TRANSPORTATION
RESEARCH
CIRCULAR

Number 373, July 1991

Interim Materials on Unsignalized Intersection Capacity

TRANSPORTATION RESEARCH BOARD / NATIONAL RESEARCH COUNCIL

TRANSPORTATION
RESEARCH
CIRCULAR

Number 373, July 1991
ISSN 0097-8515

INTERIM MATERIALS ON UNSIGNALIZED INTERSECTION CAPACITY

Subscriber category
IVA highway operations, capacity, and traffic control

Transportation Research Board
National Research Council
2101 Constitution Avenue
Washington, D.C. 20418

ACKNOWLEDGMENTS

This Interim Circular was prepared through the volunteer efforts of members of the Unsignalized Intersection Capacity Sub-committee of the Committee on Highway Capacity and Quality of Service. In addition, the TRB Committee on Highway Capacity and Quality of Service provided review comments and suggestions related to all aspects of this document before its approval.

OPERATIONS AND MAINTENANCE OF TRANSPORTATION FACILITIES
H. Douglas Robertson, Chairman, Group 3 Council

COMMITTEE ON HIGHWAY CAPACITY AND QUALITY OF SERVICE
Adolf D. May, Jr., Chairman
University of California, Berkeley, California

Richard Cunard, Transportation Research Board Staff

Unsignalized Intersection Subcommittee Members

Werner Brilon
Wayne E. Haussler
Dane Ismart
James H. Kell
Wayne K. Kittelson
Michael D. Kyte
B. Kent Lall
George F. List
Charles W. Manning
Michael P. O'Rourke
Erik O. Ruehr
Marian Tracz
John D. Zegeer

Highway Capacity Committee

Adolf D. May, Jr., Chair

Rahmi Akcelik
Ulrich Brannolte
Ken G. Courage
R.E. DeArazoza
Daniel B. Fambro
Douglas W. Harwood
Paul Jovanis
Wayne K. Kittelson
Michael D. Kyte
Herbert S. Levinson
John F. Morrall
Barbara K. Ostrom
Ronald C. Pfefer
James L. Powell
William R. Reilly
Carlton C. Robinson
Roger P. Roess
Negui M. Rouphail
Ronald C. Sonntag
Henri L. Stembord
Stan Teply
Pierre Yves Texier
Thomas Urbanik, II
Mark R. Virkler
Robert H. Wortman
John D. Zegeer

FOREWORD

The First Edition of the Highway Capacity Manual (HCM) appeared in 1950. Research leading to a Second Edition began a few years later, leading to the publication of Special Report 87: Highway Capacity Manual - 1965. A formal project for new research was initiated in 1977 under the National Cooperative Highway Research Program (NCHRP) to produce the Third Edition. These efforts resulted in the publication of Special Report 209: Highway Capacity Manual - 1985. This long publication history attests to the importance of the Highway Capacity Manual for highway engineering practitioners. In the past five years, the 1985 Manual has had more than 11,000 copies distributed. It has been translated into five languages, and is frequently called the primary reference document for planning, design, and operational analyses of highway capacity throughout the world. (Translated into Japanese and Spanish. Authorized to be translated into Arabic, Italian, and Portugese.)

As stated in the foreword to that manual, "The Committee views this publication as a milestone in the growing body of knowledge of highway capacity - not the conclusion. Research will continue." To provide the most current capacity analysis information to traffic engineers, this TRB Circular has been prepared. Since publication of the 1985 Highway Capacity Manual, research has continued in the area of unsignalized intersection capacity. This research has resulted in a new technique for the analysis of all-way stop controlled intersections. In addition, the Committee on Highway Capacity and Quality of Service through its Unsignalized Intersection Sub-Committee is attempting to obtain more information from studies conducted in the United States which represent operating characteristics at both two-way stop controlled (TWSC) and all-way stop controlled (AWSC) intersections. Thus, this Interim Circular has three purposes:

• To provide current information on the status of ongoing research conducted in the United States and Europe for unsignalized intersection capacity and to identify areas where further applied research is required.

• To describe a procedure for conducting capacity analyses at all-way stop-controlled intersections and to encourage its use so users and the committee can judge its applicability to the variety of circumstances not represented at the underlying research sites. The committee solicits word from users of this procedure on its accuracy and suitability under varied circumstances.

• To provide traffic engineers with a standard data collection technique for both all-way stop and two-way stop-controlled intersections which can be used in the United States to collect a more comprehensive data base for unsignalized intersection capacity/delay characteristics. This technique should define the data which must be collected to lead toward revision of Chapter 10 of the HCM.

Comments, suggestions, or criticisms regarding this Interim Circular should be sent to the Transportation Research Board so that careful consideration can be given to them before the development of a revised version of Chapter 10: Unsignalized Intersections. It should be emphasized that funding in the United States in the area of Unsignalized Intersection Capacity is critical but none has been allocated to date. Ongoing efforts are underway to identify funding sources. Thus, comments on the AWSC capacity technique and the data collection procedures at both TWSC and AWSC intersections as specified herein are critical to the advancement of knowledge in Unsignalized Intersection Capacity.

Although the analysis technique presented herein has not been incorporated as an element of the Highway Capacity Manual, it is the hope of the TRB Committee on Highway Capacity and Quality of Service that the AWSC analysis technique will be applied extensively, and the results thereof reported to the Committee so the technique can be considered for inclusion in a revised version of Chapter 10, when available.

CONTENTS

CHAPTER 1 STATUS OF RESEARCH IN UNSIGNALIZED INTERSECTION CAPACITY

As stated in the 1985 Highway Capacity Manual (1), "Procedures for the capacity analysis of two-way stop and yield-controlled intersections are based on a German method originally published in 1972 and translated in a 1974 publication of the Organization for Economic Cooperation and Development (OECD). The method has been modified based on a few validation studies in the United States, conducted by the Unsignalized Intersection Sub-Committee of the Highway Capacity and Quality of Service Committee of the Transportation Research Board." Since publication of the 1985 HCM, many jurisdictions in the United States have begun to require a detailed capacity analysis of unsignalized intersections in support of the review and approval process for proposed developments or for enhancing traffic operations. This section documents the research which has occurred in the area of unsignalized intersection capacity which might lead to improvements in these analysis techniques.

THE EXISTING UNSIGNALIZED INTERSECTION CAPACITY TECHNIQUE

The procedure contained in Chapter 10 of the 1985 HCM for two-way stop and yield controlled intersections is based on evaluating the number of gaps in a major traffic stream available to vehicles crossing or turning through that stream. Thus, the capacity of the approach analyzed is based on:

- The distribution of gaps in the major street traffic stream.
- Driver judgment in selecting gaps through which to execute their desired maneuvers.

Although some field observations during congested conditions have shown otherwise, the method assumes that major street traffic is not affected by minor street flows. Vehicle movements which require gaps in flow are prioritized in a systematic order:

- Right turns from the minor street
- Left turns from the major street
- Through movements from the minor street
- Left turns from the minor street

The procedure requires a determination of conflicting traffic volumes for each movement; a determination of the capacity of the intersection to accommodate each movement based on critical gap acceptance; adjustment of these capacities based on impedance factors; and a calculation of Reserve Capacity available to each minor street movement. The amount of Reserve Capacity by movement is used to identify the level of service (operating conditions) anticipated to occur. No quantification of vehicle delay is associated with these levels of service; however, a description of the relative magnitude of delay is provided for each level of service. The user is cautioned not to interpret the results as a predictor for the possible need for signalization.

For all-way stop controlled intersections, general capacity values are provided in Chapter 10 of the 1985 HCM for various demand splits and for various intersection types. This information is adapted from two sources: (2) (3). However, no detailed procedure for analyzing all-way stop controlled intersection capacity is provided.

U.S. RESEARCH ACTIVITIES IN TWSC CAPACITY (4)

For two-way stop-controlled intersection capacity, a relatively small amount of research in the United States was conducted before the publication of the 1985 HCM. Some research, however, was used to modify the critical gap values from the original German research. This research, completed by Bakare and Jovanis in 1984, involved a comparison of the unsignalized intersection capacity analysis methods of the Swedish Capacity Manual and the Interim U.S. Procedure at sites in the Chicago area (5). It was found that the methods employed by the Swedish Capacity Manual (which are based on queuing theory and operating conditions prevalent in Sweden) appeared to consistently overestimate capacity. The Interim U.S. Procedure (provided in TRB Circular 212) was empirically based and consistently underestimated capacity and produced a Level-of-Service (LOS) that Bakare and Jovanis considered to be one level too low, based on field observations. Both methods were recalibrated using different critical gaps and the capacity analyses were recomputed. The recalibrated US model then closely followed the field data observations.

Research by Solberg and Oppenlander was conducted at four intersections in Indiana (6). This research calculated acceptable gaps for drivers on cross-street approaches for left turn, right turn, and through movements. The gap acceptance time required was significantly greater for drivers attempting left turn movements than for through or right turn movements.

The Transportation Research Board participated in a series of meetings in 1987 throughout the United States (sponsored by the Institute of Transportation Engineers) to receive comments on the use of all chapters of the HCM. Although the majority of comments obtained from these 11 sessions were about the signalized intersection technique (Chapter 9), some suggestions and concerns were expressed related to unsignalized intersection capacity. The most prevalent concern which was expressed related to the use of

Reserve Capacity as a measure of effectiveness for level of service. Because this value cannot be observed in the field, users expressed concern about their ability to correlate calculated levels of service against actual operating conditions. In addition, the use of Reserve Capacity is not consistent with the prevalent use of delay as a measure of effectiveness for other interrupted flow conditions. Thus, correlation between this chapter and the signalized intersection and arterial chapters of the HCM is impossible.

In addition to the comments received from the meetings in 1987, some field observations and analysis have been conducted by TRB committee members in an attempt to validate level of service results as calculated using Chapter 10 of the HCM. One set of observations in California attempted to relate calculated Reserve Capacity to the observed average vehicle delay experienced by motorists. (Unpublished summary of data collection efforts for six samples at California State University - Chico.) This limited data collection effort indicated that Levels of Service E or F (as determined using the analysis procedure contained in Chapter 10 of the 1985 HCM) correlated with average vehicle delays of between 15 and 35 seconds. Better levels of service (A through C) were calculated when the observed average vehicle delay was less than 15 seconds. This limited data base implies that the level of service criteria have lower delay thresholds for unsignalized intersections than for signalized intersections. (For signalized intersections, Levels of Service A through C are equivalent to stopped delays per vehicle of less than 25 seconds and Levels of Service E and F are equivalent to stopped delays per vehicle of greater than 40 seconds). Further field observations in Florida (unpublished) and Oregon (4) imply that the use of the 1985 HCM technique yields overly-conservative results, based on a comparison of the length of gap accepted by vehicles in the field with the values proposed in Chapter 10 of the HCM. It was found that the critical gaps for each of the four conflicting maneuvers in the field were between two percent and six percent lower than the values specified in the HCM. Based on this comparison, it was concluded in the Florida research that the HCM procedure should be modified to exclude certain conflicting flows from the calculation of potential capacity since they did not appear to have an appreciable effect on motorist behavior. The movements which yielded poorer levels of service than actually observed in the field were the through movements and left turns from the minor street.

In 1986, Werner Brilon from the Ruhr University of Bochum in West Germany published a paper titled, "Calculation of the Capacity of Unsignalized Intersections." (7) This paper presented a revised technique for calculating cross-street stop intersection capacity. This technique provided new procedures which allow the analyst to conduct design studies (to determine lane requirements based on projected traffic volumes) as well as to determine the appropriateness of converting from cross-street stop control to traffic signal control based on the minimization of average vehicle delay. The same hierarchy of approach movements (in gap acceptance priority) was specified as in the 1985 HCM. A set of curves representing various travel speeds was developed to relate main street volumes to basic capacity for each of the four movements analyzed (major street left turns, minor street through, minor street right turns, and minor street left turns).

In an attempt to evaluate the relative accuracy of the 1985 HCM and the latest German analysis procedures under typical U.S. conditions, a limited comparative analysis was conducted by Kittelson using an example calculation from the 1985 HCM and from field data at U.S. intersections. From this initial investigation, it appeared that the German technique deserved further consideration as a basis for modifying, updating, or replacing the current 1985 HCM procedure. Both the 1985 HCM procedure and the German technique seemed to give a good estimate of actual operating conditions under low-volume conditions, but there was substantial divergence in the predictive results of the two techniques when near-capacity conditions were investigated. Further, the limited amount of field data available to this investigation supported the current German technique as a more realistic estimator of traffic operating characteristics under near-capacity conditions.

At this point, insufficient research has been conducted to identify the essential features of the German technique that contribute to the apparent difference between this and the 1985 HCM procedure. However, it is clear that, at a minimum, the following two factors are crucial:

- The German technique uses a family of curves relating conflicting traffic volumes to basic capacity, each of which is applied to a particular minor movement. Conversely, the 1985 HCM procedure uses only one family of curves, and assumes the single family of curves to be equally applicable to all minor movements.
- Both the German technique and the 1985 HCM procedure recognize that the speed of main street vehicles has a significant effect on the basic capacity of all minor movements. However, the German technique seems to be more sensitive to this parameter, and offers the user greater flexibility to account for the particular main street speed characteristics that the user encounters.

U.S. RESEARCH ACTIVITIES IN AWSC CAPACITY (4)

For AWSC capacity, early research completed by Hebert in 1963 (2) was conducted at right angle, four-way stop sign controlled intersections in the Chicago area. The capacity of all-way stop- controlled (AWSC) intersections was determined by measuring average intersection departure headways. The following variables were analyzed as part of the study: number of cross street lanes, variations in turning percentages and truck percentages, degree of vehicle queue on the cross street, and volume variations under forced flow conditions. This work by Hebert provided a basis for the part of the HCM Unsignalized Intersection chapter dealing with all-way stop control.

The primary finding of Hebert's research was that capacity of the intersection is highest when traffic volumes are evenly distributed between the intersecting streets. This finding was validated by simulation modeling conducted by Anthony Richardson of Cornell University. (8) To confirm this finding, intersections in the State of New York were observed by List, Manning, and Zion. (9) Observed delay values for vehicles approaching these all-way stop controlled intersections decreased as the volume split approached 50/50.

In September 1989, Michael Kyte published a report summarizing research conducted in the Pacific Northwest (Idaho, Oregon, and Washington) concerning AWSC capacity. (10) This research was conducted in recognition of the need to develop an improved methodology for analyzing AWSC intersection capacity. Traffic operations at twenty sites were videotaped to derive turning movement flow rates and delay data by intersection approach. As a result, an operational analysis methodology for AWSC intersections was developed to allow for the estimation of capacity and level of service, using average vehicle delay as the measure of effectiveness. Vehicle delay and capacity on the approach being analyzed were primarily found to be functions of the flow rate on the subject approach, conflicting approaches, and opposing approach. Hebert's hypothesis that the projection of traffic on the major and minor street affects intersection capacity was verified; however, his capacity estimates appeared to be low. This research forms the basis for the AWSC capacity analysis technique included in the next section of this Circular.

1988 INTERNATIONAL WORKSHOP

In March, 1988, Werner Brilon, through the auspices of the Ruhr University of Bochum chaired an International Workshop titled: "Intersections Without Traffic Signals." The intent of this workshop was to establish a dialogue among transportation professionals throughout the world related to Unsignalized Intersection Capacity Techniques. The workshop was attended by more than 130 delegates from around the world. Twenty-two papers were presented by delegates representing ten countries. An ongoing dialogue has been established with these international researchers through the TRB Committee on Highway Capacity and Quality of Service to identify common relationships and areas of application in Unsignalized Intersection Capacity.

Recent advances in Unsignalized Intersection Capacity Research which relate to current U.S. practice were reported at the Bochum Workshop from Poland, Sweden, Czechoslovakia, West Germany, and Great Britain. Pertinent highlights of these presentations follow:

- Tracz noted that a level of service approach based on vehicle delay is the basis for capacity calculations in Poland. The new procedure used in Poland relies upon computer simulation (specifically, the PICADY2 program from TRRL).
- Anveden, Hansson, and Bergh described a version of the unsignalized intersection analysis procedure developed in Sweden. A new computer program called CAPCAL uses average queue lengths, delays, number of stops, and capacity as the primary performance measures. The new procedure is currently available only in Swedish, but may also soon be available in English.
- Karlicky of Czechoslovakia described the development of nomographs for the calculation of basic capacity, critical gaps, and minimum headways. Field observations have shown that lower critical gap values should be used in future capacity charts.
- Brilon noted that critical gaps and move-up times are the basis for computing unsignalized intersection capacity in West Germany. Capacity formulas have been substantially improved since 1972 (the technique which formed the basis for the 1985 Highway Capacity Manual). New capacity curves will exclude critical gaps and move-up times from the analytic procedure. This new technique will allow for a direct quantification of average delay. The new procedure continues to assume that all left turns from major streets will have an exclusive turn lane (this condition is mandated in German road design). In addition, the delay to major street through movements due to gap interruptions by aggressive cross-street motorists is not taken into account because it represents an illegal movement.
- Kimber of the United Kingdom found that unsignalized intersection delays can best be determined by time-dependent queuing theory. He has also developed a model for predicting accident frequency at various levels of traffic flow for unsignalized three-legged intersections.
- Taylor of the United Kingdom noted that unsignalized intersection capacity is governed by lane widths, minor road approach visibility, and central median width on the major road. There is no evidence that the average speed of the controlling flows affects capacity. She described two computer simulation programs (ARCADY2 and PICADY2), which estimate capacities, v/c ratios, queue lengths, and delays for each approach of the unsignalized intersection.

