBL+SBU	WBL+WBT +*WBR*	***	NBL+*NBR* +NBU
CDI – Int I	WBL+NBU	EBL+EBT +*EBR*	***	SBL+*SBR* +SBU	***	WBT+NBL	***	***
CDI – Int II	***	EBT+SBL	***	***	EBL+SBU	WBL+WBT +*WBR*	***	NBL+NBU +*NBR*
Parclo A 4Q Int I	***	EBL+EBT	***	SBL+SBU +*SBR*	***	WBT+NBL +*NBU*+*WBL*	***	***
Parclo A 4Q Int II	***	EBT+SBL +*EBU*+*EBL*	***	***	***	WBT+WBL	***	NBL+NBU +*NBR*
Parclo A 2Q Int I	***	EBL+EBT	***	SBL+SBU +*SBR*	EBR	WBT+NBL +*WBL*+*NBU*	***	***
Parclo A 2Q Int II	WBR	EBT+SBL +*EBL*+*SBU*	***	***	***	WBL+WBT	***	NBL+NBU +*NBR*
Parclo B 4Q Int I	WBL+NBU	EBT+EBL +*EBR*	***	***	***	WBT+NBL	***	***
Parclo B 4Q Int II	***	EBT+SBL	***	***	EBL+SBU	WBL+WBT *WBR*	***	***
a Int I	WBL+NBU	EBL+EBT +*EBR*	***	***	***	WBT+NBL	***	SBR
Parclo B 2 Q Int II	***	EBT+SBL	***	NBR	EBL+SBU	WBL+WBT +*WBR*	***	***

*** Phase movement does not exist for this configuration.

Italics This movement is *not* included if it operates from a separate lane with YIELD or STOP control.

Step 2 – Critical Sum of Flow Ratios for Each Interchange Type

Single-Point Urban Interchange (SPUI)



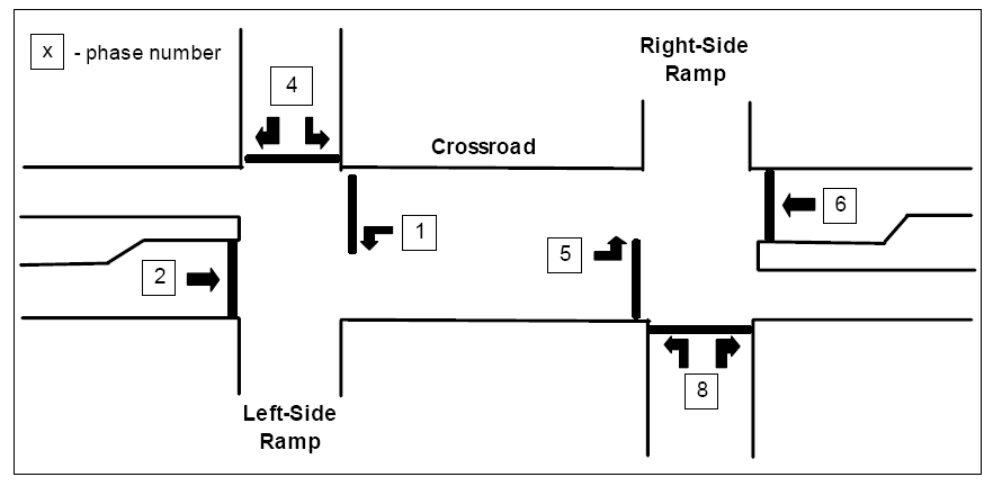
RING 1	Cross LT 1	Cross TH 2	Exit Ramp LT 3	Exit Ramp RT 4
RING 2	Cross LT 5	Cross TH 6	Exit Ramp LT 7	Exit Ramp RT 8

$$Y_c = A + B$$

$$A = \max\left[\left(\frac{v_1}{s_1 n_1} + \frac{v_2}{s_2 n_2}\right); \left(\frac{v_5}{s_5 n_5} + \frac{v_6}{s_6 n_6}\right)\right]$$

$$B = \max\left[\left(\frac{v_3}{s_3 n_3} + \frac{v_4}{s_4 n_4}\right); \left(\frac{v_7}{s_7 n_7} + \frac{v_8}{s_8 n_8}\right)\right]$$

Tight Urban Diamond Interchange (TUDI)



