Potential Accuracy of a Planning Application for the HCM Signalized Intersection Operational Procedure

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The *Highway Capacity Manual* signalized intersection planning procedure uses limited data to identify overcapacity situations. However, the planning procedure lacks an indication for level of service. The signalized intersection operational procedure requires a large amount of data but identifies flow to capacity (v/c) ratios, delay, and level of service. A planning application of the operational procedure, using the same inputs as the present planning procedure, has been suggested. The application would require a large number of default values for inputs along with a method to develop a surrogate signal timing plan. The potential accuracy of such a planning application of the operational procedure was examined through applications to morning and evening peak-period data from 40 intersections in Missouri. The default values for adjustment factors performed well. Whereas the default values generally led to an underestimation of capacity, there was still a strong relationship for the v/c and level of service results derived from the default versus the actual adjustment factors. The surrogate signal timing algorithm performed adequately. There was a reasonably consistent relationship for the results generated by the surrogate signal timings compared with the results from the actual signal timings. A planning application of the operational procedure would be a valuable asset for planning and design analyses of intersections similar to those studied here. The application should encourage agencies to calibrate typical values for such variables as saturation flow rate, peak-hour factor, percent trucks, and pedestrian volumes. For consistency, the application should use a signal timing algorithm that at least approximates the best level of service to be expected from the intersection. The application's estimates of v/c, delay, and level of service would be valuable additions to the planning and design processes.

The *Highway Capacity Manual* (HCM) planning procedure for signalized intersections (*1*) has been criticized for lacking an indication for level of service. It has been suggested that the HCM operational procedure, which does predict level of service, could be modified to be used with only planning-level information. The purpose of this study was to examine how accurately a planning application of the operational procedure could predict the outcome of a more data-intensive operational analysis for a variety of signalized intersections.

BACKGROUND

The HCM uses three levels of analysis for traffic facilities: planning, design, and operational. Planning procedures use limited information at the earliest stages of planning to provide rough estimates of the number of lanes required. Design procedures more accurately estimate the needed number of lanes through the use of detailed data on expected traffic volumes and characteristics. Operational procedures are the most detailed and flexible of the analysis approaches. Known or projected traffic demands and characteristics are compared with known or projected highway characteristics to estimate the expected level of service.

The HCM contains a planning procedure and an operational procedure for the analysis of signalized intersections. The two procedures approach the analysis of signalized intersections in vastly different ways.

Operational Procedure for Signalized Intersections

Operational analysis requires detailed data on roughly 20 types of information relating to prevailing traffic, roadway, and signalization conditions. The procedure considers service flow rates on intersection approaches, the signalization plan, quality of signal progression, geometric design, and the resulting delay. Level of service is determined by the average delay.

As shown in Figure 1, the operational methodology can be applied to solve for a variety of variables.

1. Level of service can be determined from the details of traffic demand, geometrics, and signalization (Figure 1a).
2. Allowable service flow rates (allowable demand) can be determined from geometric and signalization conditions (also through the sequence in Figure 1a).
3. A reasonable signal timing (for an assumed phase plan) can be determined from information on flows and geometrics (Figure 1b).
4. The number and directional designations of lanes can be determined for a desired level of service and the details of flows and signalization. This is the design application (Figure 1c).

The operational procedure was developed to solve directly for level of service (the first application). This use also yields flow to capacity (v/c) ratios for each lane group, the delay for each lane group, the critical v/c for the intersection, and the average delay for the intersection. The other applications can require more than one pass through the procedure.