NEED FOR ONGOING RESEARCH

After publication of the 1985 HCM, the Transportation Research Board Committee began identifying additional research needs for improving highway capacity techniques. These research problem statements were printed in a Transportation Research Circular (11). Included were four elements of research proposed for unsignalized intersection capacity. They are described below:

New Capacity Methods for Two-Way Stop and Yield Controlled Intersections

The technique used for analyzing capacity at unsignalized intersections depends on a calculation of reserve capacity. These values were not extensively validated or calibrated for United States conditions. The original computational method contained in the HCM has been revised by its German originators. Thus, additional research is needed to either validate the HCM method by providing a United States-based calibration, or to prepare a revised method. This research has a high degree of urgency because the reserve capacity computation has not gained extensive acceptance by the U.S. user community. If this research project is funded, its results will most likely be the basis for a revision to Chapter 10 of the 1985 Highway Capacity Manual.

All-Way Stop-Controlled Intersection Capacity

A shortcoming of the existing unsignalized intersection capacity chapter of the HCM is the lack of a procedure to analyze the capacity of all-way stop controlled intersections. Field research in the Pacific Northwest has been recently conducted in this area and some computer modeling has validated the general relationships contained in Chapter 10. The need for additional research is considerable, given the prevalent use of all-way stop sign control in the U.S.

The Relationship Between Levels of Service and Traffic Signal Warrants

There is no relationship between the capacity analysis procedure for unsignalized intersections in the HCM and the traffic volume warrants required to justify traffic signal installation. There is no formal guidance in the HCM which directs the engineer as to whether a congested intersection should be considered for signalization, intersection channelization, or other mitigation measures. The purpose of this research project would be to determine the relationship between the HCM capacity results and the Manual on Uniform Traffic Control Device signalization warrants.

Consideration should be given to the influence of nearby signalized intersections when determining if signalization will enhance level of service.

Design and Planning Methodologies for Unsignalized Intersections

The unsignalized intersection chapter of the HCM contains a procedure for the analysis of existing intersection operations. The procedure does not allow for design and planning methodologies to determine future lane requirements in a straight-forward fashion. Although the intersection analysis procedure for two-way stop sign control can be used to analyze various proposed configurations, the design or planning process is an iterative procedure which does not yield conclusive results. Other chapters in the HCM contain operations, design and planning procedures, whereas the calculation of reserve capacity as a measure of effectiveness for unsignalized intersections does not lend itself to design or planning techniques.

In summary, there are two fundamental problems with the analysis technique contained in Chapter 10 of the HCM:

- Almost no published field data is available to validate the two-way stop-controlled intersection (TWSC) technique for United States conditions. Some research has indicated that the TWSC technique consistently underestimates Reserve Capacity and thus yields a poorer level of service than actually occurs.
- There is no formal procedure in the HCM for capacity analysis of all-way stop-controlled (AWSC) intersections. Research conducted in the Northwestern portion of the United States has resulted in the recommended procedure contained in this circular. However, more extensive field studies and computer simulation are required to develop a procedure for inclusion in the HCM.

The need for a national program to revise Chapter 10 of the HCM is evident. The current procedures are widely used by developers and governmental agencies to determine levels of congestion and the need for improvements at unsignalized intersections. If the procedure is not valid for the conditions to be analyzed, the geometric and traffic control improvements determined by the procedure could be invalid.

At the present time, no funding for a national research activity has been allocated. The Unsignalized Intersection Sub-Committee of the TRB Committee on Highway Capacity and Quality of Service has prepared this Circular to summarize previous research; to present draft procedures for AWSC capacity analysis; and to provide a comprehensive data collection procedure for obtaining volume and delay data at unsignalized intersections. The Sub-Committee is prepared to serve as a point of contact for coordinating future research into enhanced capacity analysis techniques.

References

1. Transportation Research Board, *1985 Highway Capacity Manual*, Special Report 209, Washington, D.C. 1985.

2. Hebert, J., "A Study of Four-Way Stop-Controlled Intersection Capacities." *Highway Research Record 27*, Highway Research Board, Washington, D.C. 1963 .

3. Barton-Aschman Associates, Inc. "Energy Saving Traffic Operations Project Manual." September, 1981.

4. Brilon, W. (Editor), "Intersections Without Traffic Signals." *Proceedings of an International Workshop in Bochum, West Germany*. Springer-Verlag (Publisher). March, 1988. Information in this section of the Circular was synthesized by the US Subcommittee from pages 37-47 of the referenced publication.

5. Bakare and Jovanis. "Analysis of Unsignalized Intersection Capacity." *Transportation Research Record 971*, Transportation Research Board, Washington, D. C. 1984.

6. Solberg and Oppenlander. "Lag and Gap Acceptances at Stop-Controlled Intersections." *Highway Research Record 118*, Highway Research Board, Washington, D.C.

7. Brilon, W., "Berechnung Der Leistungsfahigkeit Fur Knotenpunkte Ohne Lichtsignalanlagen." Ruhr University-Bochum, July 4, 1986.

8. Richardson, A., "A Delay Model for Multi-Way Stop Sign Intersections." *Transportation Research Record 1112*, Transportation Research Board, Washington, D.C. 1987.

9. List, Manning, and Zion. "Analysis of Four-Way Stop Sign Intersections." Presentation at 68th Annual TRB Meeting. January, 1989.

10. Kyte, M., "Estimating Capacity and Delay at An All-Way Stop-Controlled Intersection." University of Idaho, Department of Civil Engineering Research Report, September, 1989.

11. Transportation Research Board, *Transportation Research Circular 319*, Washington, D.C. June, 1987.

12. Kyte, M., "Estimating The Capacity of An All-Way Stop-Controlled Intersection." Accepted for publication in Transportation Research Record, 1990. In Press.

13. Kyte, M. and Marek, J., "Estimating Capacity And Delay At An All-Way Stop-Controlled Intersection." Accepted for publication in Transportation Research Record, 1989. In Press.

CHAPTER 2 ALL-WAY STOP-CONTROLLED INTERSECTIONS
Draft Procedures For Capacity and Level of Service Analysis

INTRODUCTION

Need For New Procedures

One of the most important tasks of the transportation engineer is to evaluate the performance of transportation facilities. The 1985 Highway Capacity Manual (HCM) (1) presents detailed procedures for evaluating the performance of nearly all types of facilities including freeways, arterials, and signalized intersections. These procedures usually include the determination of, first, the capacity and, second, the level of service (LOS).

Unfortunately, no such procedure exists for one of the most common facilities, the all-way stop-controlled (AWSC) intersection. The HCM currently provides guidelines for estimating the capacity of an AWSC intersection based only on the demand split between the major and minor streets and the number of lanes on the intersection approaches. These guidelines are based on a study of three sites by Hebert *(2)*. While the Hebert study remains an important contribution, there are three significant problems in its use as the basis for capacity guidelines:

1. The small sample size (three sites) raises doubts about the transferrability of the study results.
2. The definition of the demand split according to the relative distribution of volumes on the major and minor streets ignores the important variation in capacity that occurs when the distribution of traffic volumes among all four intersection approaches is considered.
3. Increasing the number of lanes on each approach may not result in a proportional increase in intersection capacity.

The purpose of this report is to present a set of new procedures for capacity and level of service analysis of AWSC intersections. These procedures are based on a study of twenty-two sample sites in the United States *(3)*. While these procedures are certainly not the final word, they do represent a significant improvement in the methodology for studying AWSC intersections. It is hoped that the procedures will receive widespread review by practicing transportation engineers so that a new method can eventually be included in a revision to chapter ten of the HCM.

Notation and Terms

The procedures proposed here are based on analyzing each intersection approach independently. The approach under study is called the subject approach. See Figure 1. The opposing approach and the conflicting approaches are also illustrated in Figure 1.

The departure headway for a vehicle on the subject approach is defined as the difference between the successive times of departure of that vehicle and the previous departing vehicle on the subject approach. A departure headway is considered to be a saturation headway if, when a given vehicle arrives, there is already a vehicle ahead of it at the stop line (see Figure 2).

Nature of Operations

AWSC intersections require that every vehicle stop at the intersection before proceeding. This requirement provides a framework for studying traffic operations at AWSC intersections. Since each driver must stop, the judgement as to whether to proceed into the intersection is a function of the traffic conditions on the other approaches. If there is no traffic present on the other approaches, a driver can proceed immediately after the stop is made. If there is traffic on one or more of the other approaches, a driver proceeds only after determining that there are no vehicles currently in the intersection (i.e. it is safe) and that it is his or her turn.

While the "rules of the road" have traditionally suggested the driver-on-the-right right-of-way rule, the actual operation of AWSC intersections is somewhat more complex than this. The problem becomes one of determining, under capacity conditions for a given approach, the factors that influence the rate at which vehicles can successively depart from the stop line. The manner in which these factors influence the saturation headway for a given approach are discussed below.

If traffic is present on the subject approach only, vehicles depart as rapidly as individual drivers can safely accelerate into and clear the intersection. This is illustrated as case 1 in Figure 3.

If traffic is present on the other approaches, as well as on the subject approach, the saturation headway on the subject approach will increase somewhat, depending on the degree of conflict that results between the subject approach vehicles and the vehicles on the other

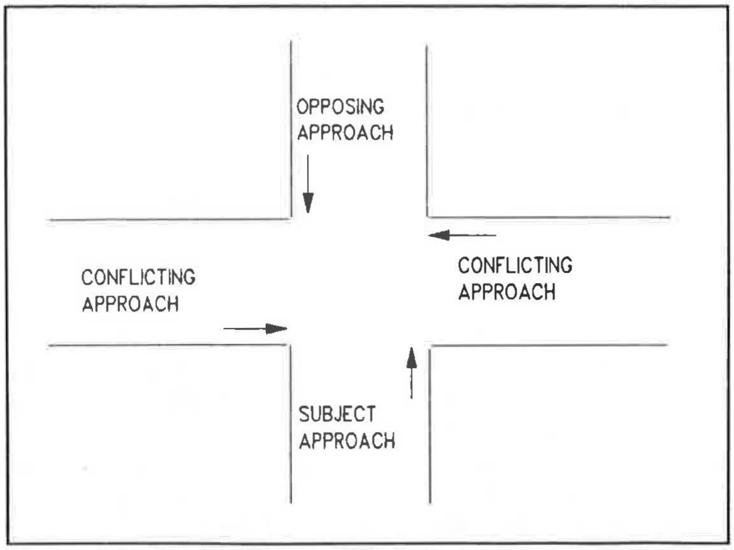


Figure 1. Definition of Intersection Approaches

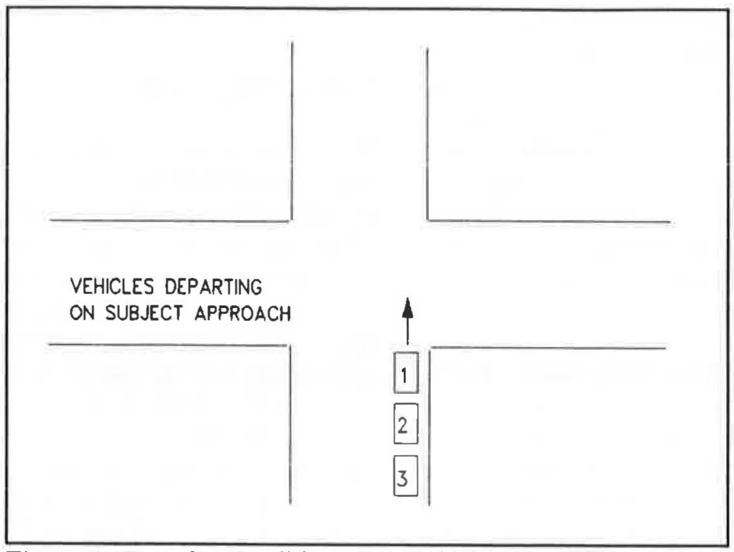


Figure 2. Capacity Conditions For Vehicle #2

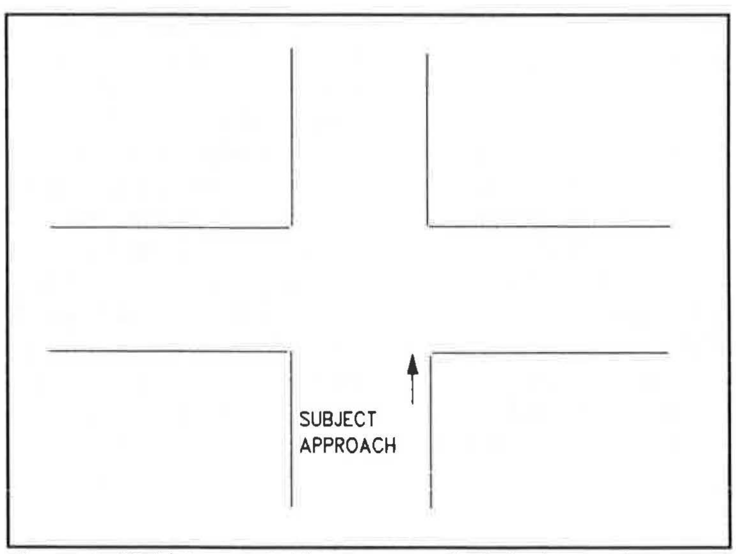


Figure 3. Vehicles on Subject Approach Only (Case 1)

approaches. In case 2 (Figure 4), there is some uncertainty introduced with a vehicle on the opposing approach and thus the saturation headway will be greater than for case 1. In case 3 (Figure 5), vehicles on the conflicting approaches further restrict the departure rate of vehicles on the subject approach, and the saturation headway will be longer than for cases 1 or 2. When all approaches are loaded, case 4 (Figure 6), saturation headways are even longer than for the first three cases as the potential for conflict between vehicles is greatest. The increasing degree of potential conflict translates directly into both longer driver decision times and saturation headways.

Factors Affecting Capacity

Volume Distribution. The headway between vehicles departing from a stop line of an AWSC intersection is a function of the conditions present on the other intersection approaches. Minimum saturation headways are achieved if there is no traffic on any of the other intersection approaches. Maximum saturation headways result if traffic is present on all of the other approaches.

This microscopic perspective has a direct analogue at the macroscopic level. The maximum flow rate on a given approach can be achieved if there is no traffic on any of the other approaches. The minimum flow rate on a given approach results if traffic is evenly distributed among all of the intersection approaches. Thus the key variable in the determination of approach capacity is the relative distribution of traffic volumes among the approaches. This variable is called volume distribution.

When traffic is evenly distributed among the approaches, the capacity of a single-lane approach is approximately 500 vehicles per hour, and the capacity of a four-leg intersection is approximately 2000 vehicles per hour under ideal conditions. The capacity of a single-lane approach, when there is no traffic on any of the other approaches, is 1100 vehicles per hour under ideal conditions (3).

Number of Approach Lanes. Unlike other highway facilities, increasing the number of lanes does not necessarily result in a corresponding increase in the capacity of an approach. This fact results from the nature of traffic flow at an AWSC intersection.

For single-lane approach intersections operating at capacity, a two-phase operation results with traffic on opposing approaches flowing simultaneously. See Figure 7.

However, for multi-lane approaches, the nature of the operation is different. The addition of lanes, particularly on the opposing and conflicting approaches, introduces uncertainty among drivers such that a four-phase operation can result. That is, traffic on each approach flows as a group. See Figure 8.

These theoretical models of two-phase and four-phase operation have been verified by field observations. If vehicles are departing from the subject approach only, with no impedance from any vehicles on the opposing or conflicting approaches (Case 1), increasing the number of lanes does result in a corresponding increase in the approach capacity. The mean saturation headway for single-lane approach sites for Case 1 conditions is 3.9 seconds per vehicle, while for multi-lane sites it is 1.5 seconds. When traffic is present on all of the intersection approaches (Case 4), there is no difference in the saturation headways for the single and multi-lane sites. This means that the potential increase in capacity to be gained from additional lanes is offset by the increased uncertainty that results from each driver deciding whether it is his or her turn. These data are summarized in Table 1.

These data have an important implication for intersection capacity. When traffic is present on only one approach, the capacity of the approach directly increases with each increase in the number of lanes. That is, under ideal conditions, if one lane can carry 1100 vehicles per hour, then two lanes can carry 2200 vehicles per hour, and three lanes can carry 3300 vehicles per hour. However, when traffic is distributed among all of the approaches, the capacity of the intersection, at worst, is about the same no matter how many approach lanes there are. At best, the addition of approach lanes may slightly increase the capacity of the intersection.

Left-Turning Movements increase the saturation headways on the subject approach and thus reduce the approach capacity. While two opposing through vehicles can travel through the intersection simultaneously without affecting each other, one vehicle is delayed if the other vehicle is turning left.

