Appendix P ***Critical Movement Summation (CMS) How-To Guide***

P.1 BACKGROUND

The critical movement summation (CMS) method focuses on "raw" intersection capacity, that is, the ability for an intersection to process a given traffic demand with a given lane use configuration and given phase sequence.

Traffic signal phasing is one component of the analysis, but it is important to note that most of the subtleties of traffic signal phasing and operation are not included in the analysis.

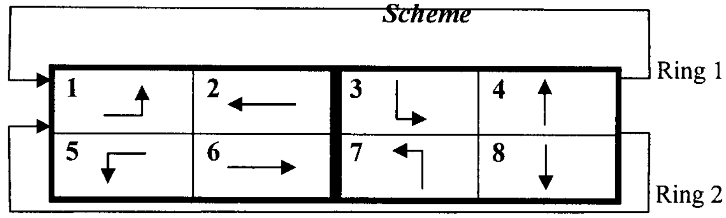
The analyst can use this simple hands-on approach to get right to the point of an intersection's ability to handle traffic demands. CMS looks at each of the "critical" movements at an intersection. It is a volume-based measure.

P.2 PROCESS

Step 1. Gather CMS Inputs

- Hourly Volumes – Use vehicles per hour. If analyzing the peak hour, use the largest sum of 4 consecutive 15-minute periods for that intersection, e.g. 7:45 – 8:45 AM.
- Lane Use Configurations – Determined through observation of existing geometry and operations.
- Signal Phasing – Use National Electrical Manufacturers Association (NEMA) standard 8-phase operation with adjustments as needed. The top line of phasing on the CMS worksheet is intended to show existing phasing. The adjacent line below is workspace intended for conceptual improvements to phasing. See Figure P.1 for a typical NEMA phase numbering schemes.

Figure P-1 Typical Phase numbering Scheme



Step 2. Fill in CMS Worksheet

For each row, fill in the columns:

- Movement (describe in words, e.g. NB through, SB through, EB left, etc.)
- Phase (indicate movement number)
- Volume (in the case of a shared lane, write each volume long-hand, and then sum, e.g. 100 + 150 + 25)
- LU (Lane Use factor, see table at bottom of worksheet.)
- Lane Volume (multiply the Volume by the Lane Use Factor.)
- OL (Opposing Lefts, to be added. See description of Permissive Only Lefts below.)

- LTC (Left Turn Credit, to be subtracted. See description of Concurrent Lefts or Lead/Lead-Lag Left below.)
- Critical Lane Volume (apply OL or LTC to the Lane Volume to get this Critical Lane Volume.)

Step 3. Determine Critical Movements

In the CM column, note the highest of each movement pair (e.g. highest of NB/SB through, highest of NB left/SB left, etc.) with an asterisk*. There should be an asterisk (*) corresponding to each block in the top line of phasing on the CMS worksheet.

Step 4. Sum the Critical Movements

Fill in the "Total" by adding the movements that have asterisks*. Assign a Level of Service (LOS) by using the Level of Service table at the bottom of the CMS worksheet.

P.3 RULES FOR TURNING MOVEMENTS

P.3.1 RIGHT TURNS

If right-turn is "hot" or "free" (i.e. has a dedicated, channelized deceleration and acceleration lanes) and is not signal controlled, leave out of computation.

If right-turn has a dedicated lane and is signal controlled with right-turn-on-red permitted, assume 50% of right-turn volume.

If right-turn has a dedicated lane and is signal controlled with "No right turn on red," assume 100% of right-turn volume.

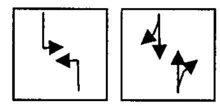
If right-turn has a dedicated lane and is signal controlled for rights to move concurrently with lefts (e.g. NB rights move with WB lefts), reduce the right-turn volume in the amount of the left-turn volume.

If there is a shared through/right lane, add through and right volumes.

P.3.2 LEFT TURNS

Left turns are to be treated as either protected (signalized left-turn arrow) or permissive (no left-turn arrow). If existing condition allows a left-turn movement to be both protected and permissive, analyze as protected (only) in CMS.

P.3.2.1 Concurrent Lefts

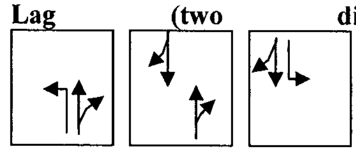


Account for Left Turn Credit (LTC) as follows:

- Calculate lane volumes for left-turn moves
- Apply lane-use factor
- Calculate difference of lefts (e.g. NB/SB lefts or EB/WB lefts)
- Subtract this difference from the through movement that's in the same direction as the greater left-turn volume.