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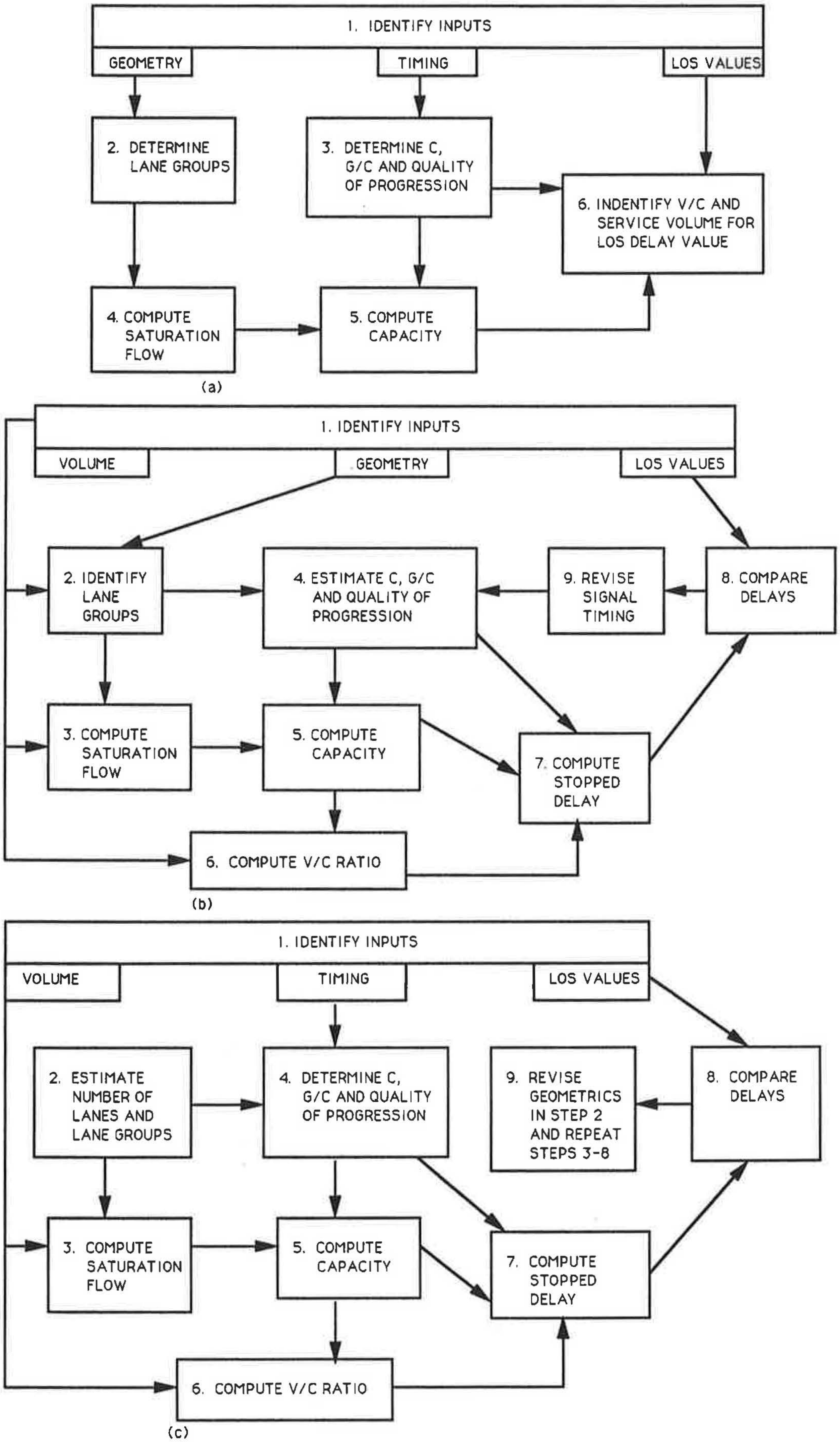

FIGURE 1 Alternative computation using operational analysis (*1*): (*a*), determining v/c ratios and service flow rates; (*b*), determining signal timing; and (*c*), determining number of lanes.

Planning Procedure for Signalized Intersections

The signalized intersection planning procedure is generally used when the detailed information required to estimate delay is not available. The planning procedure uses only the hourly traffic volumes and the number and directional designation of lanes. The method provides a determination that the intersection will be under, near, or over capacity. Since delay is not estimated, no level of service determination is made. Calculations are simple and are typically performed manually.

Highway Capacity Software

The operational procedure is generally performed on a microcomputer. The Highway Capacity Software (HCS) was developed for FHWA (*2*) and, as with a variety of similar software packages, can provide for data inputs and outputs within a matter of minutes if the analyst has the traffic, geometric, and signal timing data in hand. The HCS outputs v/c, delay, and level of service through a procedure similar to Figure 1a. Many of the HCS data inputs have default values that can be used if the actual values are unavailable. Some of the default values are recommended by the HCM. Some default values differ from or are in addition to the HCM recommendations. Default values are not available for traffic volumes, lane directional designation, and traffic signal timing plans.

It has been suggested that, since default values are available for most of the inputs, the addition of an algorithm to generate a reasonable signal timing plan would allow an HCS-type package to serve as a planning application of the operational procedure. The analyst would input only the traffic volumes, the number of lanes, and the directional designation of lanes. The software could then provide the expected level of service, critical v/c ratio, and associated measures. In other words, the same limited input data could be used to provide information that is more useful.