Right-Turning Movements reduce the saturation headways on the subject approach as potential conflicts are decreased. More vehicles can travel through the intersection at shorter headways.

Heavy Vehicles have slower acceleration characteristics and physically take up more space than standard vehicles. Thus, as the proportion of heavy vehicles increase, the saturation headways on the subject approach increase.

Pedestrians have the right-of-way at an AWSC intersection. Increasing pedestrian flow rates also increase the basic saturation headways, and thus reduce intersection capacity. While it is apparent that heavy vehicles and pedestrians affect capacity, these factors are

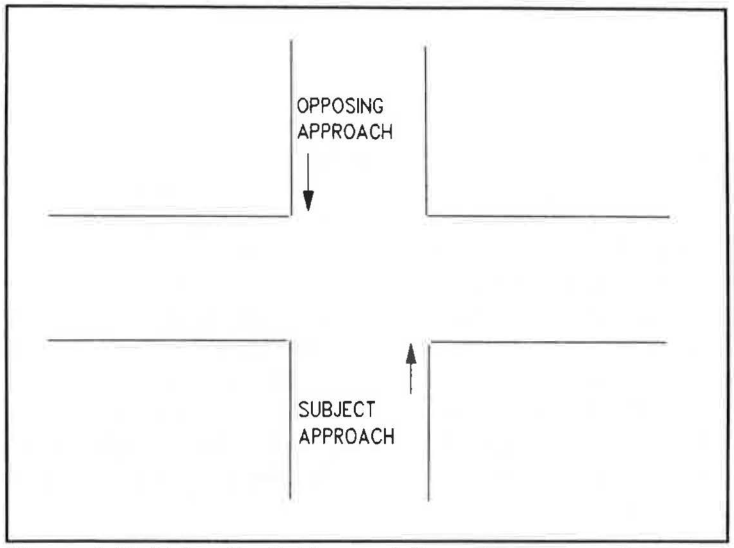


Figure 4. Vehicles On Subject and Opposing Approaches (Case 2)

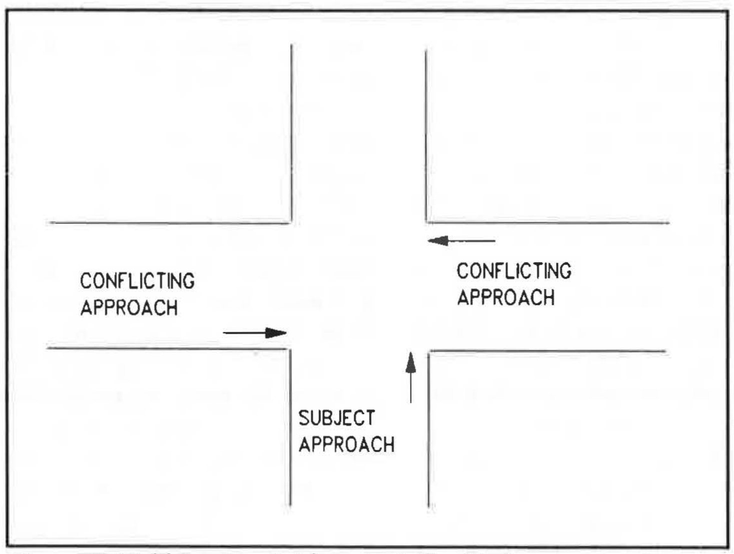


Figure 5. Vehicles On Subject And Conflicting Approaches (Case 3)

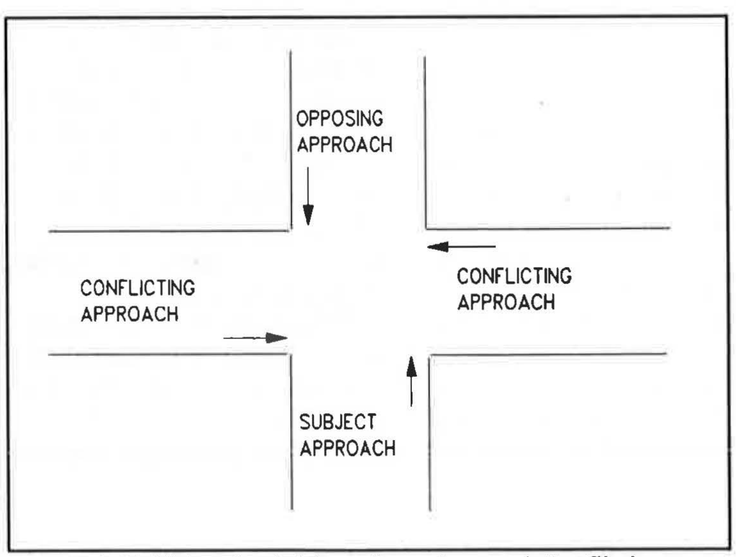


Figure 6. Vehicles On Subject, Opposing, and Conflicting Approaches (Case 4)

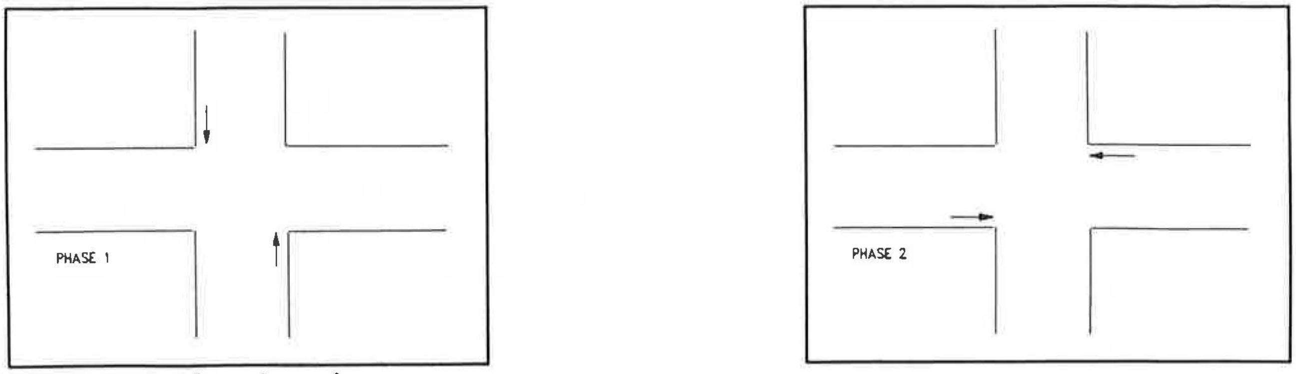


Figure 7. Two-Phase Operation

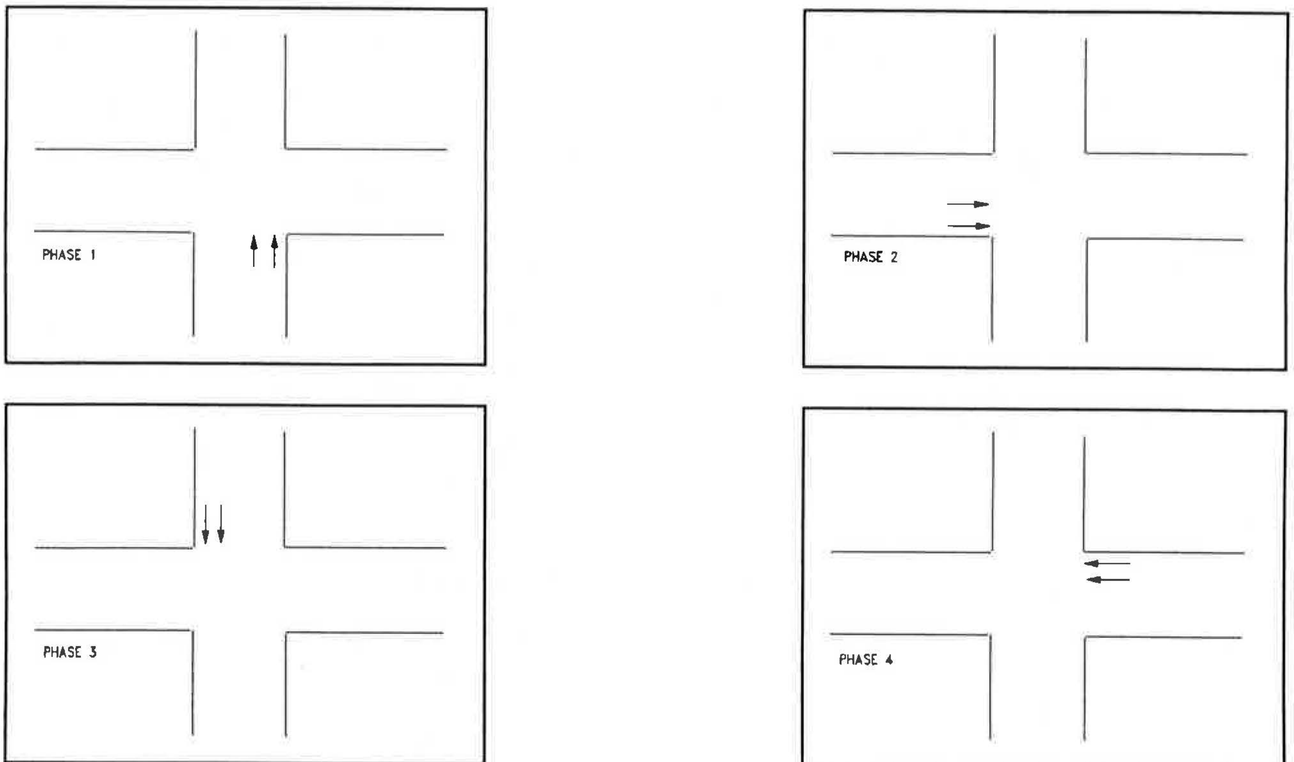


Figure 8. Four-Phase Operation

Table 1. Variation of Saturation Headway With Number Of Approach Lanes

	Mean Saturation Headway, Seconds/Vehicle			
Condition	Case 1	Case 2	Case 3	Case 4
All Data	3.5	5.5	6.5	9.0
Single-Lane Approach Sample Sites	3.9	5.6	6.5	9.0
Multi-Lane Approach Sample Sites	1.5	4.3	6.3	9.3

Data are from field observations, Kyte (3).

not included in the procedures described here. For the sites studied, there was not a sufficient variation in the two variables to show a statistically significant effect on capacity.

Factors Affecting Delay

Use as Measure of Effectiveness. Average stopped delay per vehicle is the most appropriate measure of effectiveness (MOE) for evaluating the performance of AWSC intersections because it satisfactorily describes intersection performance, it can easily be measured by the transportation engineer, and it is a concept that can be clearly communicated to the lay person. In addition, the use of average stopped delay per vehicle will result in a consistent MOE for both signalized intersections and for AWSC intersections. As used here, stopped delay is defined as the total elapsed time from when a vehicle enters the end of the queue until the vehicle departs from the stopped line.

Flow Rates. Vehicle delay for a given approach is largely a function of the flow rate on that approach. From a microscopic point of view, the more vehicles in line, the longer the wait will be. Secondarily, and this relates directly to the discussion above on saturation headways, the rate at which a vehicle can move through a queue is a function of the presence or absence of vehicles on the opposing and conflicting approaches.

If traffic is present on the subject approach only, vehicles depart as rapidly as individual drivers can safely accelerate into and clear the intersection. Delay is then only a function of the volume of traffic on the subject approach, or the queue that forms on the approach.

If traffic is present on the other approaches, as well as on the subject approach, the saturation headway on the subject approach will increase somewhat, depending on the degree of conflict that results between the subject approach vehicles and the vehicles on the other approaches. Thus, while the flow on the subject approach is still the primary factor, the saturation headway, and thus vehicle delay, will increase if vehicles are present on the other approaches.

On a macroscopic level, vehicle delay on the subject approach is primarily a function of the volume on the subject approach and secondarily a function of the volume on the opposing and conflicting approaches.

Field observations *(3)* have shown that vehicle delay on a given approach averages approximately five to ten seconds per vehicle, as long as flow rates on all approaches are low, less than 300 to 400 vehicles per hour. When subject approach flow rates exceed this level, delay begins to increase exponentially as flow rates approach capacity. Higher flows on the opposing and conflicting approaches result in the exponential portion of the curve dominating earlier (i.e. at lower subject approach flow rates).

Left-Turning Movements increase the saturation headways on the subject approach. While two opposing through vehicles can travel through the intersection simultaneously without affecting each other, one vehicle is somewhat delayed if the other vehicle is turning left.

Right-Turning Movements reduce the saturation headways on the subject approach as potential conflicts are decreased. More vehicles can travel through the intersection at shorter headways.

Heavy Vehicles have slower acceleration characteristics and physically take up more space than standard vehicles. Thus, as the proportion of heavy vehicles increase, the saturation headways on the subject approach increase.

Pedestrians have the right-of-way at an AWSC intersection. Increasing pedestrian flow rates also increase the basic saturation headways, and thus increase subject approach delay. While it is apparent that heavy vehicles and pedestrians affect delay, these factors are not included in the procedures described here. For the sites studied, there was not a sufficient variation in the two variables to show a statistically significant effect on delay.

Further Research Needs

While the procedures proposed here represent an improvement over earlier methods, there are still a number of questions that should be the subject of future research on AWSC intersections.

1. The four cases of saturation headway can be subdivided further to develop additional information on the effects of opposing and conflicting traffic on capacity. Further analysis can also be undertaken to determine the effects of the desired direction of travel (straight through vs turning movement) of the subject vehicle on the saturation headways measured for the four cases.
2. Additional multi-lane sites need to be studied to test the assertion that multi-lane approach intersections with balanced flows do not have significantly greater capacities than do single-lane approach sites.

3. Additional data needs to be collected on heavy vehicle and pedestrian flows to determine the effects that these variables have on intersection capacity and delay.
4. Equation (11) for average stopped delay is an exponential form with different characteristics than the signalized intersection delay equation utilized in Chapter 9 of the HCM, particularly in the volume/capacity ratio range of 0.9. Validation of this formula in a wide variety of circumstances is a principal reason for this circular.
5. The delay-LOS relationship given in Table 2 differs from that established for signalized intersections. The full implication of these differences is not easily determined. Results of the application of this scale, as well as alternative scales, including that provided in Chapter 9 of the HCM, will be very helpful in determining the position of the Committee on Highway Capacity and Quality of Service on this question.

METHODOLOGY

Conceptual Approach

While the operation of a given approach is dependent upon the operation of the other intersection approaches, the methodology for analyzing AWSC intersections is based on determining the capacity and level of service of each approach separately. The methodology includes the following steps:

1. Determine Input Data. Determine the input data, including the flow rates, the turning movements, and the number of lanes for each approach.
2. Estimate The Approach Capacity. Estimate the capacity of each approach as a function of the proportion of traffic on each approach, the number of lanes on each approach, and the proportion of turning movements on the opposing and conflicting approaches.
3. Estimate The Approach Delay. Estimate the average vehicle delay on each approach as a function of the volume/capacity ratio on the approach.
4. Determine The Level of Service. Determine the level of service for each approach and for the intersection.
5. Check The Range of Model Validity. Compare the input data with the ranges for which the capacity and delay estimation models are valid.

Determine Input Data

Two types of data are required for analyzing AWSC intersections, traffic data and geometric data.

Traffic Data. Vehicle volumes stated in terms of vehicles per hour for the peak hour, including turning movements, are needed for each intersection approach. The peak hour factor is needed for the intersection.

Geometric Data. The number of lanes are needed for each intersection approach.

Estimate The Approach Capacity

The capacity of each approach is a function of the proportion of traffic on the approaches (volume distribution), the number of lanes on each approach, and the proportion of turning movements. This function is given in equation [1].

$$C = 1000V_{ps}+700V_{po}+200L_s-100L_o$$
$$-300LT_{po}+200RT_{po}-300LT_{pc}+300RT_{pc} \qquad (1)$$

where

C = capacity of the subject approach, in veh/hr,

V_{ps} = the proportion of the intersection volume on the subject approach,

V_{po} = the proportion of the intersection volume on the opposing approach,

L_s = the number of lanes on the subject approach,

L_o = the number of lanes on the opposing approach,

LT_{po} = the proportion of the volume on the opposing approach turning left,

RT_{po} = the proportion of traffic on the opposing approach turning right,

LT_{pc} = the proportion of traffic on the conflicting approaches turning left, and

RT_{pc} = the proportion of traffic on the conflicting approaches turning right.

Figure 9 illustrates the definition of volumes for each of the twelve movements at an AWSC intersection when the subject approach is the northbound movement.

