SOME RECOMMENDATIONS FOR CHAPTERS 19 AND 31 – SIGNALIZED INTERSECTION METHODOLOGIES

Issues and Recommendations

Issue #1: It is difficult for new users (and even experienced users) of the HCM to find what information they need.

- Recommendation #1: Provide maps or other guidance to users to help them find what they want to know or what they want to do.

Issue #2: It is difficult to know what input data are needed for a particular problem that a user wants to solve.

- Recommendation #2: Provide guidance to the user that shows what input data are needed for a particular problem type.

Issue #3: The focus on actuated control operation, an operation not understood by many transportation engineers, makes it difficult for them to use the signalized intersection methodology.

- Recommendation #3a: Refocus the description of the methodology so that the user can select the degree of complexity needed for the problem that he or she is trying to solve.
- Recommendation #3b: Eliminate the distinction between the operational analysis and planning methodologies refocus on the complexity of the problem being addressed.

Issue #4: The example problem is difficult to follow and not related to the methodology described in the chapter.

- Recommendation #4: Revise Example Problem 1 so that it is based on the ten steps of the core automobile methodology.

Issue #5: It is difficult to know whether a given sub-model or adjustment factor makes a difference in the final results of an analysis.

- Recommendation #5a: Establish a "value added test" that determines whether a proposed new sub-model or adjustment factor enhances the final results of an analysis.
- Recommendation #5b: Review all components of the chapter to determine whether they meet the "value added test".

Recommendation #1: Provide maps or other guidance to users to help them find what they want to know or what they want to do.

The following pages present several example maps to illustrate how to help users to go where they need to go based on what they want to know or do.

Example 1: References to the Automobile Methodology

Exhibit 19.18 (p 19.41) lists the ten steps for the core automobile methodology. The figure below shows this core methodology plus primary and supplemental references that support the methodology.

Automobile Methodology	Primary Reference	Supplemental References	
Step 1. Determine Movement Groups and Lane Groups	19.41-19.43		
Step 2. Determine Movement Group Flow Rate	19.43		
Step 3. Determine Lane Group Flow Rate	19.43		
Step 4. Determine Adjusted Saturation Flow Rate	19.44-19.48	Lane group flow rate – multiple lane approaches	31.22-31.29
		Saturation flow rate – shared lanes	31.45-31.55
		Bike/pedestrian adjustment factors	31.34-31.40
		Work zone adjustment factors	31.40-31.41
		Adjustment for downstream blockage	30.13-30.30
		Adjustment for sustained spillback	29.23-29.35
Step 5. Determine Proportion Arriving During Green	19.48-19.49	Arrival flow prediction	30.9-30.12
Step 6. Determine Signal Phase Duration	19.49	Pretimed phase duration	31.30-31.34
		Actuated phase duration	31.2-31.22
Step 7. Determine Capacity and Volume-to-Capacity Ratio	19.49	Shared lane capacity	31.60-31.62
		Critical intersection v/c ratio	19.57-19.61
		Permitted LT shared lane saturation flow	31.28-31.29
Step 8. Determine Delay	19.49-19.53	Permitted LT initial queue	19.61-19.68
Step 9. Determine LOS	19.54		
Step 10. Determine Queue Storage Ratio	19.54	Concept	31.63-31.70
		Procedure	31.70-31.77

Example #2: What Do You Want To Do?

The following charts list a series of questions that a user may have and guides to answering these questions; the first is very detailed, the second and third are less so, with only major questions listed.

WHAT DO YOU WANT TO DO?

Learn about important concepts...	Reference
Types of traffic control	19.3-19.4
Intersection traffic movements	19.4
Signal phase sequence	19.4-19.6
Operational modes	19.6
Left-turn phase sequence	19.7-19.8
Traffic flow characteristics	19.8-19.11
Phase duration	19.11-19.12
Analysis type	19.12-19.13
Spatial/temporal limits	19.92
LOS critertia	19.13

Learn about the scope of the methodology...	Reference
Basic scope	19.15-19.16
Control type	19.17
Signal operation	19.17
Spatial/temporal limits	19.17-19.19
Performance measures	19.19
Limitations	19.19-19.20
Lane groups and movement groups	19-20

Learn about the required input data...	Reference
Overview	19.20-19.22
Traffic characteristics	19.22-19.31
Geometric design	19.31-19.32
Signal control	19.32-19.37
Other data	19.38-19.40

Apply the automobile methodology...	Reference
Overview	19.40-19.41
Determine movement groups and lane groups	19.41-19.43
Determine movement group flow rate	19.43
Determine lane group flow rate	19.43
Determine adjusted saturation flow rate	19.44-19.48
Determine proportion arriving during green	19.48-19.49
Determine signal phase duration	19.49
Determine capacity and v-c ratio	19.49
Determine delay	19.49-19.53
Determine LOS	19.53
Determine queue storage ratio	19.53