TABLE 1 Input Data for Operational Analysis

Type of Condition	Parameter	Study Default Value
Geometric	Area type	non-CBD *
	Number of lanes	_____
	Lane width	12 ft. *
	Approach grades	0% *
	Existence of exclusive LT or RT lanes	-----
	Parking allowed (yes or no)	no
Traffic	Volumes by movement	_____
	Peak hour factor	0.9
	Percent heavy vehicles	2%
	Conflicting pedestrian flow rate	50 peds./hr. (low)
	Number of local buses stopping	0 buses/hr.
	Number of parking maneuvers	0 man./hr.
	Quality of progression	Type 3
Signal	Cycle length (40 to 120 sec.)	_____
	Green times for each phase	_____
	Actuated vs. Pretimed	_____
	Pedestrian push button	no *
	Minimum pedestrian green	(not used)
	Phase plan	_____

* Indicates a default value used in this study which differs from the HCM default value or for which there is no HCM recommended default value.

RESEARCH APPROACH

Traffic data from signalized intersections in one large city and three smaller cities were provided by the Missouri Highway and Transportation Department (MHTD). The large-city data, for suburban St. Louis (population 450,000; 19 intersections) were from widely dispersed locations. The three smaller cities, all in central Missouri, were Columbia (population 68,000, nine intersections), Jefferson City (population 35,000, six intersections), and Sedalia (population 20,000, six intersections).

MHTD provided a recent turning movement count (actual 15-min turning movements as opposed to approach or demand volumes), a phasing timing sheet, and an intersection sketch for each location. The geometric and signal timing information were generally complete. Bus stops and on-street parking were generally not present.

The intent of the analysis was to determine how well the default data input values and a default signal timing algorithm could serve in a planning application of the operational procedure. Operational analysis calculations for v/c, delay, and level of service were performed to compare the use of default adjustment factors with the actual adjustment factors and the use of the signal timing algorithm with the actual timing.

Default Values Used in Planning Application of Operational Analysis

The default values used include some suggested by the HCM and some deemed appropriate after review of the intersections under study. The default values for geometric and traffic data are given in Table 1.

Signal Timing Rules

The default timings were based solely on peak-hour volumes and the number and designation of lanes. The HCM planning procedure was used to generate volume per lane. The rules used for the traffic signal timing are as follows:

1. If the left-turn volume on either direction of a street exceeded 100 vph, then left turns were protected. The ring concept (*3*) was then used for phasing.
2. The assumed saturation flow rate, including a consideration for a typical peak-hour factor, was 1,600 vphgpl.
3. Cycle length was found by setting the critical v/c ratio equal to 0.9, subject to the constraint that the cycle length must be between 40 and 120 sec. Green time was allocated in proportion to the volumes on the critical movements.
4. Streets with a single lane approach received a single phase.
5. Lost time equaled 3 sec per phase.

DATA

Tables 2 through 7 summarize the results of the operational analysis applications for each intersection. The results include the critical v/c for the intersection and the indicated level of service. The HCM delay equation is not recommended for a v/c ratio more than 1.2. If any lane group had a v/c ratio greater than 1.2, no intersection delay measure was calculated by the HCS.

All pretimed signals were analyzed in four ways:

1. Existing geometric and traffic conditions and existing signal timing (actual adjustment factors/actual timing or AAF/AT)—all adjustments for volume and saturation flow rate represent the appropriate HCM factors for the geometric and traffic demand conditions present. The existing signal timing plan was also used in the analysis.
2. Default geometric and traffic conditions and existing signal timing (default adjustment factors/actual timing of DAF/AT)—all adjustment factors were derived from Table 1.
3. Existing geometric and traffic conditions and signal timing from timing algorithm (actual adjustment factors/default timing or AAF/DT)—HCM adjustment factors were used for adjusting for geometrics and traffic demand characteristics. The algorithm described in the previous section was used to generate the signal timing plan.
4. Default geometric and traffic conditions and signal timing from timing algorithm (default adjustment factors/default timing or DAF/DT).

The average signal timings of the actuated signals were estimated by a method modeled after that recommended by Chapter 9, Appendix I of the HCM. The actual and default signal timings therefore did not differ for the actuated signals. The only actuated signal comparison is between actual geometric and traffic demand characteristics and default geometric and traffic demand characteristics (Tables 6 and 7).

ANALYSIS

Tables 8 through 11 compare the level of service derived for the actual geometric, traffic demand, and signal timing data with level of service derived from the other three approaches. Tables 8 and 11 indicate that the use of default geometric and traffic variables generally led to an equal or poorer level of service than that derived from the analysis of actual conditions. On the other hand, use of the traffic signal algorithm often led to a better level of service than that derived from the actual timing (see Table 9). The results were mixed when default adjustment factors and the default signal timings were both applied (see Table 10). In general, the smaller city intersections in mid-Missouri had indications of better performance with the use of all defaults. Intersections in suburban St. Louis had poorer levels of service with all defaults than with the actual geometric, traffic, and signalization conditions.