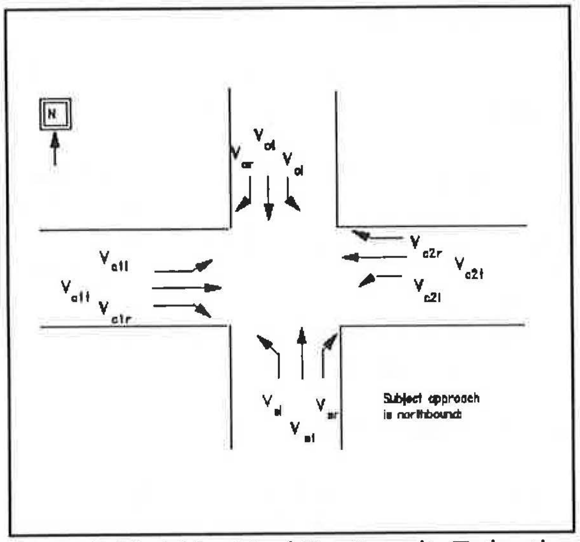


Figure 9. Variables Used For Capacity Estimation

Equations [2] through [10] below explain the terms used in the capacity estimation equation, equation [1].

$$V_s = V_{sl}+V_{st}+V_{sr} \tag{2}$$

$$V_o = V_{ol}+V_{ot}+V_{or} \tag{3}$$

$$V_c = V_{c1l}+V_{c1t}+V_{c1r}+V_{c2l}+V_{c2t}+V_{c2r} \tag{4}$$

$$V_{ps} = \frac{V_s}{V_s+V_o+V_c} \tag{5}$$

$$V_{po} = \frac{V_o}{V_s+V_o+V_c} \tag{6}$$

$$LT_{po} = \frac{V_{ol}}{V_o} \tag{7}$$

$$LT_{pc} = \frac{V_{c1l}+V_{c2l}}{V_c} \tag{8}$$

$$RT_{po} = \frac{V_{or}}{V_o} \tag{9}$$

$$RT_{pc} = \frac{V_{c1r}+V_{c2r}}{V_c} \tag{10}$$

Figure 10 shows the capacity estimates using equation [1] for a single-lane approach intersection with a range of subject approach and conflicting approach proportions, assuming no turning movements.

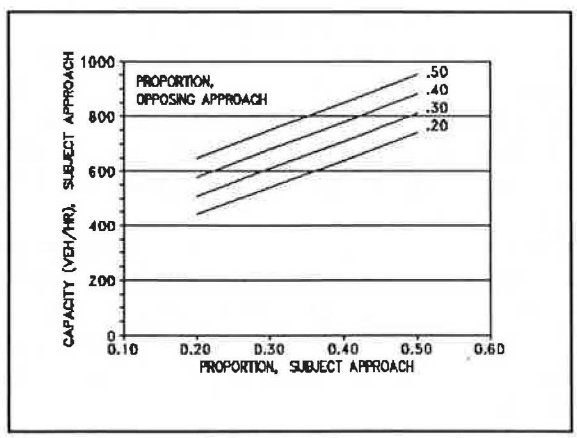


Figure 10. AWSC Intersection Capacity For A Range of Volume Distribution

Estimate the Approach Delay

The average stopped vehicle delay on each approach is a function of the volume on the approach and the capacity estimated for the approach. This function is given in equation [11].

$$D = e^{3.8V/C} \qquad (11)$$

where

D is the average stopped delay on the subject approach, sec/veh,
V is the volume on the subject approach, veh/hr,
C is the calculated capacity of the subject approach, veh/hr, and
e is the base of natural logarithms.

Figure 11 shows variation of delay with the volume-capacity ratio.

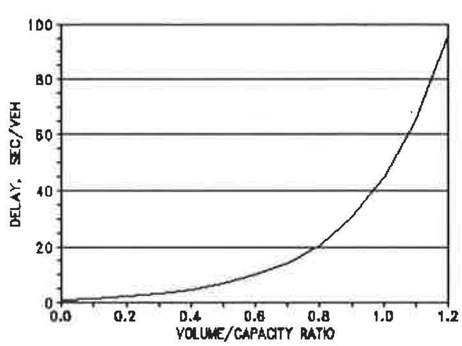


Figure 11. Delay vs. Volume/Capacity Ratio

Determine The Level-of-Service

The proposed level of service criteria are given in Table 2. Average vehicle delay less than five seconds per vehicle is defined as level of service A. Saturation headways less than five seconds per vehicle have been measured when traffic is present only on the subject approach so this range is appropriate. Equation [11] forecasts a maximum delay of 45 seconds per vehicle when the volume/capacity ratio is equal to one. This is proposed as the break point between level of service E and F.

Table 2. Level of Service Criteria

LOS	Average Stopped Delay, sec/veh
A	< 5
B	5 - 10
C	10 - 20
D	20 - 30
E	30 - 45
F	> 45

The proposed level of service criteria for AWSC intersections are somewhat different than the criteria used in Chapter 9 of the HCM for signalized intersections. The primary reason for this difference is that drivers expect different levels of performance from different kinds of transportation facilities. The expectation is that a signalized intersection is designed to carry higher traffic volumes than an AWSC intersection. Thus a higher level of delay is acceptable at a signalized intersection for the same level of service.

Check The Range of Model Validity

The capacity and delay estimation equations were developed for a specific range of data. The ranges for which the equations are valid are given in Table 3. This table should be checked each time a calculation is made for capacity and delay. Care should be taken when the equations are applied to a set of conditions outside of the ranges given in Table 3.

Table 3. Range of Valid Input Conditions

Variable	Min. Value	Max. Value
Volume Distribution:		
Subject Approach, Proportion	.20	.50
Opposing Approach, Proportion	.00	.50
Conflicting Approach, Proportion	.20	.50
Number of Approach Lanes:		
Subject Approach	1	3
Opposing Approach	0	3
Conflicting Approach	1	5
Proportion of Left Turns On:		
Opposing Approach	.00	.35
Conflicting Approach	.00	.35
Proportion of Right Turns On:		
Opposing Approach	.00	.35
Conflicting Approach	.00	.35

PROCEDURE FOR APPLICATION

The procedure for analyzing AWSC intersections is applied to existing conditions or to forecasted future conditions. The HCM defines this kind of analysis as an operational analysis.

Field Data Requirements

Several data are needed for the analysis of AWSC intersections:

1. Traffic volumes stated in terms of vehicles per hour for the peak hour, including turning movements, for each intersection approach. The peak hour factor is needed for the intersection.
2. Number of lanes on each approach.

Worksheets

This methodology is based on a set of four worksheets:

1. Input Worksheet
2. Volume Summary Worksheet
3. Capacity Analysis Worksheet
4. Level of Service Worksheet

Figure 12 shows the progression of use for each of the four worksheets. Note that a computerized version of this procedure is available in the form of an electronic spreadsheet.

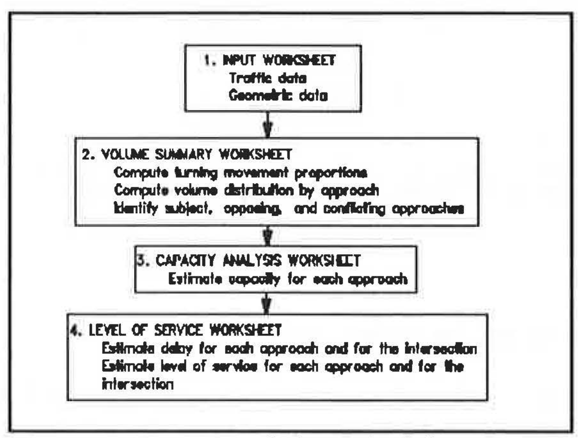


Figure 12. AWSC Analysis Methodology

Input Worksheet

The Input Worksheet is a summary of the traffic and geometric conditions for the study site. The following data are needed:

1. Traffic volumes for each approach by turning movement.
2. The peak hour factor for each approach.
3. The number of lanes on each approach.

Volume Summary Worksheet

The Volume Summary Worksheet is a summary of volumes and flow rates for the intersection. Each approach is analyzed separately.

Step 1. From the data given in the Input Worksheet, record the left-turn, through, and right turn volumes for each approach in rows (1), (2), and (3). The peak hour factor is recorded in row (4).

Step 2. Compute the left-turn, through, and right-turn flow rates for each approach. Record the results in rows (5), (6), and (7). Record the intersection flow rate in row (8).

Step 3. Record the proportion of left-turns and right-turns in rows (9) and (10). Verify that the proportions are within the ranges given in Table 3.

Step 4. Note the opposing approach direction and conflicting approach directions in rows (11) and (12). See Figure 1 for the definition of the subject, opposing, and conflicting approaches.

Step 5. Record the flow rates for the subject, opposing, and conflicting approaches in rows (13), (14), and (15). Record the total intersection flow rate in row (16).

Step 6. Compute the proportion of the total intersection volumes on the subject, opposing, and conflicting approaches. Record these proportions in rows (17), (18), and (19). Verify that the proportions are within the ranges given in Table 3.

Step 7. Record the turning movements for the opposing and conflicting approaches in rows (20), (21), (22), and (23).

Step 8. Compute the proportion of turning movements on the opposing and conflicting approaches and record in rows (24), (25), (26), and (27).

Capacity Analysis Worksheet

The purpose of the Capacity Analysis Worksheet is to compute the capacities for each approach.

Step 1. Record the proportion of traffic on the subject and opposing approaches in rows (1) and (2), from rows (17) and (18) of the Volume Summary Worksheet.

Step 2. From the Input Worksheet, record the number of lanes on the subject and opposing approaches in rows (3) and (4). Verify that the number of lanes on each approach is within the ranges given in Table 3.

Step 3. Compute the effects of volume distribution and number of approach lanes on capacity for eac h approach. The individual parameters are given in rows (5), (6), (7), and (8). Record the sum of rows (5), (6), (7), and (8) in row (9).

Step 4. Record the proportion of left and right turns on the opposing and conflicting approaches in rows (10), (11), (12), and (13), from rows (24), (25), (26), and (27) of the Volume Summary Worksheet.

Step 5. Compute the effects of turning movements on the opposing and conflicting approaches on capacity. The individual parameters are given in rows (14), (15), (16), and (17). Record the sum of rows (14), (15), (16), and (17) in row (18).

Step 6. Compute the capacity and record it in row (19) by adding the values computed in rows (9) and (18).

Level of Service Worksheet

The purpose of the Level of Service Worksheet is to determine the level of service for each approach and for the entire intersection.

Step 1. Record the approach flow rate in row (1), using the value determined in row (13) of the Volume Summary Worksheet. Record the approach capacity in row (2), using the value determined from row (19) of the Capacity Analysis Worksheet.

Step 2. Compute the volume/capacity ratio and record it in row (3).

Step 3. Compute the approach delay using the equation given in row (4). Record the delay in row (4).

Step 4. Use the table given in the Level of Service Worksheet to determine the level of service for each approach. Record the level of service in row (5).

Step 5. Compute the weighted average delay for the intersection. Record the level of service for the intersection.

SAMPLE CALCULATIONS

Calculation 1-Single Lane Approach, Four-Way Intersection

Description. This example concerns the intersection of Blaine Street and Sixth Street. Both streets are two-lane arterials and their intersection is controlled by stop signs in each direction. How well is the intersection functioning?

Solution. The operational analysis method described in this report is used to determine the level of service for this intersection.

Input Worksheet. The Input Worksheet is a summary of the traffic and geometric conditions for the study site. The following data are needed:

1. Traffic volumes for each approach by turning movement.
2. The peak hour factor for each approach.
3. The number of lanes on each approach.

Volume Summary Worksheet. The Volume Summary Worksheet is a summary of volumes and flow rates for the intersection. Each approach is analyzed separately.

Step 1. From the data given in the Input Worksheet, record the left-turn, through, and right turn volumes for each approach in rows (1), (2), and (3). The peak hour factor is recorded in row (4).

Step 2. Compute the left-turn, through, and right-turn flow rates for each approach. Record the results in rows (5), (6), and (7). Record the intersection flow rate in row (8).

Step 3. Record the proportion of left-turns and right-turns in rows (9) and (10). Verify that the proportions are within the ranges given in Table 3.

Step 4. Note the opposing approach direction and conflicting approach directions in rows (11) and (12). See Figure 1 for the definition of the subject, opposing, and conflicting approaches.

Step 5. Record the flow rates for the subject, opposing, and conflicting approaches in rows (13), (14), and (15). Record the total intersection flow rate in row (16).

Step 6. Compute the proportion of the total intersection volumes on the subject, opposing, and conflicting approaches. Record these proportions in rows (17), (18), and (19). Verify that the proportions are within the ranges given in Table 3.

Step 7. Record the turning movements for the opposing and conflicting approaches in rows (20), (21), (22), and (23).

Step 8. Compute the proportion of turning movements on the opposing and conflicting approaches and record in rows (24), (25), (26), and (27).

Capacity Analysis Worksheet. The purpose of the Capacity Analysis Worksheet is to compute the capacities for each approach.

Step 1. Record the proportion of traffic on the subject and opposing approaches in rows (1) and (2), from rows (17) and (18) of the Volume Summary Worksheet.

Step 2. From the Input Worksheet, record the number of lanes on the subject and opposing approaches in rows (3) and (4). Verify that the number of lanes on each approach is within the ranges given in Table 3.

Step 3. Compute the effects of volume distribution and number of approach lanes on capacity for each approach. The individual parameters are given in rows (5), (6), (7), and (8). Record the sum of rows (5), (6), (7), and (8) in row (9).

Step 4. Record the proportion of left and right turns on the opposing and conflicting approaches in rows (10), (11), (12), and (13), from rows (24), (25), (26), and (27) of the Volume Summary Worksheet.

Step 5. Compute the effects of turning movements on the opposing and conflicting approaches on capacity. The individual parameters are given in rows (14), (15), (16), and (17). Record the sum of rows (14), (15), (16), and (17) in row (18).

Step 6. Compute the capacity and record it in row (19) by adding the values computed in rows (9) and (18).

Level of Service Worksheet. The purpose of the Level of Service Worksheet is to determine the level of service for each approach and for the entire intersection.

Step 1. Record the approach flow rate in row (1), using the value determined in row (13) of the Volume Summary Worksheet. Record the approach capacity in row (2), using the value determined from row (19) of the Capacity Analysis Worksheet.

Step 2. Compute the volume/capacity ratio and record it in row (3).

Step 3. Compute the approach delay using the equation given in row (4). Record the delay in row (4).

Step 4. Use the table given in the Level of Service Worksheet to determine the level of service for each approach. Record the level of service in row (5).

Step 5. Compute the weighted average delay for the intersection. Record the level of service for the intersection.

Discussion. The traffic volumes at this intersection are relatively high for an AWSC intersection. The estimated delays place the level of service for the approaches at C and D. If the intersection were to be signalized, with a fixed-time 60 second cycle evenly divided between two phases, the HCM procedures of chapter nine forecast that delays would be significantly lower, with the intersection performing at level of service B. Table 4 shows a comparison between the forecasted performance of this intersection operating both with all-way stop-control and signal control.

Table 4. Comparison of Delay and Capacity Estimates For AWSC Operations and Signalized Operation

AWSC Operation	EB	WB	NB	SB
Capacity	522	510	459	450
V/C Ratio	.81	.64	.76	.67
Delay	22	11	18	13
LOS	D	C	C	C

Signal Operation	EB	WB	NB	SB
Capacity	674	595	691	659
V/C Ratio	.63	.55	.51	.46
Delay	11	10	10	9
LOS	B	B	B	B

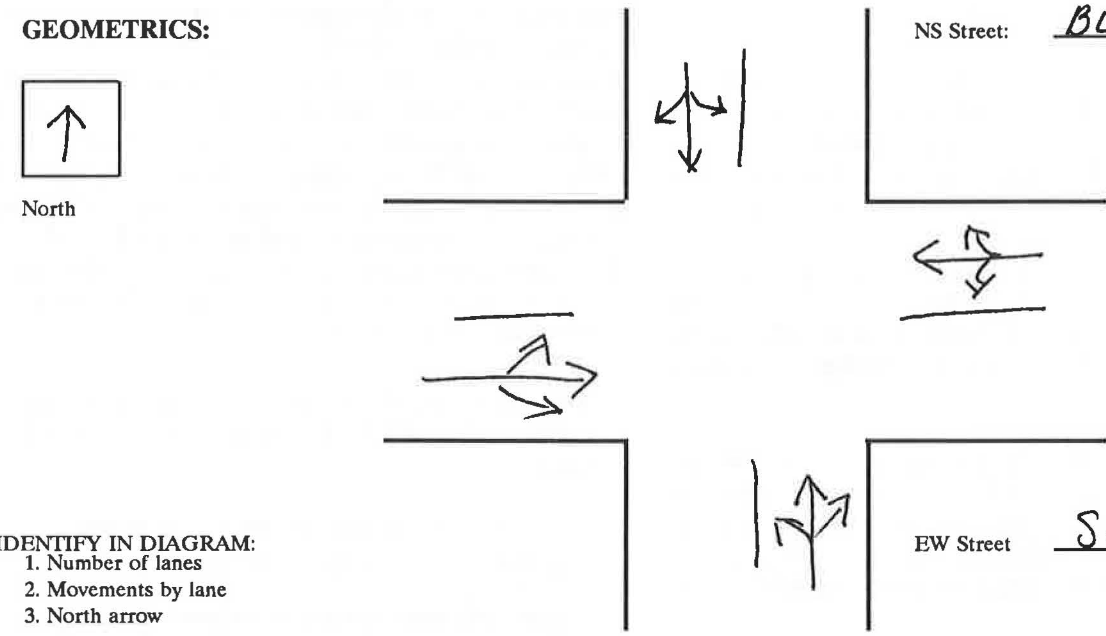
INPUT WORKSHEET

Intersection: BLAINE STREET AND SIXTH Date: 3-19-87

Analyst: MDK Time Period Analyzed: 4:30 pm - 5:30 pm

Project No: SAMPLE #1 City/State: MOSCOW, ID

GEOMETRICS:



