FIELD VALIDATION OF MOE's for UNSIGNALIZED INTERSECTION ANALYSIS

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INTRODUCTION

Purpose

The purpose of this report is to present an independent review of various software packages and methodologies utilized in the analysis of isolated unsignalized intersections. This review represents the work of the New England Section Institute of Transportation Engineers Technical Committee.

Background

The **1965 Highway Capacity Manual (HCM**) addressed unsignalized intersection analysis in approximately four pages at the end of Chapter 6, At-Grade Intersections. With an admitted lack of research data, two-way stop and four-way stop analyses are each covered by one table. No level of service criteria are presented; rather, analysis is limited to a comparison of total intersection volume to a look-up capacity from the tables. The 1965 HCM also uses a logic that is followed even today. It reads:

> "In this two-way case, capacity criteria for other than the through street are relatively meaningless if the legal meaning of two-way stop control is rigidly accepted. Very simply, in an isolated location the through-street traffic volume has complete priority over the STOP street, hence should be able to increase to capacity, while the cross-street volume gradually falls off to zero. The only feasible cross-street criteria then would be service volumes that can pass during gaps at various through-traffic service volume levels below capacity."

The general form of the methods currently used to analyze unsignalized intersections trace their lineage back to the pioneering work in Germany (1972), as adapted initially by Circular 212 in 1980. Armed with more data, the methodology allows assignment of level of service levels A-F, much like the signalized methodology. Borrowing from the theory of the 1965 HCM, Circular 212 includes the assumption that main street traffic will be unimpeded by side street traffic. Therefore, analysis and level of service assignments are limited to side street moves, and left turns from the main street to a side street. Assignment of level of service is based on a new term called "reserve capacity", which is the difference between the number of acceptable gaps in the main street traffic flow, and the side street demand. The **1985 HCM** was predominantly an update of Circular 212.

While the general form of the methodology was unchanged in the **1994 HCM**, a new method of evaluation (MOE) for level of service for unsignalized intersections was introduced; borrowing from signalized methodologies, level of service was based on stopped vehicle delay.

The **1997 HCM** and **2000 HCM** maintained the basic approach of the 1994 HCM. The level of service criterion, however, was changed to total vehicle delay, or “control delay”.

Picady2 has also been considered. Unsignalized intersection capacity has been calculated in the UK since the 1980s. The associated queues and delays have been predicted by formulae derived from time-dependent queuing theory.

Numerous software packages/methodologies have attempted to emulate the Highway Capacity Software (HCS) since 1985, and with each have come some nuances. Depending on the state or municipality, several of these packages can be accepted as an alternative to the HCS. Yet, the differences in results between these software packages can be significant. In addition, the analysis results often do not match what is observed in the field. A common assessment among traffic engineers is that the unsignalized methodologies are too conservative.

The New England Section Institute of Transportation Engineers has recognized this situation, and has recognized two types of discrepancies which need to be investigated: (1) calculated results which differ from the methodology of the HCM, and (2) calculated results which differ from actual field measurements of queues and delays. The Technical Committee was charged with the task of investigating this matter. The Committee consists of dozens of participants who have donated thousands of hours to conduct this research, in a true public/private partnership. Committee members come from an array of traffic engineers, including private consultants as well as professionals from the Massachusetts Highway Department, and the Central Transportation Planning Staff.

Scope

This project was limited to the study of isolated unsignalized intersections. In this paper, the methodology and results of the HCM were compared to the following analysis tools.

- Circular 212
- 1985 HCM
- CINCH (1988 Version)
- PICADY2 (1985)
- 1994 HCM (HCS 2.1g)
- 1997 HCM (HCS 3.2)
- HCS 2000
- SIDRA 5.2 (1997)
- SYNCHRO 5.0 (2000)

It should be noted that all methods except the British PICADY are based on the German gap-acceptance model. Therefore, there are two general methods available for the assessment of the capacity of unsignalized intersections.

Adjustments

It was necessary to make certain adjustments to some of our MOE's to ensure that the comparisons would be relevant. Following is a description of those adjustments:

- Queues – Of those packages that include a calculation of queues, some are reported as average, while others are 95th percentile. CINCH88 and PICADY report an average queue, while all others report 95^{th} percentile. ONLY the 95^{th} percentile results are shown.
- Delays – The delay reported in this paper is stopped delay. The 1997 HCM, the 2000 HCM, SIDRA 5.2 and SYNCHRO 5.0 all report total delay, which amounts to an additional five (5) seconds. Therefore, values reported by these packages were reduced by five (5) seconds.

Study Organization

The research was separated into two phases with similar approaches, yet different purposes. In Phase I the task was to compare the analysis tools to the HCM solutions to example problems in Chapter 10 of the 1994 HCM. The question answered by this comparison is, "Do the various packages emulate the HCM methodology?"

The task in Phase II was to compare the same packages and HCM to actual field conditions. This Phase II comparison answers a different question, which is, "Does the basic methodology contained in Chapter 10 of the Highway Capacity Manual accurately describe what's happening in the real world?"

PHASE I - COMPARISON OF PACKAGES TO THE HCM METHODOLOGY

In this phase of the study, analysis of the four sample problems contained in the unsignalized chapter of the 1994 Highway Capacity Manual was conducted using the study software packages and methodologies. The results of each are then compared to each other and to the results included in the sample problems. Each analysis was conducted independently by two different traffic engineers and then compared for consistency. A final review of every analysis was then conducted.

The discussions in this section are based on a comparison of various MOE's, with not all being available in each case, depending on the software and version of the HCM. A detailed comparison of results is shown in Figures 1-12. In all cases, the focus of attention is on the performance of the left turn from the side street (or its shared lane), rather than overall MOE for the intersection. The selected MOE's are delay, volume to capacity ratio (v/c), and capacity.

Sample Problem 1

This location is a tee intersection. The east-west approaches consist of one general use lane and one left turn lane. The northbound approach includes a single approach lane, which is controlled by a stop sign. Corner radii are 20 feet, terrain is flat and prevailing speeds are 30 mph. Left turns from the major street to the stem are high at 150 vph.

Sample Problem 2

This is an intersection of a collector, controlled by stop signs, intersecting with a four-lane arterial. The east-west arterial includes a left turn lane and a through/right lane on each approach. Northbound, the collector consists of a left turn lane and a through/right lane. The southbound approach consists of a single lane. Radii are 25 feet, terrain is level, and the prevailing speed is 30 mph.

Sample Problem 3

This is the same intersection as described in Sample 1, except that the westbound approach consists of a general use lane and a shared through/left lane.

Sample Problem 4

This location is the same as Sample Intersection 2, except that the side street approaches now consist of three lanes, one each for left, straight and right tuning vehicles.

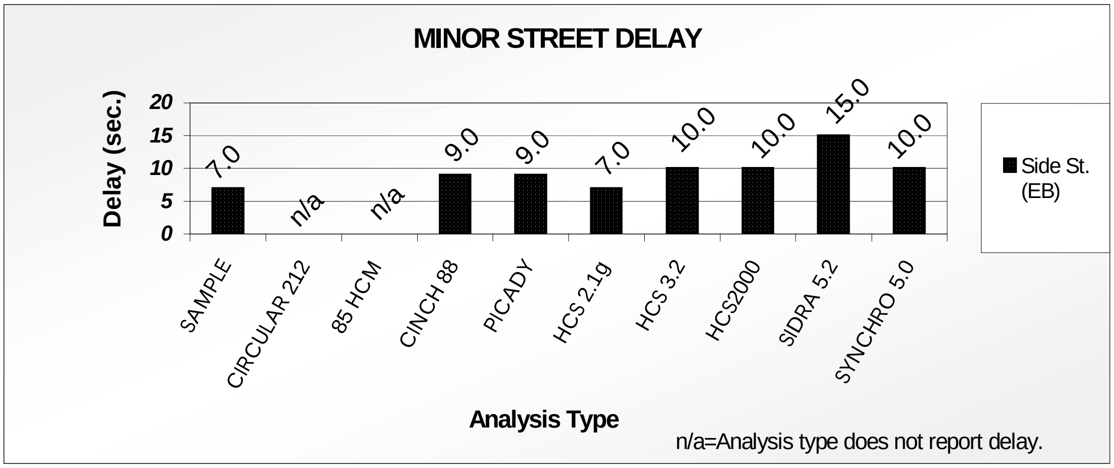
Phase I Summary Results

The comparison of the software packages to the results shown in the four sample problems are mixed. HCS 2.1g most consistently calculates matching values in all MOE categories. This result should be expected, since HCS 2.1g software is based on the 1994 HCM and the sample problems come from the 1994 HCM. The generally lower delays and v/c ratios, and higher capacities associated with HCS 2.1g are evidence of the modifications that reflect more favorable results than the 1985 HCM, and subsequent modifications that return the methodology back to a more conservative analysis.

Of the other packages, HCS versions 3.2 and 2000 provide reasonable comparisons to delay on three of the four problems, while SIDRA 5.2 provides the fewest matches. Most of the packages result in reasonable matches to volume-to-capacity ration in three of the problems, with Circular 212 providing the least matches. Besides HCS 2.1g, the rest of the packages do not match well to side street capacities reported in the sample problems.

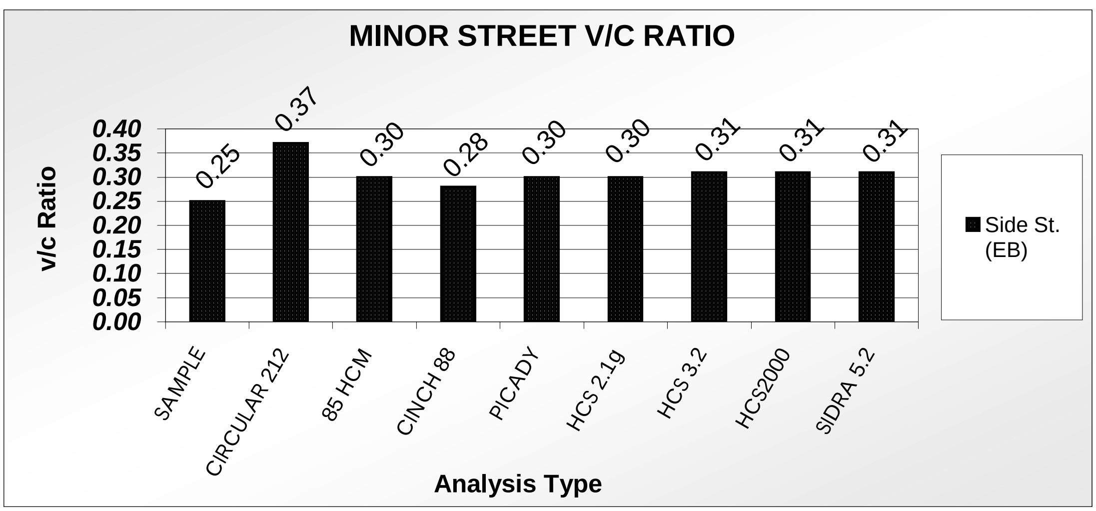
Sample 1 : Market and Jones (3-Way)

Figure 1



The reported value in the sample problem is 7.0 seconds. Most methods that report delay fall in a range of 7.0 to 10.0 seconds. The exception is SIDRA, which reports 15.0 seconds.

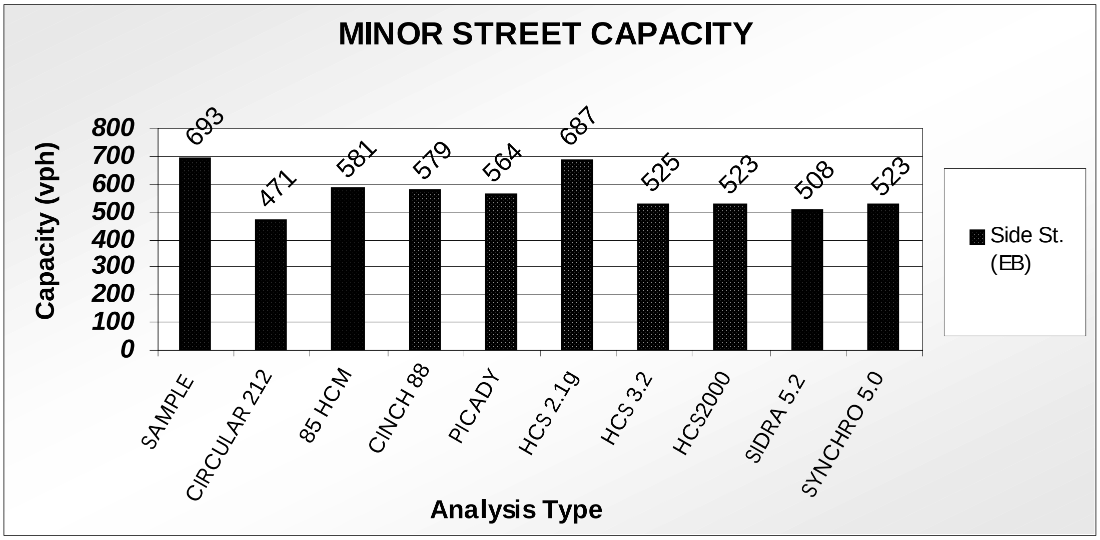
Figure 2



The sample problem reports a volume-to-capacity ratio of 0.25. The packages are consistent, with most reporting values between 0.28 and 0.31. Circular 212 reports 0.37.

Sample 1 : Market and Jones (3-Way)

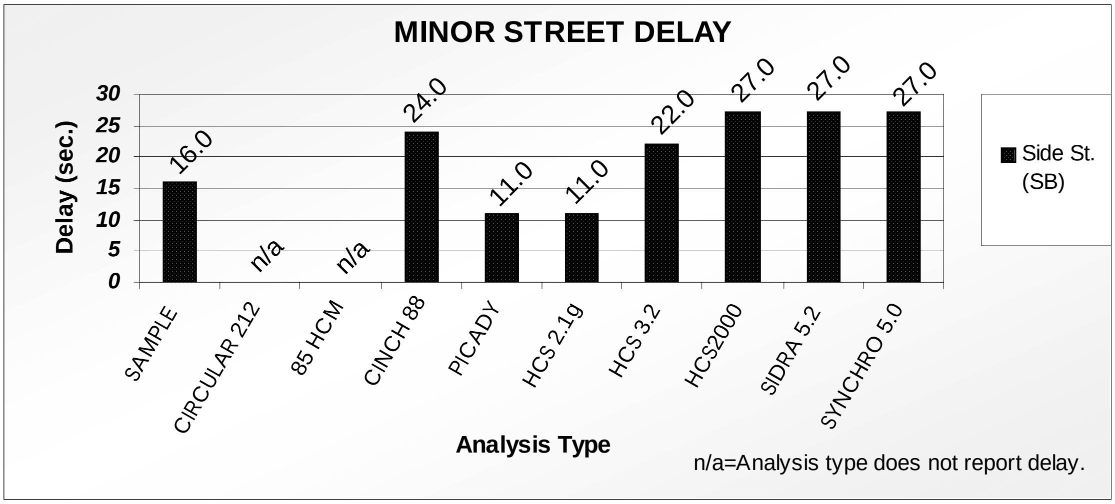
Figure 3



The side street capacity is 693 from the sample problem. Results from the software packages form two general groupings. The 1985 HCS, CINCH88, and PICADY report side street capacity values between 579 and 584, while HCS 3.2, HCS2000, SIDRA 5.2 and SYNCHRO fall between 508 and 525. Circular 212 is low at 471, and HCS 2.1g is closest at 687.