Learn about extensions to the automobile methodology...	Reference
Determine the critical intersection v-c ratio	19.57-19.61
Calculate uniform delay calculation using the QAP	19.61-19.64
Determine lane group flow rate on multiple-lane approaches	31.22-31.29
Develop a QAP	31.42-31.45
Determine saturation flow rate, capacity, and delay for LT movements	31.45-31.62
Determine saturation flow rate adjustment factors for bikes-pedestrians	31.34-31.40
Calculate the initial queue delay	19.64-19.68
Determine saturation flow rate adjustment factors for work zones	31.40-31.41
Adjustment for downstream blockage	30.13-30.30
Adjustment for sustained spillback	29.23-29.35
Arrival flow prediction	30.9-30.12
Determine phase duration for actuated operation	31.2-31.22
Determine phase duration for pretimed operation	31.30-31.34
Determine queue storage ratio	31.63-31.77

Apply the planning method...	Reference
Apply the planning method	31.78-31.97
Develop service volume tables	19.91

Conduct other tasks...	Reference
Interpret the results	19.54-19.56
Review an example problem	31.126-31.137
Measure control delay in the field	31.98-31.104
Measure saturation flow rate in the field	31.104-31.109
Use alternative tools	19.93-19.95
	31.118-31.125
Review the computational engine documentation	31.110-31.117

WHAT DO YOU WANT TO DO?	Reference
Learn about important concepts related to the signals method...	19.3 – 19.15
Learn about input data so I can use software...	19.22-19.40
Understand the core (operational analysis) automobile methodology...	19.41-19.53
See an example application of the method...	31.126-31.137
Make field measurements...	31.98-31.109
Apply the planning method...	31.78-31.97
Learn how different types of signal control are modeled...	31.2-31.21
	31.30-31.33
Learn how to interpret the results...	19.54-19.56

WHAT DO YOU WANT TO DO?	Reference
Learn about important concepts related to the signals method...	19.3-19.15
Learn about input data so I can use software...	19.22-19.40
Determine if an intersection has enough capacity...	31.78-31.97
Determine LOS for a pretimed intersection...	x-x
Determine LOS for an actuated controlled intersection...	x-x
See an example application of the method...	31.126-31.137

Example 3. Major Parts of Chapters

The following table shows the major parts of chapters 19 and 31 in a way that allows the user the find the information that they need.

CONCEPTS	Reference
Traffic signal concepts	19.3-19.12
Analysis type	19.12-19.13
	19.92
Spatial/temporal limits	19.13
LOS critertia	19.13-19.15

SCOPE (CONDITIONS)	Reference
Base conditions	19.15-19.16
Control type	19.17
Signal operation	19.17
Spatial/temporal limits	19.17-19.19
Performance measures	19.19
Limitations	19.19-19.20
Lane groups and movement groups	19-20

REQUIRED DATA	Reference
Traffic characteristics	19.22-19.31
Geometric design	19.31-19.32
Signal control	19.32-19.37
Other data	19.38-19.40

CORE METHODOLOGY	Reference
Determine movement groups and lane groups	19.41-19.43
Determine movement group flow rate	19.43
Determine lane group flow rate	19.43
Determine adjusted saturation flow rate	19.44-19.48
Determine proportion arriving during green	19.48-19.49
Determine signal phase duration	19.49
Determine capacity and v-c ratio	19.49
Determine delay	19.49-19.53
Determine LOS	19.53
Determine queue storage ratio	19.53

CORE METHODOLOGY - EXTENSIONS	Reference
Critical intersection v-c ratio	19.57-19.61
Lane group flow rate on multiple-lane approaches	31.22-31.29
Uniform delay calculation using QAP	19.61-19.64
General procedure for developing QAP	31.42-31.45
Developing QAP for LT movements	31.45-31.62
Ped-bike saturation flow rate adjustment factors	31.34-31.40
Initial queue delay calculation	19.64-19.68
Work zone saturation flow rate adjustment factors	31.40-31.41
Adjustment for downstream blockage	30.13-30.30
Adjustment for sustained spillback	29.23-29.35
Arrival flow prediction	30.9-30.12
Actuated phase duration	31.2-31.22
Pretimed phase duration	31.30-31.34
Shared lane capacity	?
Permitted LT saturation flow rate	?
Permitted LT initial queue	?