One unexpected result was the high number of instances when the critical v/c for the intersection exceeded unity (see Table 12). The traffic volumes used were actual throughput volumes rather than approach or demand volumes. If the operational procedure was completely correct, none of the intersections should have v/c ratios greater than 1.0. The likely reasons for this inconsistency include the following:

1. The actual saturation flow rates were higher than those estimated in the procedure. The default value of 1,800 pas-

TABLE 2 Critical v/c and LOS for St. Louis A.M. (SLAM) Peak

PRETIMED SIGNALS								
Intersection #	Critical v/c				Intersection LOS			
	AAF/AT	DAF/AT	AAF/DT	DAF/DT	AAF/AT	DAF/AT	AAF/DT	DAF/DT
SLAM01	0.422	0.431	0.517	0.548	B	B	B	B
SLAM04	1.225	1.439	1.179	1.295	*	*	*	*
SLAM05	1.198	1.458	0.803	0.844	*	*	*	*
SLAM06	0.819	1.017	0.856	1.089	C	*	D	*
SLAM07	0.915	0.924	0.858	0.870	*	*	C	*
SLAM09	0.852	0.878	0.902	0.938	B	B	B	*
SLAM10	1.225	1.257	1.151	1.191	*	*	F	*
SLAM11	1.126	1.202	1.207	1.091	*	*	D	*
SLAM12	1.182	1.399	1.149	1.375	*	*	*	*
SLAM13	0.681	0.681	0.970	1.153	*	*	D	*
SLAM14	1.165	1.148	1.192	1.183	*	*	*	*
SLAM15	0.481	0.596	0.652	0.740	*	*	B	C
SLAM16	0.726	0.832	0.927	1.052	*	*	C	E
SLAM17	0.505	0.590	0.596	0.696	D	*	B	B
SLAM18	0.498	0.627	0.541	0.679	B	B	B	B
SLAM19	0.940	0.943	0.967	0.971	*	*	E	E

AAF/AT: Actual adjustment factors/actual timing
DAF/AT: Default adjustment factors/actual timing
AAF/DT: Actual adjustment factors/default timing
DAF/DT: Default adjustment factors/default timing

TABLE 3 Critical v/c and LOS for St. Louis P.M. (SLPM) Peak

PRETIMED SIGNALS								
Intersection #	Critical v/c				Intersection LOS			
	AAF/AT	DAF/AT	AAF/DT	DAF/DT	AAF/AT	DAF/AT	AAF/DT	DAF/DT
SLPM01	0.550	0.602	0.818	0.904	C	C	C	C
SLPM04	-	-	-	-	-	-	-	-
SLPM05	1.309	1.588	0.954	1.104	*	*	*	*
SLPM06	0.784	1.031	1.010	1.298	C	*	D	*
SLPM07	0.694	0.759	0.802	0.869	C	C	B	*
SLPM09	0.902	0.940	1.020	1.058	*	*	D	*
SLPM10	1.688	1.812	1.444	1.450	*	*	*	*
SLPM11	1.309	1.452	1.271	1.380	*	*	*	*
SLPM12	1.007	0.998	0.976	1.050	*	*	*	*
SLPM13	0.650	0.669	0.878	0.865	*	*	E	*
SLPM14	-	-	-	-	-	-	-	-
SLPM15	0.730	0.855	1.112	1.249	*	*	F	*
SLPM16	0.800	0.927	0.785	1.110	*	*	D	F
SLPM17	0.392	0.456	0.413	0.479	C	*	D	*
SLPM18	0.473	0.583	0.501	0.614	B	B	B	B
SLPM19	0.936	1.022	1.213	1.325	*	*	*	*

AAF/AT: Actual adjustment factors/actual timing.
DAF/AT: Default adjustment factors/actual timing.
AAF/DT: Actual adjustment factors/default timing.
DAF/DT: Default adjustment factors/default timing.

