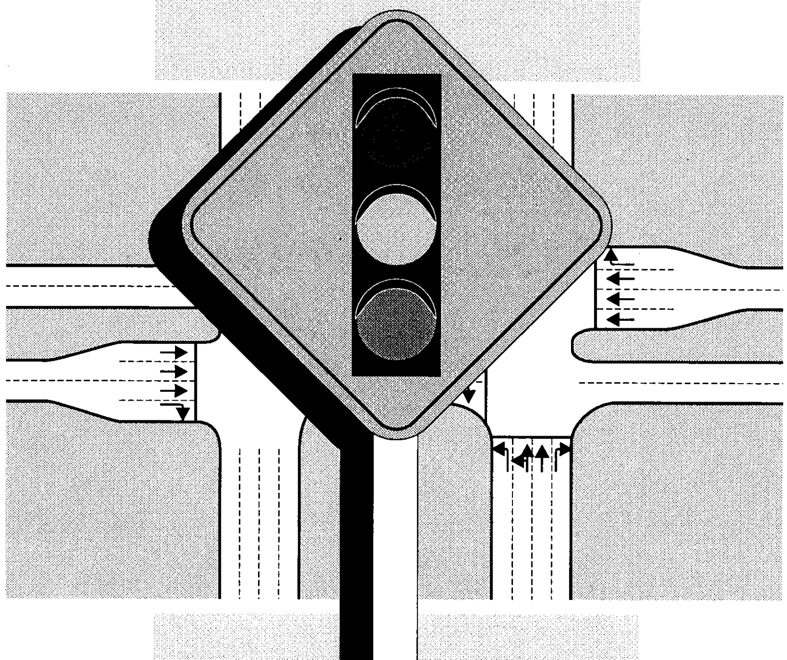
FINAL REPORT

REVIEW AND EVALUATION OF METHODS FOR ANALYZING CAPACITY AT SIGNALIZED INTERSECTIONS



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16. Abstract

VDOT's current policy is to use and accept from others the 1994 Highway Capacity Manual (HCM) as the basis for capacity analysis on Virginia's streets and highways. VDOT uses the latest version of the Highway Capacity Software (HCS). Software programs replicating the 1994 HCM may be used by others submitting work to VDOT for review; however, all input data and assumptions must be provided, and VDOT may use the HCS to check the submitted analysis. The analysis may be rejected if different results are obtained.

To recommend appropriate revisions to this policy, this study evaluated computer software other than HCS that can be used in the analysis of signalized intersections, determining which programs provide acceptable results. The study then evaluated the results from simulation models to determine when and how to use this output in the analysis of signalized intersections.

The study recommended that, in addition to HCS, VDOT use and accept from others SIGNAL94 and HCM/Cinema, or TRAF/NETSIM for capacity analysis at isolated intersections. CINCH, however, should not be used or accepted. For congested, oversaturated intersections, TRAF/NETSIM should be the preferred analysis type. Estimates of queue length at isolated signalized intersections should be derived from SIGNAL94, HCM/Cinema, or TRAF/NETSIM. For non-isolated intersections where queuing and spillback are a potential problem, simulation analysis with TRAF/NETSIM should be used instead of capacity analysis to determine the operational characteristics of the corridor .

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REVIEW AND EVALUATION OF METHODS FOR ANALYZING CAPACITY AT SIGNALIZED INTERSECTIONS

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ABSTRACT

Capacity analysis estimates the traffic-carrying capacity of transportation facilities over a range of defined operational conditions. The Virginia Department of Transportation (VDOT) frequently uses capacity analysis for transportation planning. VDOT's Transportation Planning Division (TPD) and some field offices often review and approve capacity analyses conducted by others (usually consultants), primarily in conjunction with traffic impact analyses for proposed land developments.

VDOT's policy regards the 1994 *Highway Capacity Manual* (HCM) as the basis for capacity analysis on streets and highways in Virginia. VDOT uses the latest version of the Highway Capacity Software (HCS). Software programs that replicate the procedures in the 1994 HCM may be used by others submitting work to the Department for review; however, all input data and assumptions must accompany the submittal. The Department may use the HCS to check the submitted analysis, and may reject the analysis if different results are obtained.

To recommend appropriate revisions to VDOT's policy, this study evaluated existing signalized intersection capacity analysis software other than the HCS to determine which programs provide acceptable results, and evaluating the results from simulation models to determine when and how to use this output in the analysis of signalized intersections. Tasks included a literature review, a survey of practices in other state DOTs, and a survey of experiences with capacity analysis within VDOT. From these findings and the guidance of an advisory committee formed for the study, SIGNAL94, HCM/Cinema, CINCH, and TRAF-NETSIM were selected for evaluation. These programs were applied to several signalized intersections and the resulting delay and queue estimates compared to actual field measurements.

The study recommended that, in addition to the HCS, VDOT staff use and accept from others SIGNAL94 and HCM/Cinema for capacity analysis at isolated signalized intersections. CINCH, however, should not be used or accepted because the program probably will not be updated to incorporate the changes in the recently published Third Edition of the *Highway Capacity Manual*. When desired, estimates of queue lengths at isolated signalized intersections should be derived from SIGNAL94, HCM/Cinema, or TRAF-NETSIM.

TRAF-NETSIM should also be accepted for capacity analysis at isolated intersections. TRAF-NETSIM should be the preferred analysis type for congested, oversaturated intersections. For non-isolated intersections where queuing and spillback are a potential problem, simulation analysis with TRAF-NETSIM should be used to determine the operational characteristics of the corridor instead of capacity analysis.

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INTRODUCTION AND PROBLEM STATEMENT

Capacity analysis is a set of procedures used by transportation engineers to estimate the traffic-carrying capacity of transportation facilities over a range of defined operational conditions. It provides tools for the analysis and improvement of existing facilities as well as the planning and design of future ones.[1]

Over the years, a number of capacity analysis methodologies have been used. Today, however, most practitioners use the procedures and methodologies in the latest version of the Highway Capacity Manual (HCM).[1] These procedures are continually being reviewed and updated from ongoing research conducted under the auspices of the Transportation Research Board's Committee on Highway Capacity and Quality of Service. The procedures are computerized and updated as Highway Capacity Software (HCS), a public domain package that automates the procedures in the 1994 HCM. The HCS is prepared under the sponsorship of the Federal Highway Administration and maintained by the Center for Microcomputers in Transportation (McTrans) at the University of Florida. A number of other proprietary and nonproprietary computer software programs perform capacity analysis, most of them also based on the 1994 HCM.

The Virginia Department of Transportation (VDOT) frequently uses capacity analysis for transportation planning, traffic engineering, and design activities. Further, VDOT's Transportation Planning Division (TPD) and some field offices often review and approve capacity analyses conducted by others (usually consultants), primarily in conjunction with traffic impact analyses for proposed land developments.

VDOT's policy is to use and accept from others the 1994 HCM as the basis for performing capacity analysis on streets and highways in Virginia. To assist in the analysis, VDOT uses the latest version of the HCS. Software programs that replicate the procedures in the 1994 HCM may be used by others submitting work to VDOT for review; however, all input data and assumptions must accompany the submittal. VDOT may use the HCS to check the submitted analysis, and it may be rejected if different results are obtained.

Additional review by VDOT's staff is required for capacity analysis submittals not using HCS. Also, VDOT's staff frequently has to justify the policy by analyzing the differences and then explaining to those who submitted the analysis why it is not acceptable. The additional review and justification typically arises when transportation planners review and approve the capacity analysis contained in the traffic impact analysis for a proposed development. Consultants for developers often use capacity analysis software other than the HCS and, accordingly, additional VDOT staff time is required to check the analysis with HCS and then explain the policy to the consultants. If VDOT's policy were more flexible, that is, if there were a list of acceptable or approved computer programs, time and effort in the review process could be saved.

There is another issue concerning the Department's policy regarding capacity. Simulation models such as TRAF-NETSIM have improved significantly over the last several years and are now becoming viable analysis tools. In some instances the models calculate a value for a parameter that is used in capacity analysis. Since capacity analysis and simulation procedures are fundamentally different (macroscopic vs. microscopic analysis), the application of simulation and capacity analysis procedures at the same location often yields different values for the same parameter (such as delay). VDOT's current policy of only accepting the HCM/HCS does not allow the use of output from a simulation model in capacity analysis, even if it is apparently more accurate.