CMS may over or underestimate the impact of left turn traffic on shared left-through-right lane in situations where through opposing volume is high. Additional Analysis (such as the methods of the *Highway Capacity Manual)* may be warranted.

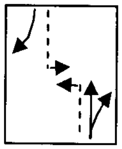
P.3.2.2 Lead Left (one direction), or Lead-Lag (two directions)



Account for Left Turn Credit (LTC) as follows:

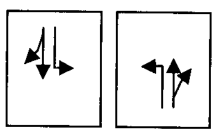
- Identify left-turn volume associated with the lead (or lag) phase.
- Apply lane-use factor.
- Subtract that left-turn volume from the through movement on the same approach.

P.3.2.3 Permissive Only Lefts (no left-turn arrow)



Account for Opposing Lefts (OL) as follows:

- Identify left-turn volume that will be awaiting gaps in the through volume. (These lefts are considered "opposing lefts" – opposing the through volume being analyzed.)
- Add that left-turn volume to the opposing through movement.
- The left turns cannot move until the opposing through movement is complete. So you must consider the total of these two movements, since they cannot move simultaneously.



P.3.2.4 Split Phasing

- Left-turn credit (LTC) does not apply.
- Opposing lefts (OL) do not apply.

P.4 SIGNAL TIMING

CMS can be used as a prerequisite to signal timings. The following steps follow CMS to determine cycle length and required green and clearance (yellow and all red) time:

Step 1. Transfer phasing and Critical Lane Volume (CLV) Inputs from CMS worksheet onto the Traffic Signal Timing Worksheet (see Figure P-2)

Step 2. Determine number of vehicles per cycle per phase. The table included in the Traffic Signal Timing Worksheet can be used to determine the number of cycles in an hour (or simply divide 3600 seconds by the cycle length).

Step 3. Determine green time required from Greenshield's model (see Figure P-3)

Step 4. Determine clearance and pedestrian timings.

Step 5. Determine total time required and compare to cycle length.

P.5 CMS SAMPLE EXERCISE PROBLEMS

See Figures P-5 through P-14 for CMS sample exercise problems.

P.6 SIGNAL TIMING SAMPLE EXERCISE PROBLEM

See Figure P-16 for a sample signal timing exercise problem.