PLANNING METHODOLOGY	Reference
Methodology	19.54-19.56
Service volume tables	19.91

INTERPRETATIONS	Reference
	19.54-19.56

APPLICATIONS	Reference
Alternative tools	19.93-19.95
Use of alternative tools	31.118-31.125
Example problems	31.126-31.137

FIELD MEASUREMENT TECHNIQUES	Reference
Saturation flow rate	31.98-31.104
Delay	31.104-31.109

COMPUTATIONAL ENGINE DOCUMENTATION	Reference
	31.110-31.117

Example 4. Major Parts of Chapters

The following table shows another view of the major parts of chapters 19 and 31, along with a brief description of each of the parts.

Topic	Reference	Description
CONCEPTS Traffic signal concepts Analysis type Spatial/temporal limits LOS concepts	19.3-19.15	Describes concepts needed to apply .methodology.
SCOPE	19.15-19.20	
REQUIRED DATA	19.20-19.40	Describes input data needed for various problem types or intersection (control) configurations.
CORE METHODOLOGY	19.41-19.54	Describes 10 computational steps of core methodology.
INTERPRETATION OF RESULTS	19.54-19.56	Describes implications of LOS, delay, and v-c ratio.
EXTENSION OF METHODOLOGY Critical intersection v-c ratio Initial queue delay calculations	 19.57-19.61 19.64-19.68	 Purpose and method for critical X. Calculation of delay resulting from initial queue.
APPLICATIONS Service volumes Analysis types Alternative tools	 19.91 19.92 19.92-19.95	 Presentation and construction of service volume table. Describes three analysis methodology types. Guidance for use of alternative tools for signalized intx.
ACTUATED PHASE DURATION Concepts Volume computations QAP Maximum allowable headway Maximum green Average phase duration Probability of max out	31.2-31.22	Describes procedure for estimating average phase duration for actuated control.
LANE GROUP FLOW RAT ON MULTIPLE-LANE APPROACHES	31.22-31.29	Iterative procedure to determine lane flow balance for multilane lane groups.
PRETIMED PHASE DURATION	31.30-31.34	Describes procedure to compute pretimed phase duration.
PED/BIKE ADJUSTMENT FACTORS	31.34-31.40	Describes procedure to determine saturation flow rate adjustment factors for bikes/peds.
WORK ZONE ADJUSTMENT FACTOR	31.40-31.41	Determines saturation flow adjustment factor for work zones.
QUEUE ACCUMULATION POLYGON Concepts General procedure LT lane procedure	31.42-31.62	Describes process to construct QAP, staring with concepts, then general procedure. Also provides specialized procedure for various LT lane configuration and control.
QUEUE STORAGE RATIO	31.63-31.77	Describes process to determine back of queue size and queue storage ratio.
PLANNING LEVEL ANALYSIS	31.78-31.97	Describes process to determine intersection capacity sufficiency and LOS at planning level.
FIELD MEASUREMENT TECHNIQUES	31.98-31.109	Describes techniques to measure control delay and saturation flow rate in the field.
COMPUTATIONAL ENGINE DOCUMENTATION	31.110-31.117	Documents computational engine using flow charts and link lists.
USE OF ALTERNATIVE TOOLS	31.118-31.125	Describes examples to use alternative tools to analyze storage bay overflow, RTOR, short lanes and closely spaced intersections
EXAMPLE PROBLEM	31.126-31.137	Describes application of auto methodology to example problem.

Recommendation #2: Provide guidance to the user that shows what input data are needed for a particular problem type.

The tables on this page and the following page show the data required for various applications of the methodology. These tables are an expansion of Exhibit 19-11, Exhibit 19-12, and Exhibit 31-32. The traditional categories of planning (column 3) and operational analysis (columns 4, 5, and 6) are shown. The latter three columns provide the user with more guidance on input requirements as a function of the signal control type present in the problem under consideration.

Traffic Characteristics					
Input Data Element	**Basis**	**Planning**	**Pretimed**	**Actuated**	**Act-Coord**
Demand flow rate	Movement	x	x	x	x
Right-turn-on-red flow rate	Approach		x	x	x
Percent heavy vehicles	Movement group	x	x	x	x
Intersection peak hour factor	Intersection	x	x	x	x
Platoon ratio	Movement group	x	x	x	x
Upstream filtering adjustment factor	Movement group		x	x	x
Initial queue	Movement group		x	x	x
Base saturation flow rate	Movement group		x	x	x
Lane utilization adjustment factor	Movement group		x	x	x
Pedestrian flow rate	Approach	x	x	x	x
Bicycle flow rate	Approach		x	x	x
On-street parking maneuver rate	Movement group	x	x	x	x
Local bus stopping rate	Approach		x	x	x
Unsignalized movement delay			x	x	x