OBJECTIVES AND SCOPE

This study had two objectives. The first was to review and evaluate existing signalized intersection capacity analysis procedures and computer programs other than those in the 1994 HCM (computerized in the HCS). The objective of this evaluation was to determine which of the procedures and computer programs that are submitted to the Department are acceptable. The second objective was to investigate the validity of using output from simulation models in traditional capacity analysis procedures. The purpose of this investigation was to determine when and how to use the output of simulation models in capacity analysis of signalized intersections.

The evaluations were undertaken only for a limited number of procedures, computer programs, and simulation models, all of which were selected in collaboration with an advisory committee established for the study. The models chosen for evaluation were those most commonly used by VDOT staff and those submitting analyses to VDOT. The evaluation was further limited by the fact that the Third Edition of the HCM was published in early 1995. Revised HCS software was released in the spring, and one of the capacity programs to be evaluated was not updated in time to be included in this research.

METHODS

To achieve the study objectives, the following tasks were undertaken:

Task 1: Establishment of Capacity Analysis Advisory Committee

An advisory committee was established to provide overall guidance of the study. Membership included representatives from TPD, the Traffic Engineering Division (TED), the Location and Design Division (L&D), and the District Offices. Appendix A lists the members of the committee.

Task 2: Survey of VDOT Staff

VDOT's experiences with non-HCM/HCS procedures and simulation models were compiled by sending a questionnaire to a sample of those who use and review capacity analysis procedures. The sample included 45 resident engineers in field offices throughout the state, 9 district traffic engineers (DTE), 8 transportation planning engineers in TPD, and 8 members of the Capacity Analysis Advisory Committee. The questionnaire is included in this report as Appendix B.

Task 3: Survey of State Departments of Transportation

All the state Departments of Transportation (DOT) were surveyed to determine which capacity analysis procedures and computer programs were used and accepted, and whether the outputs of simulation models were used in capacity analysis. A questionnaire was mailed to each state DOT representative on AASHTO's highway subcommittees on design and traffic engineering and its standing committee on planning, establishing contact with three persons representing three different disciplines from each state. A copy of the questionnaire and transmittal letter is included in Appendix C.

Task 4: Selection of Capacity and Simulation Procedures for Evaluation

A detailed evaluation of all the capacity procedures and simulation models identified from the surveys was beyond the scope of the project. Discussions were held with the advisory committee to determine which programs and procedures were most often used by or submitted to VDOT. The most common software programs for intersection capacity analysis were identified as HCS and SIGNAL85. CINCH was reportedly often used to determine queue lengths. HCM/Cinema and TRAF-NETSIM were identified as relatively new procedures that are becoming more common, especially in congested, urban areas. The project was therefore focused on these methods, comparing the measures of effectiveness (e.g. delay) produced by each to values measured in the field.

SIGNAL85, HCS, and HCM/Cinema have been updated to reflect the changes in the capacity procedures presented in the Third Edition revisions to the HCM. When contacted, the developers of CINCH stated that there were no immediate plans to update that package. It was included in the evaluation so a recommendation could be made about the validity of the queue lengths it reports.

Task 5: Selection of Sites and Evaluation of Case Studies

Specific sites were selected for evaluation based on their characteristics. The intent was to choose intersections that could be considered "typical." Intersections experiencing heavy peak hour volumes and several with moderate to low volumes were considered. The first four sites are typical isolated intersections. In this study, an "isolated intersection" is one at which the operations are not impacted by queuing from an adjacent intersection. The spacing of intersections considered to be isolated may vary depending on the traffic volumes at that intersection, as well as downstream intersections where extensive queuing would impact the operations of the intersection in question. The fifth site is a corridor, five closely spaced intersections. At each intersection, the operations at the adjacent intersections play a large role in the operations at that intersection. The required input data were collected and the appropriate software was run. A brief description of sites and the evaluation undertaken at each follows:

1. *Intersection of Route 250 (Ivy Road) and Route 29 (Emmet Street) in Charlottesville*: This isolated signalized intersection is adjacent to the University of Virginia, and has 3-lane approaches on the east and west legs and 2-lane approaches on the north and south legs. All approaches have left turn bays with exclusive signal phasing. Turning movements and stopped delay were collected on a weekday during the 7:00 to 9:00 a.m. and 4:00 to 6:00 p.m. peak periods. The intersection's capacity was analyzed using HCS, CINCH, SIGNAL94 and HCM/Cinema. Additionally, TRAF-NETSIM was applied at this site to determine the effectiveness of the model in determining stopped delay, used to determine LOS at isolated intersections. The output delay values and queue lengths were compared between the models as well as with the field measurements.

2. *Intersection of Route 631 (Rio Road) and Berkmar Drive in Charlottesville*: This isolated signalized intersection in the northern part of the Charlottesville area is approximately 0.5 km (0.3 mi) east of the intersection of Rio Road with U.S. Route 29. All approaches have three lanes with left turn bays, except southern Berkmar Road, which has a single lane approach. None of the approaches have exclusive left turn signal phasing. Turning movements and stopped delay were collected on a weekday during a 7:00 to 9:00 a.m. peak period. The intersection's capacity was analyzed using HCS, CINCH, SIGNAL94 and HCM/Cinema. The

output delay values were compared between the models as well as with field measurements.

3. *Intersection of Route 631 (Rio Road) and Northfields/Hillsdale Roads in Charlottesville*: This isolated signalized intersection in the northern part of the urbanized area is approximately 1.1 km (0.7 mi) west of the intersection of Rio Road with U.S. Route 29. The east-west Rio Road approaches have three lanes with left turn bays and exclusive signal phasing. The southern approach from Hillsdale Road has two lanes, one for right turns and one for left turns and through traffic. The northern approach from Northfields Road has one lane for all movements. Turning movements and stopped delay were collected on a weekday during the 7:00 to 9:00 a.m. and 4:00 to 6:00 p.m. peak periods. The intersection's capacity was analyzed using HCS, CINCH, SIGNAL94 and HCM/Cinema. The output delay values were compared between the models as well as with the field measurements.

4. *Intersection of Route 743 (Hydraulic Road) and Whitewood/Lambs Roads in Charlottesville*: This isolated signalized intersection is located in the northwestern part of the urbanized area adjacent to Albemarle High School. The north-south Hydraulic Road approaches have three lanes with left turn bays and exclusive signal phasing. The eastern approach from Whitewood Road has two lanes, one for left turns and one for right turns and through traffic. The western approach from Lambs Road has one lane for all movements. Turning movements and stopped delay were collected on a weekday during a 4:00 to 6:00 p.m. peak period. The intersection's capacity was analyzed using HCS, CINCH, SIGNAL94 and HCM/Cinema. The output delay values were compared between the models as well as with the field measurements.

5. *Route 3 Corridor in Fredericksburg*: The section of Route 3 analyzed in this study is a typical urban arterial with three through lanes in each direction, a continuous right turn lane, and left turn bays at each signalized intersection. The signals along this corridor are coordinated to provide optimum flow in the peak direction. Access to retail developments is provided from Route 3 , further congesting the corridor. During much of the p.m. peak period, queues extend the length of the corridor in the westbound direction (approximately 1.6 km). Traffic counts were collected at each intersection in the Route 3 study area in the fall of 1994. From these counts, the peak periods were identified and the p.m. peak was chosen for analysis. Travel time runs were conducted during the peak period on three days. The average car method of determining travel time was employed for the study, with the test car traveling as close to the average speed of traffic as possible. The corridor was analyzed using HCS, both the signal module and the arterial module, HCM/Cinema, and TRAF-NETSIM.

SUMMARY OF SURVEY RESULTS

VDOT Staff Experiences

Forty-five responses to the questionnaire were received from VDOT's resident engineers, DTEs, transportation planning engineers, and members of the Capacity Analysis Advisory Committee. A number of respondents cited the use and review of computer programs that do not actually calculate a level of service; rather, their output is used in some manner to analyze capacity. Further, some respondents cited the use or review of programs that are not traditionally considered as simulation models.

Resident engineers rarely use or review capacity analysis procedures other than the HCM and HCS. One residency used TRANSYT-7F, and one residency reported using or reviewing simulation - TRANSYT-7F and one of the PASSER versions.

District traffic engineers reported that they have used INTERCALC, COUNTS PC, and the AAP in addition to the HCM/HCS for capacity analysis and have reviewed analyses from SIGNAL85 and PASSER. DTEs have used TRAF-NETSIM and TRANSYT-7F for simulation, but have not had to review the results of any simulation models that were submitted by others.