TABLE 4 Critical v/c and LOS for Mid-Missouri A.M. (MMAM) Peak

PRETIMED SIGNALS								
Intersection #	Critical v/c				Intersection LOS			
	AAF/AT	DAF/AT	AAF/DT	DAF/DT	AAF/AT	DAF/AT	AAF/DT	DAF/DT
MMAM01	0.601	0.598	0.691	0.695	B	B	B	B
MMAM02	0.830	0.727	0.734	0.590	D	D	B	B
MMAM03	0.947	1.134	0.960	1.154	*	*	D	*
MMAM04	0.648	0.686	0.742	0.785	B	B	B	B
MMAM06	0.830	0.903	0.639	0.598	*	*	E	*
MMAM07	0.771	0.785	0.701	0.722	*	*	B	B
MMAM08	0.389	0.390	0.696	0.714	*	*	B	B
MMAM09	0.705	0.688	0.716	0.698	D	D	B	B
MMAM14	0.484	0.559	0.474	0.560	B	B	B	B
MMAM16	0.491	0.524	0.645	0.687	C	C	B	B
MMAM17	1.606	1.295	1.516	1.223	*	*	*	*
MMAM18	0.473	0.453	0.641	0.630	B	B	B	B
MMAM19	0.829	0.647	0.892	0.696	*	C	C	B
MMAM20	0.698	0.670	0.842	0.874	B	C	C	C
MMAM21	0.764	0.711	0.518	0.488	*	*	B	B

AAF/AT: Actual adjustment factors/actual timing.
DAF/AT: Default adjustment factors/actual timing.
AAF/DT: Actual adjustment factors/default timing.
DAF/DT: Default adjustment factors/default timing.

TABLE 5 Critical v/c and LOS for Mid-Missouri P.M. (MMPM) Peak

PRETIMED SIGNALS								
Intersection #	Critical v/c				Intersection LOS			
	AAF/AT	DAF/AT	AAF/DT	DAF/DT	AAF/AT	DAF/AT	AAF/DT	DAF/DT
MMPM01	1.448	1.361	0.915	1.039	*	*	B	D
MMPM02	0.814	0.892	0.778	0.801	E	E	C	D
MMPM03	0.778	1.017	0.827	1.083	B	D	C	*
MMPM04	0.787	0.785	0.967	0.965	C	C	C	*
MMOM06	0.871	0.881	0.879	0.838	C	*	E	*
MMPM07	0.539	0.598	0.725	0.796	*	*	B	B
MMPM08	0.438	0.539	0.785	0.850	*	*	B	B
MMPM09	0.675	0.802	0.748	0.882	C	*	A	B
MMPM14	0.601	0.723	0.710	0.831	C	C	B	B
MMPM16	0.475	0.575	0.564	0.687	C	C	B	B
MMPM17	1.630	1.553	1.594	1.518	*	*	*	*
MMPM18	0.594	0.606	0.883	1.616	B	B	C	C
MMPM19	1.197	0.778	1.067	0.934	*	*	E	C
MMPM20	0.724	0.950	0.876	1.085	C	*	C	*
MMPM21	0.757	0.828	0.708	0.763	*	*	E	E

AAF/AT: Actual adjustment factors/actual timing.
DAF/AT: Default adjustment factors/actual timing.
AAF/DT: Actual adjustment factors/default timing.
DAF/DT: Default adjustment factors/default timing.

TABLE 6 Critical v/c and LOS for St. Louis A.M. and P.M. Peaks

ACTUATED SIGNALS				
Intersection #	Critical v/c		Intersection LOS	
	AAF/AT	DAF/AT	AAF/AT	DAF/AT
SLAM02	1.076	1.133	F	*
SLAM03	0.929	0.996	D	E
SLAM08	0.507	0.532	A	A
SLPM02	1.239	1.411	*	*
SLPM03	1.072	1.110	E	F
SLPM08	0.804	0.879	B	*

AAF/AT: Actual adjustment factors/actual timing.
DAF/AT: Default adjustment factors/actual timing.

TABLE 7 Critical v/c and LOS for Mid-Missouri A.M. and P.M. Peaks

ACTUATED SIGNALS				
Intersection #	Critical v/c		Intersection LOS	
	AAF/AT	DAF/AT	AAF/AT	DAF/AT
MMAM05	1.005	0.835	*	*
MM1M10	0.630	0.693	B	B
MMAM11	0.452	0.467	B	B
MMAM12	0.642	0.639	B	B
MMAM13	0.450	0.450	B	B
MMAM15	0.418	0.426	A	A
MMPM05	0.697	0.757	B	C
MMPM10	0.917	0.999	D	D
MMPM11	1.040	1.080	C	D
MMPM12	0.642	0.602	B	B
MMPM13	0.525	0.601	B	B
MMPM15	0.514	0.615	B	B

AAF/AT: Actual adjustment factors/actual timing.
DAF/AT: Default adjustment factors/actual timing.

