A Comparison between Highway Capacity Manual and Critical Lane Volume Analysis Methodologies for Traffic Impact Study Applications

INTRODUCTION

The purpose of this paper is to present a summary of the advantages and disadvantages of Critical Lane Volume (CLV) and Highway Capacity Manual (HCM) techniques for analyzing intersections regarding the preparation of Traffic Impact Studies (TIS) that are required as part of an Adequate Public Facilities Ordinance (APFO) or equivalent.

BACKGROUND

Intersections generally are analyzed (using methods such as CLV and HCM) as part of a TIS in order to determine if there is adequate residual capacity available in order to add additional traffic through an intersection as a result of proposed development. If the analysis indicates that adequate residual capacity does not exist, additional analyses are performed under various improvement scenarios (i.e. adding lanes, etc.). The goal is to identify reasonable improvements that are necessary to ensure that the intersection will operate at least at the same operational level as it did before the additional generated traffic.

There are Traffic Impact Study Guidelines for many of the counties, and several cities in Maryland. These guidelines detail the analysis methodology for analyzing signalized and unsignalized intersections, the thresholds for when an intersection is considered to be above capacity, and how much impact should be mitigated (i.e. how much reduction in critical lane volume is required) in order to receive approval for the proposed development. In addition, there are guidelines for TIS development that are applicable to State Highway intersections. The Maryland State Highway Administration's Guidelines for Traffic Impact Studies notes, "all intersections will be analyzed using the SHA critical lane technique and factors as described in the Appendix No. 1 of these guidelines. In certain circumstances other methodologies including the Highway Capacity Manual (HCM) might be appropriate to identify operational problems."

INTERSECTION MEASURES OF EFFECTIVENESS

There are two primary measures of effectiveness used to evaluate the performance of an intersection in the Highway Capacity Manual: intersection control delay (seconds per vehicle) and volume-to-capacity ratio (v/c). Level of Service is determined using control delay, as shown in the Table 6-3 of the Highway Capacity Manual, 2000 Edition. As noted in the HCM, Level of Service (LOS) is a measure of the acceptability of delay levels to motorists at a given intersection, and is defined as a qualitative measure describing operational conditions within a traffic stream, based on service measures such as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience. It is subjective in that levels that are considered acceptable in a large city might be

LOS	Control Delay Per Vehicle (seconds)
A	≤10
B	>10 and ≤20
C	>20 and ≤35
D	>35 and ≤55
E	>55 and ≤80
F	>80

Table 6-3, Level of Service from Control Delay (2000 HCM)

unacceptable in a rural area. Volume-to-capacity (v/c) ratio is an approximate indicator of the overall sufficiency of an intersection. A v/c ratio of 1.0 indicates that an intersection or a movement has reached it theoretical capacity, i.e. demand volume equals maximum theoretical supply. A v/c ratio above 1.0 indicates that a residual queue (i.e., unserved demand) will be expected. In layman's terms, this means that the specific movement or intersection will fail to operate satisfactorily under such a condition.

ANALYSIS METHODOLOGIES

The following discussion is a summary of the methods and factors that are used to analyze intersections under Highway Capacity Manual and Critical Lane Volume techniques. These are presented under the assumption that a comparison between the two techniques can only be fully comprehended when the underlying theories regarding the techniques are understood.

HIGHWAY CAPACITY MANUAL

There are three different types of analyses presented in the HCM for analyzing signalized intersections: operations, design and planning. The discussion that follows applies to the operation and design methodologies. The planning type of analysis is similar to the Critical Lane Volume method in that its goal is to provide a quick estimation of the overall intersection v/c ratio using a critical volume. However, even under the HCM planning method the input data required is similar to those required for the operations and design types of analyses. The difference is that the HCM planning technique accounts for the same factors affecting capacity as the operations and design techniques, whereas the Critical Lane Volume technique does not. There are two measures that need to be evaluated independently in order to understand how an intersection is operating: volume-to-capacity ratio and Level of Service.