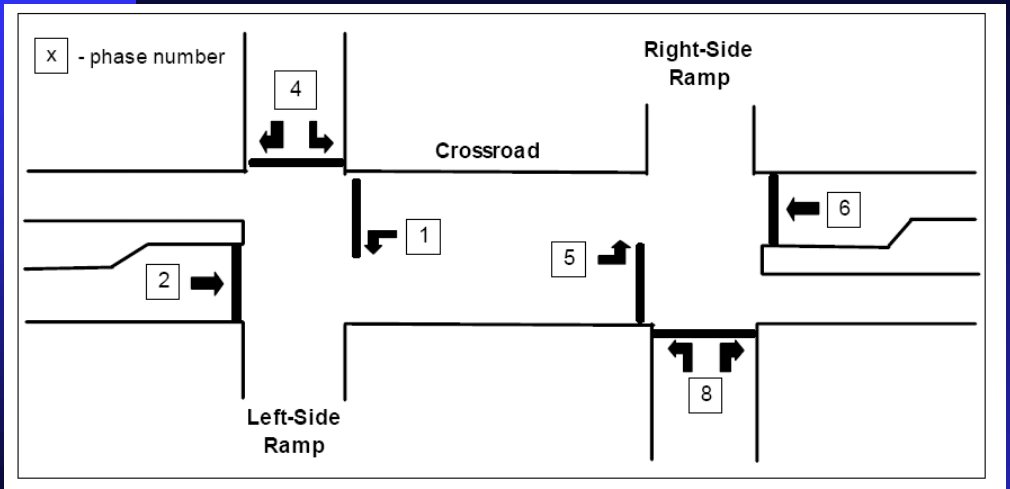
$$Y_c = A + B$$

$$A = \max\left[\left(\frac{v_2}{s_2 n_2} + \frac{v_4}{s_4 n_4} - y_3\right); \left(\frac{v_5}{s_5 n_5} + y_7\right)\right]$$

$$B = \max\left[\left(\frac{v_1}{s_1 n_1} + y_3\right); \left(\frac{v_6}{s_6 n_6} + \frac{v_8}{s_8 n_8} - y_7\right)\right]$$

$$y_3 = \min\left[\frac{v_4}{s_4 n_4}; y_t\right] \qquad y_7 = \min\left[\frac{v_8}{s_8 n_8}; y_t\right]$$

Compressed Urban Diamond Interchange (CUDI)



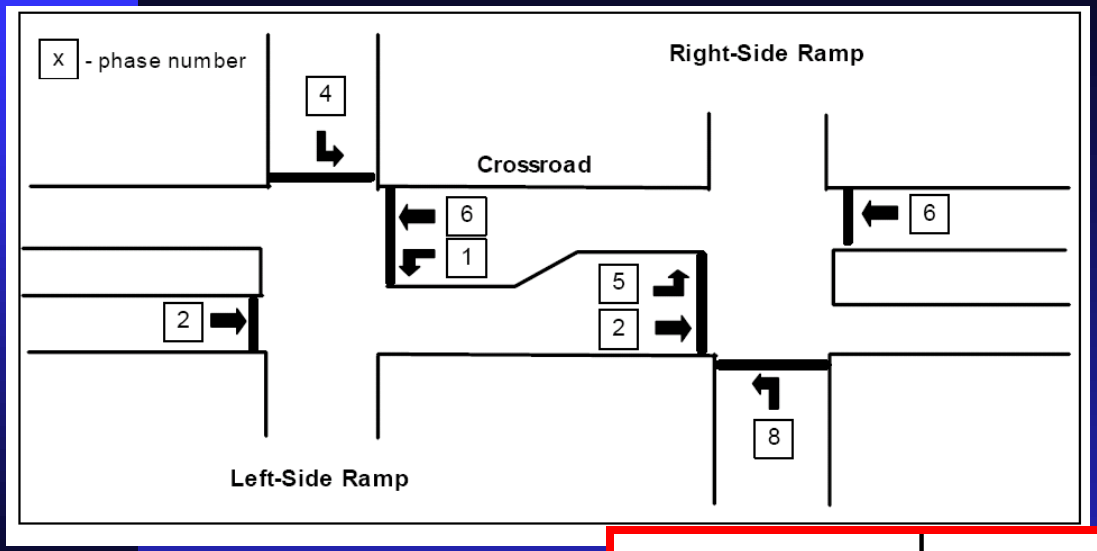
$$Y_c = A + B$$

$$A = \max\left[\left(\frac{v_1}{s_1 n_1} + y_2\right);\ \left(\frac{v_5}{s_5 n_5} + y_6\right)\right]$$

$$B = \max\left[\left(\frac{v_4}{s_4 n_4}\right);\ \left(\frac{v_8}{s_8 n_8}\right)\right]$$

$$y_2 = \max\left[\left(\frac{v_2}{s_2 n_2}\right);\left(\frac{v_5}{s_2}\right)\right] \qquad y_6 = \max\left[\left(\frac{v_8}{s_8 n_8}\right);\left(\frac{v_1}{s_6}\right)\right]$$

Conventional Diamond Interchange (CDI)