Geometric Design					
Input Data Element	**Basis**	**Planning**	**Pretimed**	**Actuated**	**Act-Coord**
Number of lanes	Movement group	x	x	x	x
Average lane width	Movement group		x	x	x
Number of receiving lanes	Approach		x	x	x
Turn bay length	Movement group		x	x	x
Presence of on-street parking	Movement group	x	x	x	x
Approach grade	Approach		x	x	x

Signal Control					
Input Data Element	**Basis**	**Planning**	**Pretimed**	**Actuated**	**Act-Coord**
Type of signal control	Intersection		x	x	x
Phase sequence	Intersection	x	x	x	x
Left-turn operational mode	Approach	x	x	x	x
Dallas left-turn phasing option	Approach		x	x	x
Passage time (if actuated)	Phase			x	x
Maximum green (or green duration if pretimed)	Phase	x	x	x	x
Minimum green	Phase			x	x
Yellow change	Phase	x	x	x	x
Red clearance	Phase	x	x	x	x
Walk	Phase		x	x	x
Pedestrian clear	Phase		x	x	x
Phase recall	Phase			x	x
Dual entry (if actuated)	Phase			x	x
Simultaneous gap-out (if actuated)	Approach			x	x
Cycle length	Intersection	x	x		x
Phase splits	Phase				x
Offset	Intersection				x
Offset reference point	Intersection				x
Force mode	Intersection				x

Other Data					
Input Data Element	**Basis**	**Planning**	**Pretimed**	**Actuated**	**Act-Coordinated**
Analysis period duration	Intersection	x	x	x	x
Speed limit	Approach		x	x	x
Stop-line detector length and detection mode	Movement group			x	x
Area type	Intersection		x	x	x

Recommendation #3a: Refocus the description of the methodology so that the user can select the degree of complexity needed for the problem that he or she is trying to solve.

Recommendation #3b: Eliminate the distinction between the operational analysis and planning methodologies refocus on the complexity of the problem being addressed.

While most traffic signal controllers are based on actuated operation, this doesn't imply that the operational analysis method should be focused on this type of operation. What this should mean is that users should be given the option of how phase durations are estimated. And, what they choose should be based on the type of problem that they are trying to solve. The HCM should provide guidance to the data required (see Recommendation #2) and the parts of Chapters 19 and 31 that are required to solve the problem. And, since nearly all analysts use software to apply the HCM method, it can be argued that the current distinction between the planning method and the operational analysis method is no longer a helpful one.

Consideration should be given to:

- Defining the performance measures required.
- The volume or v/c ratio
- The intersection geometry
- The types of control
- The arrival patterns (whether the signal is isolated or operating as part of a coordinated system and, if coordinated, the resulting quality of progression)
- The left turn phasing options
- Other adjustment factors

An example map is shown below.

WHAT DO YOU KNOW?	WHAT DO YOU WANT TO PREDICT?	REFERENCE
• Demand (turning movements) • Intersection geometry	• Intersection v/c ratio • Delay • LOS	31.78-31.89 31.79 31.89-31.93
• Demand (turning movements) • Intersection geometry • Signal phasing • Cycle length and green durations	• Delay • LOS • Queue Storage Ratio	[to be added]
• Demand (turning movements) • Intersection geometry • Signal phasing • Actuated timing parameters (isolated intersection)	• Delay • LOS • Queue Storage Ratio	[to be added]
• Demand (turning movements) • Intersection geometry • Signal phasing • Actuated timing parameters (coordinated system)	• Delay • LOS • Queue Storage Ratio	[to be added]

Recommendation #4: Revise Example Problem 1 so that it is based on the ten steps of the core automobile methodology.

EXAMPLE PROBLEM 1: AUTOMOBILES

[Note: The numbers included here still need to be checked by others.]

The Intersection

The intersection of 5th Avenue and 12th Street is an intersection of two urban arterial streets. The intersection plan view is shown in Exhibit 1.