North

NS Street: BLAINE ST

EW Street SIXTH ST

IDENTIFY IN DIAGRAM:
1. Number of lanes
2. Movements by lane
3. North arrow

TRAFFIC VOLUMES:

Approach	LT	TH	RT	Total	PHF
EB	75	300	50	425	1.00
WB	75	200	50	325	1.00
NB	50	250	50	350	1.00
SB	50	200	50	300	1.00

VOLUME SUMMARY WORKSHEET					
		EB	WB	NB	SB
	(1) LT Volume	75	75	50	50
	(2) TH Volume	300	200	250	200
	(3) RT Volume	50	50	50	50
	(4) Peak Hour Factor	1.00	1.00	1.00	1.00
	(5) LT Flow Rate, (1)/(4)	75	75	50	50
	(6) TH Flow Rate, (2)/(4)	300	200	250	200
	(7) RT Flow Rate, (3)/(4)	50	50	50	50
	(8) Approach Flow Rate, (5) + (6) + (7)	425	325	350	300
	(9) Proportion LT, (5)/(8)	.18	.23	.14	.17
	(10) Proportion RT, (7)/(8)	.12	.15	.14	.17
	(11) Opposing Approach (Direction)	WB	EB	SB	NB
	(12) Conflicting Approaches (Directions)	NB, SB	NB, SB	EB, WB	EB, WB
	(13) Subject Approach Flow Rate	425	325	350	300
	(14) Opposing Approach Flow Rate	325	425	300	350
	(15) Conflicting Approaches Flow Rate	650	650	750	750
	(16) Total Intersection Flow Rate, (13)+(14)+(15)	1400	1400	1400	1400
	(17) Proportion, Subject Approach Flow Rate, (13)/(16)	.30	.23	.25	.21
	(18) Proportion, Opposing Approach Flow Rate, (14)/(16)	.23	.30	.21	.25
	(19) Proportion, Conflicting Approaches Flow Rate, (15)/(16)	.46	.46	.54	.54
	(20) LT, Opposing Approach	75	75	50	50
	(21) RT, Opposing Approaches	50	50	50	50
	(22) LT, Conflicting Approaches	100	100	150	150
	(23) RT, Conflicting Approaches	100	100	100	100
	(24) Proportion LT, Opposing Approach, (20)/(14)	.23	.18	.17	.14
	(25) Proportion RT, Opposing Approach, (21)/(14)	.15	.12	.17	.14
	(26) Proportion LT, Conflicting Approaches, (22)/(15)	.15	.15	.20	.20
	(27) Proportion RT, Conflicting Approaches, (23)/(15)	.15	.15	.13	.13

CAPACITY ANALYSIS WORKSHEET					
		EB	WB	NB	SB
	(1) Proportion, Subject Approach Flow Rate	.30	.23	.25	.21
	(2) Proportion, Opposing Approach Flow Rate	.23	.30	.21	.25
	(3) Lanes on Subject Approach	1	1	1	1
	(4) Lanes on Opposing Approach	1	1	1	1
	(5) +1000 x (1)	300	230	250	210
	(6) +700 x (2)	161	210	147	175
	(7) +200 x (3)	200	200	200	200
	(8) -100 x (4)	-100	-100	-100	-100
	(9) (5)+(6)+(7)+(8)	561	540	497	485
	(10) Proportion LT, Opposing Approach	.23	.18	.17	.14
	(11) Proportion RT, Opposing Approach	.15	.12	.17	.14
	(12) Proportion LT, Conflicting Approaches	.15	.15	.20	.20
	(13) Proportion RT, Conflicting Approaches	.15	.15	.13	.13
	(14) -300 x (10)	-69	-54	-51	-42
	(15) +200 x (11)	30	24	34	28
	(16) -300 x (12)	-45	-45	-60	-60
	(17) +300 x (13)	45	45	39	39
	(18) (14)+(15)+(16)+(17)	-39	-30	-38	-35
	(19) Approach Capacity, (9)+(18)	522	510	459	450

LEVEL OF SERVICE WORKSHEET

	EB	WB	NB	SB
(1) Approach Flow Rate	425	325	350	300
(2) Approach Capacity	522	510	459	450
(3) Volume/Capacity Ratio, (1)/(2)	.81	.64	.76	.67
(4) Delay = exp[3.8 x (3)]	22	11	18	13
(5) Level of Service (from table)	D	C	C	C

$$\textit{Average Delay (Intersection)} = \frac{\sum (\textit{Delay x Volume})}{\sum \textit{Volume}} = \quad 17$$

Level of Service (Intersection) = C

Level of Service Criteria

LOS	Average Stopped Delay, sec/veh
A	< 5
B	5 - 10
C	10 - 20
D	20 - 30
E	30 - 45
F	> 45

Calculation 2-T-Intersection

Description. This example concerns the T-intersection of Sixth Street and Line Street. Both streets are two-lane arterials and their intersection is controlled by stop signs in each direction. How well is the intersection functioning?

Solution. The operational analysis method described in this report is used to determine the level of service for this intersection.

Input Worksheet. The Input Worksheet is a summary of the traffic and geometric conditions for the study site. The following data are needed:

1. Traffic volumes for each approach by turning movement.
2. The peak hour factor for each approach.
3. The number of lanes on each approach.

Volume Summary Worksheet. The Volume Summary Worksheet is a summary of volumes and flow rates for the intersection. Each approach is analyzed separately.

Step 1. From the data given in the Input Worksheet, record the left-turn, through, and right turn volumes for each approach in rows (1), (2), and (3). The peak hour factor is recorded in row (4).

Step 2. Compute the left-turn, through, and right-turn flow rates for each approach. Record the results in rows (5), (6), and (7). Record the intersection flow rate in row (8).

Step 3. Record the proportion of left-turns and right-turns in rows (9) and (10). Verify that the proportions are within the ranges given in Table 3.

Step 4. Note the opposing approach direction and conflicting approach directions in rows (11) and (12). See Figure 1 for the definition of the subject, opposing, and conflicting approaches.

Step 5. Record the flow rates for the subject, opposing, and conflicting approaches in rows (13), (14), and (15). Record the total intersection flow rate in row (16).

Step 6. Compute the proportion of the total intersection volumes on the subject, opposing, and conflicting approaches. Record these proportions in rows (17), (18), and (19). Verify that the proportions are within the ranges given in Table 3.

Step 7. Record the turning movements for the opposing and conflicting approaches in rows (20), (21), (22), and (23).

Step 8. Compute the proportion of turning movements on the opposing and conflicting approaches and record in rows (24), (25), (26), and (27).

Capacity Analysis Worksheet. The purpose of the Capacity Analysis Worksheet is to compute the capacities for each approach.

Step 1. Record the proportion of traffic on the subject and opposing approaches in rows (1) and (2), from rows (17) and (18) of the Volume Summary Worksheet.

Step 2. From the Input Worksheet, record the number of lanes on the subject and opposing approaches in rows (3) and (4). Verify that the number of lanes on each approach is within the ranges given in Table 3.

Step 3. Compute the effects of volume distribution and number of approach lanes on capacity for each approach. The individual parameters are given in rows (5), (6), (7), and (8). Record the sum of rows (5), (6), (7), and (8) in row (9).

Step 4. Record the proportion of left and right turns on the opposing and conflicting approaches in rows (10), (11), (12), and (13), from rows (24), (25), (26), and (27) of the Volume Summary Worksheet.

Step 5. Compute the effects of turning movements on the opposing and conflicting approaches on capacity. The individual parameters are given in rows (14), (15), (16), and (17). Record the sum of rows (14), (15), (16), and (17) in row (18).

Step 6. Compute the capacity and record it in row (19) by adding the values computed in rows (9) and (18).

Level of Service Worksheet. The purpose of the Level of Service Worksheet is to determine the level of service for each approach and for the entire intersection.

Step 1. Record the approach flow rate in row (1), using the value determined in row (13) of the Volume Summary Worksheet. Record the approach capacity in row (2), using the value determined from row (19) of the Capacity Analysis Worksheet.

Step 2. Compute the volume/capacity ratio and record it in row (3).

Step 3. Compute the approach delay using the equation given in row (4). Record the delay in row (4).

Step 4. Use the table given in the Level of Service Worksheet to determine the level of service for each approach. Record the level of service in row (5).

Step 5. Compute the weighted average delay for the intersection. Record the level of service for the intersection.

Discussion. The calculation of capacity and delay for a T-intersection is virtually identical to the method used in Calculation 1 for a four-way intersection. The major difference is that there are three legs rather than four. Note that the approach volumes and turning movement proportions must be entered as zero for the non-existant approach as these numbers are important for determining the nature of the traffic flow at the opposing and conflicting approaches.

INPUT WORKSHEET

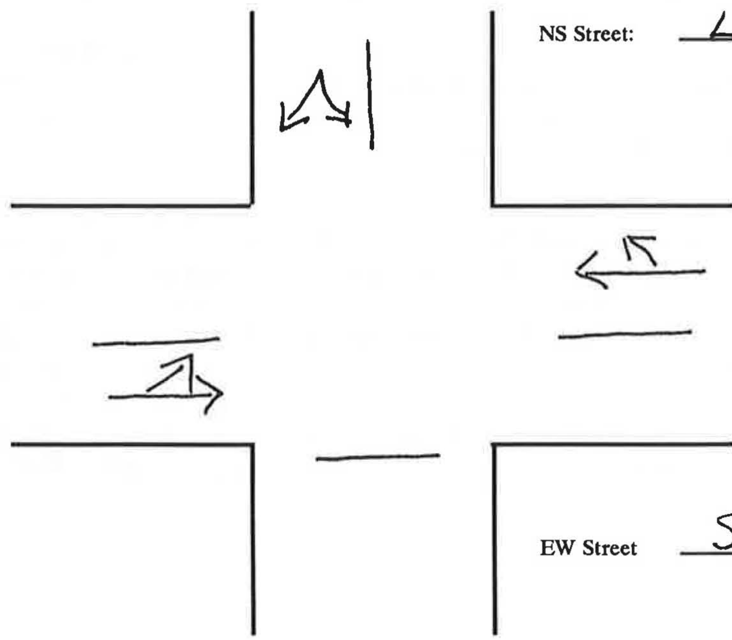
Intersection: SIXTH STREET AND LINE STREET Date: 10-15-87

Analyst: MDK Time Period Analyzed: 5⁰⁰ pm - 6⁰⁰ pm

Project No: SAMPLE #2 City/State: MOSCOW, ID

GEOMETRICS:

North



NS Street: LINE ST

EW Street: SIXTH ST

IDENTIFY IN DIAGRAM:
1. Number of lanes
2. Movements by lane
3. North arrow

TRAFFIC VOLUMES:

Approach	LT	TH	RT	Total	PHF
EB	50	300	0	350	1.00
WB	0	300	100	450	1.00
NB	0	0	0	0	—
SB	100	0	50	150	1.00

VOLUME SUMMARY WORKSHEET					
		EB	WB	NB	SB
	(1) LT Volume	50	0		100
	(2) TH Volume	300	300		0
	(3) RT Volume	0	100		50
	(4) Peak Hour Factor	1.00	1.00		1.00
	(5) LT Flow Rate, (1)/(4)	50	0		100
	(6) TH Flow Rate, (2)/(4)	300	300		0
	(7) RT Flow Rate, (3)/(4)	0	100		50
	(8) Approach Flow Rate, (5) + (6) + (7)	350	400		150
	(9) Proportion LT, (5)/(8)	.14	.00		.67
	(10) Proportion RT, (7)/(8)	.00	.25		.33
	(11) Opposing Approach (Direction)	WB	EB		—
	(12) Conflicting Approaches (Directions)	SB	SB		WB, EB
	(13) Subject Approach Flow Rate	350	400		150
	(14) Opposing Approach Flow Rate	400	350		0
	(15) Conflicting Approaches Flow Rate	150	150		750
	(16) Total Intersection Flow Rate, (13)+(14)+(15)	900	900		900
	(17) Proportion, Subject Approach Flow Rate, (13)/(16)	.39	.44		.17
	(18) Proportion, Opposing Approach Flow Rate, (14)/(16)	.44	.39		.00
	(19) Proportion, Conflicting Approaches Flow Rate, (15)/(16)	.17	.17		.83
	(20) LT, Opposing Approach	0	50		0
	(21) RT, Opposing Approaches	100	0		0
	(22) LT, Conflicting Approaches	100	100		50
	(23) RT, Conflicting Approaches	50	50		100
	(24) Proportion LT, Opposing Approach, (20)/(14)	.00	.14		.00
	(25) Proportion RT, Opposing Approach, (21)/(14)	.25	.00		.00
	(26) Proportion LT, Conflicting Approaches, (22)/(15)	.67	.67		.07
	(27) Proportion RT, Conflicting Approaches, (23)/(15)	.33	.33		.13

CAPACITY ANALYSIS WORKSHEET

		EB	WB	NB	SB
	(1) Proportion, Subject Approach Flow Rate	.39	.44		.17
	(2) Proportion, Opposing Approach Flow Rate	.44	.39		.00
	(3) Lanes on Subject Approach	1	1		1
	(4) Lanes on Opposing Approach	1	1		0
	(5) +1000 x (1)	390	440		170
	(6) +700 x (2)	308	273		0
	(7) +200 x (3)	200	200		200
	(8) -100 x (4)	-100	-100		0
	(9) (5)+(6)+(7)+(8)	798	813		370
	(10) Proportion LT, Opposing Approach	.00	.14		.00
	(11) Proportion RT, Opposing Approach	.25	.00		.00
	(12) Proportion LT, Conflicting Approaches	.67	.67		.07
	(13) Proportion RT, Conflicting Approaches	.33	.33		.13
	(14) -300 x (10)	0	-42		0
	(15) +200 x (11)	50	0		0
	(16) -300 x (12)	-201	-201		-21
	(17) +300 x (13)	99	99		39
	(18) (14)+(15)+(16)+(17)	-52	-144		18
	(19) Approach Capacity, (9)+(18)	746	669		388

LEVEL OF SERVICE WORKSHEET

		EB	WB	NB	SB
	(1) Approach Flow Rate	350	400		150
	(2) Approach Capacity	746	669		388
	(3) Volume/Capacity Ratio, (1)/(2)	.47	.60		.39
	(4) Delay = exp[3.8 x (3)]	6	10		4
	(5) Level of Service (from table)	B	B		A

$$\textit{Average Delay (Intersection)} = \frac{\sum \textit{(Delay x Volume)}}{\sum \textit{Volume}} = 7$$

***Level of Service (Intersection)* =** B

Level of Service Criteria

LOS	Average Stopped Delay, sec/veh
A	< 5
B	5 - 10
C	10 - 20
D	20 - 30
E	30 - 45
F	> 45

Calculation 3-Multi-Lane Approach, Four-Way Intersection

Description. This example concerns the intersection of Eighth Avenue and Sixteenth Street. Both streets are four-lane arterials and their intersection is controlled by stop signs in each direction. How well is the intersection functioning?

Solution. The operational analysis method described in this report is used to determine the level of service for this intersection.

Input Worksheet. The Input Worksheet is a summary of the traffic and geometric conditions for the study site. The following data are needed:

1. Traffic volumes for each approach by turning movement.
2. The peak hour factor for each approach.
3. The number of lanes on each approach.

Volume Summary Worksheet. The Volume Summary Worksheet is a summary of volumes and flow rates for the intersection. Each approach is analyzed separately.

Step 1. From the data given in the Input Worksheet, record the left-turn, through, and right turn volumes for each approach in rows (1), (2), and (3). The peak hour factor is recorded in row (4).

Step 2. Compute the left-turn, through, and right-turn flow rates for each approach. Record the results in rows (5), (6), and (7). Record the intersection flow rate in row (8).

Step 3. Record the proportion of left-turns and right-turns in rows (9) and (10). Verify that the proportions are within the ranges given in Table 3.

Step 4. Note the opposing approach direction and conflicting approach directions in rows (11) and (12). See Figure 1 for the definition of the subject, opposing, and conflicting approaches.

Step 5. Record the flow rates for the subject, opposing, and conflicting approaches in rows (13), (14), and (15). Record the total intersection flow rate in row (16).

Step 6. Compute the proportion of the total intersection volumes on the subject, opposing, and conflicting approaches. Record these proportions in rows (17), (18), and (19). Verify that the proportions are within the ranges given in Table 3.

Step 7. Record the turning movements for the opposing and conflicting approaches in rows (20), (21), (22), and (23).

Step 8. Compute the proportion of turning movements on the opposing and conflicting approaches and record in rows (24), (25), (26), and (27).

Capacity Analysis Worksheet. The purpose of the Capacity Analysis Worksheet is to compute the capacities for each approach.

Step 1. Record the proportion of traffic on the subject and opposing approaches in rows (1) and (2), from rows (17) and (18) of the Volume Summary Worksheet.