Volume-to-Capacity Ratio

In the HCM methodology, the v/c ratio is an approximate indicator of the overall sufficiency of an intersection. Capacity of a movement or a lane group is measured based on the green period-to-cycle length ratio multiplied by the saturation flow rate (default: 1,900 pcphpl) for the movement or a lane group. Volume-to-capacity ratio (v/c) is determined by computing v/c ratios for each lane group, and then aggregating them to determine a volume weighted average v/c ratio for the entire intersection. It should be noted that the Highway Capacity Manual states, ***"Capacity of the entire intersection is not a significant concept."*** The emphasis is on the "accommodation of traffic movement on approaches to the intersection." The HCM also notes that "[Volume-to-capacity ratio] can be a misleading measure when used as an indicator of the overall sufficiency of the intersection geometrics, as is often required in planning applications."

Level of Service

In HCM methodology, control delay is utilized to determine the Level of Service. The equation for control delay consists of three factors: d_1 - Uniform Delay (Webster's equation for delay), d_2 - Incremental Delay (due to nonuniform arrivals, temporary cycle failures and sustained periods of oversaturation), and d_3 - Initial Queue Delay (to account for residual queues from a previous analysis period). It should be noted that the d_1 and d_2 terms include the v/c ratio in the calculations. Control delay is calculated by lane group, and then aggregated to provide delay by approach, and the approach delays are then aggregated to provide overall intersection delay.

Correlation Between LOS and v/c Ratio

Regarding the correlation between LOS and v/c, the HCM notes the following:

- Delay and LOS are complex variables influenced by a wide range of traffic, roadway, and signalization conditions.
- Unacceptable delay can exist where capacity is a problem as well as in cases where an intersection or a movement is operating under capacity.
- Acceptable delay levels do not automatically ensure that capacity is sufficient.
- When delay levels are unacceptable but v/c ratios are relatively low, the cycle length may be too long, or the phase plan is inefficient, or both. It should be noted that when signals are part of a coordinated system, the cycle length at individual intersections is determined by system considerations, and timing intersections as if they were isolated locations is neither practical nor desirable.
- It is possible for intersection average delay to decrease with increasing traffic volumes if the volume increases occur in movements with less than the average delay. Even with increases in traffic volumes for more than one movement on an approach, the net effect can still be a decrease in the intersection average delay if the movements with less than average delay increase sufficiently.

The HCM capacity analysis methods for signalized intersections are basically operation-driven methodologies. For intersections or movements that operate at or below saturation, they provide useful macroscopic analysis techniques to evaluate and identify traffic operation problems that could be easily mitigated with short-term improvements such as optimized signal timing, more useful utilization of signal phases, changing intersection lane assignments, and enhancing actuation. For intersections and movements that operate with over saturated conditions, i.e. v/c ratio over 1.0, those improvement concepts become similar to the Critical Lane Volume (CLV) method where the concept of improving intersection operations is usually based on additional physical improvements at the intersection such as adding lanes.

CRITICAL LANE VOLUME ANALYSIS

The Critical Lane Volume analysis methodology was originally presented in the January 1971 issue of *Traffic Engineering*. ***The authors state, "the critical movement technique discussed in this article, was improvised not to replace the analysis techniques in the Highway Capacity Manual, but to meet the need for presenting a picture to the layman of how an intersection operates without losing him in a discussion of peak-hour factors and g/c ratios."*** Also, "use of the technique is to determine the increment of development which can be added as a result of each change in intersection configuration. Caution has to be exercised in this application because one is dealing in differences rather than comparing total against a standard." However, they also note that the HCM, "when dealing with future conditions, [is] overly conscientious with estimates of street width, g/c ratios, peak-hour factor adjustments, and percentages of turns and trucks, [which] is often beyond the accuracy of the base data."

There is only one overriding measure for CLV analysis: the Critical Volume. This critical volume is correlated with preset values to calculate LOS and a v/c ratio. There is no relationship at all between the LOS and v/c ratios in the CLV and the HCM methods; their derivations are significantly different. It should also be noted that the CLV methodology differs from the HCM methodology because here, LOS and v/c ratio are the only 2 ways of representing the total intersection sufficiency. Unlike the HCM methods, CLV analysis calculates overall intersection Critical Volume, whereas the HCM aggregates each MOE on a lane group, approach, and then overall intersection basis, thus identifying failed movements and approaches. Additionally, in the CLV method, the maximum capacity of the intersection is fixed; i.e. it does not vary with signal timings, grades, lane widths, etc.