TABLE 8 Accuracy of Level of Service Prediction Using Default Adjustment Factors and Actual Timing

Actual Adjustment Factors/ Actual Timing	Prediction for St. Louis A.M.						
	A	B	C	D	E	F	*
A							
B		3					
C							1
D							1
E							
F							
*							11

Actual Adjustment Factors/ Actual Timing	Prediction for St. Louis P.M.						
	A	B	C	D	E	F	*
A							
B		1					
C			2				2
D							
E							
F							
*							9

Actual Adjustment Factors/ Actual Timing	Prediction for Mid Missouri A.M.						
	A	B	C	D	E	F	*
A							
B		4	1				
C			1				1
D				2			
E							
F							
*							6

Actual Adjustment Factors/ Actual Timing	Prediction for Mid-Missouri P.M.						
	A	B	C	D	E	F	*
A							
B		1		1			
C			3				3
D							
E					1		
F							
*							6

senger cars per hour of green per lane was used in all of the analyses. The HCM recommends that agencies calibrate saturation flow rates appropriate for the intersections within their jurisdictions.

2. Right-turns-on-red may have lessened the demand for green time in right-turn-only lanes or in shared lanes with right turns. The HCM does not include a procedure for dealing with right-turns-on-red. The HCS allows the analyst to subtract right-turn-on-red volumes from the traffic demand. No such adjustments were made in this study even though several lane groups with right turns were identified as critical.

Another unexpected result was the high number of situations where at least one lane group had a v/c greater than 1.2 (and hence no indication for level of service). In several cases realistic estimates of saturation flow rates or right-turns-on-red would probably have eliminated this problem. In some cases a left-turn lane group with low demand but an even lower capacity had a very high v/c ratio. Many of these intersections may in fact have been operating reasonably well.

Table 13 gives linear regression equations derived by predicting actual v/c ratios by each of the three approaches. If a set of predicted v/c ratios had been perfect, the regression equation would have a slope of one and an intercept of zero.

Default Adjustment Factors

Parts A and D of Table 13 indicate that the v/c ratios predicted by using default values for the HCM adjustment factors are closely related to the v/c ratios derived from the actual adjustment factors (the correlation was significant at the 1 percent level in all cases). In Part D each signal's timing was derived from the raw traffic data and the HCM Chapter 9, Appendix II method for actuated signals. For the data of Part A, the actual signal timing was used. For both Parts A and D, only the adjustment factor values differed.

In St. Louis the use of default adjustment factors led to an average 10.7 percent overestimation of v/c. In mid-Missouri the average overestimation of v/c was only 3.9 percent. The average peak-hour factor in St. Louis was 0.93 and in mid-Missouri was 0.87. If the average peak-hour factors for these two areas had been used, the St. Louis data would have an average v/c overestimation of 7.1 percent, and the mid-Missouri data would have an average v/c overestimation of 7.8 percent. These overestimations would be primarily due to lane width and pedestrian flows. In many instances lanes, particularly left-turn lanes, had less than the default 12-ft width. The pedestrian flows were generally far below the default value of 50 pedestrians per hour using each crosswalk.

TABLE 9 Accuracy of Level of Service Prediction Using Actual Adjustment Factors and Default Timing

Prediction for St. Louis A.M.

Actual Adjustment Factors/ Actual Timing	A	B	C	D	E	F	*
A							
B		3					
C				1			
D		1					
E							
F							
*		1	2	2	1	1	4

Prediction for St. Louis P.M.

Actual Adjustment Factors/ Actual Timing	A	B	C	D	E	F	*
A							
B		1					
C		1	1	2			
D							
E							
F							
*				2	1	1	5

Prediction for Mid Missouri A.M.

Actual Adjustment Factors/ Actual Timing	A	B	C	D	E	F	*
A							
B		4	1				
C		1					
D		2					
E							
F							
*		3	1	1	1		1

Prediction for Mid-Missouri P.M.

Actual Adjustment Factors/ Actual Timing	A	B	C	D	E	F	*
A							
B			2				
C	1	2	2		1		
D							
E			1				
F							
*		3			2		1

Signal Timing Algorithm

Part B of Table 13 reflects use of the signal timing algorithm to predict the v/c derived from the actual signal timing. The actual adjustment factors were used in all cases. Whereas all correlations were significant at the 0.01 level, the correlation coefficients were not as high as those of Part A of Table 13.

In general the signal timing algorithm predicted the actual v/c well. However, a noticeable number of predictions differed significantly from the actual v/c, both through underestimation and overestimation of the v/c.

An algorithm to minimize the critical v/c for the intersection might have been used in place of the algorithm used in this study. One would assume that in that case the predicted v/c would never be greater than the actual v/c.

For planning purposes there is an obvious advantage to using an algorithm that would accurately predict the signal timing used in the field. One can envision that, if this had been the case, the r^2 for Part B of Table 13 would be closer to 1.