Step 2. From the Input Worksheet, record the number of lanes on the subject and opposing approaches in rows (3) and (4). Verify that the number of lanes on each approach is within the ranges given in Table 3.

Step 3. Compute the effects of volume distribution and number of approach lanes on capacity for each approach. The individual parameters are given in rows (5), (6), (7), and (8). Record the sum of rows (5), (6), (7), and (8) in row (9).

Step 4. Record the proportion of left and right turns on the opposing and conflicting approaches in rows (10), (11), (12), and (13), from rows (24), (25), (26), and (27) of the Volume Summary Worksheet.

Step 5. Compute the effects of turning movements on the opposing and conflicting approaches on capacity. The individual parameters are given in rows (14), (15), (16), and (17). Record the sum of rows (14), (15), (16), and (17) in row (18).

Step 6. Compute the capacity and record it in row (19) by adding the values computed in rows (9) and (18).

Level of Service Worksheet. The purpose of the Level of Service Worksheet is to determine the level of service for each approach and for the entire intersection.

Step 1. Record the approach flow rate in row (1), using the value determined in row (13) of the Volume Summary Worksheet. Record the approach capacity in row (2), using the value determined from row (19) of the Capacity Analysis Worksheet.

Step 2. Compute the volume/capacity ratio and record it in row (3).

Step 3. Compute the approach delay using the equation given in row (4). Record the delay in row (4).

Step 4. Use the table given in the Level of Service Worksheet to determine the level of service for each approach. Record the level of service in row (5).

Step 5. Compute the weighted average delay for the intersection. Record the level of service for the intersection.

Discussion. The calculation of capacity and delay for a multi-lane intersection is virtually identical to the method used in Calculation 1 for a four-way, single-lane approach intersection. Note that the increase in capacity is not proportional to the increase in the number of approach lanes. The saturation headways measured for traffic on multi-lane approach intersections is significantly greater than for single-lane approach intersections and it is likely that increasing the number of lanes will not significantly increase the capacity of the intersection. This fact is reflected in this sample calculation.

INPUT WORKSHEET

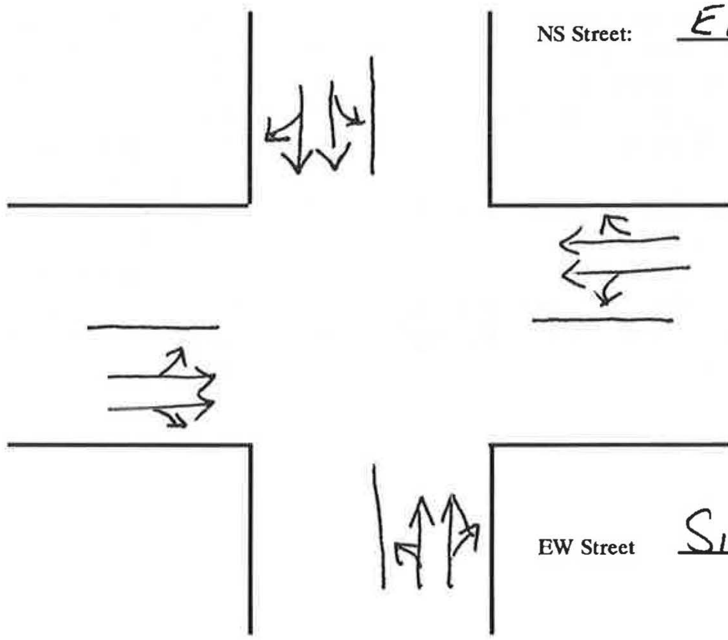
Intersection: EIGHTH AVENUE AND SIXTEENTH ST Date: 11-15-88

Analyst: MDK Time Period Analyzed: 4^00 pm – 5^00 pm

Project No: SAMPLE #3 City/State: LEWISTON, ID

GEOMETRICS:

North



NS Street: EIGHTH AVE

EW Street: SIXTEENTH ST

IDENTIFY IN DIAGRAM:
1. Number of lanes
2. Movements by lane
3. North arrow

TRAFFIC VOLUMES:

Approach	LT	TH	RT	Total	PHF
EB	100	300	50	450	1.00
WB	100	300	100	500	1.00
NB	100	350	50	500	1.00
SB	50	300	150	500	1.00

VOLUME SUMMARY WORKSHEET					
		EB	WB	NB	SB
	(1) LT Volume	100	100	100	50
	(2) TH Volume	300	300	350	300
	(3) RT Volume	50	100	50	150
	(4) Peak Hour Factor	1.00	1.00	1.00	1.00
	(5) LT Flow Rate, (1)/(4)	100	100	100	50
	(6) TH Flow Rate, (2)/(4)	300	300	350	300
	(7) RT Flow Rate, (3)/(4)	50	100	50	150
	(8) Approach Flow Rate, (5) + (6) + (7)	450	500	500	500
	(9) Proportion LT, (5)/(8)	.22	.20	.20	.10
	(10) Proportion RT, (7)/(8)	.11	.20	.10	.30
	(11) Opposing Approach (Direction)	WB	EB	SB	NB
	(12) Conflicting Approaches (Directions)	NB, SB	NB, SB	EB, WB	EB, WB
	(13) Subject Approach Flow Rate	450	500	500	500
	(14) Opposing Approach Flow Rate	500	450	500	500
	(15) Conflicting Approaches Flow Rate	1000	1000	950	950
	(16) Total Intersection Flow Rate, (13)+(14)+(15)	1950	1950	1950	1950
	(17) Proportion, Subject Approach Flow Rate, (13)/(16)	.23	.26	.26	.26
	(18) Proportion, Opposing Approach Flow Rate, (14)/(16)	.26	.23	.26	.26
	(19) Proportion, Conflicting Approaches Flow Rate, (15)/(16)	.51	.51	.49	.49
	(20) LT, Opposing Approach	100	100	50	100
	(21) RT, Opposing Approaches	100	50	150	50
	(22) LT, Conflicting Approaches	150	150	200	200
	(23) RT, Conflicting Approaches	200	200	150	150
	(24) Proportion LT, Opposing Approach, (20)/(14)	.20	.22	.10	.20
	(25) Proportion RT, Opposing Approach, (21)/(14)	.20	.11	.30	.10
	(26) Proportion LT, Conflicting Approaches, (22)/(15)	.15	.15	.21	.21
	(27) Proportion RT, Conflicting Approaches, (23)/(15)	.20	.20	.16	.16

CAPACITY ANALYSIS WORKSHEET	EB	WB	NB	SB
(1) Proportion, Subject Approach Flow Rate	.23	.26	.26	.26
(2) Proportion, Opposing Approach Flow Rate	.26	.23	.26	.26
(3) Lanes on Subject Approach	2	2	2	2
(4) Lanes on Opposing Approach	2	2	2	2
(5) +1000 x (1)	230	260	260	260
(6) +700 x (2)	182	161	182	182
(7) +200 x (3)	400	400	400	400
(8) -100 x (4)	-200	-200	-200	-200
(9) (5)+(6)+(7)+(8)	612	621	642	642
(10) Proportion LT, Opposing Approach	.20	.22	.10	.20
(11) Proportion RT, Opposing Approach	.20	.11	.30	.10
(12) Proportion LT, Conflicting Approaches	.15	.15	.21	.21
(13) Proportion RT, Conflicting Approaches	.20	.20	.16	.16
(14) -300 x (10)	-60	-66	-30	-60
(15) +200 x (11)	40	22	60	20
(16) -300 x (12)	-45	-45	-63	-63
(17) +300 x (13)	60	60	48	48
(18) (14)+(15)+(16)+(17)	-5	-29	15	-55
(19) Approach Capacity, (9)+(18)	607	592	657	587

LEVEL OF SERVICE WORKSHEET		EB	WB	NB	SB
	(1) Approach Flow Rate	450	500	500	500
	(2) Approach Capacity	607	592	657	587
	(3) Volume/Capacity Ratio, (1)/(2)	.74	.84	.76	.85
	(4) Delay = exp[3.8 x (3)]	17	24	18	25
	(5) Level of Service (from table)	C	D	C	D

$$\textit{Average Delay (Intersection)} = \frac{\sum(\textit{Delay x Volume})}{\sum \textit{Volume}} = 21$$

Level of Service (Intersection) = D

Level of Service Criteria

LOS	Average Stopped Delay, sec/veh
A	< 5
B	5 - 10
C	10 - 20
D	20 - 30
E	30 - 45
F	> 45

REFERENCES

1. Transportation Research Board, 1985 Highway Capacity Manual, Special Report 209, Washington, D.C. 1985.
2. Hebert, J., "A Study of Four-Way Stop-Controlled Intersection Capacities". Highway Research Record 27, Highway Research Board, Washington, D.C. (1963).
3. Michael Kyte. "Estimating Capacity and Delay At An All-Way Stop-Controlled Intersection". University of Idaho, Department of Civil Engineering Research Report, September, 1989.

APPENDIX

Worksheets For Use In The Analysis of All-Way Stop-Controlled Intersections

INPUT WORKSHEET

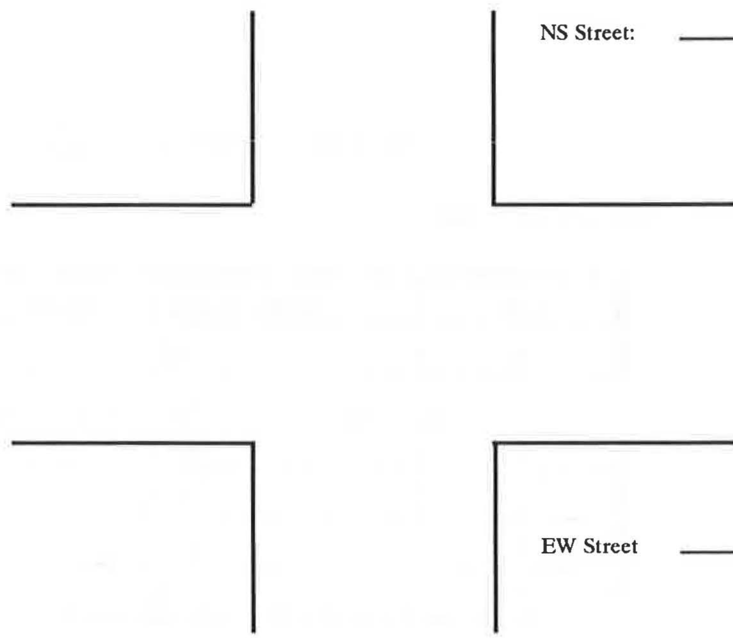
Intersection: ______________________________ Date: ____________

Analyst: ____________________ Time Period Analyzed: ____________________

Project No: ____________________ City/State: ____________________

GEOMETRICS:

North



NS Street: ____________

EW Street ____________

IDENTIFY IN DIAGRAM:
1. Number of lanes
2. Movements by lane
3. North arrow

TRAFFIC VOLUMES:

Approach	LT	TH	RT	Total	PHF
EB					
WB					
NB					
SB					

VOLUME SUMMARY WORKSHEET					
		EB	WB	NB	SB
	(1) LT Volume				
	(2) TH Volume				
	(3) RT Volume				
	(4) Peak Hour Factor				
	(5) LT Flow Rate, (1)/(4)				
	(6) TH Flow Rate, (2)/(4)				
	(7) RT Flow Rate, (3)/(4)				
	(8) Approach Flow Rate, (5) + (6) + (7)				
	(9) Proportion LT, (5)/(8)				
	(10) Proportion RT, (7)/(8)				
	(11) Opposing Approach (Direction)				
	(12) Conflicting Approaches (Directions)				
	(13) Subject Approach Flow Rate				
	(14) Opposing Approach Flow Rate				
	(15) Conflicting Approaches Flow Rate				
	(16) Total Intersection Flow Rate, (13)+(14)+(15)				
	(17) Proportion, Subject Approach Flow Rate, (13)/(16)				
	(18) Proportion, Opposing Approach Flow Rate, (14)/(16)				
	(19) Proportion, Conflicting Approaches Flow Rate, (15)/(16)				
	(20) LT, Opposing Approach				
	(21) RT, Opposing Approaches				
	(22) LT, Conflicting Approaches				
	(23) RT, Conflicting Approaches				
	(24) Proportion LT, Opposing Approach, (20)/(14)				
	(25) Proportion RT, Opposing Approach, (21)/(14)				
	(26) Proportion LT, Conflicting Approaches, (22)/(15)				
	(27) Proportion RT, Conflicting Approaches, (23)/(15)				

CAPACITY ANALYSIS WORKSHEET					
		EB	WB	NB	SB
	(1) Proportion, Subject Approach Flow Rate				
	(2) Proportion, Opposing Approach Flow Rate				
	(3) Lanes on Subject Approach				
	(4) Lanes on Opposing Approach				
	(5) +1000 x (1)				
	(6) +700 x (2)				
	(7) +200 x (3)				
	(8) -100 x (4)				
	(9) (5)+(6)+(7)+(8)				
	(10) Proportion LT, Opposing Approach				
	(11) Proportion RT, Opposing Approach				
	(12) Proportion LT, Conflicting Approaches				
	(13) Proportion RT, Conflicting Approaches				
	(14) -300 x (10)				
	(15) +200 x (11)				
	(16) -300 x (12)				
	(17) +300 x (13)				
	(18) (14)+(15)+(16)+(17)				
	(19) Approach Capacity, (9)+(18)				

LEVEL OF SERVICE WORKSHEET

		EB	WB	NB	SB
	(1) Approach Flow Rate				
	(2) Approach Capacity				
	(3) Volume/Capacity Ratio, (1)/(2)				
	(4) Delay = exp[3.8 x (3)]				
	(5) Level of Service (from table)				

$$\textit{Average Delay (Intersection)} = \frac{\sum (\textit{Delay x Volume})}{\sum \textit{Volume}} =$$

Level of Service (Intersection) =

Level of Service Criteria

LOS	Average Stopped Delay, sec/veh
A	< 5
B	5 - 10
C	10 - 20
D	20 - 30
E	30 - 45
F	> 45

Unsignalized intersections, including both two-way stop control (hereafter referred to as TWSC) and all-way stop control (hereafter referred to as AWSC) are the most prevalent type of intersection within the United States and abroad. The importance of developing a better understanding of how these intersections operate cannot be overstated:

- Improved warrants for intersection signalization may be possible. By recognizing conditions under which TWSC and AWSC intersections can continue to operate effectively, unnecessary signals (which represent a continuing maintenance cost for government agencies and unnecessary additional delay to motorists) can be avoided.
- Better access management strategies can be developed. Understanding how each TWSC and AWSC intersection operates within a systemwide context will result in a more efficient use of existing arterial streets. It will also assist in defining the appropriate number of access drives for private and public developments.
- Minimum intersection sight distance requirements can be developed for urban areas based on an improved understanding of driver gap acceptance characteristics. Current AASHTO procedures consider vehicle acceleration/deceleration dynamics, but do not specifically account for the gap acceptance characteristics of side street vehicles.

The purpose of this chapter is to describe a comprehensive data collection methodology applicable to TWSC and AWSC intersections. The Highway Capacity Committee believes that, in its complete form, this data collection procedure will provide sufficient information for development, calibration, and evaluation of a revised and/or updated unsignalized intersection analysis procedure.

Because the procedure is designed to provide maximum flexibility to researchers as they work toward developing better relationships between various dependent and independent variables, it may be too complex to be practical for day-to-day application. With relatively minor modifications, however, the procedure can be reasonably applied on a daily basis by many private consultants as well as city, county, and state agencies. Therefore, two data collection procedures are described in this chapter:

1) A comprehensive data collection procedure, which should be considered for incorporation into any formal research work aimed at updating and/or revising Chapter 10 of the *1985 Highway Capacity Manual*; and

2) A simpler, partial data collection procedure that can be applied with minimal labor and equipment resources, and which is still capable of significantly enhancing the understanding of operational characteristics of TWSC and AWSC intersections.

Overview of Traffic Operations

AWSC intersections are described in considerable detail within Chapter 2 of this Circular. TWSC are those intersections that are controlled by a stop sign on one or two approaches. The stop-controlled approaches are referred to as the minor street approaches, and can be either public streets or private driveways. The intersection approaches that are not controlled by stop signs are referred to as the major street approaches. A three-legged intersection is considered to be a special type of two-way stop-controlled intersection so long as the single minor street approach (i.e., the stem of the "T" configuration) is controlled by a stop sign. Three-legged intersections in which one or both major street approaches are controlled by stop signs represent a special form of unsignalized intersection control that is not addressed by the data collection procedure described in this chapter.

TWSC intersections generally assign the right-of-way among conflicting traffic streams according to the following hierarchy:

1) All conflicting movements yield the right-of-way to any through or right-turning vehicle on the major street approaches. These major street through and right-turning movements are hereafter referred to as the highest priority movements at a TWSC intersection.

2) Vehicles turning left from the major street onto the minor street yield only to conflicting major street through and right-turning vehicles. All other conflicting movements at a TWSC intersection yield to these major street left-turning movements.

3) Vehicles turning right from the minor street onto the major street yield only to conflicting major street through movements.

4) Minor street through vehicles yield to all conflicting major street through, right, and left-turning movements.