In addition to HCM/HCS, transportation planning engineers reported using CINCH for capacity analysis, and recently reviewed a submittal that used critical lane analysis. Simulation usage and review have included TRANSYT-7F, TRAF-NETSIM, and MINUTP.

Members of the advisory committee reported using or reviewing INTERCALC, CAPCALC, SIGNAL 85/TEAPAC, Webster Equation, NCHRP 255, PASSER, TRANSYT-7F, and HCS/CINEMA in capacity analysis. Simulation usage and review have included TRANSYT-7F, TRAF-NETSIM, SOAP, SYSTEM II, MINUTP, INTRAS, QUEWZ, SIGNAL 85/TEAPAC, HCM/CINEMA, CORFLO, and FRESIM.

Practices in State DOTs

A total of 72 completed questionnaires representing 48 states (including Virginia) were received. Like the VDOT surveys described above, several respondents cited the use and review of computer programs that do not actually calculate a level of service; rather, their output is used in some manner to analyze capacity. Further, some respondents cited the use or review of programs that are not traditionally considered as simulation models. Table 1 provides an overview of the survey responses. More detail on each of the questions and the reponses received follows.

Table 1
Summary of State DOT Survey Responses

Question	Yes	No	Comments
Does the state require a specific capacity analysis method for DOT staff?	31	17	46 of 48 respondents specified the use of HCM proceedures.
Does the state require a specific capacity analysis method for those submitting work?	35	13	HCM proceedures specified in a majority of the cases.
Does the state require the use of specific capacity analysis software by DOT staff?	21	27	HCS specified in 16 of 21 reported policies.
Does the state require the use of specific capacity analysis software by those submitting work?	13	35	HCS reported to be used in 45 states with 19 states reporting exclusive use of HCS.
Does the state have a policy or requirement concerning use of simulation model output in capacity analysis?			No state has specific policy. 18 states reported some experience with simulation models.

Question 1: *Does your state DOT require the use of specific capacity analysis methods (e.g., those defined in the Highway Capacity Manual) by DOT staff?*

Thirty-one states responded that they have a policy requiring the use of a specific method by DOT staff. Eighteen of the 31 stated that the policy was written, ten specified that it was an unwritten requirement, and three did not provide enough information to determine whether it was or was not written. Seventeen states reported having no policy regarding the method used by DOT staff for capacity analysis.

Regardless of whether they had a policy, 46 of the 48 respondents specifically referred to the Highway Capacity Manual in response to this question. The remaining two states did not provide any information on the methods used. Five states use TRB Circular 212 in addition to the HCM, and Maryland uses its own State Highway Administration (SHA) Critical Lane Method.[2] Florida has developed a Level of Service Manual that is based on the HCM but incorporates input values based on local traffic characteristics.[3] Oregon uses the HCM for all but signalized intersections, for which they use the v/c ratio to determine the level of service.[4]

Question 2: *Does your State DOT require the use of specific capacity analysis methods that is, those defined in the Highway Capacity Manual) by those who submit work to DOT staff for review and/or approval (e.g., traffic impact analyses and site plans)?*

Thirty-five state DOT's reported having policies requiring the use of specified methods for capacity analyses submitted to them. Twenty states reported a written policy, ten an unwritten policy, and five did not provide enough information to determine the status of the policy. Thirteen states reported having no policy regarding capacity analysis methods used and submitted by others.

The methods reported in response to this question were the same as those for Question 1, with the procedures described in the HCM specified in almost every case. Nevada's policy on capacity analysis methods states that an "approved method" must be used but does not specifically list which methods are approved.[5] Florida requires the use of the state-developed input values mentioned above,[3] and Oregon requires the consideration of v/c ratios for signalized intersections.[4] Maryland requires the use of its own Critical Lane Method.[2]

Question 3: Does your State DOT require the use of specific capacity analysis software (e.g., Highway Capacity Software) by DOT staff?

Twenty-one states reported that they have a policy regarding the use of capacity analysis software by DOT staff. In eight of these states, the policies are written, in eight they are unwritten requirements, and the status in five states could not be determined from the information given. Twenty-seven states reported no policy. HCS was specified in 16 of the 21 reported policies. Maryland requires the use of its Critical Lane Analysis software,[2] and Florida requests the use of its programs which include local inputs to the HCM procedures.[3] Three remaining states with policies did not specify what software they required. Twenty-five of the states responding to the survey also reported staff use of other software packages, including TRANSYT-7F (13 states), PASSER 2 or 3 (18 states), SIGNAL85/TEAPAC (8 states), and SOAP (10 states). In addition, FRESYS, CINCH, SIDRA, INTERCALC, NCAP PS1, and Expert Signal were all reported as programs in use by at least one state DOT. It is not certain whether these programs are used directly in capacity analysis or to optimize the inputs to more traditional capacity analysis methods.

Question 4: Does your State DOT require the use of specific capacity analysis software (e.g., Highway Capacity Software) by those who submit work to DOT staff for review and/or approval (e.g., traffic impact analyses and site plans)?

Thirty-five of the states responding to the survey reported that they do not have a policy requiring specific capacity analysis software for use by those submitting work for review. Thirteen states said they have policies, five of which were written, four were unwritten, and the status of four could not be determined. The software packages being used are very similar to those listed in Question 3. HCS was reported as being used in 45 states, with 19 states reporting exclusive use of the software. TRANSYT-7F, PASSER, SOAP, and SIGNAL85/TEAPAC were also listed frequently as being used by those submitting work for review. Other programs reported to be accepted by at least one state DOT include CINCH, SIDRA, NCAP PS1, HCAP, and Expert Signal. Several states reported a policy similar to Virginia's, stating that they accept output from software other than HCS but reserve the right to reject the analysis if HCS produces different results.

Question 5: Does your State DOT have a specific policy or requirement concerning the use of simulation model output in capacity analysis by either DOT staff or those submitting work to DOT staff for review and/or approval?

No state responding to the survey reported a policy on the use of simulation models. New York's policy on capacity analysis does include the following statement recognizing the value of simulation models: "There are cases when capacity and level of service are inadequate measures to document the traffic performance of an existing or proposed facility. These cases often involve complex geometric and/or signal control situations; roadways or ramps which are over-saturated; or where the proximity of controls (e.g. signalized intersection) cause spillback affecting nearby locations. In these cases, use of traffic simulation models to estimate other traffic performance measures should be considered in addition to capacity and level of service."[6]

Eighteen states reported some experience with simulation models such as HCM/ CINEMA, TRAF-NETSIM, FRESIM, FREQ, or INTRAS. In addition, many states listed programs such as TRANSYT-7F and PASSER in response to this question. Technically, these programs are considered optimization programs rather than simulation programs.

RESULTS OF CASE STUDY ANALYSES

Evaluations at Isolated Intersections

The results of running HCS, SIGNAL94, CINCH and HCM/Cinema at the four isolated, signalized intersections in the Charlottesville area are reported in Tables 2 through 7. The calculated delay and level of service (LOS) for each lane group, each approach, and each intersection are listed, as well as comparison with the delay measured in the field. Table 8 is a summary comparing the four programs to field values. Table 9 compares the queue length output by SIGNAL94, CINCH and HCM/Cinema with observed field data for the intersection that experienced the most delay throughout the peak hour and on all approaches. It is important to note the limitations to the reported maximum field queue. First, the data were obtained from the stopped delay study, which measures the number of vehicles stopped at a given time. Further, only a sample of stopped delay was obtained during the peak hour due to manpower limitations; thus the absolute maximum number of vehicles in a queue may have been missed. Accordingly, the maximum field queue reported is an approximate measurement, and should be considered as such when evaluating the queue length estimation ability of the models.