$$Y_{c,max} = \max\left[Y_{c,left}; Y_{c,right}\right]$$

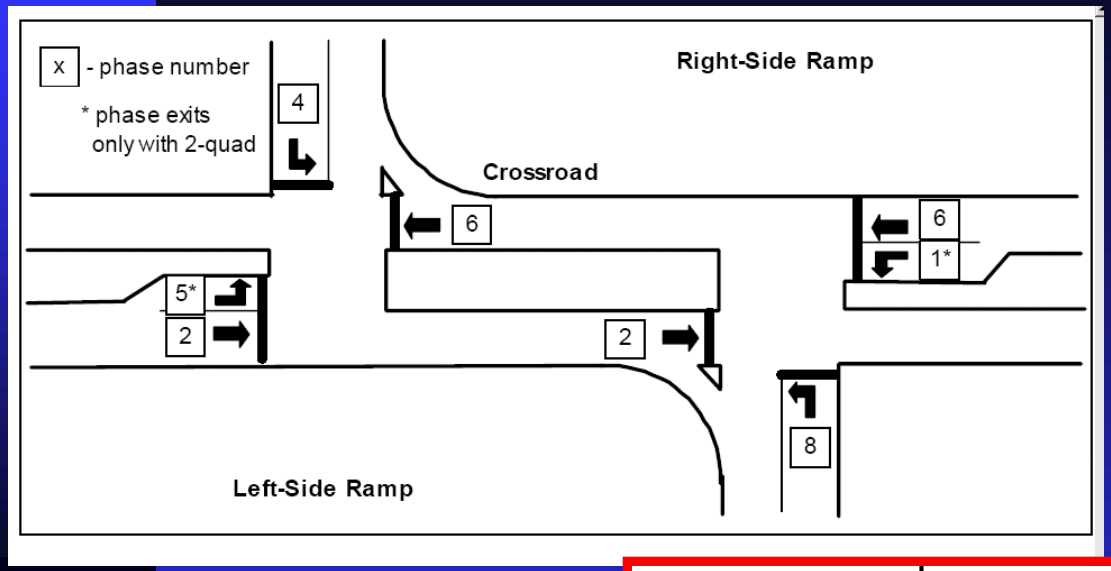
$$Y_{c,left} = A_{left} + B_{left}$$

$$Y_{c,right} = A_{right} + B_{right}$$

$$A_{left,right} = \max\left[\left(\frac{v_1}{s_1 n_1} + \frac{v_2}{s_2 n_2}\right); \left(\frac{v_5}{s_5 n_5} + \frac{v_6}{s_6 n_6}\right)\right]$$

$$B_{left,right} = \max\left[\left(\frac{v_4}{s_4 n_4}\right); \left(\frac{v_8}{s_8 n_8}\right)\right]$$

Partial Cloverleafs A, 4Q and 2Q (Parclo A)



$$Y_{c,max} = \max\left[Y_{c,left}; Y_{c,right}\right]$$

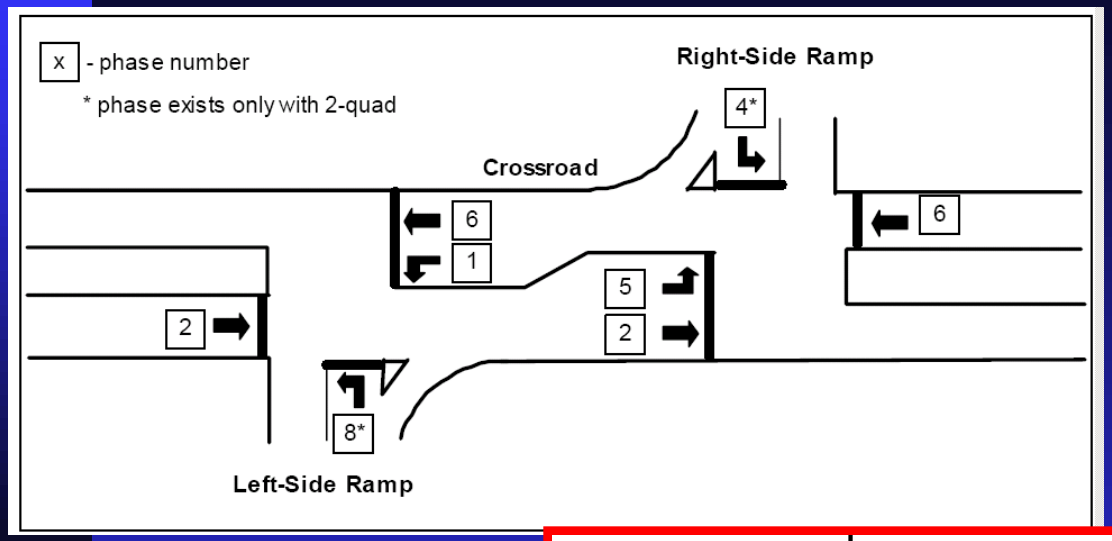
$$Y_{c,left} = A_{left} + B_{left}$$

$$Y_{c,right} = A_{right} + B_{right}$$

$$A_{left,right} = \max\left[\left(\frac{v_1}{s_1 n_1} + \frac{v_2}{s_2 n_2}\right); \left(\frac{v_5}{s_5 n_5} + \frac{v_6}{s_6 n_6}\right)\right]$$

$$B_{left,right} = \max\left[\left(\frac{v_4}{s_4 n_4}\right); \left(\frac{v_8}{s_8 n_8}\right)\right]$$

Partial Cloverleaf B, 4Q and 1Q (Parclo B)



$$Y_{c,max} = \max\left[Y_{c,left}; Y_{c,right}\right]$$

$$Y_{c,left} = A_{left} + B_{left}$$

$$Y_{c,right} = A_{right} + B_{right}$$

$$A_{left,right} = \max\left[\left(\frac{v_1}{s_1 n_1} + \frac{v_2}{s_2 n_2}\right); \left(\frac{v_5}{s_5 n_5} + \frac{v_6}{s_6 n_6}\right)\right]$$

$$B_{left,right} = \max\left[\left(\frac{v_4}{s_4 n_4}\right); \left(\frac{v_8}{s_8 n_8}\right)\right]$$