5) Minor street left turning vehicles yield to all conflicting major street through, right and left-turning vehicles, and also to all conflicting minor street through and right-turning vehicles.

Some unsignalized TWSC intersections have unusual operating characteristics. For example, there are situations in which one or more left-turning movements are allowed to travel unimpeded through the intersection, and are given the right-of-way over opposing through movements. While it is recognized that such operating conditions may legitimately and appropriately exist under special circumstances, they are not the focus of this section.

Even though the hierarchy described above suggests that the highest priority movements experience no delay as they travel through a TWSC intersection, experience shows that their right-of-way is sometimes preempted by other conflicting movements. Such preemption most often occurs during periods of congestion when vehicles in the conflicting movements are experiencing long delays and queues.

With the exception of the highest priority movements, all vehicles approaching a TWSC intersection must stop and wait for an acceptable gap in the conflicting traffic flows before proceeding. The length of an acceptable gap has not yet been well-defined, but is believed to depend on such variables as the number of lanes available on the major street, the speed of approaching vehicles, the presence or absence of nearby traffic signals, pedestrian interference, and the cumulative amount of stopped delay already incurred.

The level of service afforded to any movement at a TWSC intersection is expected to be highly correlated with average stopped delay. It is common for there to be a wide range in service levels simultaneously experienced by different movements at a TWSC intersection. Under these conditions, it is difficult to establish a single intersection LOS descriptor that is equally applicable to all approaches.

The capacity of a TWSC intersection is not yet well-defined, but may be correlated with the number of excess available and acceptable gaps for minor movements that pass through the intersection. Even so, the capacity of the intersection to accommodate minor movements may remain constant or decrease only slightly as conflicting volumes increase. This would be true if, as noted above, the definition of an acceptable gap changes according to the cumulative amount of stopped delay that has been incurred. And in the extreme, the ability of the intersection to accommodate minor movements may actually increase as conflicting volumes continue to increase. A common example of this would be a major street left turning movement that receives courtesy breaks in the opposing through traffic stream only when the queue from a downstream intersection extends near to or through the unsignalized TWSC intersection.

Data Collection Methods

The primary objective in collecting traffic flow and delay data is to assemble a comprehensive and readily available data base for use in the study of traffic operations at AWSC and TWSC intersections. The immediate value of the resulting data base will be in its usefulness for understanding the significance and relationships among the independent variables, developing procedures for forecasting delay, defining appropriate level of service measures, and estimating unsignalized intersection and/or approach capacity. Ultimately, the data base can be used for developing, calibrating, and validating a revised and/or updated procedure for the analysis of unsignalized intersections.

Three categories of data should be collected at AWSC and TWSC intersections: general information, physical characteristics data, and intersection/operations data. A summary of the required data elements within each of these categories is presented in Table 1.

General Information

Data within this category can be obtained at any time through on-site survey and field work. The Data Collection Forms 1 and 2, found in the Appendix, can be used for this purpose. The following specific data base elements are included as general information:

1. *Number of approach legs:* This information is provided on Data Collection Form 1. Generally, all investigated unsignalized intersections should have either three or four approach legs. While it is recognized that there may be stop-controlled intersections with more than four approaches, the operational analysis of such intersections is very complex and beyond the scope of this effort.

The type of intersection control (AWSC or TWSC) should be noted on Data Collection Form 1. For AWSC intersections, all approaches must be controlled by a stop sign. For TWSC intersections, the data collection procedure is designed to accommodate two optional design configurations:

- In the case of three-legged intersections, only one of the approaches should be controlled by a stop sign, and no through movements should be required to stop. Thus, the stop sign at such intersections generally faces the approach that forms the stem of the "T".

- In the case of four-legged intersections, two approaches should be controlled by a stop sign, and of these should clearly function as minor street approaches. Further, these minor street approaches should be directly opposite each other.

2. *Year, month, day, day of week:* This information is provided on Data Collection Form 2. These data base elements are self-explanatory. If the data are collected on a day marked by unusual traffic flow patterns (for example, a local or national holiday, a parade day, or the opening of hunting season along a recreational route), than this should be noted as a parenthetical statement next to the *day of week* entry.

3. *Begin time:* This information is provided on Data Collection Form 2, and represents the time at which the collection of intersection/operations data is initiated. The begin time is recorded in military format to the

Table 1 TWSC Intersections Data Base Elements

I. GENERAL INFORMATION

1. Number of approach legs
2. Year, month, day, day of week
3. Begin time for data collection activities (military)
4. End time for data collection activities (military)
5. City, county, state where data were collected
6. Major street, minor street names
7. Name, address, telephone number for persons/agency collecting the data
8. Weather condition
9. Pavement condition
10. General location (CBD vs. other)
11. Presence/absence of flashing/warning beacons

II. PHYSICAL CHARACTERISTICS DATA

12. Major street through lanes (and widths) in each direction
13. Major street left turn lanes (and widths) in each direction
14. Major street right turn deceleration lanes in each direction
15. Major street right turn acceleration lanes in each direction
16. Minor street lane configuration and lane widths
17. Major street shoulder width and condition
18. Minor street shoulder width and condition
19. Distance on major street to nearest upstream signalized or AWSC intersection
20. Presence/absence of upstream traffic signal coordination
21. Type of control at nearest upstream intersection (pretimed, actuated, AWSC)
22. Number of phases at nearest upstream intersection, if signalized
23. Posted speed limit and/or 85th-percentile speed in each direction on the major street
24. Description of and distance to any major upstream volume sources (for example freeway ramps)
25. Width and type of median (if any) on each approach
26. Right turn curb radius on each approach
27. Angle of intersection approach
28. Functional classification of major, minor, and adjacent streets
29. Grade on each approach
30. Intersection sight distance for each minor movement
31. Location of on-street parking on all approaches

III. INTERSECTION/OPERATIONS DATA

32. Vehicle arrival time (at back of queue) and lane occupancy on all major and minor movements
33. Vehicle follow-up time on all stop-controlled approaches
34. Vehicle departure time and lane occupancy on all minor approaches
35. Vehicle departure time and lane occupancy on all major movements
36. Begin time and end time for all pedestrian crossing movements by approach and direction
37. Begin time and end time for all bicyclist crossing movements by approach and direction
38. Vehicle type
39. Begin and end times for onset of congestion

nearest minute. For this purpose, the begin time should always be recorded as a four-digit number, with 0000 representing midnight (12:00 a.m.), 1300 representing 1:00 p.m., and 2359 representing 11:59 p.m.

4. *End time:* The end time is recorded on Data Collection Form 2. This represents the time at which the collection of intersection/operations data is terminated, and is recorded in military format to the nearest minute.

5. *City, County, State:* The City, County, and State are recorded on Data Collection Form 2. This data base element defines the city and the state in which the data were collected (e.g. Portland, Oregon or Washington, D.C.).

6. *Major street, minor street names:* The major street and minor street names are recorded on Data Collection Form 1. Combined with the city and state information described above, this data base element defines the specific location where the data were collected.

7. *Information on data collection personnel:* Information on data collection personnel is recorded on Data Collection Form 2. This data base element includes the name of the individual primarily responsible for the field data collection effort, the name of the organization for which this individual works, the organization's mailing address, and the individual's telephone number.

8. *Weather condition:* Ambient weather conditions are recorded on Data Collection Form 2. This data base element defines weather conditions existing during the data collection period that might affect driver performance characteristics. Thus the term weather refers to existing atmospheric conditions, precipitation status, and the ambient temperature during the data collection period.

Existing atmospheric conditions are described according to one of the following terms:

Clear	Sunny and without the opportunity for cloud shadows.
Partly Cloudy	Primarily sunny, but with scattered clouds that occasionally block the sun from view.
Partly Sunny	Primarily overcast, but with occasional openings through which the sun appears.
Cloudy	Completely overcast, and without any opportunity for viewing the sun.
Foggy	A condition in which the driver's field of vision is significantly reduced because of fog, mist, dust, smoke, or some other atmospheric condition.

Existing precipitation status is defined according to one of the following categories:

None	No precipitation of any kind throughout the data collection period.
Occasional (rain, sleet, snow and/or hail	Principally without precipitation during the data collection period, but with occasional rain, sleet, snow, and/or hail. In this case, the field crew should also record the type(s) of precipitation that occur.
Frequent (rain, sleet, snow and/or hail	A condition in which precipitation generally persists throughout the data collection period, but with brief periods of respite. In this case, the field crew should also record the type(s) of precipitation that occur.
Steady (rain, sleet, snow and/or hail	A condition in which precipitation persists throughout the data collect-ion period without respite. In this case, the field crew should also record the type(s) of precipitation that occur.

To each of these categories it would also be useful for the field crew to provide additional descriptive information (for example, "steady hard rain" versus "steady drizzle rain"). The ambient temperature should be defined as closely as possible, and should be expressed in Fahrenheit dimensions. Where the temperature changes significantly during the course of the data collection period, then a range of temperatures representing the extremes that were encountered should be recorded.

9. *Pavement Condition*: Pavement condition during the data collection period is recorded on Data Collection Form 2. This data base element defines the general condition of the pavement surface as follows:

Dry	The pavement is not wet, nor is it covered by snow or ice.
Wet	The pavement is wet, and no snow or ice is present.
Snow	The pavement is partially or completely covered by snow.
Ice	The pavement is partially or completely covered by ice. This condition most commonly occurs during or after a freezing rain.
Other	The pavement is partially or fully covered by some other substance that significantly affects driver performance characteristics. In this case, the substance should be identified.

10. *General Location*: The general location of the intersection is recorded on Data Collection Form 2. This data base element describes the area type within which the unsignalized intersection is located. AWSC and TWSC intersections should be classified as being either inside the central business district (CBD) or outside the CBD.

11. *Presence or Absence of Flashing/Warning Beacons*: The presence of a flashing beacon (if any) is recorded on the schematic diagram provided on Data Collection Form 1. The presence of a flashing beacon can have an effect on driver behavior on both the major street and minor street approaches. This data base element identifies whether a flashing beacon is present at the intersection.

Physical Characteristics Data

Data within this category can be obtained at any time through on-site survey and field work. The attached Data Collection Forms 1 and 2 can be used for this purpose.

All of the data items identified below should be collected at TWSC intersections. However, some of these data items do not need to be collected for AWSC intersections. Those data items that are not necessary for AWSC intersections are marked with an asterisk (*).

The following specific data base elements are included as physical characteristics information:

12. *Major street through lanes:* The field crew should illustrate this information schematically on Data Collection Form 1, thereby defining the number of lanes (and their width) available to the movement of through vehicles on each major street approach. This includes through lanes as well as lanes shared with one or two turning movements. In the case of AWSC intersections, the major street can be arbitrarily defined, although a good rule of thumb would be to define the major street as the roadway serving the higher volume of traffic.

13. *Major street left turn lanes:* The field crew should illustrate this information schematically on Data Collection Form 1, thereby defining the number, length, and width of lanes devoted exclusively to left turn movements on each major street approach. If no exclusive left turn lanes are provided on one or both major street approaches, then this fact should be so noted.

14. *Major street right turn deceleration lanes:* The field crew should identify the width and length of all major street right turn deceleration lanes schematically on Data Collection Form 1.

15. *Major street right turn acceleration lanes:* The field crew should identify the width and length of all major street right turn acceleration lanes schematically on Data Collection Form 1.

16. *Minor street lane configuration:* The field crew should illustrate this information schematically on Data Collection Form 1, identifying both the number of lanes available on each minor street approach and also the through/turning movements allowed from each lane. As for Data Item 12, the minor street on an AWSC intersection can be arbitrarily defined, although a good rule of thumb would be to define the minor street as the roadway serving the lower volume of traffic.

17. *Major street shoulder width and condition:* The field crew should illustrate this information schematically on Data Collection Form 1, identifying both the width and the condition of any major street shoulders that might be present. The field crew should also indicate whether curbs are present and, if so, the curb type (mountable or barrier).

18. *Minor street shoulder width and condition:* The field crew should illustrate this information schematically on Data Collection Form 1. The field crew should also indicate whether curbs are present and, if so, the curb type (mountable or barrier).

19*. *Distance to nearest upstream controlled intersection*: This information is recorded on Data Collection Form 2, and is necessary only for TWSC intersections. This data item identifies the proximity of upstream traffic control (either a signalized intersection or a stop-controlled intersection with stop control on the street defined as the major street). This information should be recorded only for the major street approaches on a TWSC intersection. If, for example, the major street is a north-south facility, then the distance to the nearest upstream controlled intersection should be recorded only for the northbound and southbound approaches.

The distance measurement can be recorded in either feet or miles. If the measured distance is greater than 2.0 miles, then a more definitive measurement is not necessary; in this case, the field crew may record the distance as "greater than 2.0 miles".

20*. *Upstream interconnection/coordination:* This data item is necessary only for TWSC intersections. If the TWSC intersection being investigated is within an interconnected and currently coordinated signal system, then this fact should be so noted on Data Collection Form 2. This information should be recorded only for the major street approaches.

21*. *Type of control at nearest upstream intersection:* This data item is necessary only for TWSC intersections. The type of control at the nearest upstream controlled intersection is recorded in the space provided on Data Collection Form 2. This information should be identified for each major street approach according to the following categories:

P	Pretimed signal
SA	Semi-actuated signal
FA	Fully actuated signal
AWSC	All-way stop control

If the measured distance to the upstream controlled intersection is greater than 2.0 miles, than this data item need not be specified.

22*. *Number of phases at upstream signalized intersection:* This data item is necessary only for TWSC intersections. In the event that one or more of the upstream controlled intersections are signalized and the intersection(s) are within 2.0 miles of the unsignalized TWSC intersection, then the number of signal phases at each such intersection should be identified. In the event that the upstream intersection is controlled by an actuated signal, then the total number of possible phases should be identified. This information is recorded on Data Collection Form 2 in the space provided.

23*. *Major street approach speed:* This data item is necessary only for TWSC intersections. Major street approach speeds are recorded on Data Collection Form 2. The posted speed and/or the 85th-percentile speed should be identified for each major street approach. This information is not necessary for the minor street approach. If both the posted speed and the 85th-percentile speed are available, then both should be provided. If the field crew have a choice as to which speed parameter to provide, then it would be preferable to obtain the 85th-percentile speed. If an 85th-percentile speed is provided, then it should reflect the results of at least 100 observations of unimpeded vehicles.

24*. *Major street upstream volume sources:* This data item is necessary only for TWSC intersections. If there are any major upstream volume sources between the TWSC intersection and the nearest upstream controlled intersection, then these sources should be described and the distance to them should be defined. An example of a significant uncontrolled upstream volume source includes a freeway off-ramp or an exit drive from a large parking facility. If the measured distance to the volume source is greater than 2.0 miles, then this data item need not be specified. This information is recorded on Data Collection Form 2 in the space provided.

25. *Medians:* The presence of medians should be described schematically for each approach by the field crew on Data Collection Form 1. Two items of information are necessary for each identified median:

a) The width of the median, measured to the nearest foot.

b) The type of median (painted, raised, or separated roadways).

26. *Right-turn curb radius:* The curb (or pavement) radius on each approach should be defined on Data Collection Form 1. This radius should be defined to the nearest foot.

27. *Approach Angle:* The angle of approach (in degrees) should be defined on Data Collection Form 1. It is implicitly assumed within Data Collection Form 1 that there is no change in the direction of the major street as it passes through the unsignalized intersection. This represents a limitation on the type of AWSC and TWSC intersections considered acceptable for investigation.

28. *Functional classification:* The functional classification of each approach road should be recorded on Data Collection Form 2 in accordance with AASHTO's suggested functional highway system classification for urbanized areas. With respect to the major street, the functional classification of the cross streets at each of the nearest upstream controlled intersections should also be defined. The functional classification of each roadway should be defined as follows:

A = Arterial	C = Collector
L = Local	F = Freeway off-ramp

29. *Approach grade:* The approximate grade of each approach (expressed as a percentage) should be recorded on Data Collection Form 2. For this purpose, a positive percentage indicates an uphill grade in the direction of travel on each approach, and a negative percentage indicates a downhill grade. Thus, a value of +3.0 in the northbound approach column indicates an uphill grade of 3.0 percent for northbound vehicles as they approach the AWSC or TWSC intersection.

30*. *Intersection sight distance:* This data item is necessary only for TWSC intersections. The parameter is recorded on Data Collection Form 2, and is defined only for the minor street approaches and for the major street left turning movements. The parameter includes two values on each minor street approach (one for the sight distance to the left, and the other for the sight distance to the right), and one for each major street left turn movement (i.e., the sight distance ahead).

Intersection sight distance is measured according to AASHTO standards, and should reflect conditions existing at the time that operational data are collected. Thus, the driver's eye is assumed to be 10 feet behind the stop bar (or at the typical stopping point as observed in the field) and at a vertical height of 3.5 feet above the pavement. The object viewed by the driver is assumed to be in the center of the approaching travel lane and at a height of 4.25 feet above the pavement.

31. *Approach parking locations:* Data Collection Form 1 should be used to record the location of on-street parking on all approaches. For the minor street approaches at TWSC intersections and for all approaches at AWSC intersections, the upstream distance from the stop bar to where the first on-street

parking space is provided should be specified. For the major street approaches at TWSC intersections, the upstream distance from the minor street curb line extensions to where the first on-street parking space is provided should be identified.