Table 2
Comparison of Output from Capacity Software
Rio Road and Hillsdale/Northfield Roads, A.M. Peak Hour

Movement	Field Delay (sec.)	LOS	HCS Delay (sec.)	Diff From Field	LOS	Signal94 Dealey (sec.)	Diff From Field	LOS	CINCH Delay (sec.)	Diff From Field	LOS	Cinema Delay (sec.)	Diff From Field	LOS
EB - LT	1.0	A	3.1	2.1	A	2.5	1.5	A	4.2	3.2	A	3.1	2.1	A
EB - TH/RT	2.5	A	9.2	6.7	B	9.2	6.7	B	12.5	10.0	B	9.2	6.7	B
WB - LT	10.1	B	4.8	-5.3	A	2.8	-7.3	A	5.5	-4.6	B	4.8	-5.3	A
WB - TH/RT	2.0	A	8.3	6.3	B	8.3	6.3	B	11.4	9.4	B	8.3	6.3	B
NB - LT/TH	23.8	C	12.2	-11.6	B	11.9	-11.9	B	14.7	-9.1	B	11.9	-11.9	B
NB - RT	4.6	A	13.1	8.5	B	13.1	8.5	B	17.2	12.6	C	13.1	8.5	B
SB - LT/TH/RT	14.7	B	14.0	-0.7	B	14.0	-0.7	B	15.7	1.0	C	14.0	-0.7	B
AVG DIFF				5.9			6.1			7.1			5.9	
EB APPROACH	2.5	A	9.1	6.6	B	9.1	6.6	B	12.4	9.9	B	9.1	6.6	B
WB APPROACH	3.5	A	7.7	4.2	B	7.3	3.8	B	10.4	6.9	B	7.7	4.2	B
NB APPROACH	9.4	B	12.9	3.5	B	12.8	3.4	B	16.6	7.2	C	12.8	3.4	B
SB APPROACH	14.7	B	14.0	-0.7	B	14.0	-0.7	B	15.7	1.0	C	14.0	-0.7	B
AVG DIFF				3.8			3.6			6.3			3.7	
INTERSECTION	4.4	A	9.2	4.8	B	9.4	5.0	B	12.2	7.8	B	9.3	4.9	B

Table 3
Comparison of Output from Capacity Software
Rio Road and Hillsdale/Northfield Roads, P.M. Peak Hour

Movement	Field Delay (sec.)	LOS	HCS Delay (sec.)	Diff From Field	LOS	Signal94 Delay (sec.)	Diff From Field	LOS	CINCH Delay (sec.)	Diff From Field	LOS	Cinema Delay (sec.)	Diff From Field	LOS
EB - LT	12.4	B	5.2	-7.2	B	2.5	-9.9	A	4.3	-8.1	A	5.2	-7.2	B
EB - TH/RT	5.8	B	10.1	4.3	B	10.1	4.3	B	14.7	8.9	B	10.1	4.3	B
WB - LT	11.7	B	6.8	-4.9	B	2.9	-8.8	A	7.5	-4.2	B	6.8	-4.9	B
WB - TH/RT	3.3	A	13.2	9.9	B	13.2	9.9	B	21.1	17.8	C	13.2	9.9	B
NB - LT/TH	18.1	C	13.2	-4.9	B	12.8	-5.3	B	15.2	-2.9	C	12.7	-5.4	B
NB - RT	10.6	B	15.5	4.9	C	15.5	4.9	C	19.4	8.8	C	15.5	4.9	C
SB - LT/TH/RT	13.6	B	12.4	-1.2	B	12.4	-1.2	B	14.9	1.3	B	12.4	-1.2	B
AVG DIFF				5.3			6.3			7.4			5.4	
EB APPROACH	5.9	B	10.0	4.1	B	9.9	4.0	B	14.5	8.6	B	10.0	4.1	B
WB APPROACH	4.6	A	12.3	7.7	B	11.8	7.2	B	19.1	14.5	C	12.3	7.7	B
NB APPROACH	13.1	B	14.7	1.6	B	14.5	1.4	B	18.0	4.9	C	14.5	1.4	B
SB APPROACH	13.6	B	12.4	-1.2	B	12.4	-1.2	B	14.9	1.3	B	12.4	-1.2	B
AVG DIFF				3.7			3.5			7.3			3.6	
INTERSECTION	6.3	B	11.8	5.5	B	11.4	5.1	B	17.2	10.9	B	11.7	5.4	B

Table 4
Comparison of Output from Capacity Software
Rio Road and Berkmar Drive, A.M. Peak Hour

Movement	Field Delay (sec.)	LOS	HCS Delay (sec.)	Diff From Field	LOS	Signal94 Delay (sec.)	Diff From Field	LOS	CINCH Delay (sec.)	Diff From Field	LOS	Cinema Delay (sec.)	Diff From Field	LOS
EB - LT	9.4	B	4.8	-4.6	A	4.8	-4.6	A	5.9	-3.5	B	4.8	-4.6	A
EB - TH	5.1	B	4.2	-0.9	A	4.2	-0.9	A	6.2	1.1	B	4.2	-0.9	A
EB - RT	1.0	A	3.5	2.5	A	3.5	2.5	A	5.1	4.1	B	3.5	2.5	A
WB - LT	6.5	B	3.8	-2.7	A	3.8	-2.7	A	5.2	-1.3	B	3.8	-2.7	A
WB - TH	3.4	A	3.6	0.2	A	3.6	0.2	A	5.3	1.9	B	3.6	0.2	A
WB - RT	1.0	A	3.5	2.5	A	3.5	2.5	A	5.0	4.0	B	3.5	2.5	A
NB - LT/TH/RT	9.8	B	6.1	-3.7	B	6.1	-3.7	B	7.8	-2.0	B	6.1	-3.7	B
SB - LT	13.9	B	5.9	-8.0	B	5.8	-8.1	B	7.5	-6.4	B	5.8	-8.1	B
SB - TH	10.4	B	5.7	-4.7	B	5.7	-4.7	B	7.4	-3.0	B	5.7	-4.7	B
SB - RT	2.8	A	8.9	6.1	B	8.9	6.1	B	11.6	8.8	B	8.9	6.1	B
AVG DIFF				3.6			3.6			3.6			3.6	
EB APPROACH	6.0	B	4.3	-1.7	A	4.3	-1.7	A	6.0	0.0	B	4.3	-1.7	A
WB APPROACH	3.5	A	3.6	0.1	A	3.6	0.1	A	5.2	1.7	B	3.6	0.1	A
NB APPROACH	9.8	B	6.1	-3.7	B	6.1	-3.7	B	7.8	-2.0	B	6.1	-3.7	B
SB APPROACH	5.3	B	7.9	2.6	B	7.9	2.6	B	10.5	5.2	B	7.9	2.6	B
AVG DIFF				2.0			2.0			2.2			2.0	
INTERSECTION	5.6	B	5.3	-0.3	B	5.3	-0.3	B	7.2	1.6	B	5.3	-0.3	B

Table 5
Comparison of Output from Capacity Software
Hydraulic Road and Whitewood/Lambs Roads, P.M. Peak Hour

Movement	Field Delay (sec.)	LOS	HCS Delay (sec.)	Diff From Field	LOS	Signal94 Delay (sec.)	Diff From Field	LOS	CINCH Delay (sec.)	Diff From Field	LOS	Cinema Delay (sec.)	Diff From Field	LOS
EB - LT/TH/RT	33.3	D	(1)		(1)	170.9	137.6	F	66.1	32.8	F	(1)		(1)
WB - LT	39.5	D	(1)		(1)	46.3	6.8	E	23.5	-16.0	C	46.3	6.8	E
WB - TH/RT	19.4	C	23.1	3.7	C	23.1	3.7	C	23.8	4.4	C	23.1	3.7	C
NB - LT	16.7	C	15.6	-1.1	C	3.7	-13.0	A	5.9	-10.8	B	15.6	-1.1	C
NB - TH	13.6	B	29.0	15.4	D	28.9	15.3	D	41.1	27.5	E	29.1	15.5	D
NB - RT	0.0	A	6.1	6.1	B	6.1	6.1	B	7.5	7.5	B	6.1	6.1	B
SB - LT	19.8	C	13.9	-5.9	B	3.6	-16.2	A	7.1	-12.7	B	13.9	-5.9	B
SB - TH	6.4	B	10.8	4.4	B	10.8	4.4	B	13.6	7.2	B	10.8	4.4	B
SB - RT	0.0	A	5.6	5.6	B	5.6	5.6	B	7.0	7.0	B	5.6	5.6	B
AVG DIFF				6.0			9.2			11.0			6.1	
EB APPROACH	33.3	D	(1)		(1)	170.9	137.6	F	66.1	32.8	F	(1)		(1)
WB APPROACH	27.3	D	(1)		(1)	31.9	4.6	D	23.7	-3.6	C	31.9	4.6	D
NB APPROACH	12.2	B	24.9	12.7	C	23.8	11.6	C	34.6	22.4	D	25.0	12.8	C
SB APPROACH	7.1	B	10.8	3.7	B	9.9	2.8	B	12.8	5.7	B	10.8	3.7	B
AVG DIFF				8.2			7.2			14.1			5.3	
INTERSECTION	14.6	B	(1)		(1)	33.9	19.3	D	28.9	14.3	D	(1)		(1)

