



WYDOT

TRAFFIC STUDIES MANUAL

March 2011





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CHAPTER 1 – INTRODUCTION

PURPOSE

This manual will be used to establish minimum standards for conducting traffic engineering studies on roads under the jurisdiction of the Wyoming Department of Transportation (WYDOT). In addition, local governmental agencies are recommended and encouraged to use the Traffic Studies Manual as a guideline in conducting traffic engineering studies within their area of responsibility.

AUTHORITY

Federal Code of Regulations, 23 CFR 655.603; Wyoming Statute 31-5-112; Manual on Uniform Traffic Control Devices for Streets and Highways, 2009 Edition (*MUTCD*); Wyoming Department of Transportation Operating Policy, Policy Number 25-1.

SCOPE

This manual affects the WYDOT Traffic Program, WYDOT District Traffic Offices, WYDOT Planning Program, and anyone else who performs traffic studies on the state highway system in Wyoming.

BACKGROUND

Section 1A.09 of the *MUTCD* recommends that early in the processes of location and design of roads and streets, engineers should coordinate such location and design with the design and placement of the traffic control devices to be used with such roads and streets. The decision to use a particular device at a particular location should typically be made on the basis on an engineering study or the application of engineering judgment. The *MUTCD* requires that an engineering study shall be performed by an engineer, or by an individual working under the supervision of an engineer, through the application of procedures and criteria established by the engineer. An engineering study shall be documented.

This manual will provide a more efficient, standardized process for compiling and analyzing data collected during traffic engineering study activities. This manual will serve as a basic tool for district traffic operations studies and as a guideline for local agencies in Wyoming.

This manual will constitute the minimum standards for use in conducting traffic engineering studies on state highways in Wyoming. The manual's chapters and data collection sheets are not shown in any particular order. Accordingly, sections applicable to a specific situation or concern should be considered on an individual basis.

District Traffic Engineers should ensure that studies performed by their staff or by consultants conform, as a minimum, to the practices and techniques prescribed by this manual and shall incorporate the manual by reference in consultant contract documents.

This manual was originally based on the organization and format of the Florida Department of Transportation's Manual on Uniform Traffic Studies (FDOT Manual Number 750-020-007), January 2000 (as revised March 2003). Copies of the original Florida manual can be purchased from Florida Department of Transportation, Maps and Publications, 605 Suwannee Street, Mail Station 12, Tallahassee, Florida 32399-0450, Phone (850) 414-4050, Fax (850) 487-4099. This Wyoming adaptation of that manual has significantly modified the original manual.

1. DISTRIBUTION

The official recipients of this manual will be the District Traffic Engineers, District Traffic Technicians, Traffic Program managers and staff.

1.1 ADDITIONAL COPIES

Consultants and other public users may request copies of the manual from Wyoming Department of Transportation Traffic Program, 5300 Bishop Blvd., Cheyenne, WY 82009. Phone (307) 777-4491; Fax (307) 777-3993.

2. REVISIONS AND ADDITIONS

- (1) The State Traffic Engineer, both Assistant State Traffic Engineers, District Traffic Engineers and the Traffic Studies Engineer will constitute the Manual Review Committee.
- (2) The Traffic Studies Engineer will periodically review, amend, or revise the manual to ensure its compatibility with current technology and state-of-the-art methods and practices.
- (3) Comments or suggestions for improving the manual may be submitted in writing to the Traffic Studies Engineer, 5300 Bishop Blvd., Bldg. 6101, Cheyenne, WY 82009, along with appropriate supporting information or data. Any time a revision is initiated by the Traffic Studies Engineer, comments will be solicited from the District Traffic Engineers and any other affected offices. Their concerns, when appropriate, will be incorporated into the revision.
- (4) Substantive revisions, as determined by the Manual Review Committee, will be approved by the State Traffic Engineer following the process established in the Standard Operating Policy.

3. FORMS ACCESS

We have standardized all of the forms in this manual and they are available in the Forms Library. Reproducible copies of all of the forms are in the Appendix.

- Form TR-01 – Traffic Signal Warrants Worksheet (Excel Spreadsheet)
- Form TR-01a – School Crossing Warrant Sheet (Excel Spreadsheet)
- Form TR-01b – Intersection Near a Grade Crossing Warrant Sheet (Excel Spreadsheet)
- Form TR-03 – Signal Removal Analysis Worksheet
- Form TR-04 – Worksheet for Estimating Daily Impacts of Signal Removal and Replacement by Two-Way Stop
- Form TR-10 – Speed Study Data Collection Sheet
- Form TR-11 – Speed Study Worksheet (Excel Spreadsheet)
- Form TR-12 – Pedestrian Gap Study
- Form TR-16 – Curve Advisory Speed Study
- Form TR-17 – Rural Intersection Lighting Criteria
- Form TR-18 – Operational Review Signalized Intersection Checklist
- Form TR-19 – Left Turn Phase Operational Review
- Form TR-22 – PC-Travel Field Worksheet
- Form TR-25 – Traffic Impact Study Review Checklist

CHAPTER 2 – TRAFFIC SIGNAL STUDY PROCEDURE

2.1 *PURPOSE*

- (1) The purpose of this chapter is to present to the traffic engineer a guide for conducting comprehensive traffic signal studies. The information, techniques, and instructions presented herein were formulated from the *MUTCD* and experiences of practicing traffic engineers.
- (2) This manual is not all-inclusive in addressing traffic signal study situations; rather, it is a general guide for the traffic engineer to follow while investigating conditions and circumstances regarding the installation of a new traffic signal or improvement of the operation of an existing traffic signal. This manual will begin with an alleged problem concerning traffic control at a particular location. The observation of the symptoms, establishment of areas of concern, collection and analysis of data, and preparation of a traffic signal study report will be outlined in subsequent chapters.
- (3) This chapter provides a logical and systematic data collection procedure for investigating traffic signal requirements which allows the traffic engineer to use judgment to analyze local conditions and interpret data as effectively and efficiently as possible with the resources available. By following this chapter it is intended to minimize the collection of unnecessary or inappropriate data and/or to reduce the number of trips to the field to collect additional data.