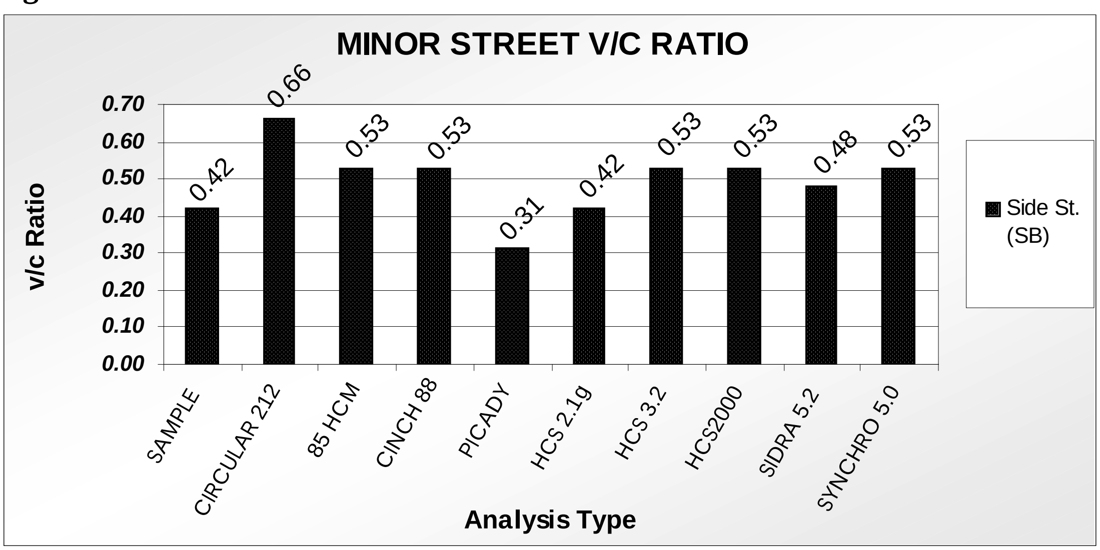
Sample 2 : Walnut and Elm (4-Way)

Figure 4



In this example only the southbound results will be discussed, because of incomplete data included for the northbound approach in the sample. Southbound, the sample problem reports delay as 16.0 seconds. HCS 3.2, HCS2000, SIDRA and SYNCHRO all report delays 27.0 seconds, while CINCH is at 24.0 seconds. PICADY and HCS 2.1g report 11.0 seconds.

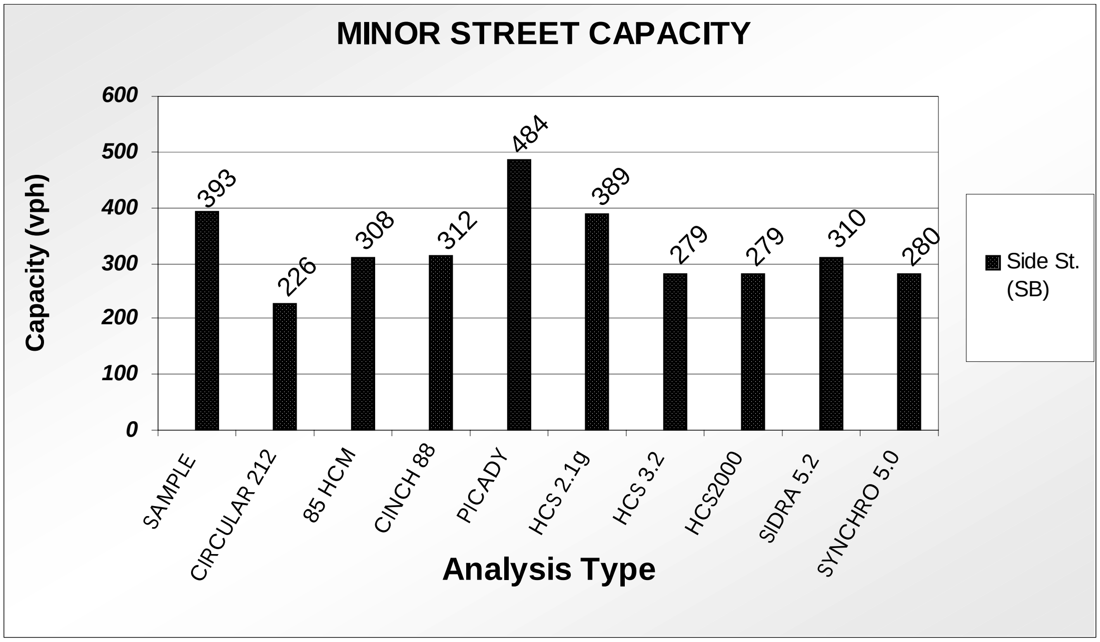
Figure 5



Southbound, v/c in the sample is reported as 0.42, PICADY reports 0.31, HCS 2.1g reports 0.42, and Circular 212 reports 0.66. All other packages report 0.53.

Sample 2 : Walnut and Elm (4-Way)

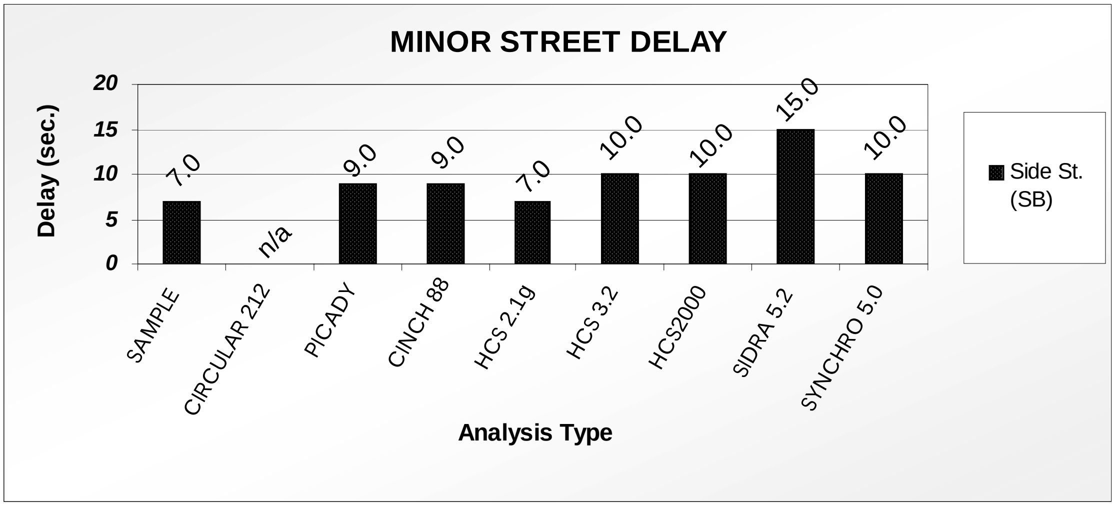
Figure 6



The southbound side street capacity is reported as 393 on the sample problem. HCS 2.1g is closest with a calculated value of 389. PICADY reports a higher value of 484, while others fall between 226 and 312.

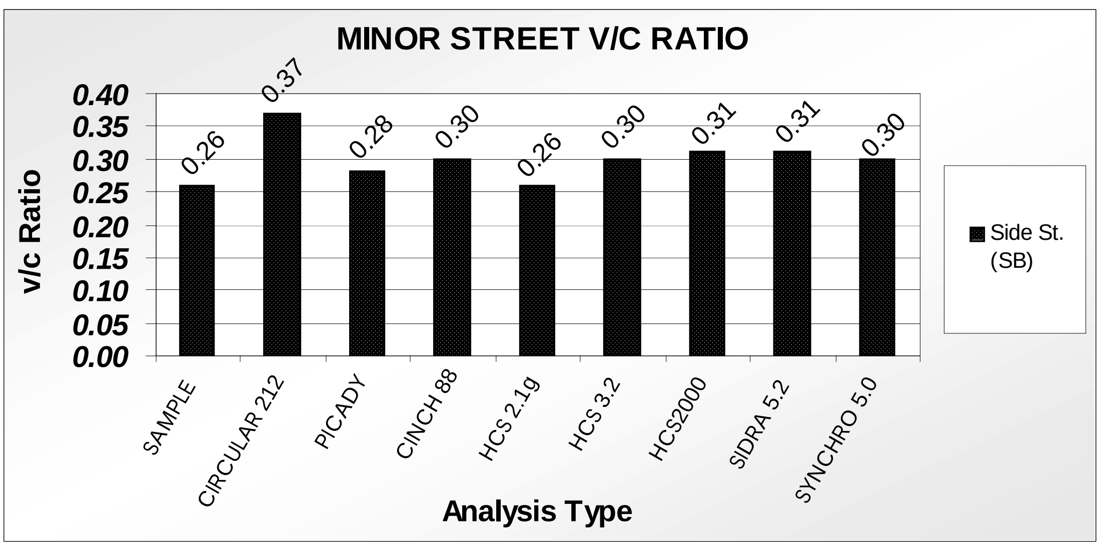
Sample 3 : Market and Jones (3-Way)

Figure 7



The reported delay in the sample problem is 7.0 seconds. HCS 2.1g matches with 7.0 seconds, SIDRA is high at 15.0, while all other values are between 7.0 and 10.0 seconds.

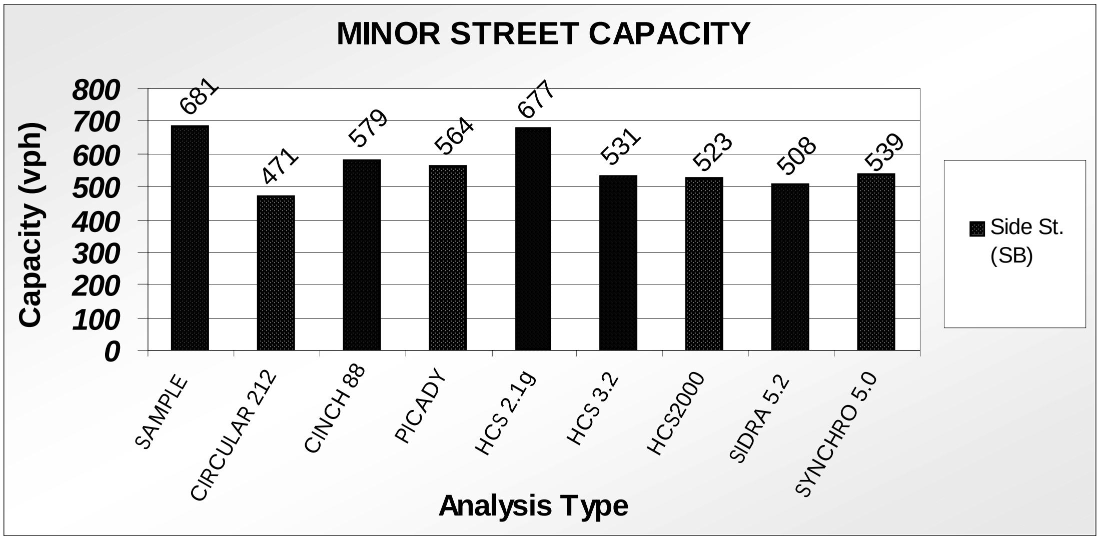
Figure 8



The sample problem value for v/c is 0.26. HCS 2.1g matches that value and PICADY reports 0.28. Most of the remaining packages calculate a v/c of 0.30 or 0.31. Circular 212 reports 0.37.

Sample 3 : Market and Jones (3-Way)

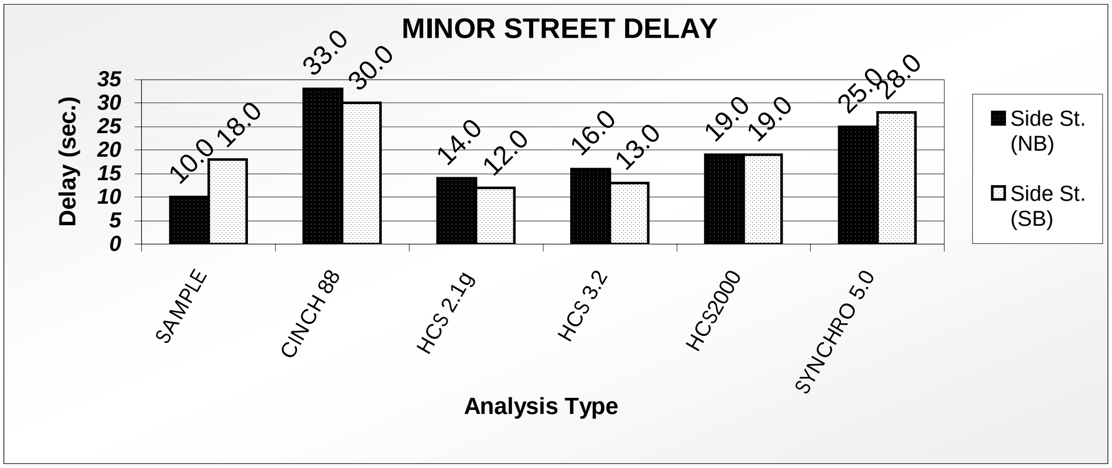
Figure 9



A side street capacity of 681 is calculated in the sample problem. HCS 2.1g reports a value of 677, while all other packages range between 471 and 584.

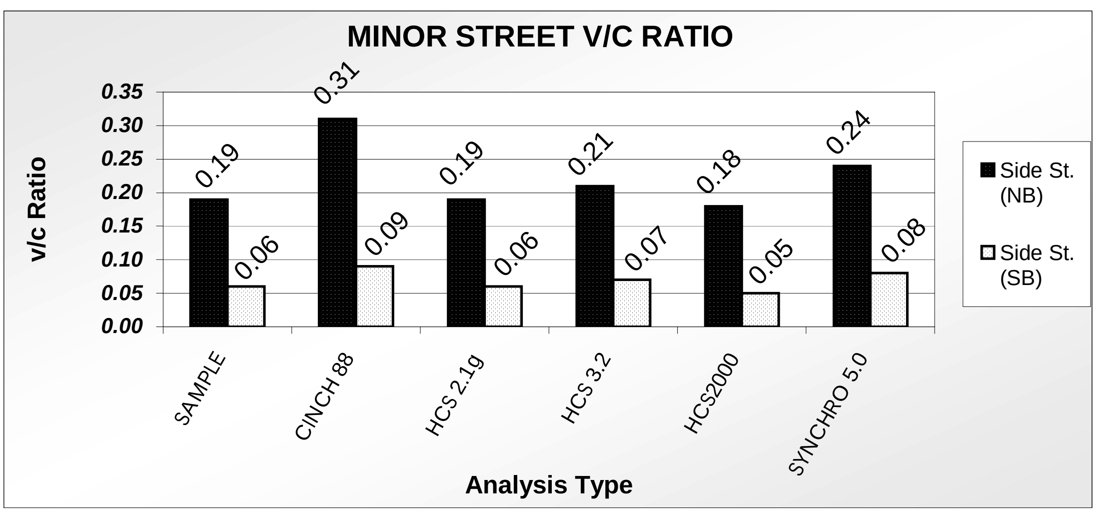
Sample 4 : Market and Jones (4-Way)

Figure 10



By omission, Circular 212, 1985 HCM, SIDRA 5.2, and PICADY were not used to analyze this problem. Northbound, the delay was calculated as10.0 seconds in the sample problem. HCS 2.1g, HCS 3.2 and HCS2000 calculate values of 14.0, 16.0 and 19.0 seconds, respectively. SYNCHRO 5.0 and CINCH88 report delays of 25.0 and 33.0 seconds, respectively. Southbound, the sample problem reports a delay of 18.0 seconds. HCS 2.1g, HCS 3.2 and HCS2000 calculate delays of 12.0, 18.0 and 19.0, respectively. SYNCHRO 5.0 and CINCH88 are both higher, with values of 28.0 and 30.0, respectively.