Table 6
Comparison of Output from Capacity Software
Emmet Street and Ivy Road, A.M. Peak Hour

Movement	Field Delay (sec.)	LOS	HCS Delay (sec.)	Diff From Field	LOS	Signal94 Delay (sec.)	Diff From Field	LOS	CINCH Delay (sec.)	Diff From Field	LOS	Cinema Delay (sec.)	Diff From Field	LOS
EB - LT	42.7	E	33.9	-8.8	D	34.3	-8.4	D	44.6	1.9	E	33.9	-8.8	D
EB - TH	33.4	D	26.4	-7.0	D	26.9	-6.5	D	29.1	-4.3	D	26.4	-7.0	D
EB - RT	19.3	C	17.7	-1.6	C	16.5	-2.8	C	18.2	-1.1	C	17.7	-1.6	C
WB - LT	38.8	D	37.0	-1.8	D	36.3	-2.5	D	47.2	8.4	E	37.0	-1.8	D
WB - TH	33.1	D	27.4	-5.7	D	27.2	-5.9	D	29.7	-3.4	D	27.4	-5.7	D
WB - RT	10.8	B	13.0	2.2	B	13.1	2.3	B	14.8	4.0	B	14.2	3.4	B
NB - LT	52.0	E	36.4	-15.6	D	36.9	-15.1	D	48.7	-3.3	E	36.4	-15.6	D
NB - TH	30.9	D	26.8	-4.1	D	25.6	-5.3	D	29.1	-1.8	D	26.8	-4.1	D
SB - LT	38.1	D	36.7	-1.4	D	39.3	1.2	D	57.4	19.3	E	36.7	-1.4	D
SB - TH/RT	23.4	C	39.7	16.3	D	29.3	5.9	D	37.5	14.1	D	38.3	14.9	D
AVG DIFF				5.9			5.1			5.6			6.4	
EB APPROACH	31.3	D	25.4	-5.9	D	25.5	-5.8	D	29.0	-2.3	D	25.4	-5.9	D
WB APPROACH	25.1	D	23.5	-1.6	C	22.9	-2.2	C	26.2	1.1	D	23.9	-1.2	C
NB APPROACH	34.1	D	28.1	-6.0	D	27.3	-6.8	D	32.1	-2.0	D	28.1	-6.0	D
SB APPROACH	27.3	D	39.0	11.7	D	31.9	4.6	D	42.8	15.5	E	37.9	10.6	D
AVG DIFF				6.3			4.9			5.2			5.9	
INTERSECTION	29.2	D	31.3	2.1	D	28.0	-1.2	D	35.1	5.9	D	30.9	1.7	D

Table 7
Comparison of Output from Capacity Software
Emmet Street and Ivy Road, P.M. Peak Hour

Movement	Field Delay (sec.)	LOS	HCS Delay (sec.)	Diff From Field	LOS	Signal94 Delay (sec.)	Diff From Field	LOS	CINCH Delay (sec.)	Diff From Field	LOS	Cinema Delay (sec.)	Diff From Field	LOS
EB - LT	57.0	E	62.7	5.7	F	62.9	5.9	F	80.3	23.3	F	62.9	5.9	F
EB - TH	49.4	E	34.2	-15.2	D	34.2	-15.2	D	37.6	-11.8	D	34.2	-15.2	D
EB - RT	25.8	D	20.8	-5.0	C	19.5	-6.3	C	21.2	-4.6	C	20.8	-5.0	C
WB - LT	50.8	E	43.3	-7.5	E	43.3	-7.5	E	54.9	4.1	E	43.3	-7.5	E
WB - TH*	37.5		35.4	N/A*	D	35.4	N/A*	D	37.5	N/A*	D	35.4	N/A*	D
WB - RT*			18.8	N/A*	C	18.8	N/A*	C	20.4	N/A*	C	20.2	N/A*	C
NB - LT	59.2	E	49.4	-9.8	E	49.3	-9.9	E	61.6	2.4	F	49.3	-9.9	E
NB - TH	58.5	D	46.3	-12.2	E	46.3	-12.2	E	49.5	-9.0	E	46.3	-12.2	E
SB - LT	47.5	E	55.9	8.4	E	55.9	8.4	E	74.4	26.9	F	55.9	8.4	E
SB - TH/RT	46.0	E	31.1	-14.9	D	31.1	-14.9	D	33.7	-12.3	D	30.7	-15.3	D
AVG DIFF				9.8			10.0			11.8			11.5	
EB APPROACH	47.5	E	40.2	-7.3	E	40.0	-7.5	E	47.3	-0.2	E	40.3	-7.2	E
WB APPROACH	39.1	D	28.9	-10.2	D	28.9	-10.2	D	31.9	-7.2	D	29.6	-9.5	D
NB APPROACH	58.6	E	46.9	-11.7	E	46.9	-11.7	E	51.7	-6.9	E	46.9	-11.7	E
SB APPROACH	46.5	E	38.6	-7.9	D	38.6	-7.9	D	46.2	-0.3	E	38.3	-8.2	D
AVG DIFF				9.3			9.3			3.7			9.2	
INTERSECTION	47.9	E	38.4	-9.5	D	38.4	-9.5	D	44.1	-3.8	E	38.5	-9.4	D

*NOTE: Field data for WB-TH/RT were combined; comparisons infeasible.

Table 8
Summary of Average Differences Between Observed and Calculated Delays

	HCS	SIGNAL94	CINCH	HCM/Cinema
Lane Group Delay	6.1 sec.	6.7 sec.	7.8 sec.	6.5 sec.
Overall Approach Delay	5.6 sec.	5.1 sec.	6.5 sec.	5.0 sec
Total Intersection Delay	4.4 sec.	4.2 sec.	6.0 sec.	4.3 sec.

Table 9
Comparison of Estimated Queues from Capacity Software
Emmet Street and Ivy Road

Time	Movement	Max Field Q (vehicles)	Signal94 90% Q (vehicles)	CINCH 96% Q(vehicles)	Cinema Max Q (vehicles)
A.M. Peak Hour	EB - LT	6	7	4	6
	EB - TH	12	16	8	11
	EB - RT	8	7	3	6
	WB - LT	4	4	3	3
	WB - TH	9	11	5	8
	WB - RT	4	6	3	6
	NB - LT	5	5	4	4
	NB - TH	14	19	11	13
	SB - LT	12	15	14	11
	SB - TH/RT	21	29	24	30
P.M. Peak Hour	EB - LT	8	13	12	15
	EB - TH	11	19	10	11
	EB - RT	5	6	3	4
	WB - LT	5	8	5	5
	WB - TH*	N/A*	21	11	17
	WB - RT*	N/A*	16	8	11
	NB - LT	8	11	7	7
	NB - TH	35	35	25	20
	SB - LT	10	19	16	14
	SB - TH/RT	30	31	17	22

*Field data for WB - TH/RT were combined; comparisons infeasible.

HCS

The public domain HCS is generally considered to be the standard in capacity analysis among practitioners. Of course the HCS does not duplicate the observed field delay exactly. The HCS produced estimates of delay that were reasonably close to the observed delay for all intersections.

Differences between the observed and the estimated delay for lane groups ranged from 0.2 seconds to 16.3 seconds for all intersections; however, the average lane group difference per intersection ranged from only 3.6 seconds to 9.8 seconds, with an overall lane group average difference of 6.1 seconds. Differences between the observed and the estimated delay for intersection approaches ranged from 0.1 seconds to 12.7 seconds for all intersections; however, the average approach difference per intersection ranged from only 2.0 seconds to 9.3 seconds, with an overall approach average difference of 5.6 seconds. Total intersection delay differences ranged from 0.3 seconds to 9.5 seconds with an overall average of 4.4 seconds.

SIGNAL94

The proprietary SIGNAL94 is based on the procedures in the Third Edition of the HCM. The input and output, while basically the same as the HCS, are re-ordered slightly. SIGNAL94 produces an estimate of the maximum queue length within a 90% level of confidence. While producing reasonably close estimates of delay, the program did not duplicate the observed field delay exactly.