Table 1 summarizes the differences in analysis methodologies between Highway Capacity Manual signalized intersection analysis and Critical Lane Volume analysis.

TABLE 1. COMPARISON OF ANALYSIS METHODS: CLV AND HCM

Analysis Method:	**CLV**	**HCM**	
MOE:	***Critical Volume***	***v/c Ratio***	***Control Delay***
Factors Affecting MOE's	• Overall Intersection Capacity (1600) • Lane Use • Lane Configuration • Signal Phasing for Concurrent versus Split	• Saturation Flow Rate (1900) ➢ Number of Lanes ➢ Lane width ➢ Area Type ➢ Heavy vehicles ➢ Grade ➢ Parking ➢ Bus Stops ➢ Lane Utilization ➢ Right and Left Turn factors ➢ Pedestrian and Bike Factors • Green Time • Cycle Length • Lane Group v/c • Approach v/c	• Uniform Delay ➢ Progression ➢ v/c for lane group ➢ Cycle Length ➢ Green Time • Incremental Delay ➢ Actuated or pretimed signal control ➢ Upstream metering • Initial Queue Delay • Lane Group Delay • Approach Delay
Factors **NOT** Affecting MOE's	• Lane Group Capacity & Delay • Approach Capacity & Delay • Left Turn Phasing • Signal Timing ➢ Cycle Length ➢ Green Times • Geometrics • Peds and Bikes • Area Type • Progression • Upstream Metering • Signal Control Type	• None	• None

Table 1 demonstrates that the HCM method is more appropriate to evaluating and mitigating operational problems at intersection, where as the CLV method is designed more towards planning applications to project improvements under various global traffic conditions, without considering the sensitivity and correlation of intersection signal timings and geometrics to capacity.

APPLICATIONS

The Highway Capacity Manual techniques are applicable to a wide range of applications. However, they require detailed input data regarding intersection geometry and signal timings (In the HCM planning application, a methodology is provided to estimate signal timings where none are available). The Critical Lane Volume technique is a very quick and simple method that requires a minimal amount of input data. Regarding planning applications, both are proven methods for evaluating the overall sufficiency of an intersection based on future conditions. However, the CLV method doesn't require a computer to run or any software licensing, and doesn't require the technical sophistication as the HCM method. Furthermore, the CLV method is simpler and could take approximately 75-percent less time to perform than the HCM method.

DIFFERENCES IN APFO APPLICATIONS

The primary differences between the two methodologies in APFO applications pertain to comparing the "before" development with the "after" development conditions. First, different results may be obtained in the evaluation of whether or not improvements are needed, and second, differences may be obtained in the evaluation and selection of improvements to mitigate "after" development traffic.

DETERMINATION OF WHETHER OR NOT IMPROVEMENTS ARE REQUIRED

When evaluating the sufficiency of an intersection to accommodate additional traffic, any increase in traffic under the CLV method will increase the Critical Volume. Since the Critical Volume is the only MOE computed under the CLV method, the method will always show a deficiency in operations with additional traffic. Due to the same reason, and the fact that the CLV method does not consider signal timings or geometrics, the opposite may also be true, and the CLV method may incorrectly show that an intersection operates acceptably. This would be the case where there are inappropriately timed traffic signals, inefficient phasing, or substandard geometrics.

EVALUATION OF IMPROVEMENTS

The CLV analysis method is solely based on the entire intersection, and does not consider individual approaches or lane groups. Therefore, individual approaches may operate at a poor LOS, but the overall intersection may be shown to have sufficient reserve capacity. This phenomenon could lead an inexperienced analyst to identify improvements that appear to increase overall intersection capacity without addressing the critical movements, and thus not mitigating the existing, or potential future problems. Regarding this conclusion, some hypothesize that an improvement to the intersection, even if not on the critical approach, will still result in improvements to the critical approach since the green time will be reallocated among the phases. This may not be true, especially for intersections under system control. Needless to say, signal timing should not be considered as a long-term solution or as a substitute to physical improvements, when intersections are expected to operate under failing conditions. The alternative way to determine if proposed improvements will have a positive effect is to utilize the HCM methodology or more precise microscopic methodologies such as SimTraffic or CORSIM.