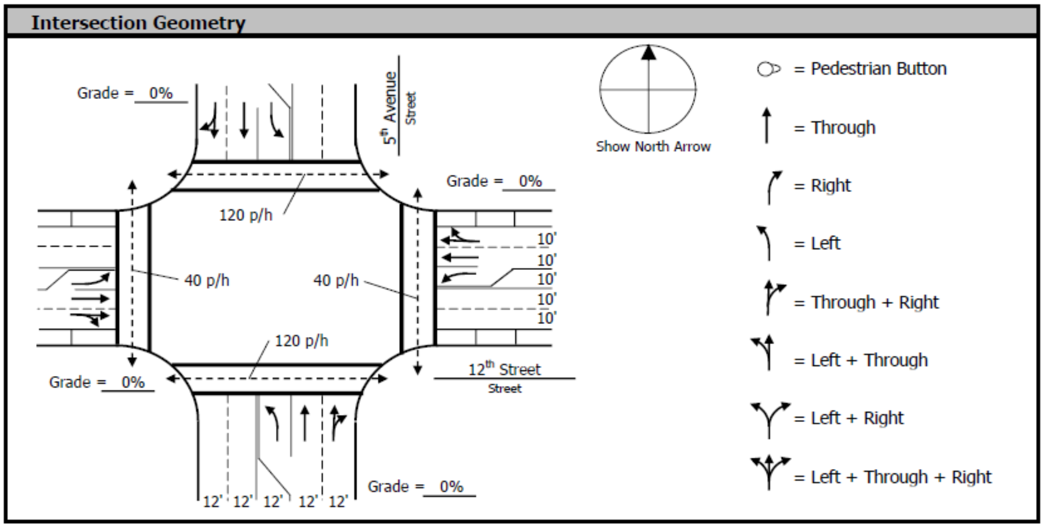

Exhibit 1 Example Problem 1: Intersection Plan View

The Question

What is the motorist delay and LOS during the analysis period for each lane group and the intersection as a whole?

The Facts

The intersection's traffic, geometric, and signalization conditions are listed in Exhibit 2, Exhibit 3, Exhibit 4, and Exhibit 5.

Traffic Characteristics												
Input Data Element	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
	L	T	R	L	T	R	L	T	R	L	T	R
Demand flow rate	71	318	106	118	600	24	133	1644	111	194	933	111
Right-turn-on-red flow rate									22			33
Percent heavy vehicles	5	5	5	5	5	5	2	2	2	2	2	2
Intersection peak hour factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Platoon ratio	1.00	1.00		1.00	1.00		1.00	1.00		1.00	1.00	
Upstream filtering adjustment factor	1.00	1.00		1.00	1.00		1.00	1.00		1.00	1.00	
Initial queue	0	0		0	0		0	0		0	0	
Base saturation flow rate	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane utilization adjustment factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Pedestrian flow rate		120			120			40			40	
Bicycle flow rate		0			0			0			0	
On-street parking maneuver rate			5			5						
Local bus stopping rate			0			0			0			0

Exhibit 2. Example Problem 1: Traffic Characteristics

Geometric Design												
Input Data Element	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
	L	T	R	L	T	R	L	T	R	L	T	R
Number of lanes	1	2	0	1	2	0	1	2	0	1	2	0
Average lane width	10.0	10.0		10.0	10.0		12.0	12.0		12.0	12.0	
Number of receiving lanes		2			2			2			2	
Turn bay length	200			200			200			200		
Presence of on-street parking	No		Yes	No		Yes	No		No	No		No
Approach grade	0	0	0	0	0	0	0	0	0	0	0	0

Exhibit 3. Example Problem 1: Geometric Design

Signal Control								
Input Data Element	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Type of signal control	Actuated		Actuated		Actuated		Actuated	
Phase sequence		2		6	3	8	4	7
Movement		L+T+R		L+T+R	L	T+R	L	T+R
Left-turn operational mode		Perm		Perm	Prot/Perm		Prot/Perm	
Dallas left-turn phasing option					No		No	
Passage time		2.0		2.0	2.0	2.0	2.0	2.0
Maximum green		30		30	25	50	25	50
Minimum green		5		5	5	5	5	5
Yellow change		4.0		4.0	4.0	4.0	4.0	4.0
Red clearance		0		0	0	0	0	0
Walk		5		5		5		5
Pedestrian clear		14		14		16		16
Phase recall		No		No	No	No	No	No
Dual entry		Yes		Yes	No	Yes	No	Yes
Simultaneous gap-out	Yes				Yes			
Cycle length	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Phase splits	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Offset	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Offset reference point	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Force mode	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Exhibit 4. Example Problem 1: Signal Control

Other Data												
Input Data Element	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
	L	T	R	L	T	R	L	T	R	L	T	R
Analysis period duration	0.25											
Speed limit	35	35	35	35	35	35	35	35	35	35	35	35
Stop-line detector length and detection mode	Pres 40	Pres 40		Pres 40	Pres 40		Pres 40	Pres 40		Pres 40	Pres 40	
Area type	CBD											

Exhibit 5. Example Problem 1: Other Data

The intersection is located in a central business district–type environment. Adjacent signals are somewhat distant so the intersection is operated by using fully actuated control. Vehicle arrivals to each approach are characterized as "random" and are described by using a platoon ratio of 1.0.