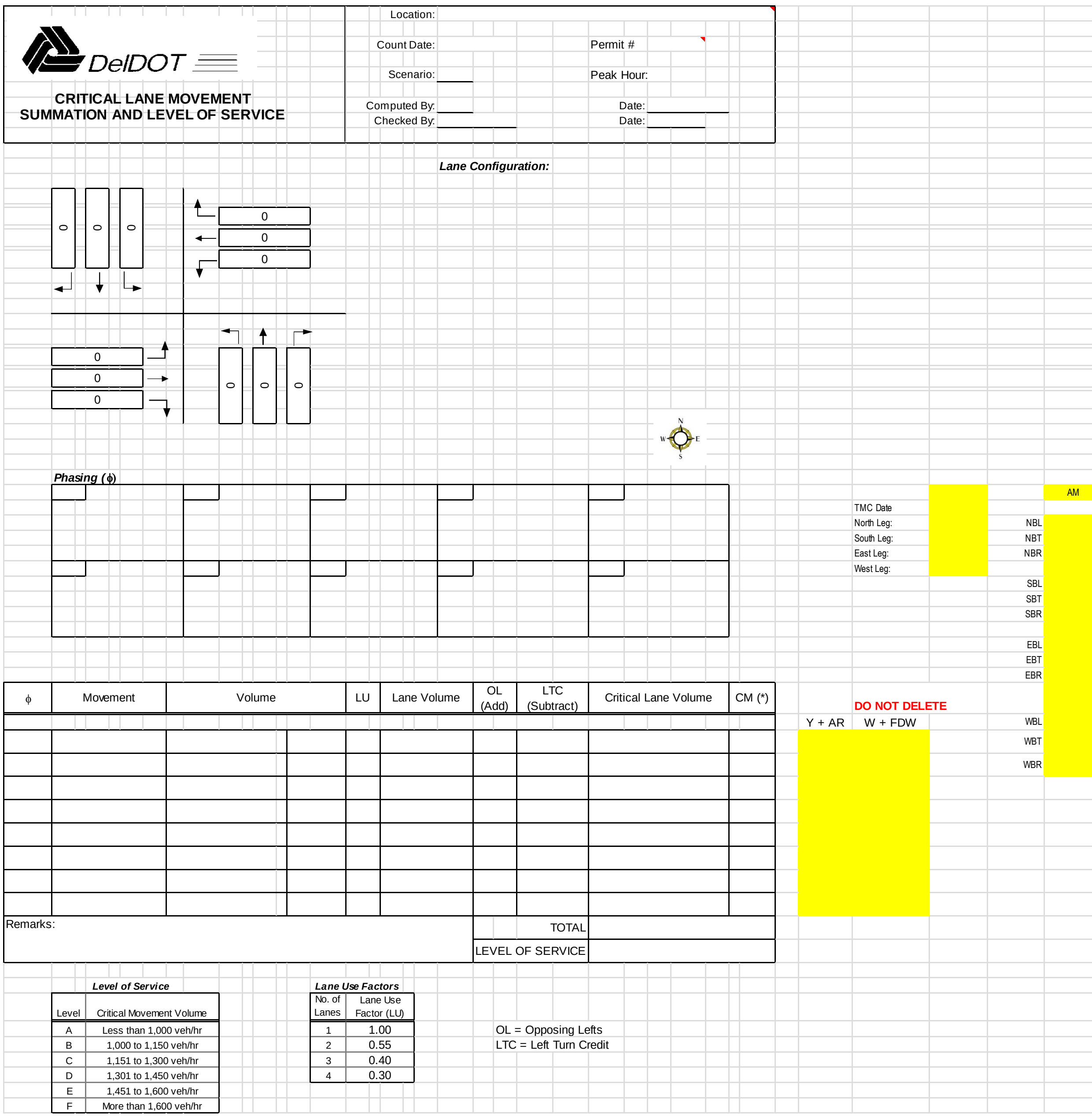
Critical Movement Sheets (CMS) How-to

The goal of the CMS sheets is to determine the level of service (LOS) at specific intersections for peak periods. CMS sheets do not take into account delay or timing of traffic signals so the CMS LOS is a basis of what the intersection could get to if timed perfectly with the current volume. You will need the count data for the intersection and phase data or the timesheet. For more information, refer to Appendix P.

Needed to Complete CMS:

- Count Data
- Phase Data/Timesheet
- Lane Configuration

1. Start with the CMS template shown below.



DelDOT

CRITICAL LANE MOVEMENT SUMMATION AND LEVEL OF SERVICE

Location:
Count Date: Permit #
Scenario: Peak Hour:
Computed By: Date:
Checked By: Date:

Lane Configuration:

Phasing (ϕ)

TMC Date
North Leg:
South Leg:
East Leg:
West Leg:

AM
NBL
NBT
NBR
SBL
SBT
SBR
EBL
EBT
EBR
WBL
WBT
WBR

DO NOT DELETE
Y + AR W + FDW

ϕ	Movement	Volume	LU	Lane Volume	OL (Add)	LTC (Subtract)	Critical Lane Volume	CM (*)

Remarks:

TOTAL

LEVEL OF SERVICE

Level of Service

Level	Critical Movement Volume
A	Less than 1,000 veh/hr
B	1,000 to 1,150 veh/hr
C	1,151 to 1,300 veh/hr
D	1,301 to 1,450 veh/hr
E	1,451 to 1,600 veh/hr
F	More than 1,600 veh/hr

Lane Use Factors

No. of Lanes	Lane Use Factor (LU)
1	1.00
2	0.55
3	0.40
4	0.30

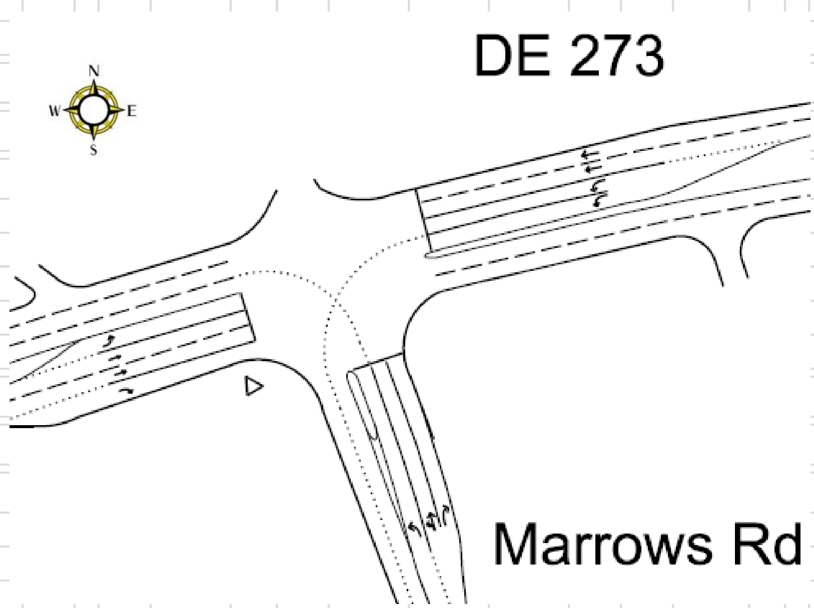
OL = Opposing Lefts
LTC = Left Turn Credit

2. Begin by inputting data into the title block. This includes intersection name, count data, permit #, peak hour, whether the sheet is for AM or PM peak (separate sheets must be computed for both), your name, date you are working on the sheet, name of whoever will check your work, and the date the sheet is checked. An example is shown below.