Default Adjustment Factors and Signal Timing Algorithm

Part C of Table 13 shows how well the use of both the default adjustment factors and the default signal timing predicted the actual v/c. Three of the correlations were significant at the 0.01 level and the fourth, mid-Missouri p.m. peak data, was significant at the 0.05 level.

For the St. Louis data the predicted v/c ratios were generally too high. For the mid-Missouri a.m. data the regression equation had a slope close to one and passed near the origin. However, the spread of the data from the curve was fairly large. For the mid-Missouri p.m. data, the regression curve differed markedly from a slope of one. Whereas the judicious removal of one or two data points could make the slope close to one, the remaining data points would still be far from a perfect fit to the ideal relationship.

RECOMMENDATIONS

Default Values

The worth of the default values used in a planning application of the operational procedure can be measured by how well the default values represent the actual values. When the actual signal timing plan was used, the v/c ratios derived from the default adjustment factors had a high correlation with the v/c ratios derived for the actual conditions. However, the predicted v/c ratios derived from default adjustment factors were generally too high. Similarly, the predicted level of service was often poorer than that for actual conditions.

TABLE 10 Accuracy of Level of Service Prediction Using Default Adjustment Factors and Default Timing

Actual Adjustment Factors/ Actual Timing	Prediction for St. Louis A.M.						
	A	B	C	D	E	F	*
A							
B		2					1
C							1
D		1					
E							
F							
*			1		2		8

Actual Adjustment Factors/ Actual Timing	Prediction for St. Louis P.M.						
	A	B	C	D	E	F	*
A							
B		1					
C			1				3
D							
E							
F							
*						1	8

Actual Adjustment Factors/ Actual Timing	Prediction for Mid Missouri A.M.						
	A	B	C	D	E	F	*
A							
B		4	1				
C		1					
D		2					
E							
F							
*		4					3

Actual Adjustment Factors/ Actual Timing	Prediction for Mid-Missouri P.M.						
	A	B	C	D	E	F	*
A							
B			1				1
C		3					3
D							
E				1			
F							
*		2	1	1	1		1

TABLE 11 Accuracy of Level of Service Prediction Using Default Adjustment Factors for Actuated Signals

Actual Adjustment Factors/ Actual Timing	Prediction for St. Louis AM & PM						
	A	B	C	D	E	F	*
A	1						
B							1
C							
D					1		
E							
F					1		1
*							1

Actual Adjustment Factors/ Actual Timing	Prediction for Mid Missouri AM & PM						
	A	B	C	D	E	F	*
A	1						
B		7	1				
C				1			
D				1			
E							
F							
*							1

TABLE 12 Categories of Intersection Critical v/c Ratios Resulting from Use of Actual Timing and Adjustment Factors

	Number of Intersections with Critical v/c		
	v/c < 1	1 < v/c < 1.2	v/c > 1.2
St. Louis	23	8	5
Mid-Missouri	36	3	3

TABLE 13 Regression Equations Derived from Using Predicted v/c Ratios To Estimate Actual v/c Ratios

How "x" Was Derived	Location[a]	Regression Equation[b]	r^2
A. Using Default Ajustment Factors with Actual Signal Timing	SL a.m.	y= 0.040 + 0.864x	0.929
	SL p.m.	y= 0.000 + 0.893x	0.964
	MM a.m.	y=-0.057 + 1.108x	0.848
	MM p.m.	y=-0.120 + 1.096x	0.802
B. Using Actual Adjustment Factors with Default Signal Timing	SL a.m.	y=-0.135 + 1.129x	0.741
	SL p.m.	y=-0.126 + 1.060x	0.677
	MM a.m	y=-0.040 + 1.023x	0.744
	MM p.m.	y=-0.007 + 0.916x	0.635
C. Using Default Adjustment Factors with Default Signal Timing	SL a.m.	y=-0.057 + 0.946x	0.585
	SL p.m.	y=-0.150 + 0.971x	0.594
	MM a.m.	y= 0.024 + 0.963x	0.463
	MM p.m.	y= 0.273 + 0.561x	0.186
D. Using Default Adjustment Factors for Actuated Signals	SL	y= 0.061 + 0.868x	0.982
	MM	y=-0.010 + 0.986x	0.888

[a] SL = St. Louis
MM = Mid-Missouri

[b] x = predicted v/c for intersection
y = v/c for intersection derived from adjustment factors and actual signal timing.

If an area average peak-hour factor had been used, the predicted v/c ratios would have averaged about 7 to 8 percent too high for both locations. Almost all of this average difference was due to lane width and pedestrian volume differences. A traffic organization will generally have data for or a reasonable estimate of existing lane width, percent trucks, and pedestrian flows. A planning application should encourage agencies to use their own default values for these variables. Similarly, an agency should be encouraged to develop appropriate estimates for a.m. and p.m. peak hour factors.