The left-turn movements on the north–south street operate under protected permitted control and lead the opposing through movements (i.e., a lead–lead phase sequence). The left-turn movements on the east–west street operate as permitted.

All intersection approaches have a 200-ft left-turn bay, an exclusive through lane, and a shared through and right-turn lane. The average width of the traffic lanes on the east–west street is 10 ft. The average width of the traffic lanes on the north–south street is 12 ft.

Crosswalks are provided on each intersection leg. A two-way flow rate of 120 p/h is estimated to use each of the east–west crosswalks and a two-way flow rate of 40 p/h is estimated to use each of the north–south crosswalks.
On-street parking is present on the east–west street. It is estimated that parking maneuvers on each intersection approach occur at a rate of 5 maneuvers/h during the analysis period.

The speed limit is 35 mi/h on each intersection approach. The analysis period is 0.25 h. There is no initial queue for any movement.

As noted in the next section, none of the lane groups at the intersection has two or more exclusive lanes. For this reason, the saturation flow rate adjustment factor for lane utilization is equal to 1.0 for all approaches. Any unequal lane use that may occur due to the shared through and right-turn lane groups will be accounted for in the lane group flow rate calculation, as described in the subsection titled "Lane Group Flow Rate on Multiple-Lane Approaches" of Section 2.

Outline of Solution

The solution will follow the steps described in Exhibit 19-18 of Chapter 19 and repeated here.

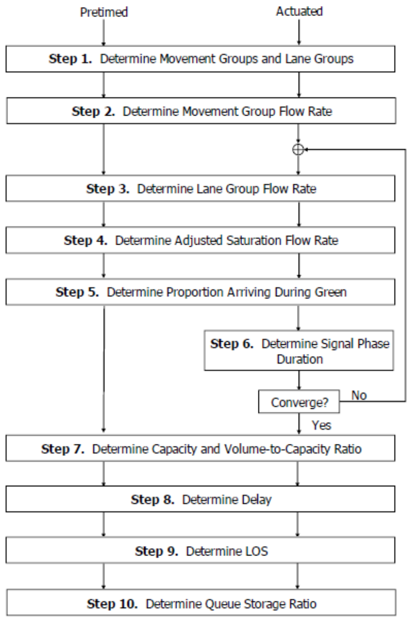

Exhibit 6. Operational Analysis Methodology (from Exhibit 19-18)

Step 1. Determine movement groups and lane groups.

The LT lanes are designated as separate movement groups, as per the rules described in Chapter 19 (page 19.42). The TH and TH/RT lanes are combined into one movement group on each approach. The movement group designations are shown in Exhibit 7 with brackets showing how the individual movements are combined into groups.

Each lane will be analyzed as a separate lane group, as per the rules in Chapter 19 (page 19.42). The lane group designations are shown in Exhibit 8 with brackets showing how the individual lanes are combined into groups.

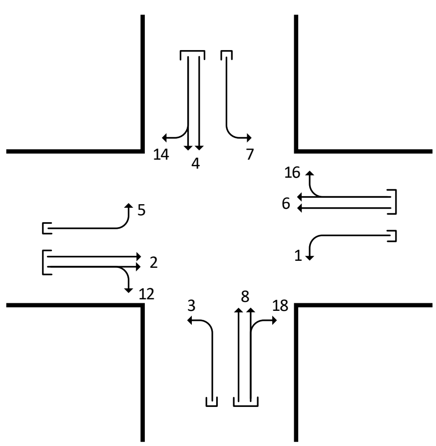

Exhibit 7. Movement groups

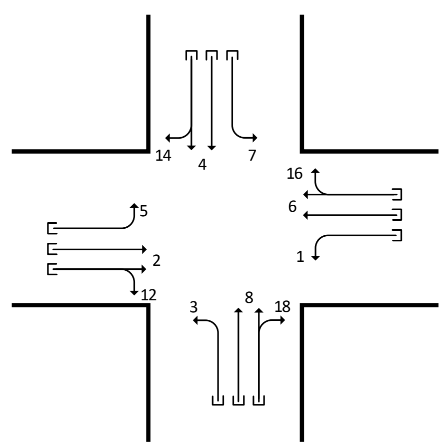

Exhibit 8. Lane groups

Step 2. Determine movement group flow rate.
Based on the movement groups identified in Exhibit 7, the movement group flow rates are shown in Exhibit 9.