Location:	DE 273 & Marrows		
Count Date:	4/10/2012	Permit #	N247
Scenario:	PM Peak	Peak Hour:	4:30-5:30
Computed By:	CDM	Date:	4/18/2012
Checked By:	MJL	Date:	4/23/2012

3. Next, insert a Microstation drawing or Google Earth image of the intersection under where it says Lane Configuration. Make sure that the picture is sent backwards in order to see the north arrow clip art. The drawing should show the number of lanes in each direction and the general layout of the intersection. Make sure that the top of the intersection is north because of the different formulas located within the spreadsheet.

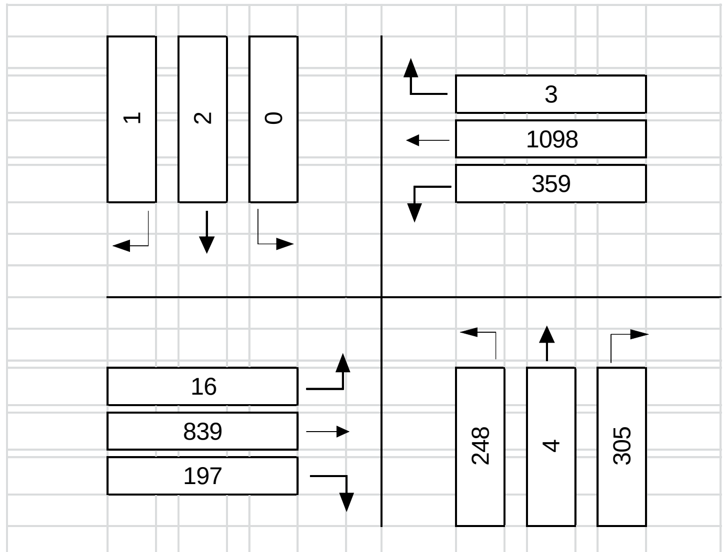
Lane Configuration:



4. Because of how the template is set up, volumes get entered into the highlighted boxes, and the individual turning volumes will populate into the boxes by themselves. Inputting data here:

NBL	248
NBT	4
NBR	305
SBL	0
SBT	2
SBR	1
EBL	16
EBT	839
EBR	197
WBL	359
WBT	1098
WBR	3

will populate here:



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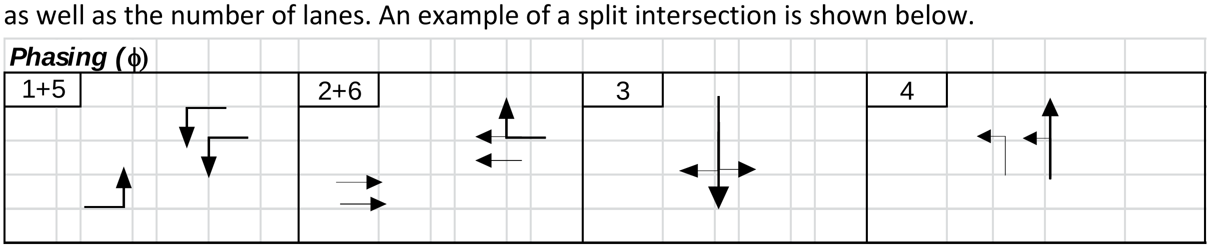
Volumes inputted are all peak hour volumes, not two hour count data.

5. The next input needed is the phasing data. All of this can be found on the timesheet for the intersection. The timesheet will indicate the phase number of each turning movement, as well as the ring structure for the whole intersection and whether there are any overlaps. If the ring structure is standard and there are no overlaps, the phasing is as follows:

Ring 1	1	2	3	4
Ring 2	5	6	7	8

where phases 1 & 5 are the major street left turns, phases 2 & 6 are the major street through movements, phases 3 & 7 are the minor street left turns, and phases 4 & 8 are the minor street through movements. If the intersection is considered to be a split intersection, where each minor street runs independently of the other, phases 7 & 8 will be excluded. Phase 3 would be considered left and through movements of minor street 1 and phase 4 would be considered left and through movements of minor street 2. Examples of different phasing are can be found at the end of the document. The phasing data must be filled in in the correct order that traffic moves in the field. The phase numbers are placed in the upper left-hand corner box and directional arrows are placed in the box to show the direction of traffic as well as the number of lanes. An example of a split intersection is shown below.