Step 3 – Estimating Interchange Delay

Int. Type	Valid Range of D_r (ft)	Interchange Delay (d_I) *Right Turns Signalized CASE A*	Interchange Delay (d_I) *Right Turns Free or YIELD-Controlled CASE B*
SPUI	150 - 400	$15.1 + (0.01 D_r + 16.0)\left(\frac{Y_c}{1 - Y_c}\right)$	$15.1 + (0.008 D_r + 5.9)\left(\frac{Y_c}{1 - Y_c}\right)$
TUDI	200 - 400	$13.4 + 14.2\left(\frac{Y_c}{1 - Y_c}\right)$	$13.4 + 12.8\left(\frac{Y_c}{1 - Y_c}\right)$
CUDI	600 - 800	$19.2 + [9.4 - 0.011(D_r - 700)]\left[\frac{Y_c}{1 - Y_c}\right]$	$19.2 + [8.6 - 0.009(D_r - 700)]\left[\frac{Y_c}{1 - Y_c}\right]$
CDI	900-1300	$17.1 + [5.0 - 0.011(D_r - 1100)]\left[\frac{Y_c}{1 - Y_c}\right]$	$17.1 + [4.6 - 0.009(D_r - 1100)]\left[\frac{Y_c}{1 - Y_c}\right]$
Parclo A 4Q	700-1000	$11.7 + [7.8 - 0.011(D_r - 800)]\left[\frac{Y_c}{1 - Y_c}\right]$	$11.7 + [6.6 - 0.009(D_r - 800)]\left[\frac{Y_c}{1 - Y_c}\right]$
Parclo A 2Q	700-1000	$19.1 + [8.3 - 0.011(D_r - 800)]\left[\frac{Y}{1 - Y_c}\right]$	$19.1 + [8.3 - 0.009(D_r - 800)]\left[\frac{Y_c}{1 - Y_c}\right]$
Parclo B 4Q	1000-1400	$9.3 + [3.5 - 0.011(D_r - 1200)]\left[\frac{Y_c}{1 - Y_c}\right]$	$9.3 + [3.4 - 0.009(D_r - 1200)]\left[\frac{Y_c}{1 - Y_c}\right]$
Parclo B 2Q	1000-1400	$26.2 + [3.9 - 0.011(D_r - 1200)]\left[\frac{Y_c}{1 - Y_c}\right]$	$26.2 + [3.2 - 0.009(D_r - 1200)]\left[\frac{Y_c}{1 - Y_c}\right]$

Level of Service Cannot Be Determined Using the Planning Methodology

Sample Problems Under Development

Interpretation of Results

Methodology yields comparison values of Interchange delay.

Other decision factors must be considered: cost, land use, environmental factors, etc.

Land consumption and distance between intersections are significant issues that are greatly influenced by interchange type.

Next Steps:

- Draft Final Report and Chapter to be reviewed by the panel and by the ICRT/HCQS.
- Subcommittee and committee vote.
- Software development (McTrans)

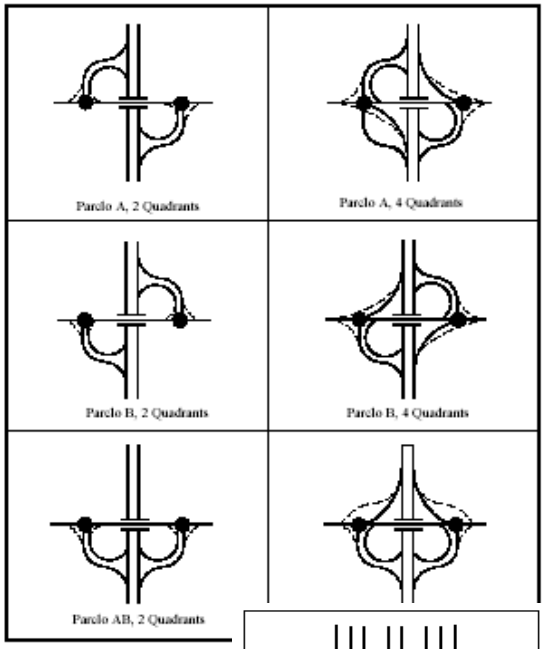
Interchange Ramp Terminals

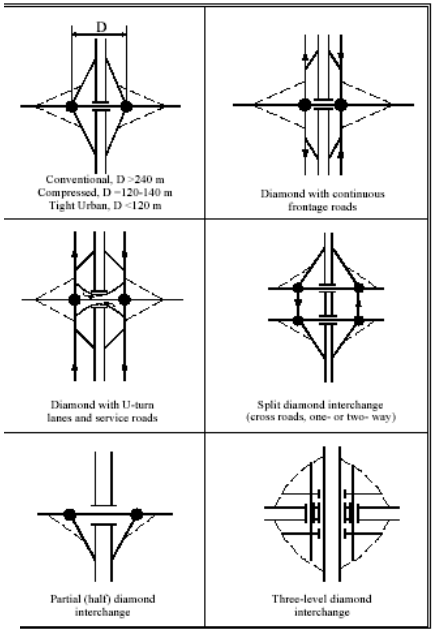
- Highway Capacity Software
  - HCM Chapter 26
- Using *HCS+*
  - Modifying Signals