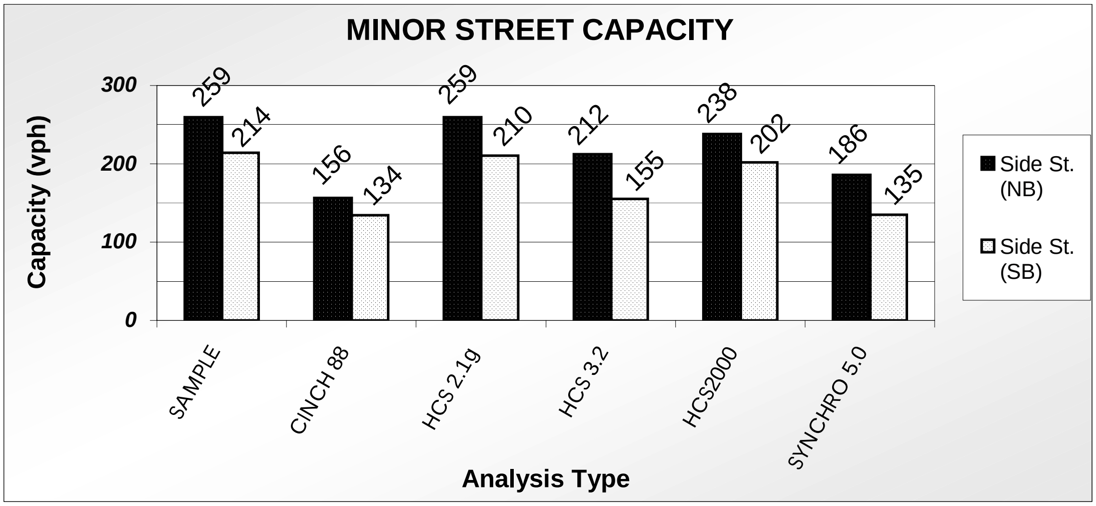
Figure 11



The northbound volume-to-capacity ratio was calculated as 0.19 in the sample problem. HCS 2.1g also calculated 0.19, HCS2000 calculated 0.18, and HCS 3.2 calculated 0.21. SYNCHRO 5.0 and CINCH88 reported values of 0.24 and 0/31, respectively. Southbound, the sample problem results in a volume-to-capacity ratio of 0.06. All packages fall between 0.05 and 0.09.

Sample 4 : Market and Jones (4-Way)with Exclusive Left Turn Lanes

Figure 12



Northbound, the sample problem calculated side the street capacity at 259, which is also calculated by HCS 2.1g. HCS 2000 reports 238. CINCH88, SYNCHRO 5.0 and HCS 3.2 result in capacities of 158, 186 and 212, respectively. The southbound capacity reported in the sample problem is 214. HCS 2.1g and HCS 2000 are again closest, reporting values of 210 and 202. CINCH88, HCS 3.2 and SYNCHRO 5.0 result in capacities of 134, 155 and 135, respectively.

PHASE II - COMPARISON OF HCM METHODOLOGY TO FIELD CONDITIONS

In this phase of the research, analysis results of study software packages and methodologies are compared to measures of effectiveness (MOE's) collected in the field. Data were collected at seven isolated unsignalized intersections. An isolated intersection is defined as one not affected by operation of an adjacent location. In addition, an attempt was made to select locations of varying characteristics (e.g., four-way vs. 3-way, congested vs. free flow, exclusive turn lanes vs. shared lanes). The data collected at these seven intersections were used as the basis of comparisons for this study, and are described in Figures 13-19.

An attempt was made to select locations with varying characteristics, with the result that three were tee intersections, three were four-way intersections, and one was primarily a tee, except that a fourth leg was one-way away from the intersection. Four measurements were made during morning peak flow, two during mid-day peaks, and one during the afternoon peak. One had restricted sight lines, two had angled approaches, and two had four-lane roads. One had a median. Four were urban and three were suburban.

A discussion of research methodologies and results follows.

Methodology

The methodology and assumptions for data collection and analysis, and limitations to field data are described in this section. Data collection included input values and MOE's. Recommended procedures found in ITE and TRB publications were followed where possible. A list of data collected at each intersection is listed below.

- Turning movement counts were conducted for a full hour. Pedestrian volumes were also noted where applicable.
- Heavy vehicles were counted for a full hour.
- Geometric features and lane use were collected.
- Average vehicle delay was measured on all approaches.
- Queues were inventoried.

Due to the complexity of the gap generation at the various intersections, the Technical Committee used a locally developed program, MEASURE-8, which allowed for a detailed and permanent record of traffic movements to be saved on disk using a laptop computer and a mouse. The data included a time stamp on each event, as well as general comments and notes on pedestrian and bicycle activity.

Measurements were made continuously at all locations for approximately an hour, with a record of every vehicle movement during the measurement period. Typical raw data files for an entire intersection were about 100 KB.

In operation, a team of two to four people uses a combination of mouse clicks and function keys to trigger the screen display and the recording of specific events. A text label such as "RIGHT TURN FROM SIDE STREET" is combined with the time stamp. By determining the difference between any two times, the relative time between two events was calculated as a gap or flow rate.

Subsequent steps in data processing include formatting the times and text to allow for direct importation into two spreadsheets. The first spreadsheet yields a count of each turning movement and vehicle type. The second spreadsheet calculates the number and size of gaps refused or gaps accepted. Delays and queues are also displayed, with special emphasis on the times where there are no vehicles queued on the side street.

The gap spreadsheets assessed each movement and its relative gaps, position in the queue, and subsequent activity. Because 1500 to 2000 vehicle movements were being recorded each hour, the spreadsheet size became large, in the range of 12 to 17 MB.

Capacity was determined by a count of the side-street turn volumes that occur during periods when the side street has a queue of at least one vehicle. For example, Route 2A/Hanscom Road had side street queues about 92 percent of the time with 246 left turns. In other words, during eight percent of the peak 15-minute period, any gaps offered will not be utilized because there is no side street queue, or demand. The v/c ratio becomes 0.92. Therefore, if vehicles were queued for 100 percent of the time, the capacity would be 246/0.92, or 270 vph. This is the methodology to calculate side street capacities at all seven unsignalized intersections.

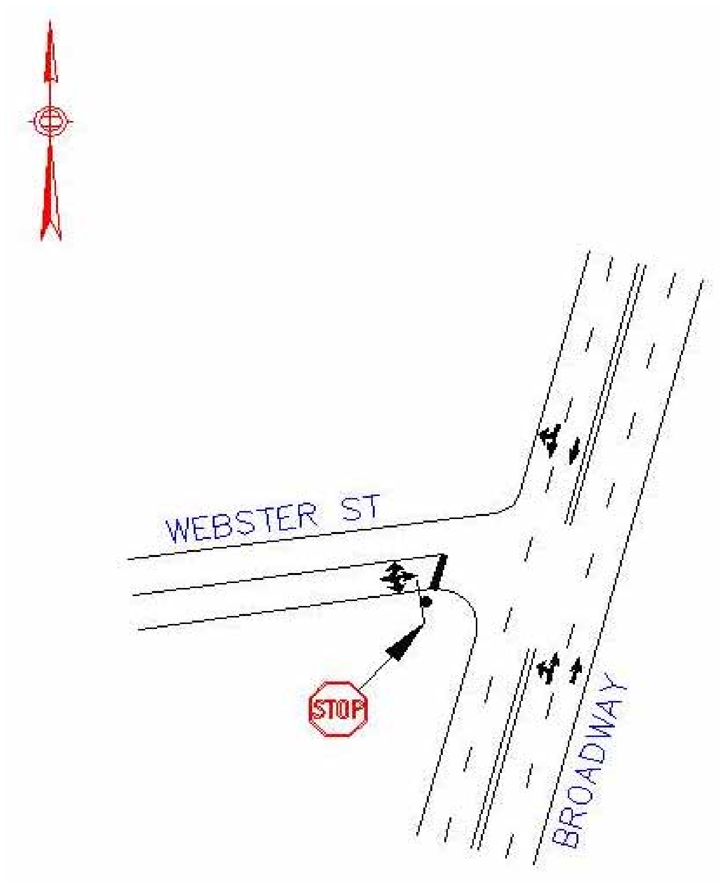
Analysis was conducted using the tools provided by each software package included in the comparisons. Each analysis was conducted independently by two different traffic engineers and then compared for consistency. A final review of every analysis was then conducted.

Intersection A – Broadway and Webster Street in Malden , MA.

Broadway is a north-south arterial that varies from two to four lanes. At this tee intersection, Broadway consists of one approach lane in each direction, although northbound through vehicles usually have enough width to pass vehicles waiting to turn left to Webster Street. Webster Street includes one approach lane, controlled by a stop sign. Parking occurs on all approaches. Occasionally, parking on the east side of Broadway blocks northbound through traffic attempting to pass vehicles turning left. There are no sight restrictions.

Traffic volumes are heavy on Broadway and less than 100 on Webster Street. Only one pedestrian was observed crossing at this intersection.

Figure 13

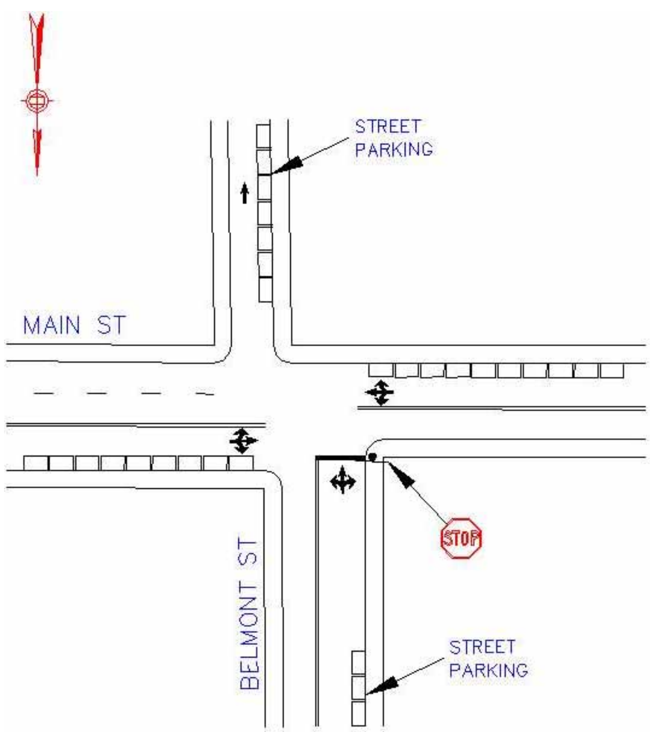


Intersection B – Main Street and Belmont Street in Malden, MA

While there are four legs at this intersection, one is one-way from the intersection; as such this was analyzed as a tee intersection. Main Street runs north-south and includes one lane on each approach. To the east, Belmont Street approaches the intersection with one northbound lane. On the north side of the intersection, and slightly offset to the south, Wyllis Avenue is a one-lane departure leg. The Belmont Street approach is controlled by a stop sign. Traffic volumes are heavy on Main Street, and the Belmont Street approach includes a heavy right turn. Parking is prevalent on both sides of Main Street, and through traffic cannot maneuver around turning vehicles. There were no observed pedestrian crossings. The terrain is level, and no sight restrictions are evident.

One of the criteria for this project was that the intersections be isolated. During the selection process this location was observed during off-peak hours, and the flashing operation approximately 300 feet to the south did not appear to have an impact. During the morning peak, when this intersection was counted, the signals operate as a mid-block pedestrian crossing, and are occasionally activated. While the signalized intersection did not back up into the study intersection, the queue at times did extend far enough north to slow southbound through traffic on Main Street. During field measurements, a double-parked truck was located near the southerly signal for approximately 30 minutes, which affected vehicle flow.

Figure 14

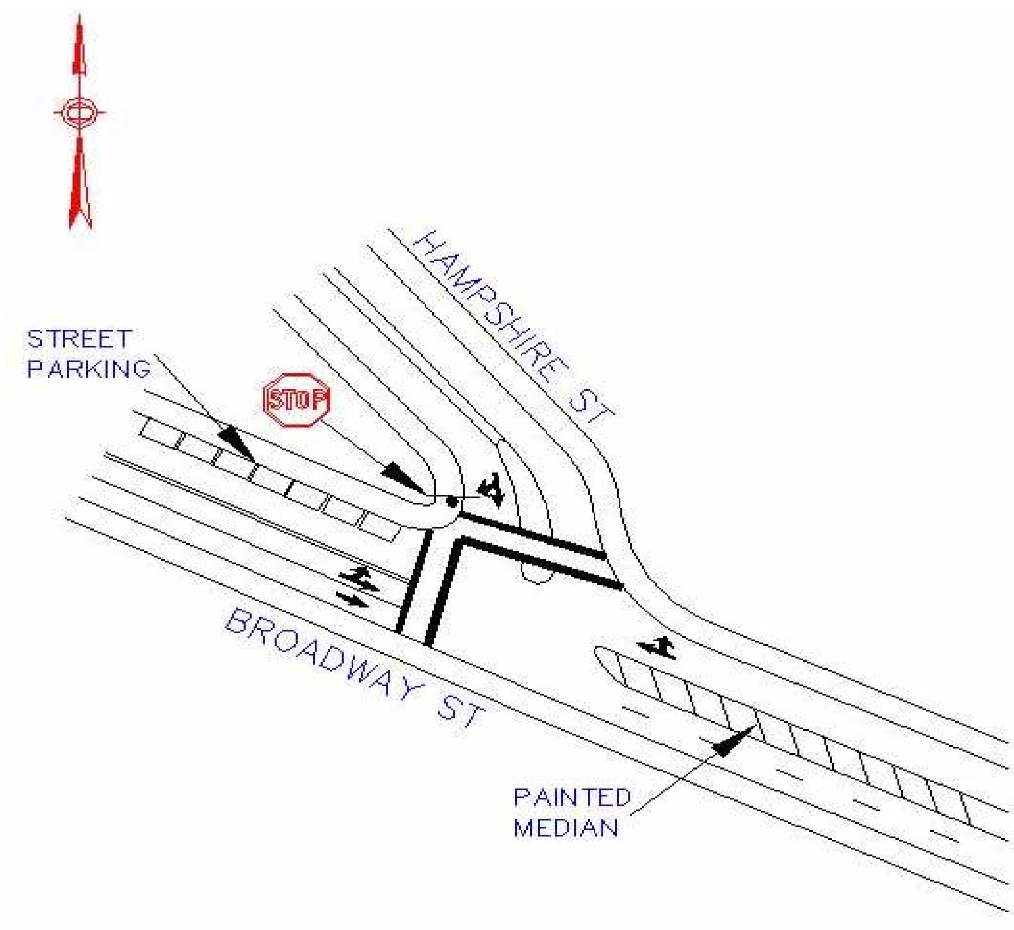


Intersection C – Broadway and Hampshire Street in Cambridge, MA

Broadway is a wide commercial urban street, with one through lane in each direction. Hampshire Street is a two-lane road with dense parking on both sides, except that on the Broadway approach parking is prohibited in the right lane for 200 feet. Thus, the left lane from Hampshire Street becomes a de facto left turn only lane. Left turns from Broadway are minimal, so the entire conflict is between through vehicles on Broadway and the left turn out of Hampshire. Numerous pedestrian crossings, as well as heavy bicycle flow on Hampshire Street and Broadway were recorded, but were not included in the gap acceptance.

Hampshire Street approaches the intersection at a 45 degree angle, but it curves to ultimately form a 90 degree alignment with Broadway. A small median island separates the two directions of Hampshire Street at the stop line.