Placing the arrows on top of each other indicates that there is a shared lane. If right turning traffic has a dedicated lane, they are not included in the CMS sheet.

6. Now that all of the data has been inputted, it is time to calculate LOS. First list each phase number and the respective turning movement in order of how they were shown in the phasing

diagram above. If the intersection is split (as above) and has multiple lanes, list each lane separately. This is only if the intersection is split and the side road includes more than one lane. If the intersection is a standard 8-phase intersection, ignore splitting up each lane. The diagram below shows the correct phases and movements from the phasing diagram above. Notice how phase 4 is split into two different rows. The first row includes ½ NB L because there is one lane that is only left turns. The second lane is a shared through and left turn lane, meaning that ½ NB L turners and all of the through traffic will be utilizing that lane. The reason that the movement needs to be split up is that you need to determine which lane will be the critical movement for determining how much green time is needed.

Split Intersection

ϕ	Movement
1	WB L
5	EB L
2	EB T
6	WB TR
3	SB LTR
4	1/2 NB L
4	NB T + 1/2 L

Standard 8-Phase Intersection

ϕ	Movement
1	WB L
5	EB L
2	EB T
6	WB T
3	SB L
7	NB L
4	NB T
8	SB T

7. The next step is to input the volumes. For a standard 8-phase intersection, this is simply pulling the data from the volumes that you have already entered. In the case of a split intersection, you may have to do some calculations to determine what percentage of traffic uses one lane over another. For the split intersection shown above, ½ NB L and NB T + ½ NB L must be calculated.

Split Intersection

Standard 8-Phase Intersection

Movement	Volume		Standard 8-Phase Volume
WB L		359	247
EB L		16	157
EB T		839	786
WB TR		1101	1943
SB LTR		3	32
1/2 NB L	.=.5*248	124	508
NB T + 1/2 L	.=.5*248 + 4	128	54
			21

You can see above how there are no calculations that need to be completed for the standard 8-phase intersection.

8. Next, lane usage factors must be applied. At the bottom of the spreadsheet, there is a table with factors depending on how many lanes there are in each direction. A shared lane is considered to only be one lane even though there are two turning movements using the same lane.

Lane Use Factors

No. of Lanes	Lane Use Factor (LU)
1	1.00
2	0.55
3	0.40
4	0.30

9. The next step is to multiply the volumes by the lane use factor to get lane volumes. Make sure to round up the lane volume. There cannot be a fraction of a car.

Volume		LU	Lane Volume
	359	0.55	197
	16	1.00	16
	839	0.55	461
	1101	0.55	606
	3	1.00	3
.=.5*248	124	1.00	124
.=.5*248 + 4	128	1.00	128

10. The next step is to identify if there are any opposing lefts. Opposing lefts are only calculated if the left turning movement is permissive only (there is no left turn arrow). They do not apply to split intersections. First, identify if there are left turners who must wait for gaps in the opposing through traffic. That volume is then placed in the OL column of the opposing through movement and will later be added to the lane volume.

11. The next column is the left turn credit (LTC). This is to take into account if one left turning movement is higher than the other so that the through movement can move while the left turning traffic is still clearing through the intersection. If EB L and WB L are green at the same time but EB L has 100 more cars than WB L, the WB L signal is going to turn red while the EB L is still green to allow a certain amount of EB T vehicles to move through the intersection before the WB T vehicles are allowed to go. That number of through vehicles is what is being accounted for in the LTC. To determine the volume for LTC, calculate the difference of the left turn lane volumes (not just volumes) and place in the column for the through movement that is in the same direction as the higher left turn volume. This will later be subtracted from the lane volume. This does not apply to split intersections.

Movement	Volume		LU	Lane Volume	OL (Add)	LTC (Subtract)
WB L		359	0.55	197		
EB L		16	1.00	16		
EB T		839	0.55	461		
WB TR		1101	0.55	606		181
SB LTR		3	1.00	3		
1/2 NB L	.=.5*248	124	1.00	124		
NB T + 1/2 L	.=.5*248 + 4	128	1.00	128		

In the table above, WB L are significantly higher than EB L. Subtract 16 from 197 to get a difference of 181 vehicles. Since WB L volumes are higher than EB L, 181 vehicles is subtracted (placed in the LTC column) from WB T lane volumes. 181 through vehicles are moving through the intersection before the through signal even technically turns green and those vehicles are already accounted for under the WB L lane volume. If those vehicles were not subtracted out, those vehicles would be accounted for twice and could drastically change the LOS of the intersection.