Interchange Ramp Terminals

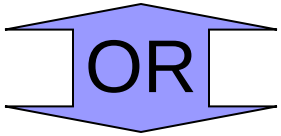
- Interchange Type
  - Initially Select from List
    - Diamond
    - Six Parclos
    - SPUI
  - Ultimately
    - Preliminary Planning Method
    - Present Prioritized List
    - User Selects





Interchange Ramp Terminals

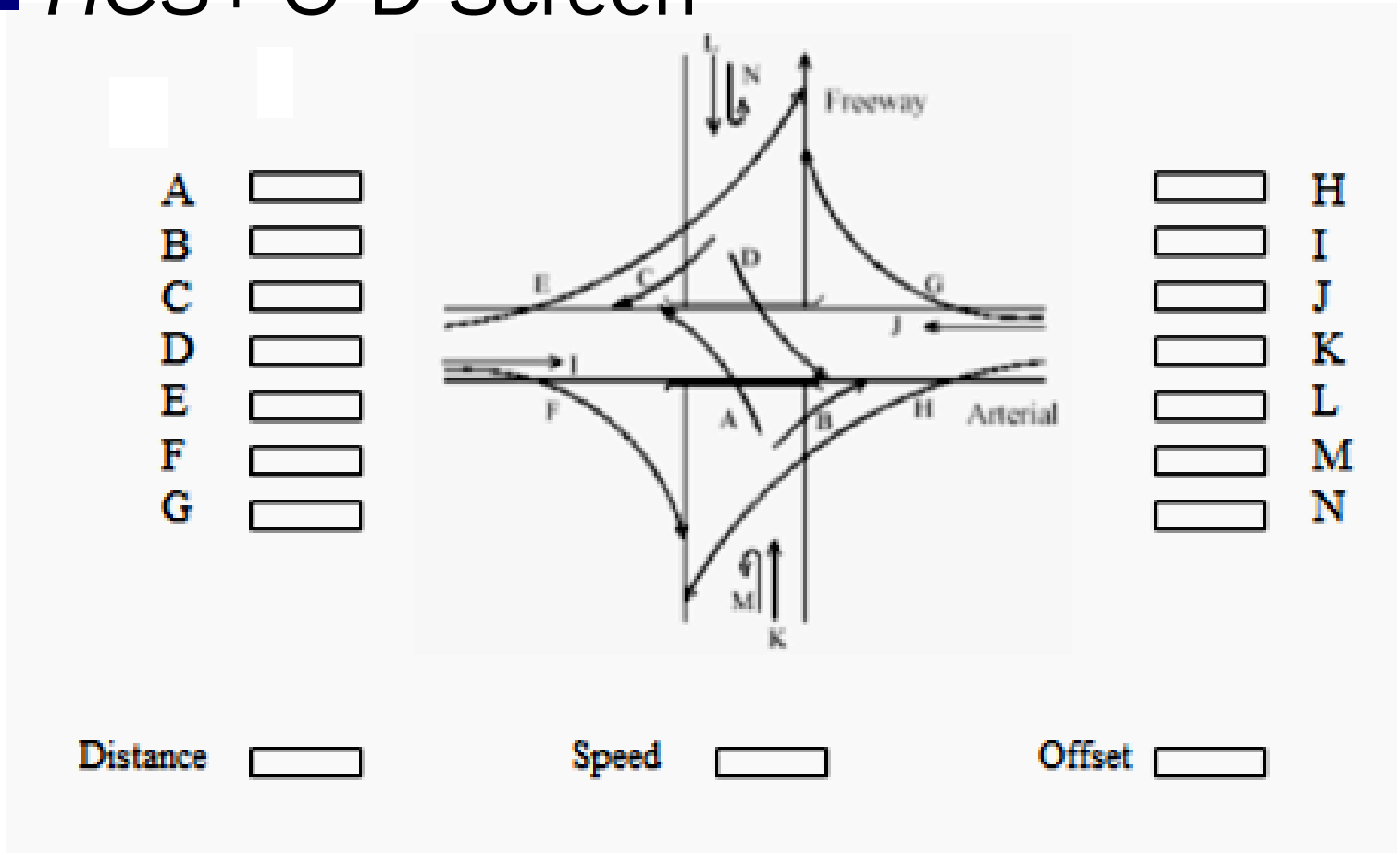
- *HCS*+ Data Entry
  - Special Two-Intersection Case
  - SPUI Treated as One Signal
- O-D Matrix
  - Defined in Chapter 26