Figure 15



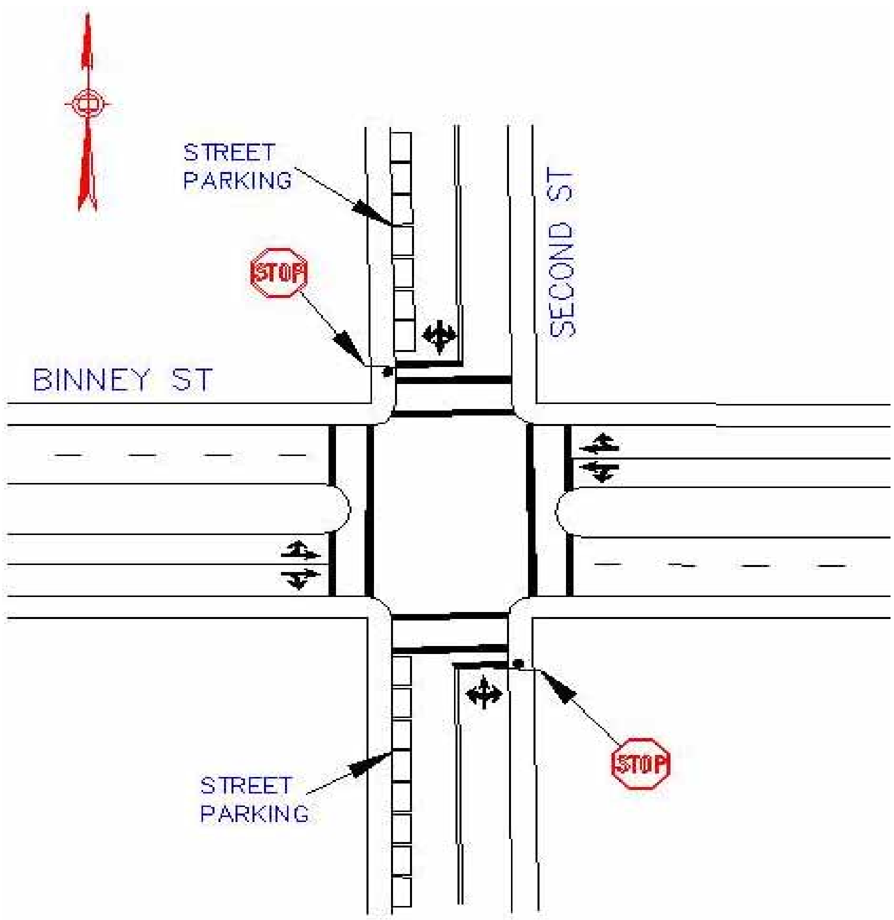
Intersection D – Binney Street and Second Street in Cambridge, MA

Binney Street is a four-lane urban arterial, with a narrow median and no parking. Second Street forms a four-way crossing with one lane each way and dense parking on both sides. Left turns from Binney Street must be made from the high speed lane. Adjacent signals on both sides of Second Street result in some platooned flows in both directions on Binney Street, although no queue blockage was noted.

By observations, the intersection was generally free flowing. There was a tendency for Second Street traffic to make a segmented gap acceptance, which sometimes resembled a "barge and block" maneuver. Such maneuvers tended to reduce side street delays, but increase delays for other movements, especially the southbound left turn from Binney Street.

A moderate number of pedestrians were noted, primarily crossing Binney Street. Few bicycles were noted. Northbound Second Street carried a large percentage of heavy vehicles.

Figure 16

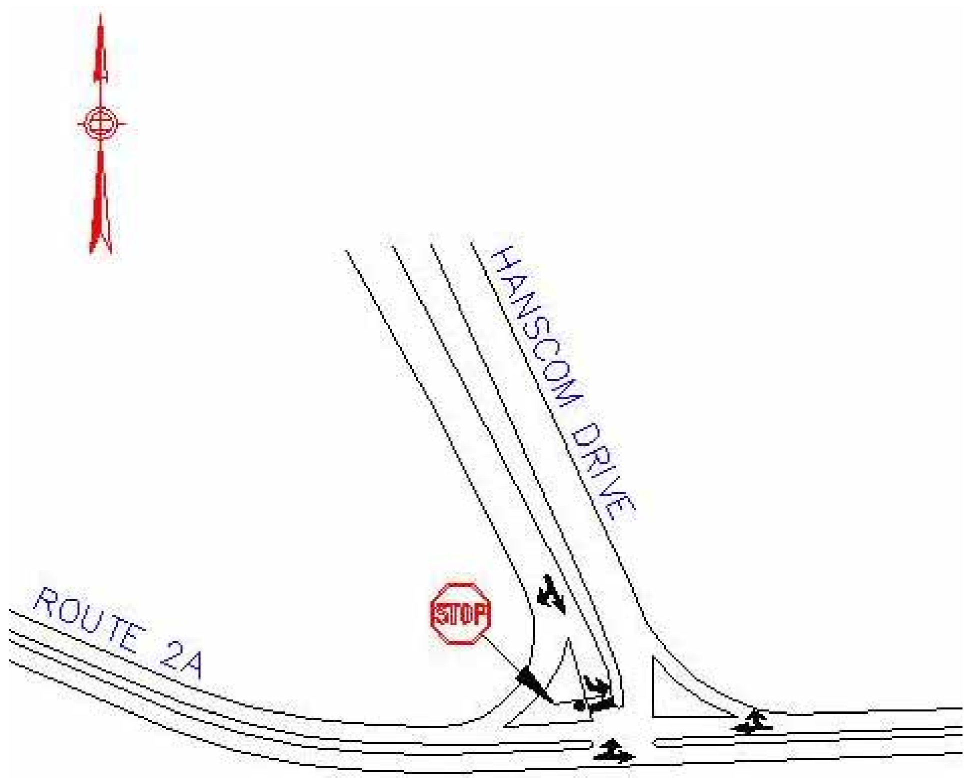


Intersection E –Route 2A and Hanscom Road in Lincoln, MA

Route 2A is a 25-30 foot wide two-lane suburban arterial which passes in part through the Minuteman National Park in an east-west direction. Hanscom Road is a four lane divided arterial, which services Hanscom Airport and an industrial area. Hanscom Road forms a tee intersection with Route 2A, with one lane for left turns and one for right turns. This location is distant from any adjacent traffic signals and is ideally isolated.

Although the filed data were collected at noon, heavy congestion was noted, with long queues occurring for the left turn from Hanscom Road.

Figure 17

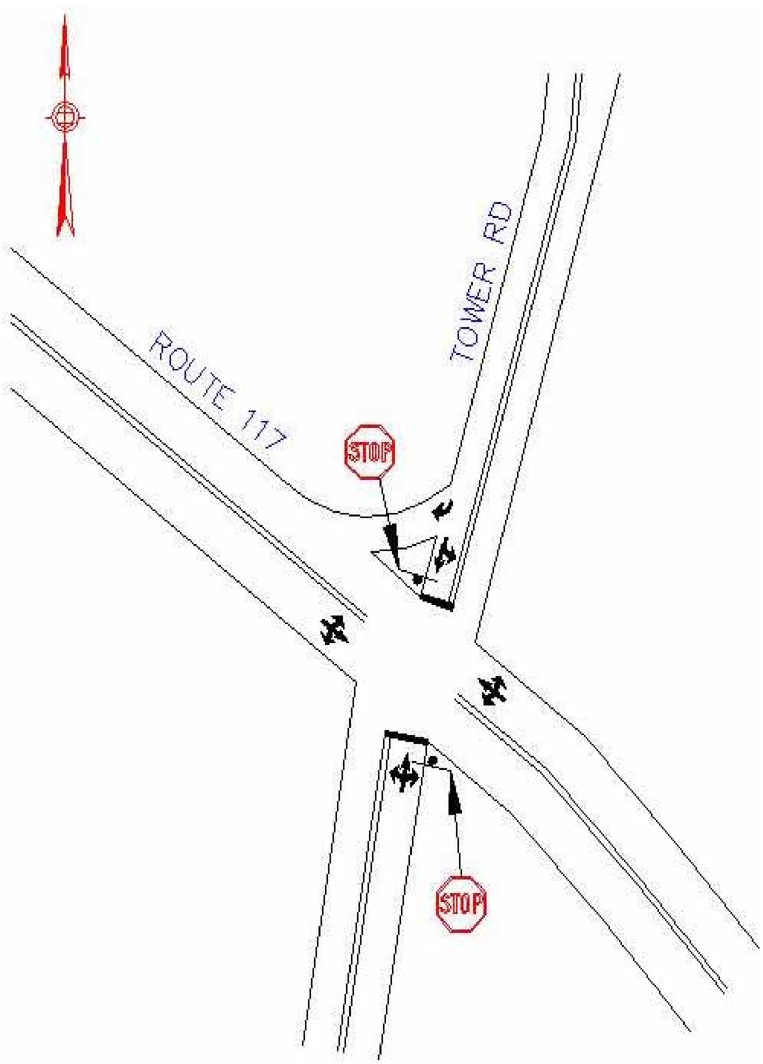


Intersection F – Route 117 and Tower Road in Lincoln, MA

Route 117 is a 25-30 foot two-lane rural /suburban roadway with no turn lanes. Tower Road is a lightly traveled two-lane rural roadway. Field observers noted poor sight lines for drivers on Tower Road. Large radius turns exist on all corners.

Generally, traffic counts were fairly low, but a high proportion of unaccepted gaps was noted for vehicles turning right from Tower Road, possibly due to the poor sight lines.

Figure 18

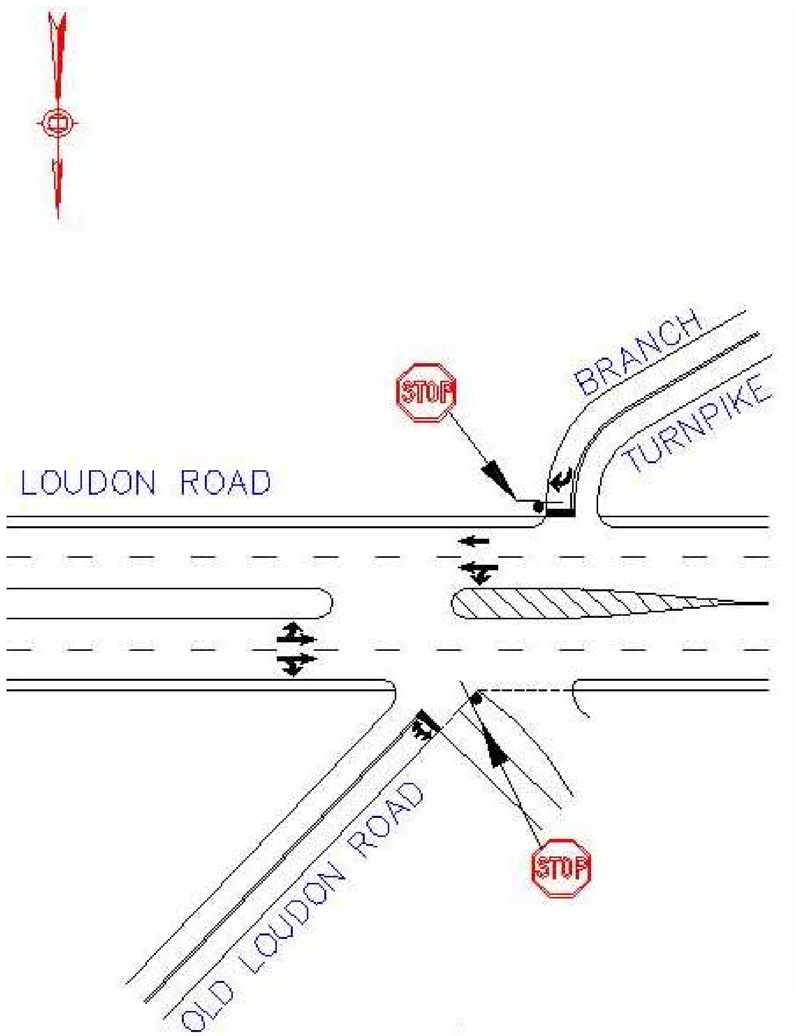


Intersection G – Loudon Road, Branch Turnpike and Old Loudon Road in Concord, MA

Loudon Road is a four-lane east-west suburban arterial with no parking. Old Loudon and Branch Turnpike both approach at 45 degree angles, although Branch Turnpike is slightly curved to ultimately form a 90 degree approach. The side streets are offset by approximately 200 feet. The westbound Loudon Street approach includes a median.

Generally, flows on Loudon Road were high, while side street volumes were low. Pedestrian activity was negligible.

Figure 19



Results

Analyses results are summarized for average stopped delay, volume to capacity ratio (v/c), queues, and side street capacity. Comparisons of these measures are summarized in detail in Figures 20-47. A brief summary of trends follows.

1. Average Stopped Delay

Results are mixed in this category. PICADY seems to be the most accurate predictor of average stopped delay. At each of the seven study locations PICADY was the closest or next to closest package. At the other extreme, SIDRA 5.2 was least accurate.

At intersection A, PICADY's delay of 10.7 matched up to the measured delay of 12.8. HCS 2.1g calculated a delay of 14.9 seconds. The other packages are all in the 20 second range, with SIDRA at 30.0 seconds.

At intersection B, HCS 2.1g calculated the same delay as the field measured 11.0 seconds. PICADY was next with a delay of 13.5 seconds. The other packages are in the 15-20 second range, except for SIDRA 5.2, which was at 26.0 seconds.

At intersection C, PICADY was the only package that was reasonably close, with a calculated delay of 36.0 seconds, compared to the measured value of 31.0. The next closest was SYNCHRO 5.0 at 98.0 seconds, with all others ranging between 372 and 830 seconds.

PICADY is again the closest at intersection D, with a calculated delay of 15.1 seconds, compared to the measured value of 10.0 for the northbound approach. At the southbound approach, PICADY calculated 14.4 seconds, compared to the measured value of 16.0 seconds. The next closest value is 146 for the northbound approach, and 36 for the southbound approach.

None of the packages was very close at intersection E, although PICADY was again closest, with 27.2 seconds compared to the field measured value of 41.0. The next closest value is 377.

Most of the packages are reasonably close to the measured delay at intersection F. The northbound measured delay is 8.0 seconds, with CINCH 88 calculating the same value. PICADY, HCS 2000, SIDRA 5.2 and SYNCHRO 5.0 all calculate delay at approximately 7 seconds. The southbound measured delay is 10.0 seconds. The calculated delay for all other packages range from 7.6 to 8.0 seconds.

At intersection G, PICADY's calculated values are closest on both side street approaches. Northbound, PICADY's delay of 9.4 compares to the measured value of 10.0. Most of the other packages calculate values between 21.0 and 27.0. SIDRA 5.2's calculated value is 55.0 seconds. Southbound, the measured value is 12.0 seconds, compared to PICADY's delay of 9.2 seconds. The other packages range from 25 to 152 seconds.

2. Volume-to-Capacity Ratio (v/c)

PICADY's calculated values are among the closest to measured values in five of the seven intersections studies. SIDRA 5.2 is among the least accurate in five of the locations. While not necessarily matching the measured value, more consistency is evident in the comparison of v/c, with several groupings of results.

At intersection A, HCS 2.1g's calculated v/c is 0.22, compared to the measured value of 0.25. PICADY is reasonably close at 0.19. The other packages range between 0.30 and 0.34, except for SIDRA 5.2, which calculates a v/c of 0.42.

At location B, the measured v/c of 0.59 is closely matched by most packages. The values range from 0.51 to 0.62. Only HCS 2.1g is out of that range, with a v/c of 0.46.

Only PICADY, with a calculated v/c of 0.80, accurately emulates the measured value of 0.77 at intersection C. The other packages calculate v/c's greater than 1.0, with SIDRA 5.2 calculating 1.69.

At intersection D PICADY is the most accurate on both approaches. Northbound, the measured value is 0.34, compared to PICADY's 0.38. Te next closest value is 0.74, with the rest ranging from 0.99 to 2.30. Southbound, a measured value of 0.41 compares to PICADY's calculation of 0.35.

At intersection E, the packages do not closely emulate the measured value of 0.92. PICADY comes closest with 0.69, followed by HCS 2.1g at 1.22. The other packages resulted in v/c's ranging from 1.59 to 1.84.

At intersection F, the results suggest an anomaly. On the northbound approach, the field measured value is 0.36, but eight of the nine packages calculate a value of 0.03, with the ninth at 0.04. Similarly, the southbound approach v/c is measured at 0.23, but the other packages calculate values between 0.08 and 0.11.

HCS 2.1g is the most accurate at intersection G. Northbound, the HCS 2.1g calculated v/c is 0.22, compared to the measured value of 0.23. Southbound, HCS 2.1g calculates a value of 0.27, which compares well to the field measured v/c of 0.25. PICADY is the only package that calculates v/c's less than the measured values.

3. Minor Street Capacity

Overall, the packages did not accurately calculate side street capacity, as compared to the field measured capacity. No single package was more accurate than the others. In fact, in most cases a discussion of which packages were most accurate is not meaningful, given the gap between "closest" and field measured. The discussion below will be limited to those cases in which at least one package emulated the field measured value.

At intersection A, HCS 2.1g's calculation of 326 compared to the measured value of 310.

At location B, the measured value of 530 was closely matched by HCS 2.1g (531) and PICADY (536), and to CINCH 88 (500).

At location C, PICADY's calculated capacity of 387 matches well to the measured value of 380.

4. 95th Percentile Queues

The comparison in this category is limited, since not all packages calculate queues, and some that do will calculate average queue instead of the 95th percentile. The results are uneven.