12. The critical lane volume must be calculated for each phase. The critical lane volume is simply the lane volume + opposing lefts – left turn credit. If there are neither opposing lefts nor a LTC, then the lane volume equals the critical lane volume. Once the critical lane volume is calculated for

each phase, the critical movement for each phase grouping must be determined. This relates back to the phase diagram. Since phases 1 and 5 typically move together, only one of them can be the critical movement for that phase group. There should be four critical movements at both a standard 8-phase intersection and a split intersection. Since each side road moves independently at a split intersection, that movement automatically becomes the critical movement. However, if there is more than one lane on a side road at a split intersection, you must determine which of those lanes the critical movement for that phase is. An asterisk (*) is placed in the same row as the critical movement so that the spreadsheet can calculate the total critical volume, and then calculate the LOS of the intersection based on the total critical volume.

ϕ	Movement	Volume		LU	Lane Volume	OL (Add)	LTC (Subtract)	Critical Lane Volume	CM (*)
1	WB L		359	0.55	197			197	*
5	EB L		16	1.00	16			16	
2	EB T		839	0.55	461			461	*
6	WB TR		1101	0.55	606		181	425	
3	SB LTR		3	1.00	3			3	*
4	1/2 NB L	.=.5*248	124	1.00	124			124	
4	NB T + 1/2 L	.=.5*248 + 4	128	1.00	128			128	*
Remarks: EB/NB rights in dedicated lanes and not included.							TOTAL	790	
						LEVEL OF SERVICE		A	

In this example, it is a split intersection with multiple lanes in the NB direction. Since NB T + ½ NB L is greater in critical lane volume than ½ NB L, NB T + ½ NB L is considered to be the critical movement for that phase group.

The remarks box at the bottom of the table is where any notes on right turning movements should go. In this case, two right turn movements are included and two are excluded.

13. The last step is to calculate the LOS for the intersection. As mentioned above, the critical movement volumes are totaled and then the LOS can be calculated. A separate table is shown below for calculating LOS:

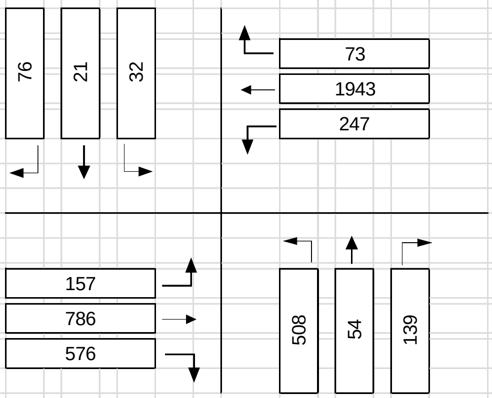
	Level of Service
Level	Critical Movement Volume
A	Less than 1,000 veh/hr
B	1,000 to 1,150 veh/hr
C	1,151 to 1,300 veh/hr
D	1,301 to 1,450 veh/hr
E	1,451 to 1,600 veh/hr
F	More than 1,600 veh/hr