- Turning Movement
  - Internal Percentages

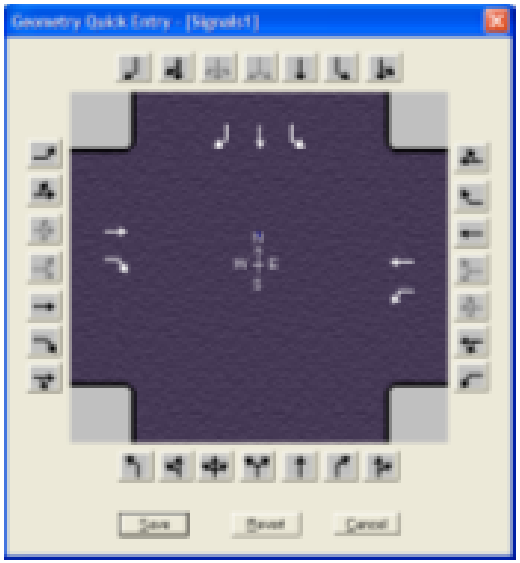
Interchange Ramp Terminals

- *HCS*+ O-D Screen



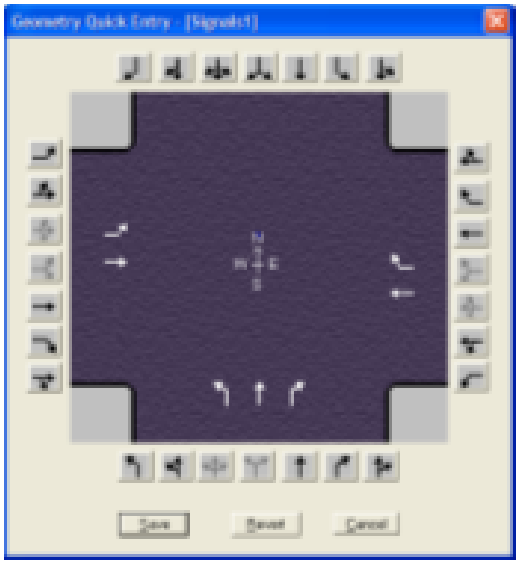
Interchange Ramp Terminals

- *HCS*+ Turns Screens



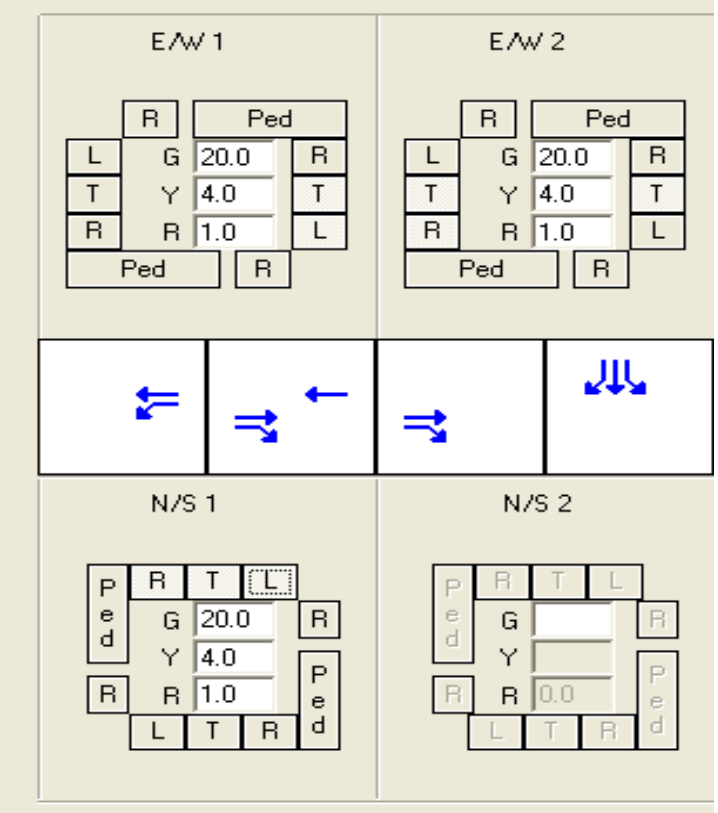
Internal Turn Percentages

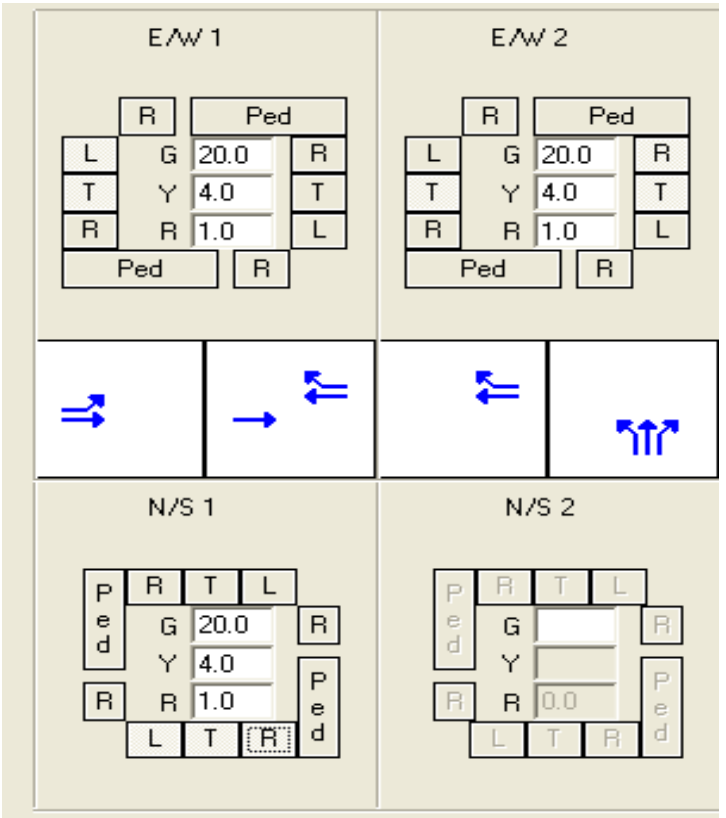
EBT		Thru (I)
		Left (E)
SBL		Thru (D)
		Left (N)
WBT		Thru (J)
		Left (H)
NBL		Thru (A)
		Left (M)