Differences between the observed and the estimated delay for lane groups ranged from 0.2 seconds to 137.6 seconds for all intersections; however, the average lane group difference per intersection ranged from only 3.6 seconds to 10.0 seconds, with an overall lane group average difference of 6.7 seconds. The 137.6 second error in the delay estimate is due to the fact that the intersection operates differently than depicted in the software. The approach has one lane for all movements; however, the intersection flares out slightly at the intersection, thus allowing right turns to be made more easily. Since the traffic was very light on the approach, most of the right turns were made without the significant delay that is reflected in the model estimate. It is noted that the HCS and HCM/Cinema did not estimate delay for the lane group for which SIGNAL94 had the above 137.6 second delay because the (g/c)*(v/c) is greater than 1.0 (see Table 4); therefore, the large error is not shown in the discussions of either model.

Differences between the observed and the estimated delay for intersection approaches ranged from 0.1 seconds to 137.6 seconds for all intersections; however, the average approach difference per intersection ranged from only 2.0 seconds to 9.3 seconds, with an overall approach average difference of 5.1 seconds. Note the explanation for the 137.6 second error above. Total intersection delay differences ranged from 0.3 seconds to 19.3 seconds with an overall average of 6.7 seconds. If the one intersection having the 137.6 second error is omitted due to its field operation, the overall average drops to 4.2 seconds.

The HCS and SIGNAL94 produced estimates of delay that were essentially identical in most cases. Practically all the differences were in estimates of delay for exclusive-permissive left turn phases. The developer of SIGNAL94 has stated that the HCS is incorrect, and McTrans is currently evaluating that assertion. If the differences are eventually resolved, then the two programs may produce identical results for all movements.

Table 9 reports the maximum queues observed in the field compared with the 90% queue estimated by SIGNAL94. In most cases the estimate is reasonably close, particularly in light of the limitations on the field data collection discussed previously.

CINCH

CINCH is a public domain program developed in the late 1980s by the Central Transportation Planning Staff, the Metropolitan Planning Organization for the Boston region. The procedures are based on the 1985 HCM. There are currently no definite plans to update the program to the 1994 HCM. The input and output are similar to the HCS; however, CINCH was reportedly used mostly because it produces an estimate of maximum queue length. The methodology used to estimate the queue length varies slightly from that used by SIGNAL94. Generally, differences between the estimates of delay produced by CINCH and the observed field delays were relatively high compared to the other two programs.

Differences between the observed and the estimated delay for lane groups ranged from 1.0 second to 32.8 seconds for all intersections; however, the average lane group difference per intersection ranged from only 3.6 seconds to 11.8 seconds, with an overall lane group average difference of 7.8 seconds. The 32.8 second error in the delay estimate is due to the fact that the intersection operates differently than depicted in the software as explained above. Again, it is noted that the HCS did not estimate delay for this lane group (see Table 4).

Differences between the observed and the estimated delay for intersection approaches ranged from 0.0 seconds to 32.8 seconds for all intersections; however, the average approach difference per intersection ranged from only 2.2 seconds to 14.1 seconds, with an overall approach average difference of 6.5 seconds. Note the explanation for the 32.8 second error above. Total intersection delay differences ranged from 1.6 seconds to 14.3 seconds with an overall average of 7.4 seconds. If the one intersection having the 32.8 second error is omitted due to its field operation, the overall average drops to 6.0 seconds.

Table 9 reports the maximum queue observed in the field compared with the 95th percentile queue estimated by CINCH. The estimated queues are not identical to the field queues, and in most cases (13 out of 18), the estimate is lower than that measured in the field.

HCM/Cinema

HCM/Cinema is a software package designed to combine HCM-based analyses with TRAF-NETSIM. The latest version of HCM/Cinema, released in mid-1995, incorporates the changes in the HCM found in the 1994 update as well as the most recent version of TRAF-NETSIM. The inputs to HCM/Cinema are basically the same as HCS (signal module) with some additions such as turn bay lengths and link lengths. The program provides standard HCM output similar in format to the output provided by HCS. In addition, the TRAF-NETSIM portion of HCM/Cinema provides measures of effectiveness relating to the storage capacity of turn bays, such as the average and maximum queue lengths and the percent of signal cycles during which a turn bay capacity is exceeded or the bay is blocked by queued vehicles. This particular feature addresses a shortcoming of HCS, where all lanes are considered to be full lanes and vehicles are assumed to be able to reach them. While TRAF-NETSIM also models turn bays directly, taking into account lane blockages and queuing, the percentage of cycles during which such events happen is not directly output. HCM/Cinema also provides average speed, spillback information, fuel consumption, and pollution emissions, MOE's that are not provided by traditional HCM procedures.

Differences between the observed delay and HCM/Cinema estimated delay for lane groups ranged from 0.2 to 15.6 seconds for all intersections. The average difference in lane group delay per intersection ranged from 3.6 to 11.5 seconds and the overall lane group average difference was 6.5 seconds. Differences in intersection approach delays ranged from 0.1 to 12.8 seconds and the average difference in approach delays by intersection ranged from 2.0 to 9.2 seconds. The overall average difference in approach delay was 5.0 seconds. The average difference in total intersection delay ranged from 0.3 to 9.4 seconds with an overall average difference of 4.3 seconds. While HCM/Cinema does not produce results that exactly replicate conditions measured in the field, they are reasonably close for all intersections. In addition, the values of delay produced by HCM/Cinema are almost identical to those produced by HCS in almost every case.

Table 9 also contains estimates of queue lengths produced by the TRAF-NETSIM portion of HCM/Cinema. The estimates are reasonably close to those measured in the field. It should be noted that TRAF-NETSIM considers only stopped vehicles to be part of the queue, as was the case in the stopped delay counts from which the field queue estimates are derived.

TRAF-NETSIM for LOS

TRAF-NETSIM has been used to determine capacity and level of service at isolated intersections. TRAF-NETSIM provides stopped delay in seconds per vehicle for each link in the network. Since stopped delay is the criteria by which signalized intersection LOS is measured in the HCM procedures, the value produced by TRAF-NETSIM should be acceptable as well. The method of determining stopped delay in TRAF-NETSIM is different from the HCM and questions have been raised as to the accuracy of the TRAF-NETSIM delay.

In addition to the analysis techniques discussed above, TRAF-NETSIM was run for the Emmet Street/Ivy Road intersection. The results of the HCS, SIGNAL94, and HCM/Cinema analyses for this intersection during the p.m. peak showed the greatest difference between field and calculated LOS. During the afternoon peak at this intersection, some congestion exists and phase failures occur. Traditional analysis methods are not designed for oversaturated conditions, resulting in less accurate delay values. The stopped delay determined by TRAF-NETSIM and measured in the field is shown in Table 10, along with the delay values for a simulation of the a.m. conditions at the Emmet Street/Ivy Road intersection. Both the a.m. and p.m. TRAF-NETSIM results show good correlation to field values.

In addition to stopped delay, TRAF-NETSIM provides average and maximum queue values for each lane on a link (approach). The maximum queue values are compared to the field values for both the a.m. and p.m. periods in Table 11. As discussed previously, queue lengths were not collected directly in the field, but are extrapolated from the data collected for stopped delay computations.

Table 10
Comparison of TRAF-NETSIM and Field Delay and Level of Service
Emmet Street and Ivy Road

Approach	A.M. Field Delay	A.M. NETSIM Delay	P.M. Field Delay	P.M. NETSIM Delay
Eastbound	31.3 (D)	31.3 (D)	47.5 (E)	48.6 (E)
Westbound	25.1 (D)	28.0 (D)	39.1 (D)	32.7 (D)
Northbound	34.1 (D)	34.7 (D)	58.6 (E)	59.4 (E)
Southbound	27.3 (D)	29.8 (D)	46.5 (E)	44.6 (E)
Total Intersection	29.2 (D)	30.8 (D)	47.9 (E)	46.3 (E)

Table 11
Comparison of TRAF-NETSIM and Field Queue Lengths
Emmet Street and Ivy Road
Through Movements

Approach	A.M. Field Queue	A.M. NETSIM Max Queue	P.M. Field Queue	P.M. NETSIM Max Queue
Eastbound	12	10	11	11
Westbound	9	8	N/A	15
Northbound	14	12	35	32
Southbound	21	19	30	20

Evaluations at Non-Isolated Intersections

Route 3 in Fredericksburg was the field site for the analyses of non-isolated intersections. Due to the congested nature of the corridor, average speed and delay and total travel time through the corridor were the measures of effectiveness used for comparison between field conditions and model runs. The HCS arterial module, TRAF-NETSIM, and HCM/Cinema were used to analyze the corridor. The westbound direction of Route 3 is the peak direction of flow in the afternoon and therefore it is the westbound through movement statistics that were compared. Tables 12 and 13 provide the speed and delay values, respectively, that were observed in the field, calculated by HCS, HCM/Cinema, and TRAF-NETSIM. The following sections provide details on the models and the results of the analyses conducted with each.