Intersection/Operations Data

All of the data items identified within this category in Table 1 should be collected at both AWSC and TWSC intersections. However, Data Item 38 (the onset of congestion) is defined differently for AWSC and TWSC intersections:

- For an AWSC intersection, congestion is assumed to occur whenever vehicles are delayed in their departure from one or more approaches for reasons that are solely associated with downstream conditions (i.e., the delays are not caused by the operating characteristics of the intersection itself).
- For a TWSC intersection, congestion is assumed to occur whenever major street vehicles are required to slow or stop. Such slowing or stopping can occur either because of downstream conditions not related to the current operating characteristics of the intersection, or because their right-of-way is preempted by side street vehicles.

All data within this category must be collected simultaneously during the particular time period that is to be investigated. It is not practical to collect all of the identified data items simultaneously through manual techniques. Instead, two alternate procedures are provided:

1) *Comprehensive data collection procedure:* All formal research projects focusing upon AWSC and TWSC intersections should attempt to develop a complete data set consisting of all the intersection/operations data identified in Table 1 (data items 32 through 38). For this purpose, a synchronized video camera system may be used to collect the following information:

- The arrival time, direction, lane occupancy, and type of every approaching vehicle.
- The departure time, direction, lane occupancy, and type of every departing vehicle.
- The presence or absence of congestion as defined above for either an AWSC or a TWSC intersection, by direction.
- The begin and end time for all pedestrian and bicyclist crossing movements recorded by approach and direction.

These data require that a full view be provided of each intersection approach. Therefore, a three- or four-camera system must typically be employed, using synchronized video cameras. Also, a digital time clock accurate to the nearest second must be displayed in each video image. Examples of field data collection setups employing three- and four-camera systems are shown in Figure 1.

2) *Partial data collection procedure*: For all other purposes except formal research projects, a simpler data collection procedure can be used to collect all intersection/operations data in Table 1 except Data Item 38. A one- or two-camera system can be used as shown in Figure 2. For the purposes of this partial data collection procedure, it will be sufficient to record a view of the intersection that clearly shows at all times the back of queue for all minor movements (including left turns from the major street).

All data collection forms and video tapes obtained through application of these procedures should be delivered to the Unsignalized Intersections Subcommittee at the following address:

Transportation Research Board
Attention: Engineer of Traffic Operations
Committee A3A10
2101 Constitution Avenue N.W.
Washington, D.C. 20418

It is estimated that a video recording of a four-legged TWSC intersection might require the following equipment and manpower:

1) *Comprehensive data collection procedure*: Four persons will be required to videotape the traffic events on each intersection approach using this procedure. Each of these persons should be equipped with a portable VHS camera system, and the time clocks on each video system should be synchronized. Alternatively, the video cameras may be set up in advance of the data collection activities, providing they are equipped to begin recording simultaneously at a pre-set time.

2) *Partial data collection procedure*: One to two persons will be required to videotape the traffic events on each intersection approach using the partial data collection procedure. Each person should be equipped with a portable VHS camera system and positioned as shown in Figure 2. Alternatively, the video cameras may be set up in advance of the data collection activities, providing they are equipped to begin recording simultaneously at a pre-set time.

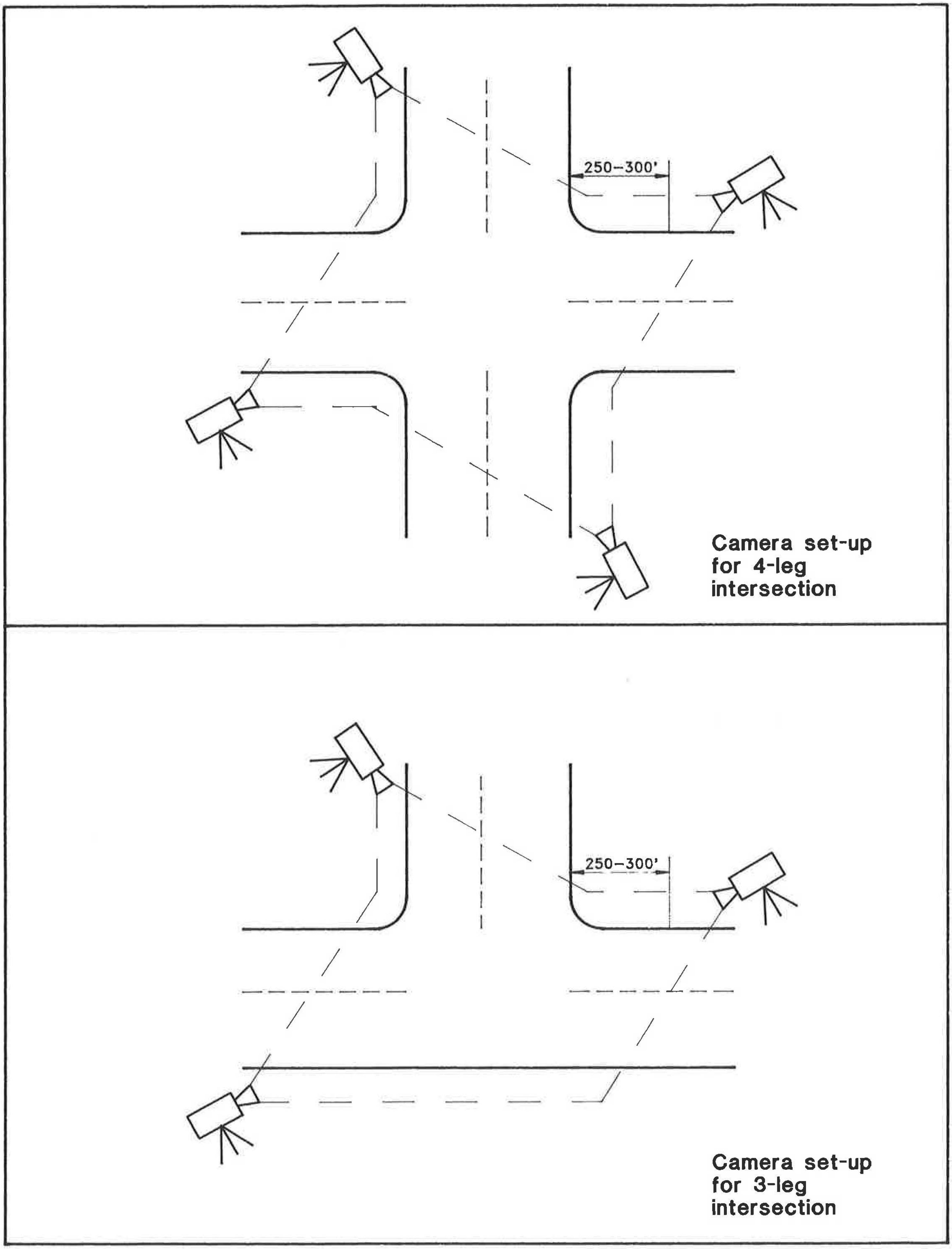


Figure 1. Video Camera Placement:
Comprehensive Data Collection Procedure

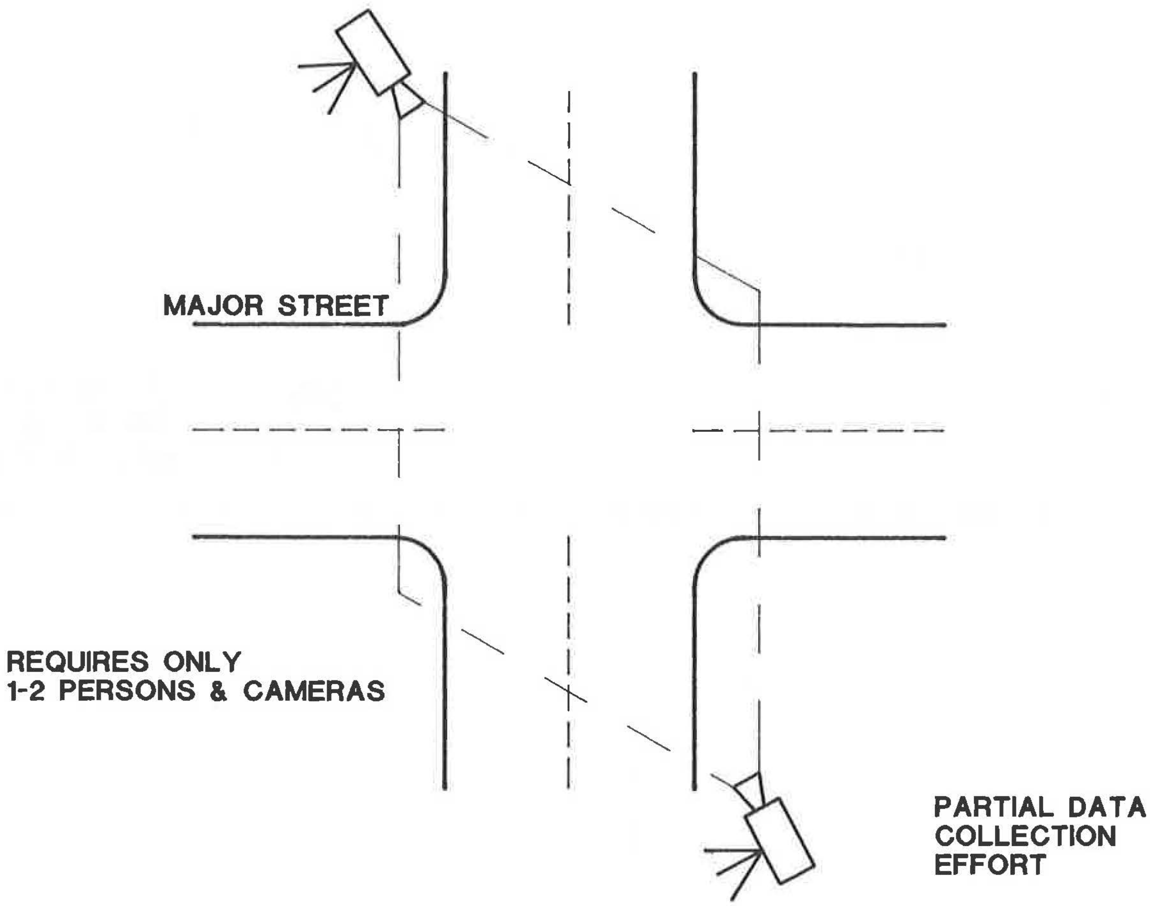
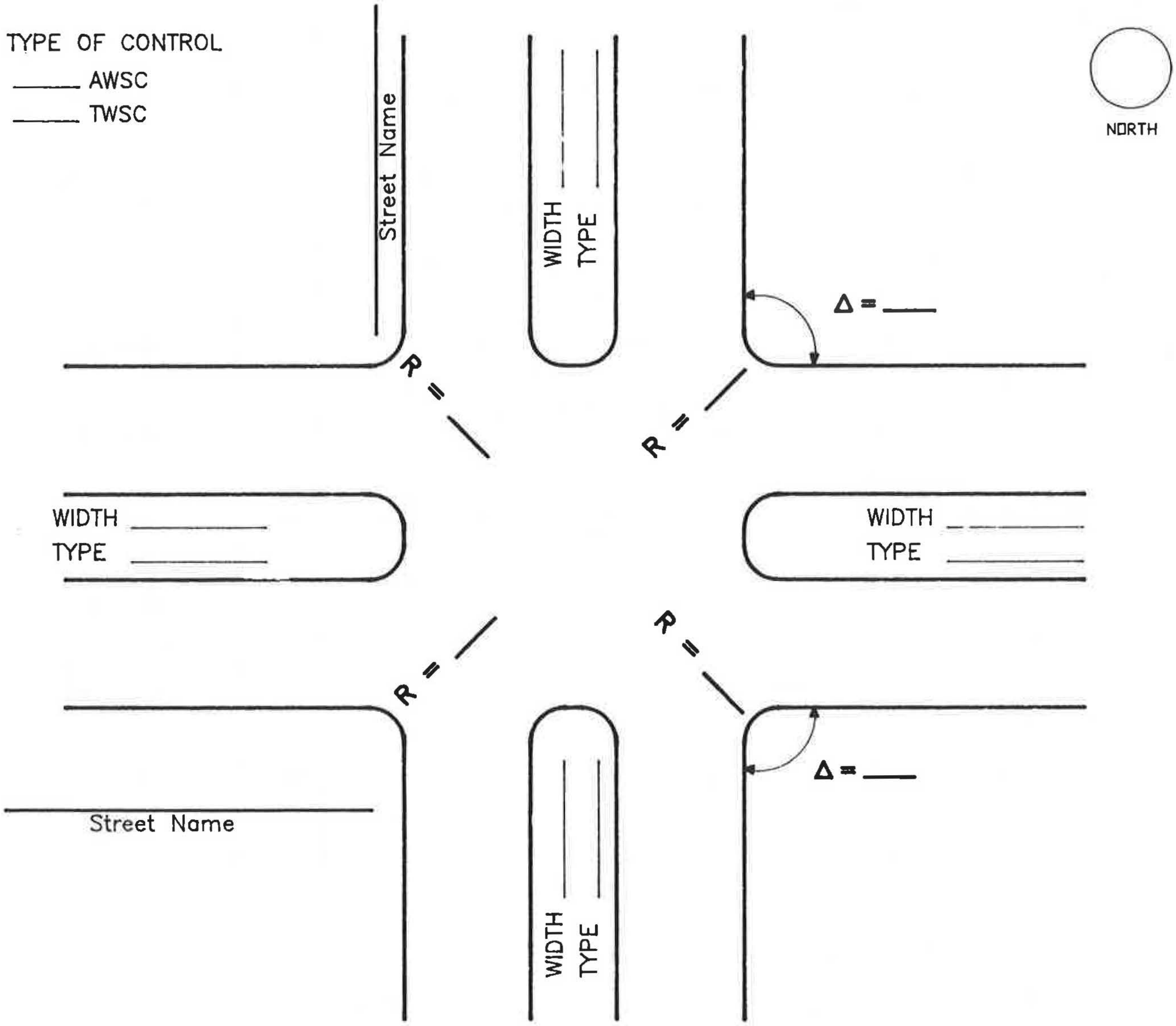


Figure 2. Video Camera Placement:
Partial Data Collection Procedure

APPENDIX

Unsignalized Intersections Data Collection Forms



Please provide the following information on the sketch above:

- O Number of lanes and lane designation on each approach
- O Width of each lane
- O Median type and width
- O Right turn curb radii
- O Length of any right turn acceleration or deceleration lanes
- O Intersection approach angles
- O Location of parking on all approaches
- O Name of major street and minor street
- O North orientation
- O Location and type of control (stop vs. yield, and presence/absence of a flashing/warning beacon
- O Horizontal alignment of major street: _______ degrees curvature

UNSIGNALIZED INTERSECTIONS
DATA COLLECTION FORM 1

		APPROACH			
		EB	WB	NB	SB
INDICATE MAJOR OR MINOR STREET (MAJ OR MIN)					
MAJOR STREET APPROACHES ONLY: DISTANCE TO NEAREST UPSTREAM CONTROLLED INTERSECTION (Feet or miles)					
MAJOR STREET APPROACHES ONLY: TYPE OF CONTROL AT NEAREST UPSTREAM INTERSECTION P = Pretimed Signal FA = Fully Actuated Signal SA = Semi-Actuated Signal AWSC = All-Way Stop Control					
MAJOR STREET APPROACHES ONLY: IS THERE AN OPERATING UPSTREAM INTERCONNECTION?					
MAJOR STREET APPROACHES ONLY: NUMBER OF PHASES AT UPSTREAM SIGNALIZED INTERSECTION					
MAJOR STREET APPROACHES ONLY: MAJOR UPSTREAM VOLUME SOURCES	DESCRIPTION OF THE SOURCE				
	DISTANCE TO SOURCE (FT OR MI)				
MAJOR STREET APPROACHES ONLY: APPROACH SPEED	POSTED SPEED				
	85th-PERCENTILE SPEED				
FUNCTIONAL CLASSIFICATION A = Arterial C = Collector L = Local F = Freeway	ALL APPROACH ROADS				
	UPSTREAM CROSS STREETS (Major street approaches only)				
INTERSECTION SIGHT DISTANCE	TO THE LEFT OR AHEAD				
	TO THE RIGHT				
APPROACH GRADE					
APPROACH SHOULDERS	WIDTH				
	CONDITION (Good, Fair, Poor)				

CITY/COUNTY/STATE ____________________

INTERSECTION LOCATION: CBD ______ Other ____________________

YEAR ________ MONTH ________ DAY ______ DAY OF WEEK ____________

DATA COLLECTION BEGIN TIME __________ END TIME ____________

ATMOSPHERIC CONDITIONS ______________ PRECIPITATION ____________

TEMPERATURE ____________ PAVEMENT CONDITION ____________

INFORMATION ON DATA COLLECTION PERSONNEL

Name ____________________

Agency ____________________

Address ____________________

City/State/Zip Code ____________________

Telephone ____________________

UNSIGNALIZED INTERSECTIONS
DATA COLLECTION FORM 2

A3A10F02