Interchange Ramp Terminals

- *HCS*+ Timing Screens

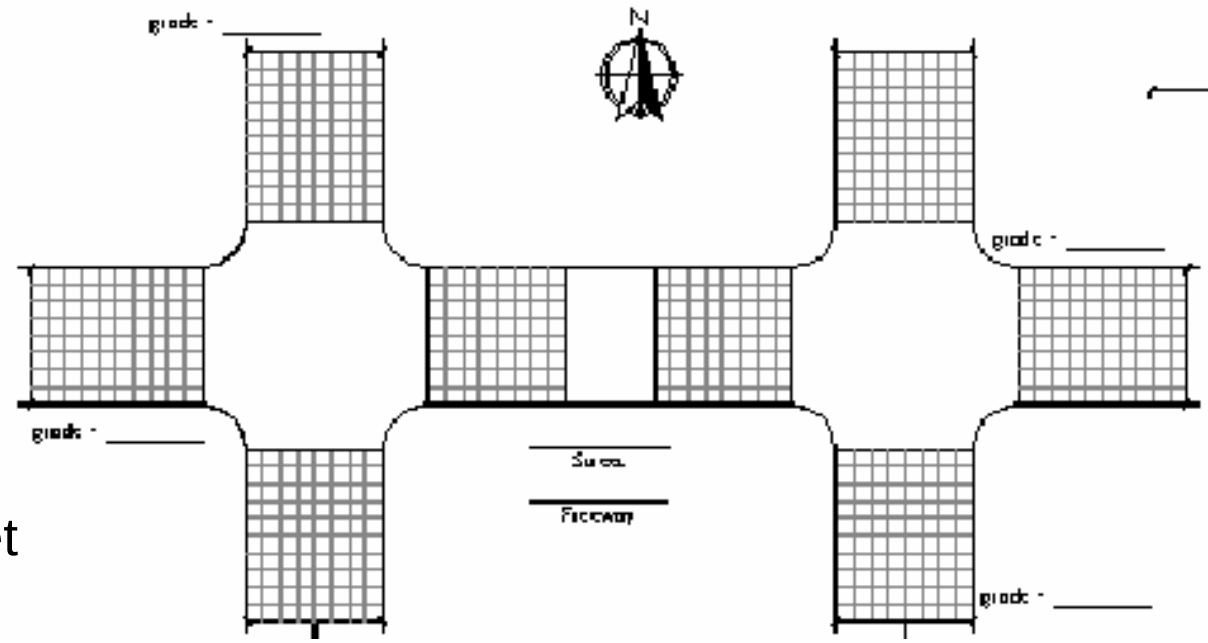




Interchange Ramp Terminals

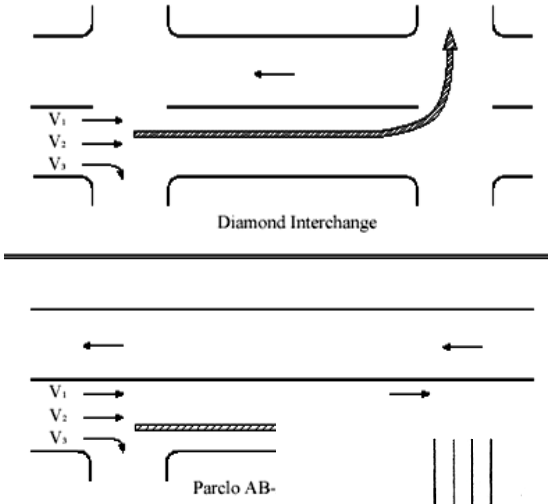
- Incorporate:
  - Speed
  - Distance
  - Offset
- Signal Timing
  - User Coded
  - Optimization