Table 12
Comparison of Field and Calculated Speeds (KPH)
Westbound Through Movement

Segment	Field	HCS - Arterials	TRAF-NETSIM	HCM/ Cinema
Mall to Bragg	35.6	18.3	32.2	17.9
Bragg to Rt. 710	31.7	21.4	31.5	18.2
Rt. 710 to Rt. 694	11.7	8.7	14.2	10.5
Rt. 694 to Salem Church	34.9	18.3	29.5	12.2

Table 13
Comparison of Field and Calculated Delays (sec/veh)
Westbound Through Movement

Segment	Field	HCS - Arterials	TRAF-NETSIM	HCM/ Cinema
Mall to Bragg	47.8	37.3	41.9	28.7
Bragg to Rt. 710	20.4	29.2	23.2	21.8
Rt. 710 to Rt. 694	106.8	141.8	91.8	*
Rt. 694 to Salem Church	32.5	53.1	39.0	76.3

* Note: Delay not reported because (v/c) is greater than 1.0.

HCS - Arterial Module

HCS includes a module designed to evaluate arterials consisting of several consecutive intersections. The arterial module uses the results of individual signal module runs to estimate the speed and delay along a segment of road. The distance from one intersection to the next is entered along with the arterial type as defined in the HCM and the corresponding free flow speed.

The estimates of speed generated by HCS were considerably lower than those measured in the field and the corresponding delay estimates were higher. The overall travel time for the westbound direction estimated by HCS is 352.6 seconds, while the overall average travel time observed in the field was only 279.6 seconds.

TRAF-NETSIM

TRAF-NETSIM is a microscopic simulation model developed by the Federal Highway Administration, capable of modeling very complex geometric and operational situations for single intersections as well as systems comprised of many intersections operating in a coordinated fashion. In the case of non-isolated signalized intersections along a corridor, the effects of queuing at adjacent intersections that often impacts upstream intersections can be captured. Vehicles are modeled individually and their movements are based on car following and gap acceptance theory. This detailed level of analysis provides very detailed output including maximum and average queue lengths, stopped, queued, moving, and total delays by approach and by movement, average speed, etc. Spillback messages are also provided by the program when queues extend beyond the length of a particular link. The detailed nature of TRAF-NETSIM requires more detailed input than traditional analysis methods such as HCS. Specific geometric information including number of lanes, distance between intersections (link length), turn bay lengths and number of lanes, channelization of lanes, and grades are required for each approach, as are traffic volumes by turning movement and signal timings. The time required to prepare an input file for TRAF-NETSIM is significantly longer than for HCS, SIGNAL94, or CINCH.

The results of the TRAF-NETSIM run for the Route 3 corridor showed good agreement between observed and simulated speeds in the westbound direction, the peak direction of flow in the afternoon. The corresponding delays are also consistent with the delay measured in the field. The link between Route 710 and Route 694 has the largest difference in measured and simulated delay. A lane drop occurs in this section and while this was coded in TRAF-NETSIM, further calibration of vehicle behavior in the area of the drop is necessary to achieve closer agreement between observed and simulated delays for this link. The simulation run for this analysis assumes that all drivers are aware of the drop and change lanes in advance of the drop location, thereby reducing delay. Casual observations of field behavior indicate that a percentage of drivers wait until the last minute to change lanes, causing increased turbulence in the flow and increased delays. The overall travel time for the westbound through movement produced by TRAF-NETSIM was 274.1 seconds as compared to the 279.6 seconds observed in the field.

HCM/Cinema

HCM/Cinema was previously described as a program that combines the ease of an HCS type analysis with the detailed analysis provided by TRAF-NETSIM. It is important to realize that although HCM/Cinema does incorporate TRAF-NETSIM logic, it analyzes one intersection at a time. That is, it does not simulate systems operations as does a complete TRAF-NETSIM run. In the case of a corridor analysis like the Route 3 example used in this study, caution must be taken to ensure that the effects of queuing between intersections are considered. For example, the program provides information on the percentage of time that an approach experiences spillback; however because it is analyzing only one intersection at a time, the effects of spillback on upstream intersections cannot be directly measured. To account for spillback, the saturation flow at upstream intersections must be adjusted or the green time reduced for the movements that are affected.

The results of the HCM/Cinema runs for Route 3 show poor agreement between observed and calculated speeds. It is interesting to note that the speeds calculated by HCM/Cinema are very similar to those calculated by the arterial module in HCS. The delay values calculated by HCM/Cinema also do not reflect those observed in the field. In fact, at one intersection no value was given because of the high calculated v/c ratio.

CONCLUSIONS

Examination of VDOT's Experiences

While there are individual exceptions, Resident Engineers and District Traffic Engineers and their staffs in VDOT field offices have seldom used non-HCM/HCS procedures and software for capacity analysis. Likewise, they are seldom required to review capacity analysis from other procedures and software. On the other hand, transportation planning engineers and members of the advisory committee have used and reviewed non-HCM/HCS procedures and software much more frequently.

Based on the above submitted responses, there seems to be some confusion among VDOT practitioners as to what is truly capacity analysis and what might be termed "operational analysis." This was apparent from the responses that listed programs such as TRANSYT-7F and PASSER as capacity analysis methods when they are actually signal timing optimization programs. TRANSYT-7F and MINUTP, a planning model, were listed as simulation models, indicating a difference of opinion as to what is meant by simulation models.

Practices in State DOTs

The results of the survey of state DOTs indicated that, not surprisingly, HCM and HCS are very prevalent in capacity analysis. A majority of the state DOTs have requirements or policies specifying the method to be used, and in most cases the method specified is the HCM. A majority do not have policies regarding the software to be used, but when a policy does exist, HCS is the specified program. In many cases, even when a policy exists specifying the use of HCS, other programs are used and accepted. None of the state DOTs responding to the survey have a requirement or policy concerning the use of simulation model output in capacity analysis.

Again, there seems to be nationwide confusion among practitioners as to the difference between capacity analysis and what might be termed "operational analysis." There seems to be a similar difference of opinion in defining simulation models.

Evaluation of Isolated Intersections

Based on the case study evaluations, HCS, SIGNAL94, and HCM/Cinema all produce acceptable estimates of delay when compared to observed field measurements. None of the programs produce the exact values observed in the field, but on average the differences between observed and calculated values are relatively small. The estimates of delay produced by HCS, SIGNAL94, and HCM/Cinema are essentially identical. The difference between estimates of delay produced by CINCH and those observed in the field is higher than for the other programs. HCS, SIGNAL94, and HCM/Cinema appear acceptable for capacity analysis for isolated intersections.

SIGNAL94 and HCM/Cinema produce good estimates of queue length as determined form the field data obtained in this study. CINCH generally underestimates the maximum queue length when compared to field values.

At isolated intersections, TRAF-NETSIM provides stopped delay values that closely approximate values measured in the field. These values can then be compared to the ranges of stopped delay corresponding to levels of service A through F in the HCM, to produce a level of service. For congested isolated intersections, the results from TRAF-NETSIM appear to be more accurate that those produced by HCS and SIGNAL94.

TRAF-NETSIM produces maximum queue lengths that are similar to the queue lengths observed in the field.

Evaluation of Non-Isolated Intersections

TRAF-NETSIM produces corridor speeds and delays comparable to values measured in the field. The simulation model is capable of replicating conditions observed in congested corridors where queuing and slow speeds are prevalent. The results obtained by simulation for the Route 3 corridor are more accurate than those obtained using the HCS arterial module.