Examples

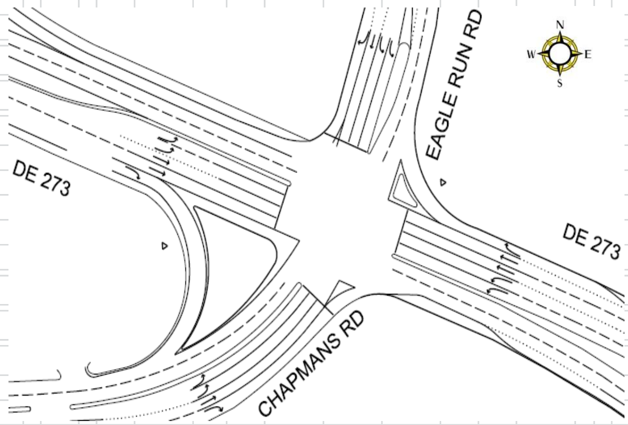
Standard 8-Phase intersection

CRITICAL LANE MOVEMENT SUMMATION AND LEVEL OF SERVICE

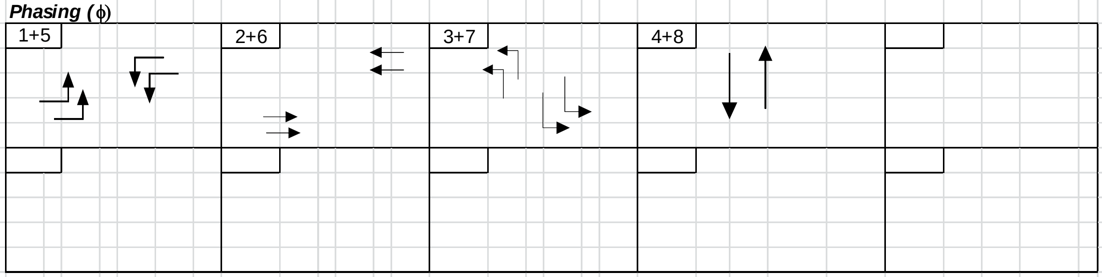
Location:	DE 273 & Chapmans Rd		
Count Date:	10/4/2011	Permit #	N367
Scenario:	AM Peak	Peak Hour:	7:15-8:15
Computed By:	CDM	Date:	4/17/2012
Checked By:	MJL	Date:	4/24/2012



Lane Configuration:



Phasing (ϕ)



ϕ	Movement	Volume	LU	Lane Volume	OL (Add)	LTC (Subtract)	Critical Lane Volume	CM (*)
1	WB L	247	0.55	136			136	*
5	EB L	157	0.55	86			86	
2	EB T	786	0.55	432			432	
6	WB T	1943	0.55	1069		50	1019	*
3	SB L	32	0.55	18			18	
7	NB L	508	0.55	279			279	*
4	NB T	54	1.00	54		261	0	
8	SB T	21	1.00	21			21	*
						TOTAL	1455	
						LEVEL OF SERVICE	E	

Remarks: All rights in dedicated lanes and not included.

Split Intersection with one lane in each direction of the Side Rd

CRITICAL LANE MOVEMENT SUMMATION AND LEVEL OF SERVICE

Location: SR 4 and State St

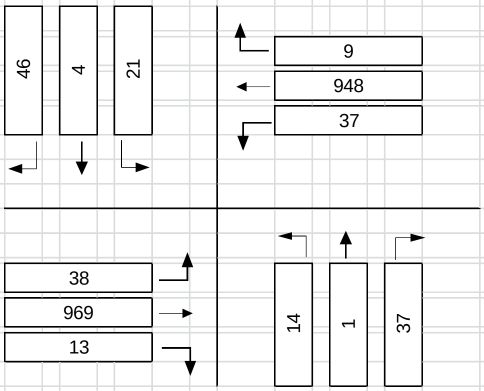
Count Date: 9/25/2012 Permit # N338

Scenario: AM Peak Peak Hour: 7:15-8:15

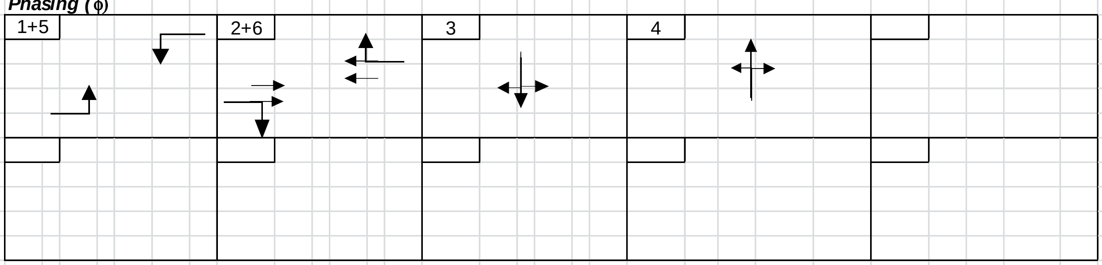
Computed By: MJL Date: 1/19/2013

Checked By: Date:

Lane Configuration:



Phasing (ϕ)



ϕ	Movement	Volume		LU	Lane Volume	OL (Add)	LTC (Subtract)	Critical Lane Volume	CM (*)
5	EB L		38	1.00	38			38	*
1	WB L		37	1.00	37			37	
6	WB TR		957	0.55	526			526	
2	EB TR		982	0.55	540		1	539	*
3	SB LTR		71	1.00	71			71	*
4	NB LTR		52	1.00	52			52	*

Remarks: All rights included.