At intersection A, the measured value of 1.5 is closely emulated by four of the five packages that report 95th percentile queue. HCS 3.2 calculates 1.5, HCS 2000 and SYNCHRO 5.0 calculate 1.4, and HCS 2.1g calculates 1.2. SIDRA 5.2 calculates a value of 3.8.

At intersection B, the calculated queue is 2.9 vehicles. Four of the five packages are reasonably close, ranging from calculated values of 2.2 to 3.9. SIDRA 5.2 calculates 8.6.

Only SYNCHRO 5.0's calculation of 8.0 reasonably compares to the field measured value of 6.4 vehicles at intersection C.

At intersections D, E and F, all models vary significantly from measured values.

At intersection G, HCS 3.2, HCS 2000 and SYNCHRO 5.0 most closely match the measured value of 1.4 vehicles on the northbound approach, with calculated values of 1.5, 1.3 and 1.3, respectively. HCS 2.1g's calculated value is 1.0. SIDRA 5.2's calculation is high at 3.6. On the southbound approach, HCS 21.g, HCS 3.2, HCS 2000 and SYNCHRO 5.0 match the measured value of 1.5, with calculated values of 1.5, 1.3, 1.1 and 1.2. SIDRA 5.2's calculation is higher at 4.9.

Phase II Summary Results

Table 1 provides a summary of the average stopped delay results for the combined data for all of the intersections, and for the v/c results for all data except that contained in Intersection F, due to uncertainty over the validity of v/c calculations at that intersection. In Table 1, an examination of the computerized packages reveals that the average error (comparing calculated to field measured results) for all locations ranges from 22 percent (PICADY) to 1282 percent (HCS 3.2 and HCS 2000). The next closest results to PICADY's 22 percent is SIDRA 5.2 at 592 percent.

PICADY also comes closest to field measured delay values, at 23 percent, with HCS 2.1g at 32 percent. The next closest is CINCH88 at 82 percent, with the range from PICADY's 23 percent to SYNCHRO 5.0 at 120 percent.

Table 1 Phase II Summary Results *

	Average Error From Measured Value	
Analysis Method	Stopped Delay	V/C Ratio
CIRCULAR 212	N/A	119 %
1985 HCM	N/A	94 %
CINCH88	1808 %	82 %
PICADY	22 %	23 %
HCS 2.1g	609 %	32 %
HCS 3.2	1282%	118 %
HCS 2000	1282 %	119 %
SIDRA 5.2	592 %	83 %
SYNCHRO 5.0	952 %	120 %

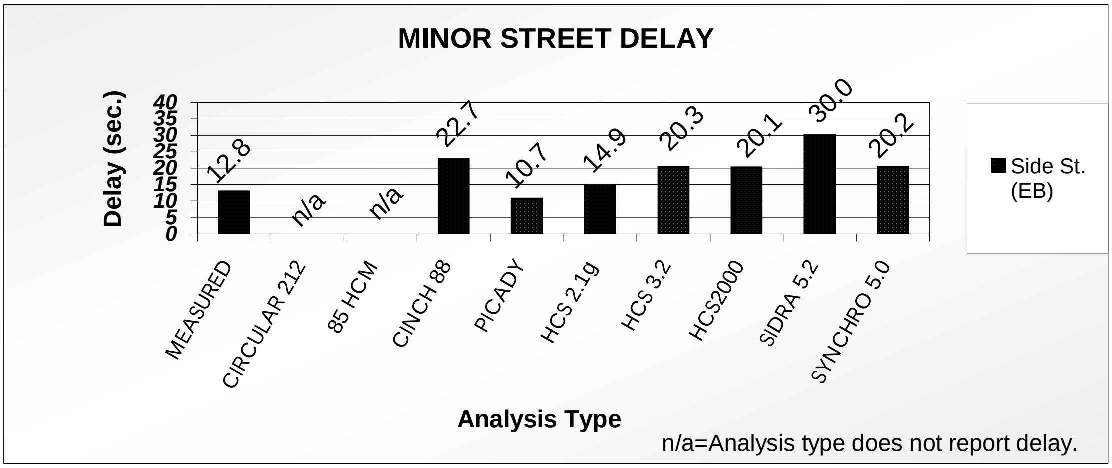
* The stopped delay calculations in this table represent a composite of all seven intersections. The v/c calculations, however, omit Intersection F due to uncertainty of v/c calculations at that intersection.

The examination of queue data shows that at four of the seven locations, none of the packages studied accurately calculate field measured values. At the other three locations (A, B, G), however, HCS 2.1 g, HCS 3.2, HCS 2000, and SYNCHRO 5.0 calculations are very close to field measured values. Each of these three intersections has relatively low delays and volume to capacity ratios. Intersection D, however, also meets these criteria and no package accurately calculates the field measured queue at this location.

The only noteworthy conclusion from an examination of the side street capacity comparisons is that none of the packages accurately calculate actual values. Several packages compare well at one location (Intersection B), and PICADY also compares well at a second location (Intersection C). There is, however, no basis for any meaningful positive conclusion.

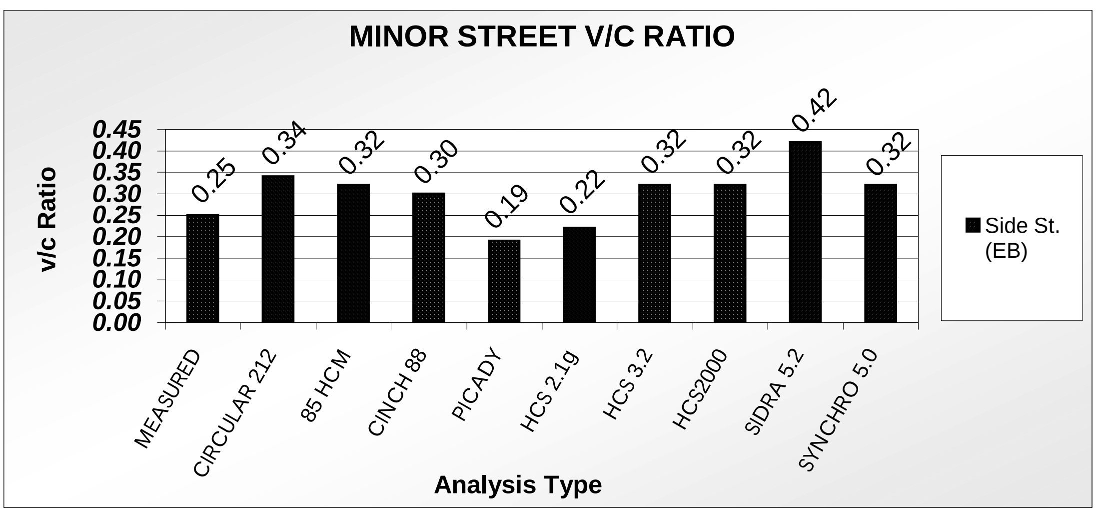
INTERSECTION A : Broadway at Webster Street (3-Way)

Figure 20



The filed-measured delay was 12.8 seconds. PICADY's calculated value is 10.7 (-16%), while HCS 2.1g yielded 14.9 (+16%), both within approximately 2 seconds. CINCH, HCS 3.2, HCS2000 and SYNCHRO 5.0 form a grouping between 20.1 (+57%) and 22.7 (+77%). SIDRA 5.2 is at 30 (+134%).

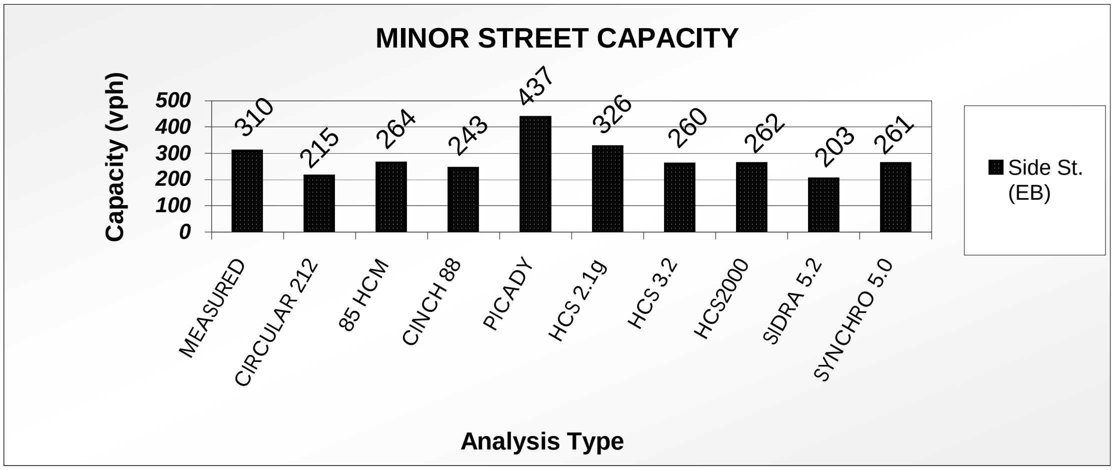
Figure 21



HCS 2.1g, at 0.22, is closest to the calculated value of 0.25, although PICADY is at 0.19. Most of the other packages form a grouping in the 0.30 to 0.34 range. SIDRA 5.2 calculates a value of 0.42 (+68%).

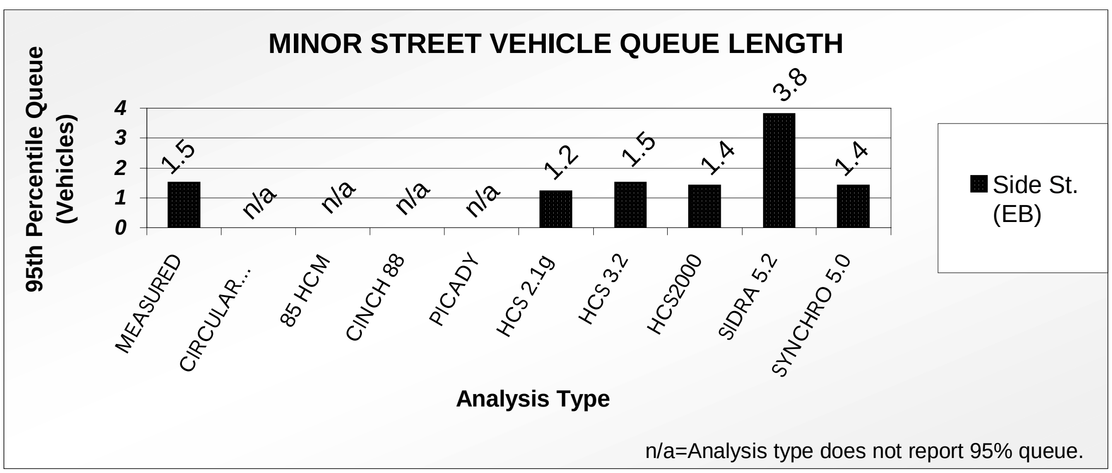
INTERSECTION A : Broadway at Webster Street (3-Way)

Figure 22



HCS 2.1g, with a calculated value of 326, comes closest to the measured value of 310. Several of the packages form a grouping between 260 and 264 (-20%). Circular 212 results in the lowest capacity of 215 (-34%), while PICADY is highest at 437 (+34%).

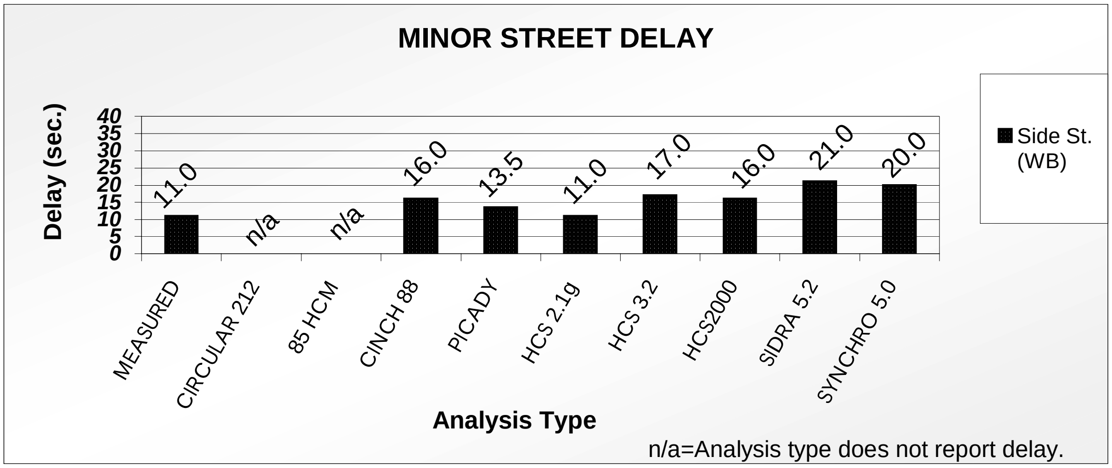
Figure 23



Most of the packages that yield a 95th percentile queue are close to the measured value of 1.5. Only SIDRA 5.2 is high at 3.8.

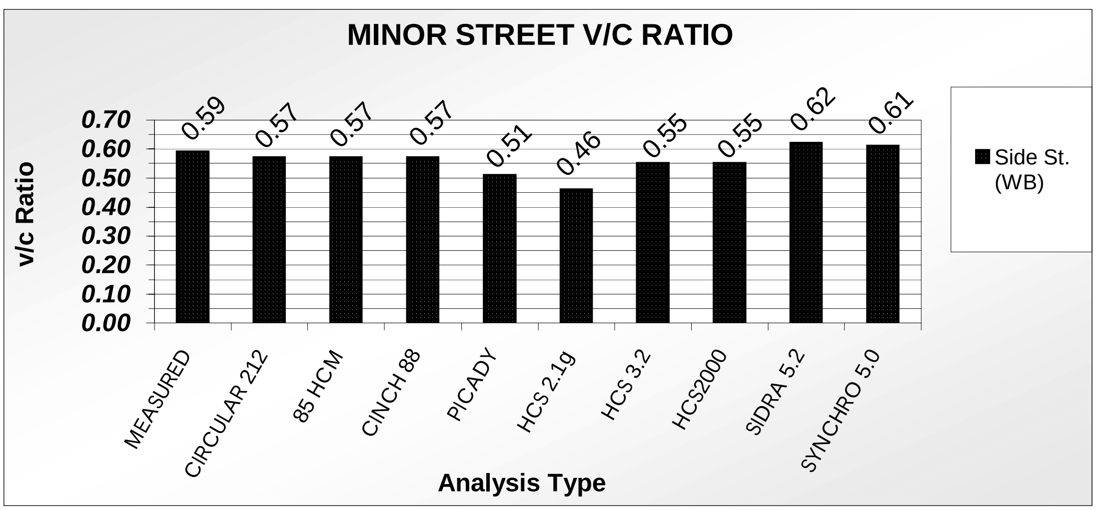
INTERSECTION B : Main Street at Belmont Street (3-Way)

Figure 24



HCS 2.1.g yields a value of 11.0 seconds, which is equal to the measured value. PICADY is also close with a value of 13.8 (+25%). CINCH88, HCS 2.1g and HCS 2000 form a grouping between 16.0 and 17.0 seconds (+50%).