Input Data Element	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Movement	L	T+R	L	T+R	L	T+R	L	T+R
Movement group flow rate	71	318+106=424	118	600+24=624	133	1644+89=1733	194	933+78=1011

Exhibit 9. Movement group flow rates

Step 3. Determine lane group flow rate.
Since there is one shared lane and two or more lanes on each approach, the lane group flow rates for the TH and RT movements are computed by the procedures in Chapter 31 (see pp 31.22-31.29, "Lane Group Flow Rate on Multiple-Lane Approaches"). The result of these calculations, which show the predicted flow rates for the TH lane and the shared TH-RT lane, are given in Exhibit 10. The LT volumes remain unchanged from Exhibit 9 as the movement groups and the lane groups are the same for the LT lanes.

Input Data Element	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
	L	T	T+R	L	T	T+R	L	T	T+R	L	T	T+R
Lane group flow rate	71	224	200	118	316	309	133	870	863	194	513	498

Exhibit 10. Lane group flow rates

Step 4. Determine adjusted saturation flow rate
The base saturation flow rate is 1900 vehicles per hour per lane for each lane group. Adjustments are made to each of the movements as summarized in the bullet list below.

- The LT movements for the EB and WB approaches operate with permitted LT control. The saturation flow rate of a permitted LT movement (s_P) is determined using Equation 31.99.
- The parking adjustment factor (f_P) is applied to the RT movements for the EB and WB approaches.
- The heavy vehicle adjustment factor (f_{HV}) and the area adjustment factor (f_a) are applied to each of the movements.

The adjusted saturation flow rate for each movement is shown in Exhibit 11.

Saturation Flow Rates	**Eastbound**			**Westbound**			**Northbound**			**Southbound**		
	L	T	T+R	L	T	T+R	L	T	T+R	L	T	T+R
Base saturation flow rate, s_o	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Permitted left turn saturation flow rate, s_p	692			814								
Left turn adjustment factor, f_{LT}	.952			.952			.952			.952		
Heavy vehicle adjustment factor, f_{HV}	.952	.952	.952	.952	.952	.952	.980	.980	.980	.980	.980	.980
Parking adjustment factor, f_p			.875			.875						
Bike-ped adjustment factor, f_{pb}	.992		.878	.971		.878	1.000		.976	1.000		.977
Area adjustment factor, f_a	.900	.900	.900	.900	.900	.900	.900	.900	.900	.900	.900	.900
Lane utilization adjustment factor, f_{LU}	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Adjusted saturation flow rate, s	692	1692	1380	814	1629	1587	1597	1677	1642	1597	1677	1625
Adjusted saturation flow rate, s (MK check)		1628	1251			1251			1636			1637

Exhibit 11. Adjustment saturation flow rates

Step 6. Determine signal phase duration.
The duration of each signal phase is determined using the procedure in Chapter 31 for actuated control (pp 31.2-31.22). The results of this iterative process are shown in Exhibit 12. The resulting cycle length is 99.1 sec.

Phase Parameter Elements (Ch 31)	Eastbound	Westbound	Northbound		Southbound	
Movement	LTR	LTR	L	TR	L	TR
Phase	2	6	3	8	7	4
Phase duration	34.0	34.0	10.2	54.0	13.9	57.7
Maximum allowable headway	3.4	3.4	3.1	3.1	3.1	3.1
g_s	31.1	29.5	6.2	52.0	9.6	23.3
g_e	0.0	0.2	0.2	0.0	0.3	7.8
Phase call probability	1.00	1.00	0.98	1.00	1.00	1.00
Max out probability	1.00	1.00	0.0	1.00	0.0	0.18

Exhibit 12. Signal phase duration

Step 5. Determine proportion arriving on green

The proportion arriving on green P is computed using equation 19.5. C is estimated using the results from Step 6.

	Eastbound			Westbound			Northbound			Southbound		
	L	T	T+R	L	T	T+R	L	T	T+R	L	T	T+R
Effective green, $g = g_s + g_e + e$	34.0	34.0	34.0	34.0	34.0	34.0	8.4	54.0	54.0	11.9	31.1	31.1
Effective green ratio, g/C	.34	.34	.34	.34	.34	.34	.08	.54	.54	.12	.31	.31
Proportion arriving on green, P (MK)	.34	.34	.34	.34	.34	.34	.08	.54	.54	.12	.31	.31
Proportion arriving on green, P (Engine)	.296	.296	.296	.296	.296	.296	.060	.504	.504	0	.523	.523

Exhibit 13. Proportion arriving on green (HCS results for signal phase duration)

Step 7. Determine capacity and volume-capacity ratio.