Under the CLV method, there are only three ways to improve the intersection LOS: add lanes, change the lane configuration, or change to concurrent phasing from split phasing, if applicable.

CONCLUSIONS

It is important to note that both v/c and LOS must be considered in order to determine how an intersection is operating. The v/c ratio evaluates for capacity sufficiency; LOS is a qualitative measure of the acceptability of delay. The HCM calculates each of these using separate methods, whereas in the CLV method these are derived from only the critical volume and a fixed capacity.

The HCM method allows for the evaluation of each lane group and/or approach to an intersection. The CLV method does not. If the CLV method is used for intersection analysis, the TIS study may show that an intersection needs improvements where an improvement may not be necessary due to the fact that there is only a single MOE. Also, the CLV method may be used to justify improvements that do not mitigate an existing congestion problem since CLV does not analyze lane groups and approaches separately from the overall intersection.

The CLV method is a proven and reliable method for determining whether or not an intersection has sufficient reserve capacity for planning studies. The primary benefit in using the CLV methodology is that it is easy to use, easy for reviewers to check, requires minimal input data, and requires minimal time to compute. However, as noted above, under many scenarios the CLV method may not be the most appropriate tool to use. The HCM methodologies are also proven and reliable methods, which are based on nationally accepted guidelines. The inconveniences of the HCM methods are the relatively large amount of input data required; accuracy of the data, and the fact that the analysis is almost always performed by computer may make review inconvenient. Also, it is noteworthy that the CLV method has not gone under any improvement since it inception, whereas standards for intersection analysis have gone under major streamlining and improvements during the last 20 years. A tabulated summary of the strengths and weaknesses of each method is shown in Table 2 below.

TABLE 2. STRENGTHS AND WEAKNESSES: CLV AND HCM

Application	CLV	HCM
Can be used for planning analysis?	Yes	Yes
Can be used for operations analysis?	**NO**	Yes
Intersection capacity affected by operations measures?	**NO**	Yes
Analyze lane group?	**NO**	Yes
Analyze intersection approaches?	**NO**	Yes
Analysis more prone to operator error?	**NO**	Yes
Favors geometric improvements?	Yes	**NO**
Favors short-term improvements?	**NO**	Yes
Favors long-term improvements?	Yes	**NO**
Suggest more accurate geometric improvements?	**NO**	Yes

Application	CLV	HCM
Easy to use?	Yes	**NO**
Requires more user judgment?	Yes	**NO**
Expensive to use?	**NO**	Yes
Easy to check by a reviewer?	Yes	**NO**
Procedure improved since inception?	**NO**	Yes

OPINIONS

Based on the above, the following observations are made:

- The CLV method for reviewing intersections for overall capacity sufficiency should be maintained, but not in the context of determining which physical improvements are required as part of an APFO.
- For analyzing impacts to intersection as part of a TIS, the planning application of HCM could be used as an alternative to the CLV method but is not necessary.
- Mitigation measures involving changes to signal timing only (such as changing the cycle length, splits, offsets, phases, etc.) should not be considered as the sole measure for improvement in a TIS, and as a substitute to long-term improvements. Signal timing should not be viewed as a solution in TIS, but rather as an enhancement.
- The CLV method is more conservative than the HCM method. It is a method that suites the APFO process more appropriately than the HCM method. The CLV method is based on the concept that once an intersection has failed under its optimum lane and phase assignments, the only other means to increase the intersection capacity is to add more lanes. This concept obviously favors the APFO process because it provides long-term means to increase capacity and improve intersection operations. However, the CLV method doesn't provide good justification where the additional lanes should be added. Such recommendations should always be analyzed using alternate methods; either the HCM or microscopic models such as SimTraffic and CORSIM.