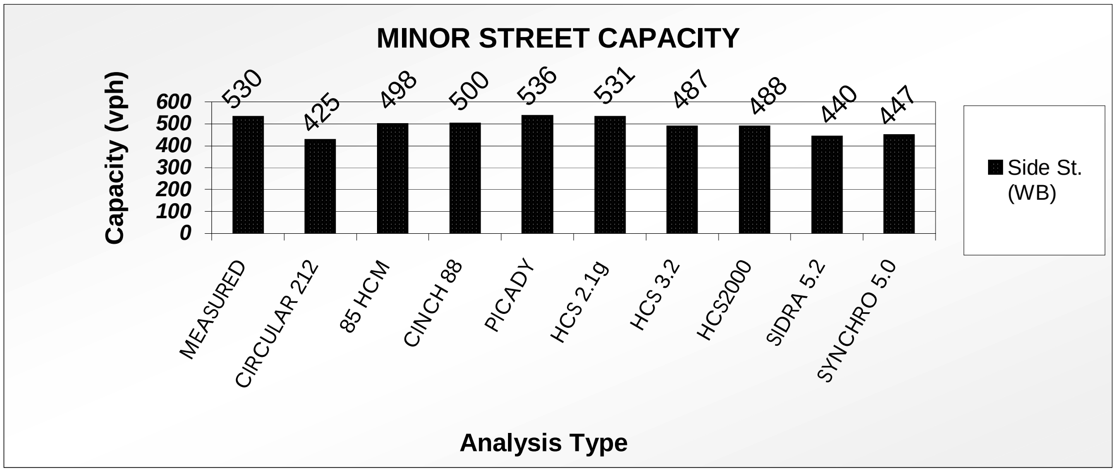
Figure 25



Several packages come close to the measured value of 0.59, ranging from 0.55 to 0.62. PICADY is at 0.51, and HCS 2.1g is lowest at 0.46.

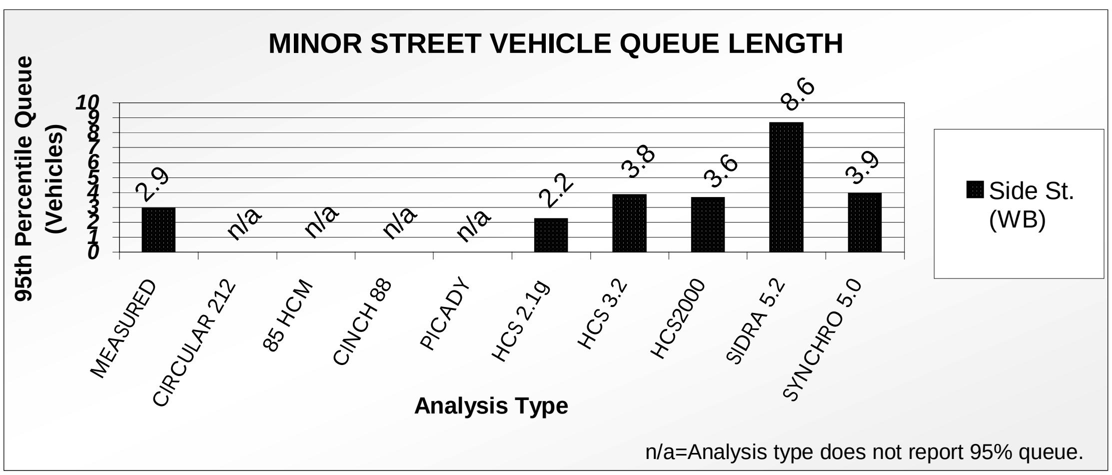
INTERSECTION B : Main Street at Belmont Street (3-Way)

Figure 26



PICADY (536) and HCS2.1g (531) yield values very close to the measured value of 530. Another grouping forms between 486 (-8%) and 500 (-7%). Circular 212 at 425 (-20%), SIDRA 5.2 at 440 (-18%) and SYNCHRO 5.0 at 447 (-16 %) result in the lowest grouping.

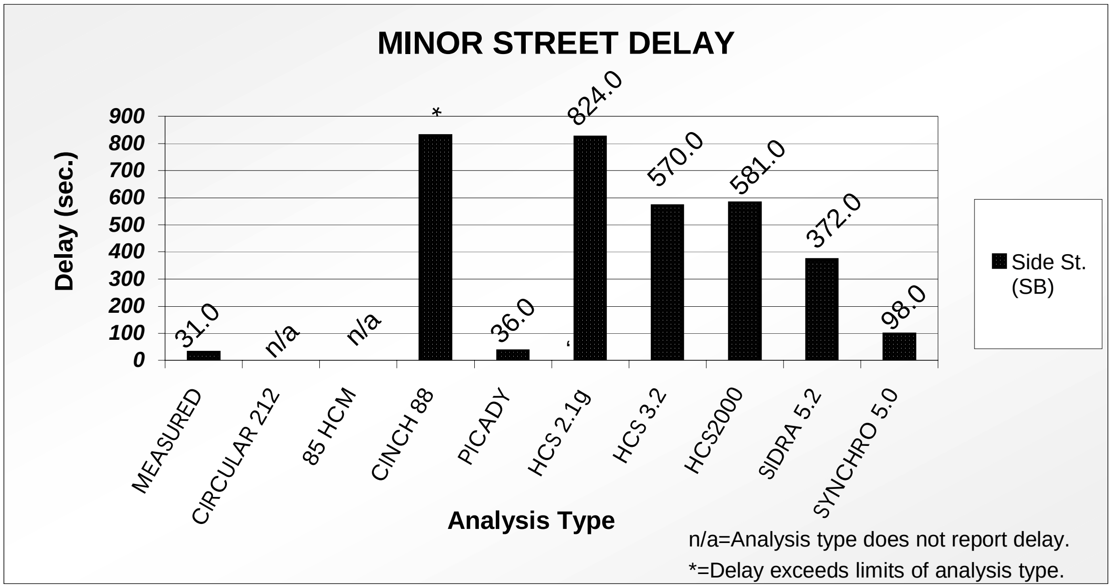
Figure 27



Four of the five packages reporting 95th percentile queue result in values relatively close to the measured value of 2.9. SIDRA 5.2 results in a value of 8.6, nearly three times the measured value.

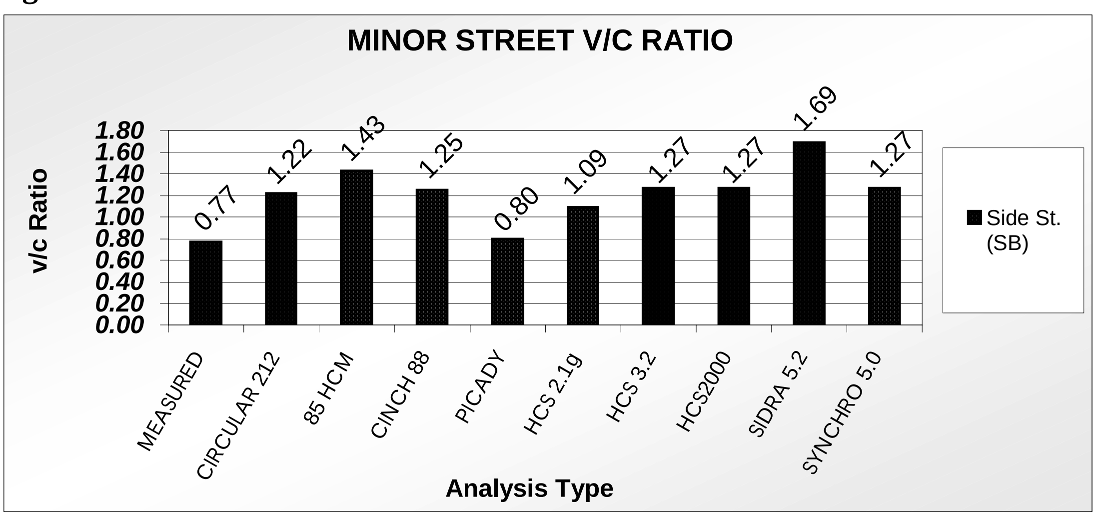
INTERSECTION C : Broadway at Hampshire Street (3-Way)

Figure 28



PICADY, with a delay of 36.0 seconds, is the only value close to the measured delay of 31.0. The other packages ranged from 98.0 to hundreds of seconds. The calculation of delay exceeds the limits of CINCH88.

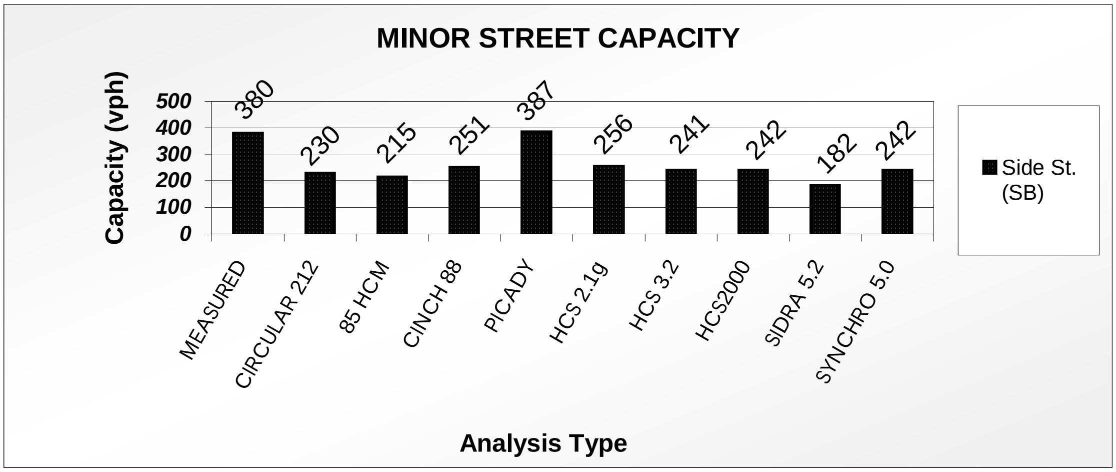
Figure 29



PICADY, with a value of 0.80 is the only package that came close to the measured v/c of 0.77. All others are greater than 1.0, ranging from 1.09 to a high of 1.69 from SIDRA 5.2.

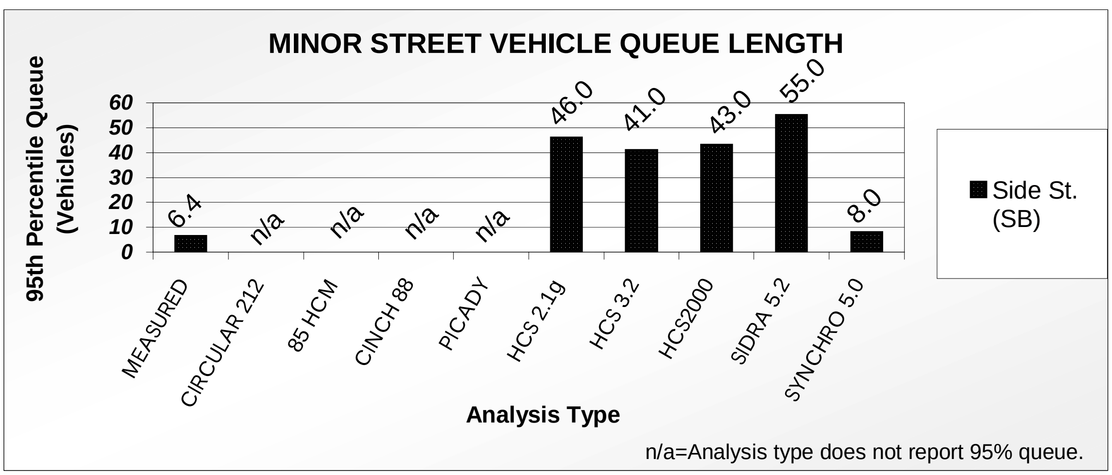
INTERSECTION C : Broadway at Hampshire Street (3-Way)

Figure 30



The measured value of 380 is closely emulated by PICADY's value of 387. Most of the other packages are in the 200 to 250 range, and SIDRA 5.2 is lowest at 182.

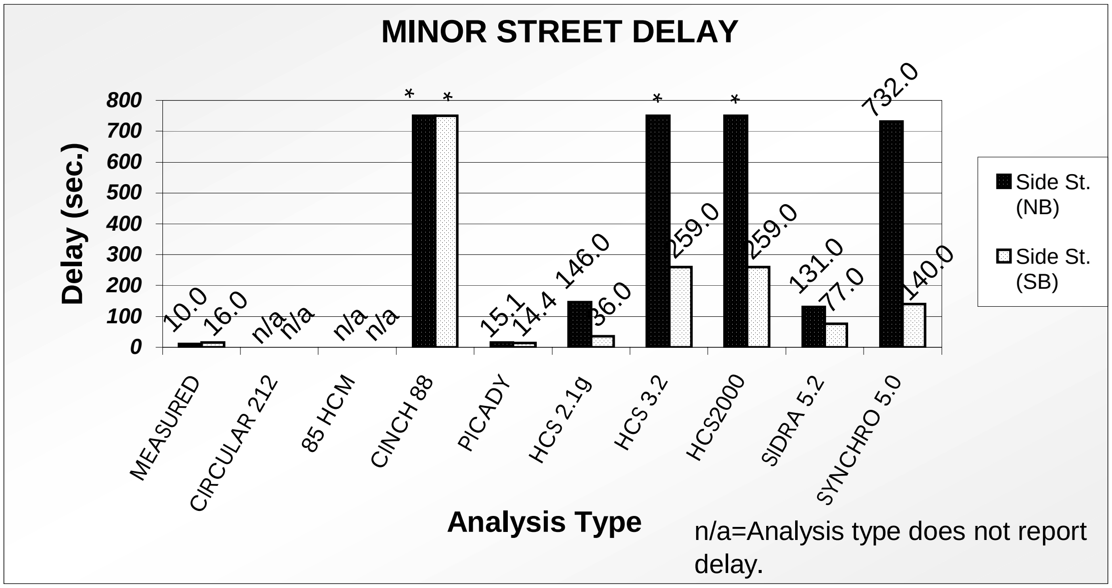
Figure 31



SYNCHRO 5.0 (8) is closest to the measured value of 6.4. The other packages are all greater than 40, or five times the measured value.

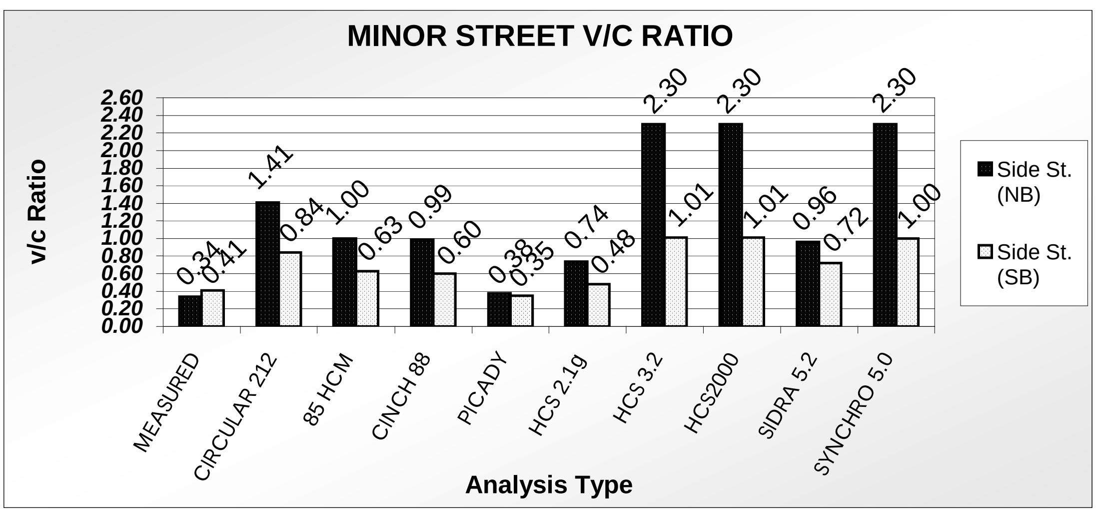
INTERSECTION D : Binney Street at Second Street (4-Way)

Figure 32



The measured values are 10.0 seconds for the northbound side street, and 16.0 for the southbound side street. PICADY's values are the closest, with 15.1 and 14.4 seconds for the northbound and southbound side streets, respectively. All other values are much higher, ranging from 36.0 to 750 seconds.