The capacity of each movement group is computed using equation 19.6. The results for capacity and volume-capacity ratio are shown in Exhibit 14. [Check movement group usage]

Lane Group Results for Capacity	Eastbound			Westbound			Northbound			Southbound		
	L	T	T+R	L	T	T+R	L	T	T+R	L	T	T+R
Volume	71	240	184	118	337	287	133	928	805	194	548	463
Saturation flow rate	692	1629	1380	814	1629	1587	1597	1677	1642	1597	1677	1625
Green ratio, g/C	0.23	0.30	0.30	0.27	0.30	0.30	0.20	0.50	0.50	0.12	0.52	0.52
Capacity	160	482	408	216	482	469	325	846	828	198	877	850
Volume-capacity ratio, X	0.45	0.47	0.49	0.55	0.66	0.66	0.41	1.03	1.03	0.98	0.59	0.59

Exhibit 14. Capacity and volume-capacity ratio

Step 8. Determine Delay

The control delay for each movement and approach, and for the intersection as a whole, is calculated using the method described on pages 19.49-19.54. The results are shown in Exhibit 15.

Lane Group Results for Delay	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
Uniform delay, d_1	42.2	28.5	28.7	39.3	30.5	30.5	12.7	24.6	24.6	32.5	16.3	16.3
Incremental delay, d_2	0.7	0.3	0.4	1.4	2.4	2.5	0.3	38.6	42.8	0.0	0.7	0.7
Initial queue delay, d_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control delay, d	42.9	28.1	29.1	40.7	32.8	33.0	13.1	63.1	67.3	32.5	16.9	17.0
Approach delay, d_A	30.9 (D)			34.2 (D)			61.5 (F)			19.5 (C)		
Intersection delay, d_i	71.7 (E)											

Exhibit 15. Delay calculations

Step 9. Determine LOS

The level of service is based on the control delay. The levels of service for each approach and for the entire intersection are shown in Exhibit 15. The determination of LOS is described on pages 19.13-19.15.

Step 10. Determine queue storage ratio

The back of queue size and queue storage ratio are calculated as described on pages 31.63-31.77. The results are shown in Exhibit 16.

HCS Results	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
Back of queue	1.7	4.3	3.8	2.9	6.7	6.6	1.3	27.1	27.5	5.1	7.6	7.4
Queue storage ratio	0.22	0.11	0.10	0.36	0.17	0.17	0.17	0.69	0.70	0.65	0.19	0.18

Exhibit 16. Queue storage ratio calculations

Queue Accumulation Polygon

The queue accumulation polygon is a useful way of illustrating the signal timing and operation of a signalized intersection. The variables needed to construct the QAP for the NBTH movement are given in Exhibit 17. The QAP for this movement is shown in Exhibit 18 .

Volume, v	928
Saturation flow rate, s	1677
Cycle length, C	99.1
Effective green, g	52.0
Effective red, r	47.1
Queue service time, g_s	52.0
Extension of effective green, g_e	0.0
Queue length at end of effective red, Q_r	1.9

Exhibit 17. Calculations for construction of QAP

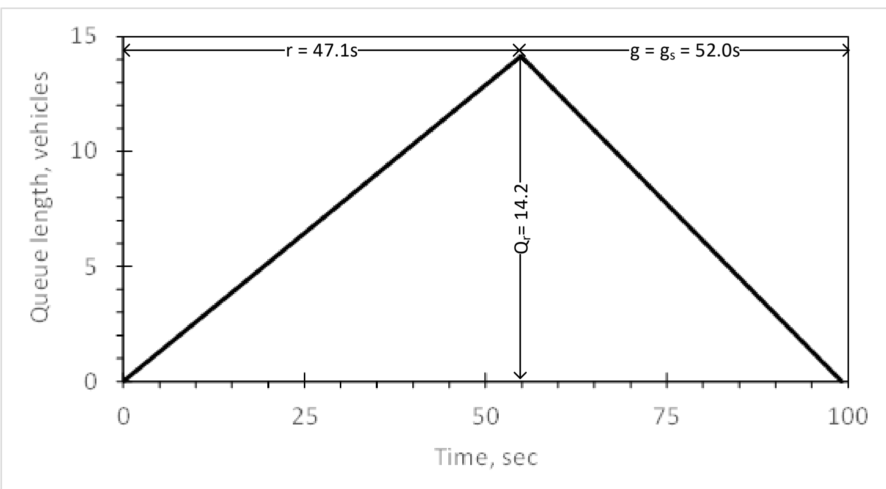

Exhibit 18. QAP for NBTH movement

Recommendation #5a: Establish a "value added test" that determines whether a proposed new sub-model or adjustment factor enhances the final results of an analysis.

Recommendation #5b: Review all components of the chapter to determine whether they meet the "value added test".

- Define "value added" of each method component. How to define this. Example from TWSC/upstream signal work. Planning method: protected plus permitted operations.
- Future vision: contractor should focus on exercising computational process to test "value" of component, and to illustrate application for various problem types.