It is likely that an agency will often not have accurate information on approach grades, number of local buses stopping, and number of parking maneuvers. The present HCM default values should be used in those cases.

Signal Timing Plan

The signal timing algorithm performed adequately for the purposes of this study by generating reasonable timing plans. The algorithm was fairly accurate in predicting the v/c and level of service derived from the actual signal timing. The algorithm would be viewed by many as too simplistic to serve as a default signal timing algorithm for a planning application of the operational procedure.

Two alternative performance measures for a signal timing algorithm are apparent. One measure would be how well the algorithm predicts the signal timing plan that would be used at the signal. The other would be how closely the algorithm comes to optimizing some objective.

MHTD allows a wide latitude to the individual responsible for developing the signal timing plan. The guidelines are such that two individuals could easily develop significantly different, yet appropriate, plans for the same intersection. Further, it is the author's understanding that many signals are retimed in the field through observation of traffic during peak periods. It is doubtful that any algorithm would consistently predict both the phase plan and the green times used at MHTD intersections. Since various traffic agencies might use a variety of means to generate signal plans, a single algorithm would probably often be unsuccessful in predicting signal timing plans for a wide variety of agencies.

Many computerized algorithms exist for timing traffic signals. It is likely that an algorithm to minimize v/c or delay could be incorporated into a planning application of the operational procedure. Since level of service is based on delay, a planning application of the operational procedure should include a signal timing procedure that either minimizes delay or comes close to that optimal solution. Such a procedure might not be the best approach for matching the actual level of service at signalized intersections. However, it would be consistent with the philosophy of the HCM that the most important measure of signalized intersection operation is delay. It also would encourage traffic agencies to view the purpose of signal timing to be the minimization of delay to the motorist.

Design

A planning application of the operational procedure is feasible. The same software could easily be used as an aid in the design of signalized intersections. At the design stage many of the input data would be available. With a reasonable signal timing algorithm incorporated into the software, an iterative design approach would be easily accomplished. A designer could examine a wide variety of alternative lane arrangements for v/c and level of service in much less than 1 hr.

Other Considerations

To gain wide acceptance, a planning application of the operational procedure must yield realistic results. The operational procedure indicated that the output volumes of many of the intersections were above the theoretical capacity. The reasons identified for these inconsistent results were higher-than-expected saturation flow rates and the lack of a method for dealing with right-turns-on-red. If these problems are not rectified, it is likely that a planning application will not receive as wide a use as possible.

A planning application should encourage agencies to calibrate saturation flow rates for their own intersections. It is likely that significant increases in accuracy would result.

An optional procedure to predict right-turns-on-red could also be beneficial. The procedure might be made available to the user when a lane group containing right turns has been identified as a critical lane group.

One difficulty in the availability of an HCM-type software package with a signal timing algorithm is that the signal timing algorithm might be viewed by some as the accepted way to time a traffic signal. The purpose of the HCM is to provide a means to measure the performance of facilities rather than to describe how traffic should be controlled. Care will be required if the planning application is not to be viewed as a guide for traffic signal timing.

CONCLUSIONS

For intersections similar to those of this study, a planning application of the HCM signalized intersection operational procedure could be practical and reasonably accurate. A planning application requires reasonable default values and a means to estimate an appropriate signal timing. Such an application can provide very accurate estimates of an intersection's critical v/c ratio and a likely estimate of achievable level of service. The only intersection-specific data required would be peak-hour volumes and lane usage.

A planning application should have the following characteristics:

1. The application should encourage an agency to develop its own appropriate estimates for peak-hour factor, percent trucks, and pedestrian volumes.
2. The application should encourage an agency to calibrate accurate estimates of ideal saturation flow rates for the intersections within its jurisdiction.
3. The application should use a signal timing algorithm that at least approximates the best level of service to be expected at the intersection.
4. Since some agencies will have more data readily available than will others, the application should allow the analyst to input site-specific values in place of default values.
5. If the application is also to serve as a design procedure, the application should provide a simple means to examine the results of changes in input data.
6. The level of accuracy for v/c and level of service predictions should be made clear to the user.
7. The signal timing algorithm should be presented as a representation of a reasonable signal timing rather than as a suggested signal timing.
8. A means to estimate the likely number of right-turns-on-red turning movements should be developed and considered for inclusion as an optional calculation for both the operational procedure and a planning application of the operational procedure.

A planning application with the above characteristics could be a useful tool for traffic engineers and planners. The application's predictions for v/c and level of service would add useful information to the planning process.

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