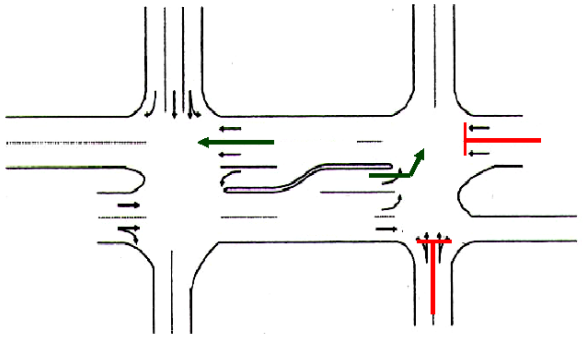
    →Including Offset



Interchange Ramp Terminals

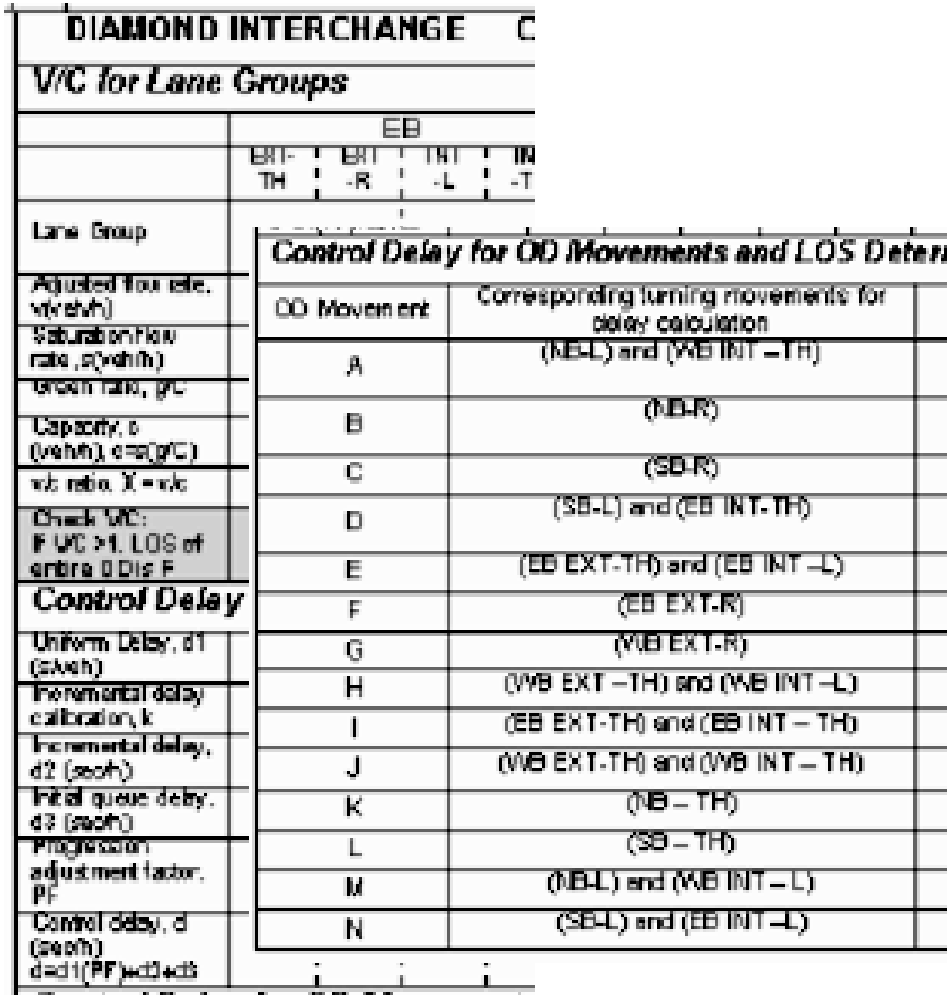
- Run Signals Analysis
  - Two Signals
  - One Signal for SPUI
- Modify for:
  - Lane Utilization
  - Effective Green
    - External Downstream Queue
    - Internal Demand Starvation





Interchange Ramp Terminals

- Results
  - v/c Ratios
  - Queue-Storage Ratios
  - Control Delay
- Level of Service
  - Control Delay
    - v/c or R_Q > 1 → LOS F
  - O-D Movements
  - Approach Lane Groups



DIAMOND INTERCHANGE C

V/C for Lane Groups

	EB			
	EBT-TH	EBT-R	THT-L	IN-T
Lane Group				
Adjusted flow rate, v(veh/h)				
Saturation flow rate, s(veh/h)				
Green ratio, g/C				
Capacity, c (veh/h), c=s(g/C)				
v/c ratio, X = v/c				
Check V/C: If V/C >1, LOS of entire I Dis F				
Control Delay				
Uniform Delay, d1 (s/veh)				
Incremental delay calibration, k				
Incremental delay, d2 (sec/h)				
Initial queue delay, d3 (sec/h)				
Progression adjustment factor, PF				
Control delay, d (sec/h) d=d1(PF)+d2+d3				

Control Delay for OD Movements and LOS Deter

OD Movement	Corresponding turning movements for delay calculation
A	(NB-L) and (WB INT – TH)
B	(NB-R)
C	(SB-R)
D	(SB-L) and (EB INT-TH)
E	(EB EXT-TH) and (EB INT –L)
F	(EB EXT-R)
G	(WB EXT-R)
H	(WB EXT – TH) and (WB INT –L)
I	(EB EXT-TH) and (EB INT – TH)
J	(WB EXT-TH) and (WB INT – TH)
K	(NB – TH)
L	(SB – TH)
M	(NB-L) and (WB INT – L)
N	(SB-L) and (EB INT –L)

Interchange Ramp Terminals

- *HCS*+ Interface
  - Quick Entry for Lane Configuration
  - Signal Timing with Preset Phasing
  - Split-Screen Design
  - Full & Context-Sensitive Help
- HCS Standard Report
  - Text & Formatted Reports
  - Follow HCM Worksheets

Interchange Ramp Terminals

- HCS Modular Design
  - Existing HCS Framework
  - Modified Signals Engine
- Software Development
  - *HCS*+ Release Eminent
  - Initiate Development Now
- Planned Schedule
  - Probably Spring 2006
  - No Good Estimates ☺