TOTAL	700
LEVEL OF SERVICE	A

Split Intersection with multiple lanes on the Side Road

DelDOT

CRITICAL LANE MOVEMENT SUMMATION AND LEVEL OF SERVICE

Location: DE 273 & Appleby

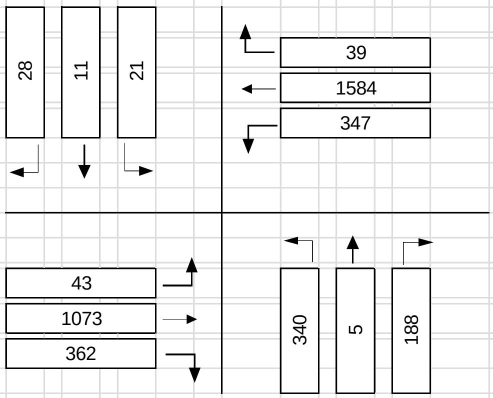
Count Date: 1/20/2011 Permit # N460

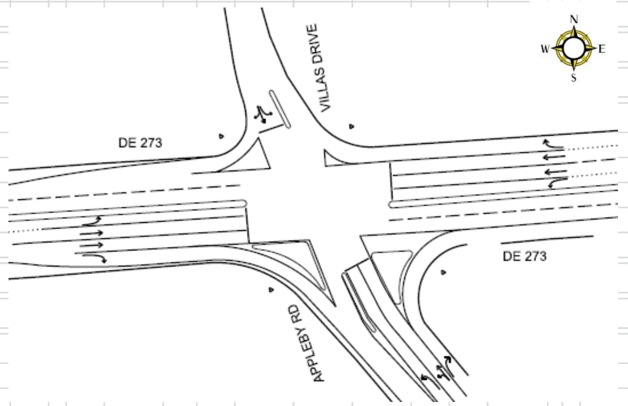
Scenario: PM Peak Peak Hour: 4:45-5:45

Computed By: CDM Date: 4/16/2012

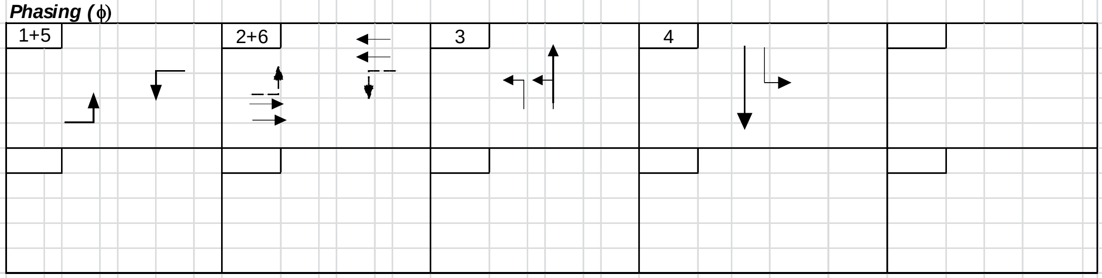
Checked By: MJL Date: 4/25/2012

Lane Configuration:





Phasing (ϕ)



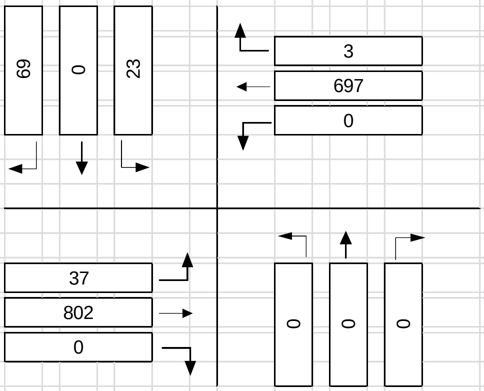
ϕ	Movement	Volume		LU	Lane Volume	OL (Add)	LTC (Subtract)	Critical Lane Volume	CM (*)
1	WB L		347	1.00	347			347	*
5	EB L		43	1.00	43			43	
2	EB T		1073	0.55	590			590	*
6	WB T		1584	0.55	871		304	567	
3	1/2 NB L	.=0.5*340	170	1.00	170			170	
3	1/2 NB L + NB T	.=0.5*340 + 5	175	1.00	175			175	*
4	SB T		11	1.00	11			11	
4	SB L		21	1.00	21			21	*
							TOTAL	1133	
							LEVEL OF SERVICE	B	

Remarks: All rights in dedicated lanes and not included.

3-Legged T Intersection

DelDOT	Location: SR 4 and Troy Ave
	Count Date: 9/20/2012 Permit #: N202
	Scenario: AM Peak Peak Hour: 7:00-8:00
CRITICAL LANE MOVEMENT SUMMATION AND LEVEL OF SERVICE	Computed By: AD Date: 1/15/2013
	Checked By: MJL Date: 1/21/2013

Lane Configuration:



Phasing (ϕ)

2+6

4

ϕ	Movement	Volume		LU	Lane Volume	OL (Add)	LTC (Subtract)	Critical Lane Volume	CM (*)
2	EB LT		839	0.55	461			461	*
6	WB TR		700	0.55	385			385	
4	SB LR		92	1.00	92			92	*

Remarks: All rights included.

TOTAL	553
LEVEL OF SERVICE	A