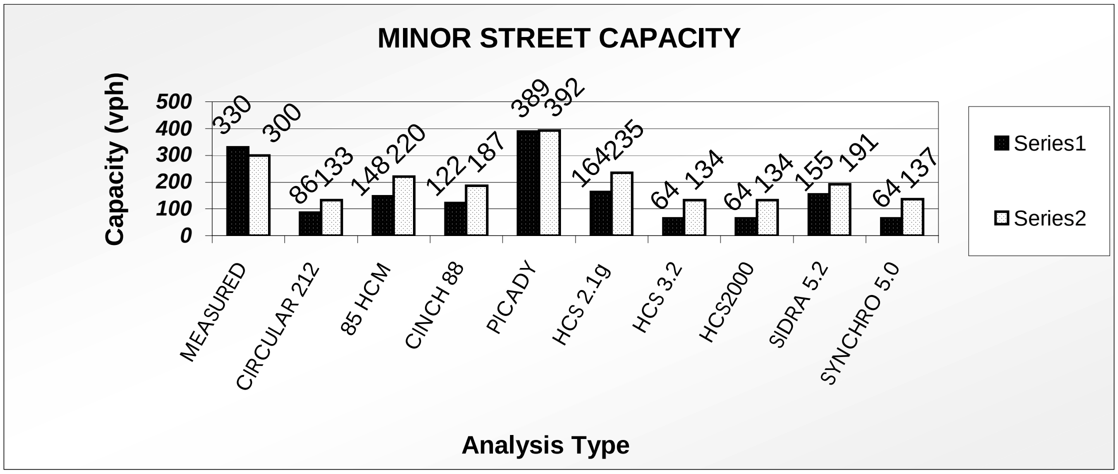
Figure 33



The measured values are 0.34 and 0.41 for the northbound and southbound approaches, respectively. PICADY's values are closest, with corresponding values of 0.38 and 0.35. The HCS 2.1g value of 0.48 is close to the measured v/c for the southbound minor street, but the northbound value of 0.74 is almost twice the measured value. The remainder of the packages yield results much higher than the measured values.

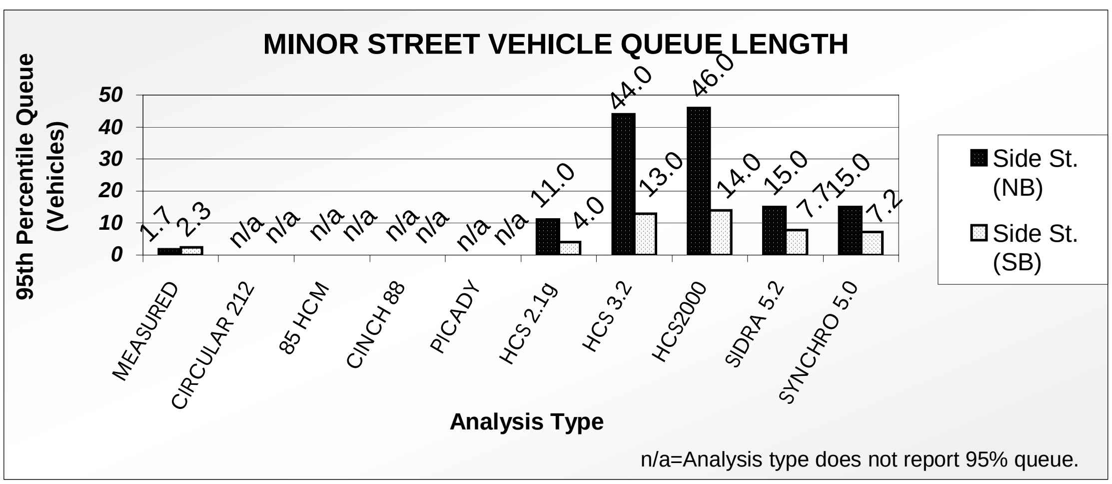
INTERSECTION D : Binney Street at Second Street (4-Way)

Figure 34



The measured values are 330.8 and 300.0 for northbound and southbound approaches, respectively. PICADY is the only package that yielded results that are higher than those measured, with 388.0 (+17%) and 392.0 (+31%) for northbound and southbound. The remaining packages resulted in much lower capacities. The range the northbound approach is from 64 (- 81%) to 164 (- 50%). For the southbound approach, the range is from 133 (-66%) to 235 (-22%).

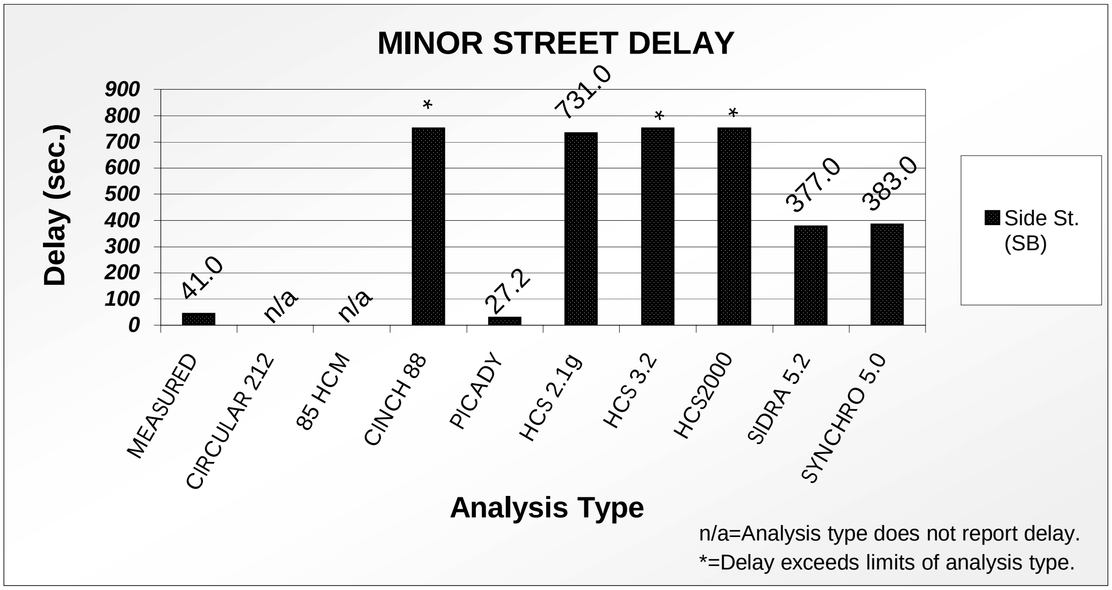
Figure 35



Field measured values are 1.7 and 2.3 for northbound and southbound approaches, respectively. HCS 2.1g yields values of 11.0 and 4.0. HCS 3.2 and HCS 2000 result in values of 44 and 46 for the northbound approach, and values of 13 and 14 for the southbound approach. SIDRA5.2 and SYNCHRO 5.0 are consistent with each other, with reported queues of 15 for the northbound approach, and values of 7.7 (SIDRA) and 7.2 (SYNCHRO).

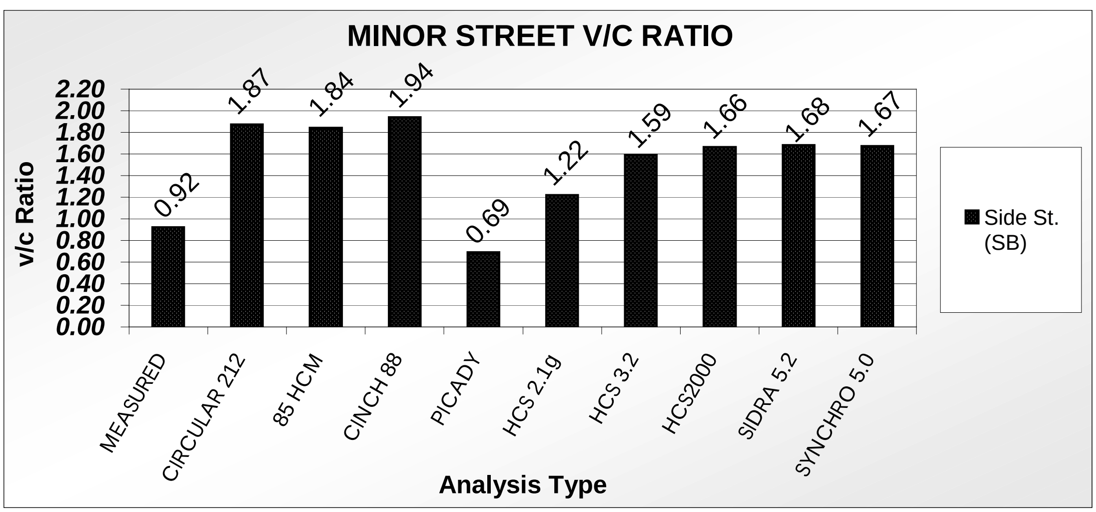
INTERSECTION E : Route 2A at Hanscom Road (3-Way)

Figure 36



PICADY, with a value of 27.2 seconds, is closest to the measured delay of 41.0 seconds. The closest any of the other packages comes is 377.0 seconds.

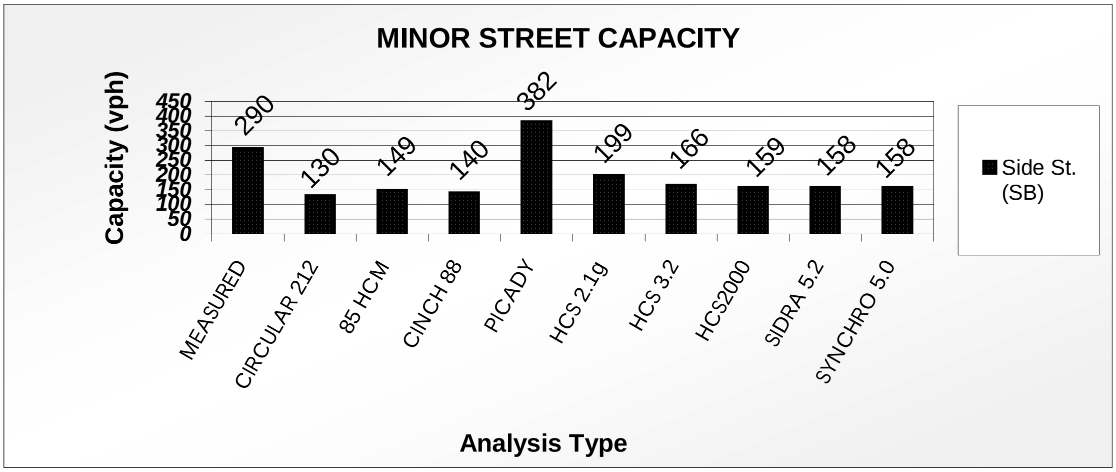
Figure 37



The measured value is 0.92. PICADY is closest at 0.69 (-25%), while HCS 2.1g is at 1.22 (+33%). Other values for v/c ratio range from 1.59 (+73%) to 1.94 (+110 %).

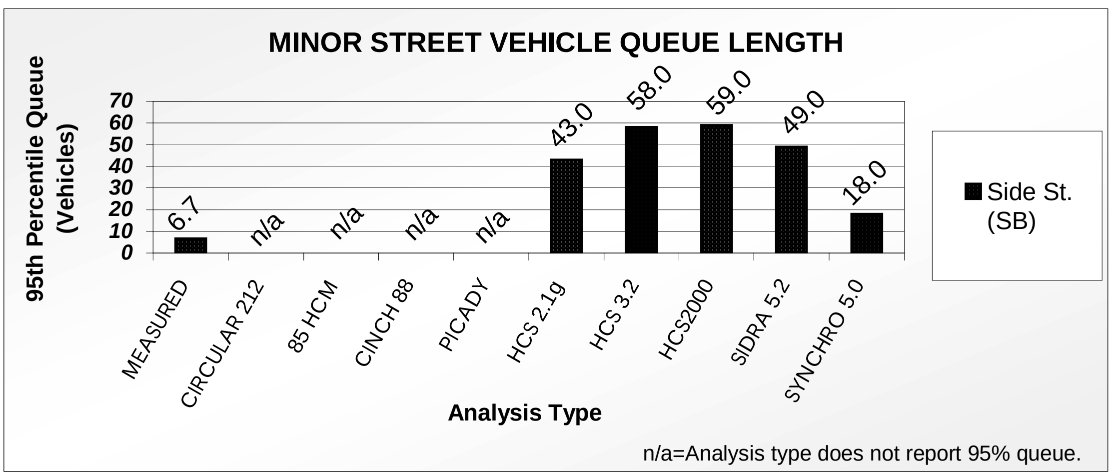
INTERSECTION E : Route 2A at Hanscom Road (3-Way)

Figure 38



The field measured value of minor street capacity is 290. PICADY is the only package that yields a value greater than measured (382, +32%)). The HCS 2.1g calculation is 199 (-31%). The other packages result in calculated values between 130 (-55%) and 166 (-32%).

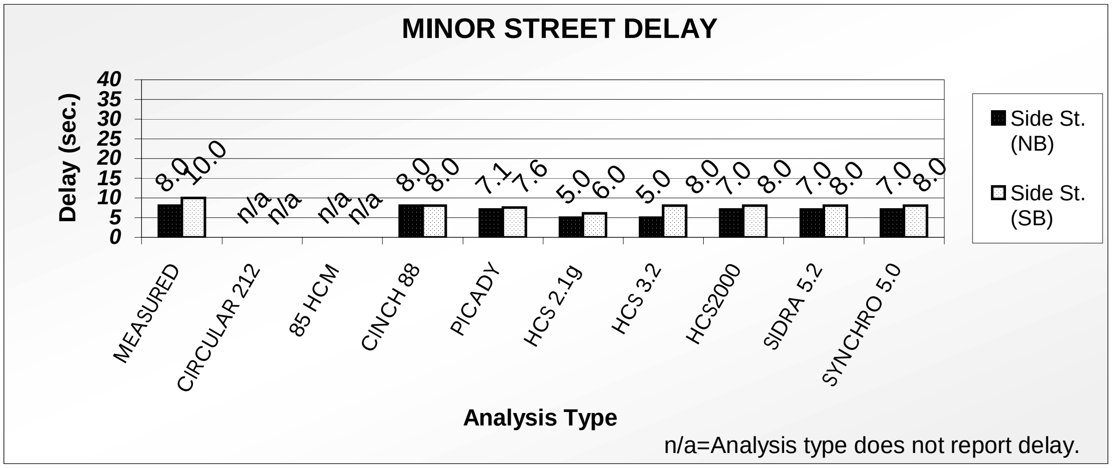
Figure 39



None of the packages match well against the field measured value of 6.7. SYNCHRO results in a value of 18 (+19%), while other values range from 43 to 58.

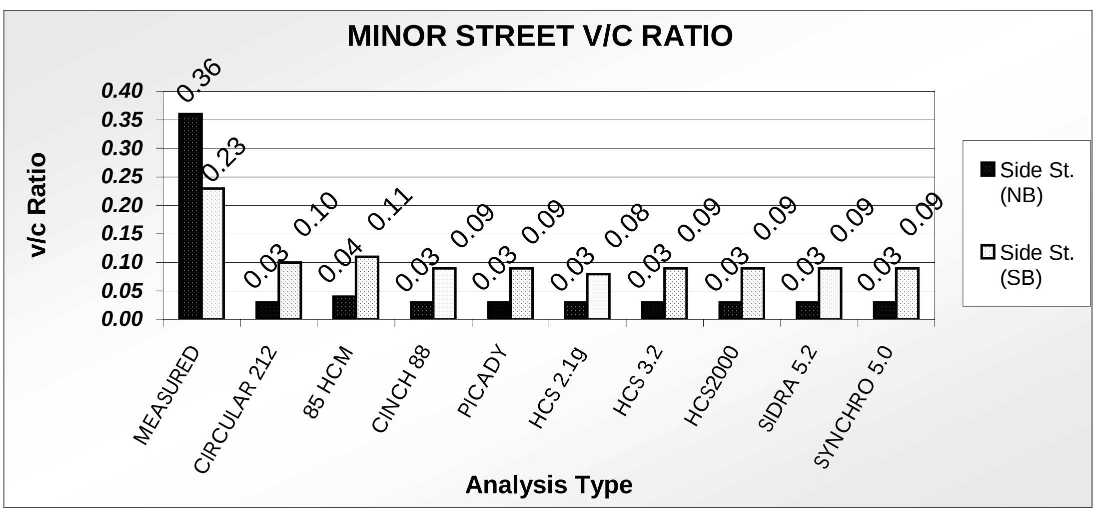
INTERSECTION F : Route 117 at Tower Road (4-Way)

Figure 40



The measured values are 8.0 and 10.0 for northbound and southbound approaches, respectively. SIDRA 5.2 results in longer queues, with 13.0 and 15 for northbound and southbound approaches. Calculations from the other packages show a range of 5.0 to 8.0 for the northbound approach, and 6.0 to 8.0 for the southbound approach.