Calibration is an important step in performing simulation analyses. Driver behavior can have a significant effect on operational characteristics, and because driver behavior can vary greatly from one area to another, sufficient calibration is required to produce accurate results for local conditions. Geometric conditions can also affect driver behavior, resulting in more aggressive or less aggressive driving. In the case of Route 3, drivers are more aggressive in the area of the lane drop than in other areas of the corridor and the model requires additional calibration to replicate this behavior.

HCM/Cinema does not produce accurate estimates of speeds for congested arterials. The program, like the HCS signal module, is designed to analyze one intersection at a time. Although the program developer states that adjustments can be made to account for excessive queuing and spillback, they are manual adjustments that must be made by the user. The program does appear to have great potential in identifying intersections where queuing is a problem thereby alerting the user that special attention should be paid to the effects of this queuing on adjacent intersections.

RECOMMENDATIONS

Based on the findings of this study, the VDOT policy governing capacity analysis for streets and highways in Virginia should be revised to incorporate the following:

1) VDOT staff should use the latest version of HCS, SIGNAL94, or HCM/Cinema when conducting capacity analysis for site plan review, geometric design, signal design, or other purposes at signalized, isolated intersections. When accepting work from consultants, the results of HCS, SIGNAL94, or HCM/Cinema should be considered acceptable. Isolated intersections are defined as those that are not impacted by queuing from adjacent intersections. In the case of an existing intersection, a field review during the peak period should be undertaken to determine if an intersection can be considered isolated. For planned intersections, intersections that will be adjacent to the planned intersection should be examined to determine if queuing from a downstream intersection might impact the planned intersection. If an intersection is found to be affected by adjacent intersections, it should be treated as a non-isolated intersection and a corridor analysis should be undertaken.

2) CINCH should not be used by VDOT staff for capacity analysis. Capacity analysis submitted to VDOT by consultants using CINCH should not be accepted.

3) When desired, estimates of queue lengths at isolated intersections should be derived from SIGNAL94, HCM/Cinema, or TRAF-NETSIM.

4) The results of TRAF-NETSIM should be accepted for capacity analysis at isolated intersections. In the case of congested, oversaturated intersections, a TRAF-NETSIM analysis should be the prefered analysis type.

5) For non-isolated intersections where queuing and spillback are a potential problem, simulation analysis with TRAF-NETSIM should be used to determine the operational characteristics of the corridor in lieu of capacity analysis.

ACKNOWLEDGMENTS

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REFERENCES

1. *Highway Capacity Manual*. 1985. Special Report No. 209, Transportation Research Board. Washington, D.C.: National Research Council.

2. *Guidelines for Traffic Impact Reports/Studies*. 1994. Engineering Access Permits Division, Maryland State Highway Administration.

3. *Florida's Level of Service Standards and Guidelines Manual for Planning*. 1992. Report 525-000-005-c, Florida Department of Transportation.

4. *Oregon Department of Transportation Position Paper on Volume/Capacity Versus Delay in Analyzing Signalized Intersections*. 1993. Oregon Department of Transportation.

5. *Encroachment Permit Manual*. Nevada Department of Transportation.

6. *Engineering Instruction Manual, Highway Capacity Policy*. 1993. New York State Department of Transportation.

APPENDIX A

MEMBERSHIP

CAPACITY ANALYSIS ADVISORY COMMITTEE

MEMBERSHIP

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APPENDIX B

QUESTIONNAIRE

SURVEY OF VDOT EXPERIENCES

CAPACITY ANALYSIS SURVEY

1. Over the last year or so, have you or anyone in your office used any capacity analysis procedures other than those in the HCM/HCS?

   If yes, please name or describe them.

2. Over the last year or so, have you or anyone in your office reviewed any capacity analysis procedures other than those in the HCM/HCS that were submitted by others to you (e.g., a traffic impact analysis or site plan review)?

   If yes, please name or describe them.

3. Over the last year or so, have you or anyone in your office used any simulation models?

   If yes, please name or describe them as well as providing a very brief description of how they were used.

4. Over the last year or so, have you or anyone in your office reviewed the output of any simulation models that was submitted by others to you?

   If yes, please name or describe the models used as well as providing a very brief description of how they were used.

APPENDIX C

QUESTIONNAIRE

SURVEY OF STATE DEPARTMENTS OF TRANSPORTATION

April 8, 1994

MEMORANDUM

TO: Members, AASHTO's Hwy. Subcommittee on Design
Members, AASHTO's Hwy. Subcommittee on Traffic Engineering
Members, AASHTO's Standing Committee on Planning

FROM: E. D. Arnold, Jr., Senior Research Scientist
C. A. Cragg, Research Scientist

The Virginia Transportation Research Council, a division of the Virginia Department of Transportation (VDOT), has undertaken a research study investigating VDOT's policy on highway capacity analysis. The Department's policy is to use and accept from others (usually consultants) the 1985 Highway Capacity Manual (HCM) as the basis for performing capacity analysis on streets and highways in Virginia. To assist in the analysis, VDOT uses the latest version of the Highway Capacity Software (HCS). Other software programs that replicate the procedures in the 1985 HCM may be used by those submitting work to the Department for review; however, all input data and assumptions must accompany the submittal. The Department may use the HCS to check the submitted analysis, and the analysis may be rejected if different results are obtained.

Three specific questions are being addressed in the study:

1. Should VDOT use, or accept from others, non-HCM capacity analysis methods and any software developed for those methods?

2. Should VDOT use, or accept from others without question, HCM-based software other than the HCS?

3. Should VDOT use, or accept from others, the output of simulation models in capacity analysis? For example, can the average delay calculated by TRAF-NETSIM be used directly to determine the level of service at a signalized intersection?

As a part of the research, the Council is interested in determining your Department's policy on capacity analysis as well as its experiences with the questions being addressed. Accordingly, we would appreciate it if you would complete the enclosed survey and return it by May 6, 1994.

Please note from the above addressees that the survey has been sent to three members from your Department who represent transportation planning, traffic engineering, and design. We chose this distribution to ensure that all potential users of capacity analysis and simulation models are included. If appropriate, however, feel free to combine your responses into one survey reply.

1. Does your State DOT require the use of specific capacity analysis methods (e.g., those defined in the Highway Capacity Manual) by DOT staff?

_ Yes _ No

a. If yes, please attach a copy of any documentation that describes the requirement.

b. If no, or if specific methods are not listed in the requirement, please list and describe (if necessary) the methods most often used by DOT staff.

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2. Does your State DOT require the use of specific capacity analysis methods (e.g., those defined in the Highway Capacity Manual) by those who submit work to DOT staff for review and/or approval (e.g., traffic impact analyses and site plans)?

_ Yes _ No

a. If yes, please attach a copy of any documentation that describes the requirement.

b. If no, or if specific methods are not listed in the requirement, please list and describe (if necessary) the methods most often used by others.

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3. Does your State DOT require the use of specific capacity analysis software (e.g., Highway Capacity Software) by DOT staff?

_ Yes _ No

a. If yes, please attach a copy of any documentation that describes the requirement.

b. If no, or if specific software is not listed in the requirement, please list and describe (if necessary) the software most often used by DOT staff.

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4. Does your State DOT require the use of specific capacity analysis software (e.g., Highway Capacity Software) by those who submit work to DOT staff for review and/or approval (e.g., traffic impact analyses and site plans)?

_ Yes _ No

a. If yes, please attach a copy of any documentation that describes the requirement.

b. If no, or if specific software is not listed in the requirement, please list and describe (if necessary) the software most often used by others.

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5. Does your State DOT have a specific policy or requirement concerning the use of simulation model output in capacity analysis by either DOT staff or those submitting work to DOT staff for review and/or approval?

_ Yes _ No

a. If yes, please attach a copy of any documentation that describes the policy or requirement.

b. If no, or if specific models are not listed in the policy or requirement, please list the simulation models most often used in conjunction with capacity analysis. Also include the specific simulation output variables used.

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6. Is this reply applicable to:

_ Transportation planning   _ Traffic engineering
_ Highway design   _ All of the above

7. If your State DOT has any policy or guidelines regarding capacity analysis that have not been attached in response to the above specific questions, please enclose a copy with the survey.

8. Your name: ______________________
Phone No.: ______________________
Address: ______________________
____

9. Do you want to receive a copy of the report on the research when it is completed (scheduled for spring 1995)?

_ Yes _ No

THANK YOU!
Please return your completed survey by May 6, 1994, to:

E. D. Arnold, Jr.
Virginia Transportation Research Council
P. O. Box 3817 University Station
Charlottesville, VA 22903