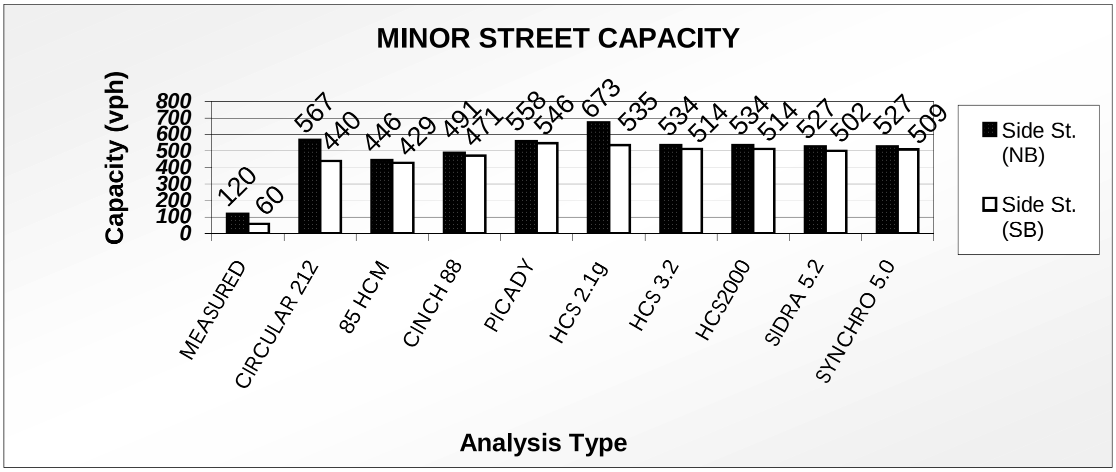
Figure 41



The measured values are 0.36 and 0.23 for northbound and southbound approaches, respectively. While none of the packages studied matches the field-measured values, they are all strikingly close to each other. Northbound volume-to-capacity ratios range from 0.2 to 0.04, while all southbound values fall in the 0.08 to 0.11 range.

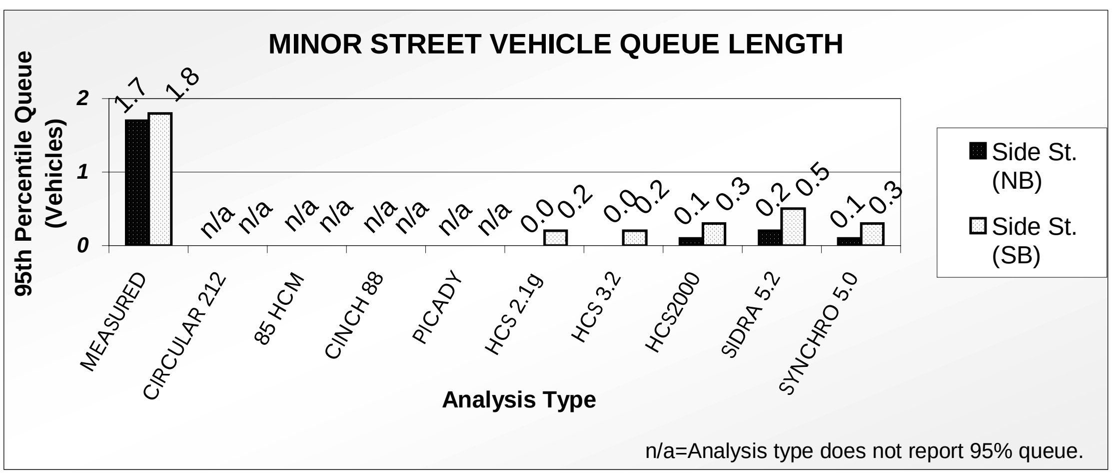
INTERSECTION F : Route 117 at Tower Road (4-Way)

Figure 42



The field measured values for capacity are 120 and 60 for northbound and southbound approaches. All of the packages yield capacities much higher than measured values. Northbound capacities range from 446 to 673, while southbound values range from 429 to 546.

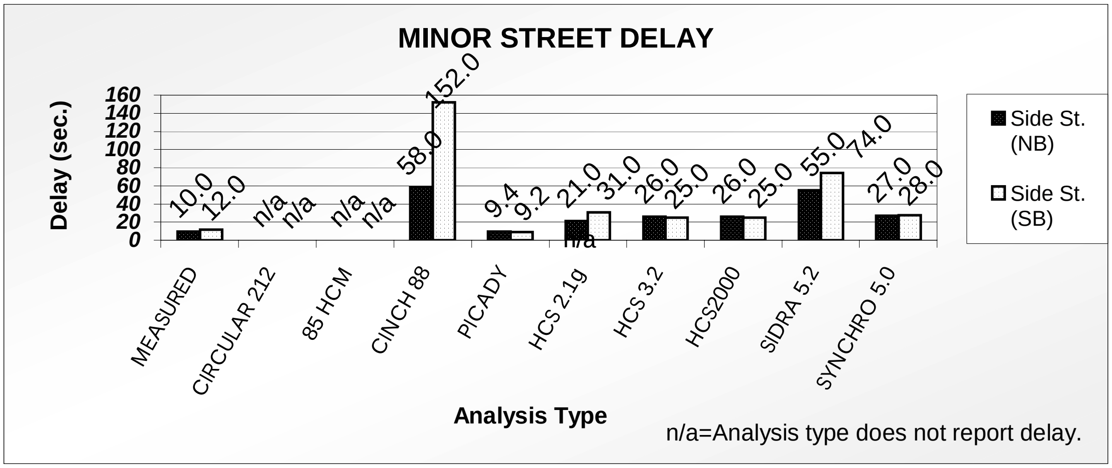
Figure 43



The measured values for the northbound and southbound approaches are 1.7 and 1.8, respectively. All of the packages resulted in values of 0.1 to 0.5. Due to the magnitude of these values, this graph does not provide a meaningful comparison.

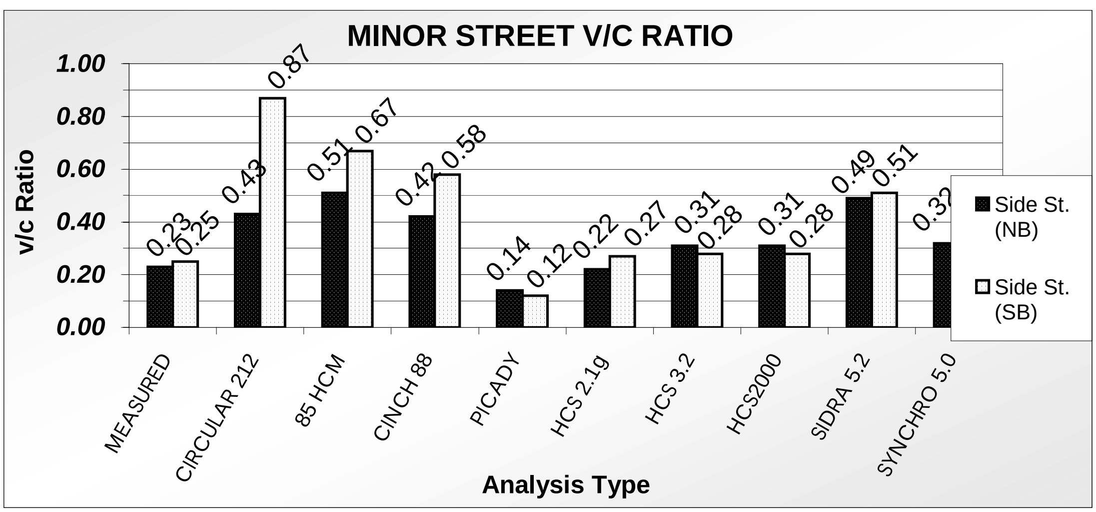
INTERSECTION G : Loudon Rd. at Branch Turnpike (4-Way)

Figure 44



The field-measured values are 10.0 and 12.0 seconds or northbound and southbound approaches, respectively. PICADY values are closest with reported delays of 9.4 and 9.2. CINCH delays are highest, with 58.0 seconds reported northbound and 152.0 reported southbound. SIDRA delays are also high, with values of 55.0 and 74.0 seconds. The remaining packages produce values between 21.0 and 28.0 seconds.

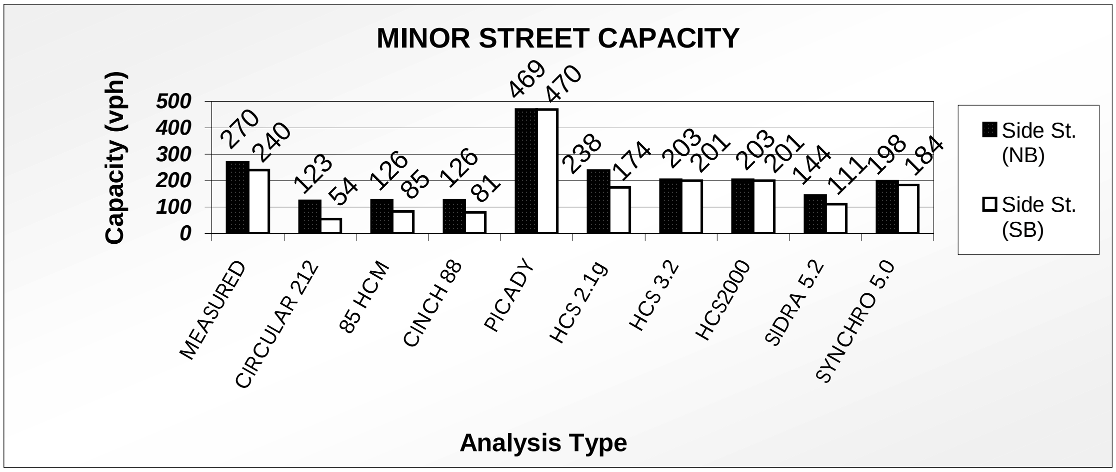
Figure 45



HCS 2.1g, HCS 3.2 and HCS 2000 yield values that are very close to the measured volume-to-capacity ratios of 0.23 and 0.25, for northbound and southbound approaches, respectively. PICADY is the only package that produces lower than measured values, at 0.14 and0.12, respectively. Circular 212 results in the highest values (0.43 and 0.87).

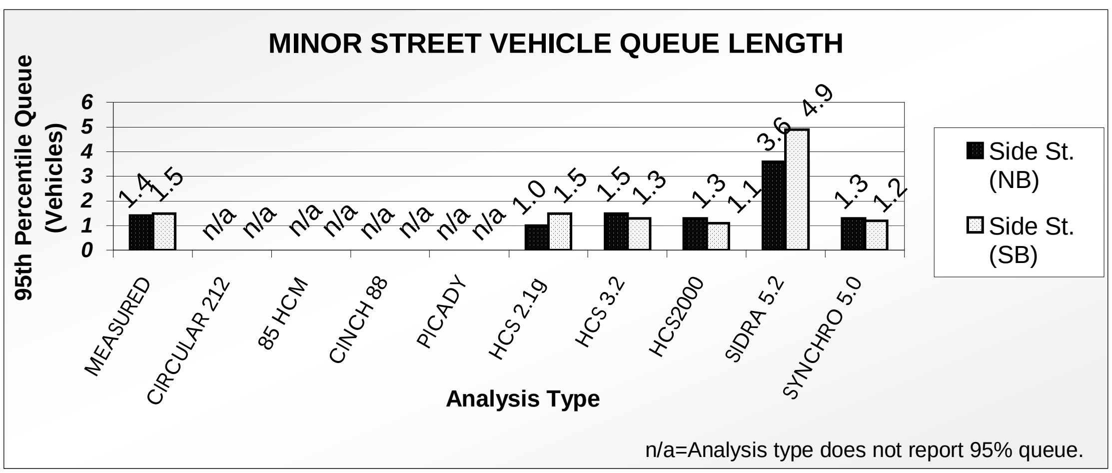
INTERSECTION G : Loudon Rd. at Branch Turnpike (4-Way)

Figure 46



Field measured values of capacity are 270 and 240 for the northbound and southbound approaches, respectively. The study packages produce results that range from highest values of 469 (+74%) and 470 (+96%) from PICADY, to lowest values of 123 (-74%) and 64 (-76%) from the 85HCM. The closest to measured values come from HCS 3.2 and HCS 2000, at 203 (-25%) and 201 (-17%).

Figure 47



The field measured values for northbound and southbound approaches are 1.4 and 1.5, respectively. Most of those packages that report on 95th percentile queue match up well against measured values. SIDRA, however, has higher values of 3.6 and 4.9.

SUMMARY

The results presented study indicate that the examined software packages exhibit the following trends:

- Only PICADY reasonably replicates field measured average stopped delay, with a composite variance of 22 percent. The next closest package shows a 592 percent variance.
- PICADY (23 percent variance) best replicates actual volume-to-capacity ratio, while HCS 2.1g is second best (32 percent variance). The next closest package shows an 82 percent variance.
- HCS 2.1 g, HCS 3.2, HCS 2000, and SYNCHRO 5.0 calculations are very close to field measured values for 95th percentile queue at three of the seven intersections, which all exhibit relatively low delays and volume to capacity ratios.
- None of the packages studied accurately calculate actual side street capacities.
- The gap-based models tend to be more conservative in calculations of measured capacity, and PICADY was consistently higher in this calculation.
- Most of the intersection anomalies (poor sight distance, angled approaches, parking) should tend to reduce intersection operations, and the software packages studied all tended to calculate delays and v/c's greater than those field measured. It is possible that the models exaggerate the expected impacts of these anomalies.

An additional study output is the gap acceptance, and in particular the critical gap. This measure is actually an input to the models and not an MOE, but the critical gap values have varied somewhat over the years and have consequently affected the calculated capacities. Many engineers have observed gap acceptance values in New England that are much lower that the published values.

The measured values of left turn critical gaps at tee intersections was 5.5 to 6.0 seconds, which are lower than the vales of 6.5 to 7.5 seconds contained in the literature. At four way intersections, however, the measured critical gaps were close to 8.0 seconds, which approximates published values.

It should be noted that the critical gap is defined as the point at which half the drivers will accept the gap and half will refuse it. Thus, there are many instances of individual drivers accepting much longer or much shorter gaps. Indeed the shape of the gap acceptance curve was much more linear than the expected and theoretical S-curve. It may well be that certain elements of the population are accepting much shorter gaps, while another segment of the driving public remains cautious and will take the time to wait for a longer and more comfortable gap.

A second input variable was not measured: the follow-up time. This measure was set for many years at 60 percent of the critical gap values, but in recent years the follow-up times have been set independently for each move. Proper measurement would require additional personnel measuring the movements of the first two vehicles in line relative to each other and should be a topic for future study.

The measurement method was complete and allowed for the identification of acceptance of long gaps by more than one vehicle. Such movement are not allowed in the conventional gap-acceptance theory, but are readily observed in the field. For example, at one study intersection 37 gaps were shared by two vehicles, five were shared by three and one long gap was used by five vehicles.

Recommendations

This project presents numerous results obtained from examining seven intersections in New England. Much more data representing a greater geographical cross section would be required to make definitive conclusions about the software packages studied. Two years ago, the New England Section Technical Committee completed a similar study of signalized intersections. In both studies, the results have been somewhat alarming.

While the data for both studies were statistically and geographically limited, the results do, however, show trends that cannot be ignored.

There can be several reasons for the disappointing comparisons. Do the algorithms for delay, v/c and queue determination need to be addressed? Do the intersections chosen for this study contain anomalies that challenge the methodologies beyond the norm?

Recommendations for further study include the following:

- Include a wider geographical base.
- Study the validity of regional critical gap differences.
- Expand the scope to include the effect of follow-up time, and the ability of more than one vehicle to accept the same gap.
- Build on the standardize procedures for data collection and analysis that have been developed for this project.
- Collect more data and evaluate the results independently.

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ENDNOTES

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