2.2 *LEARNING OF THE CONCERN*

- (1) The problem facing traffic engineers at this point has yet to be defined. This is the stage during which the traffic engineer receives notice from the public, a civic organization, business, etc., regarding their desire or need for a traffic signal to be installed or modified at a given site. Often, the traffic engineer or one of his/her staff has observed the situation, or another governmental agency has brought it to their attention.
- (2) Regardless of the source, the traffic engineer is obligated to respond. However, to respond in a professional manner requires some systematic investigation of the situation. Before a full scale investigation is launched requiring a large amount of manpower and equipment, the traffic engineer should conduct an observation of the site. If a great deal of delay is encountered, the engineer should contact the reporting party about the action to be initiated.

2.3 *OBSERVATION OF CONCERN SYMPTOMS*

- (1) During the initial observation or field investigation of the site, a number of items should be noted. The preparation of a condition diagram (Chapter 5) should be made at this time if none exists for the site. The condition diagram shows the location of traffic control devices, intersection geometry, and other physical features. If the engineer has an existing condition diagram, it should be updated if necessary. Note that it is not necessary for this diagram to be drawn to scale.
- (2) In addition to preparing a condition diagram, the engineer should observe the operational characteristics of the location and note any unusual or significant circumstances. Ideally, this observation should be made during the hours of the day when the operational concerns were reported to have occurred. Photographs of each approach often save subsequent trips back to the study location.
- (3) With an understanding of the operation and a representation of conditions at the location, the engineer is in a position to determine if a real problem exists or no further investigation is warranted. If it is decided after the field investigation that no problem exists, the engineer should respond either in writing or verbally to that person responsible for the initial contact regarding the site. However, should it be determined that further investigation is warranted, the engineer should continue the investigation. At this point, the engineer should notify the concerned

party(ies) of his/her intention to investigate the site for possible signalization and inform them of an approximate completion date.

2.4 ESTABLISHING BASIC AREAS OF CONCERN

- (1) Establishing the basic area(s) of concern draws a great deal from the traffic engineer's experience and judgment. Some cases can be easily diagnosed, such as excessive vehicle delays. Other cases are more subtle in nature. Of course, the issue under consideration may be the result of more than one basic area of concern.
- (2) Decisions made by the traffic engineer at this point will provide the basis for data collection efforts to be made during the investigation. The areas of concern can be grouped into three basic categories: vehicle, pedestrian, and crashes and are addressed in this section. Warrants for signal installation, taken from the *MUTCD*, will be correlated with the studies indicated. This manual will be of assistance in conducting many of the studies indicated as we have noted the appropriate chapter or section.

2.4.1 VEHICLE

- (1) A vehicle problem can normally be diagnosed during the field observation without great difficulty. Some of these characteristics are: excessive queue lengths, slow queue dissipation rates, and/or large traffic volumes using the intersection, etc.
- (2) Typically, the data collected to determine the extent of a vehicle problem includes one or more of the following:
 - (a) Hourly approach volumes – from the turning movement count (Chapter 4) – for the highest 8 hours of an average day, as required for *MUTCD* Warrants 1 – 5 and 7 – 9 (*MUTCD* Sections 4C.02 – 4C.06 and 4C.08 – 4C.10)
 - (b) Stop sign delay study (Chapter 8)
 - (c) Verification – from the condition diagram (Chapter 5) – that the distance to the nearest signal in each direction is greater than 1000 feet as required for *MUTCD* Warrant 6 (*MUTCD* Section 4C.07), and the location meets the recommended signal spacing in WYDOT's access policy (see Chapter II of the WYDOT Access Manual).
 - (d) Determination – from the condition diagram (Chapter 5) – of the clear storage distance as required for *MUTCD* Warrant 9 (*MUTCD* Section 4C.10)
 - (e) Travel time and delay study (Chapter 14)

2.4.2 PEDESTRIAN

- (1) A pedestrian problem can also be diagnosed through field observation. However, the severity of this problem is difficult to ascertain without field data collection.
- (2) The types of data which may be needed for this investigation are summarized below:
 - (a) Turning movement count (Chapter 4), that includes hourly approach volumes for the highest 8 hours of an average day as required for *MUTCD* Warrants 1, 2, 3 and 8, and pedestrian volumes, as required for *MUTCD* Warrants 4 and 5
 - (b) Pedestrian gap study (Chapter 9) as required for *MUTCD* Warrants 4 and 5
 - (c) Verification – from the condition diagram (Chapter 5) – that the distance to nearest crosswalk, or signalized intersection is greater than 300 feet as required for *MUTCD* Warrants 4 and 5
 - (d) Characteristics of pedestrians such as age, disability, average walking speed, etc.

2.4.3 CRASHES

- (1) The determination of an intersection's crash potential during a short field observation is difficult. Some obvious features of a high crash location may be damaged sign supports or excessive tire skid marks; however, the number of crashes is not normally shown by the previous features. The quickest and cheapest method of determining if crashes are a problem (e.g., significantly higher than average for similar intersections), is to review past crash records for a minimum of three but preferably five years. Crashes many times can also be related to the previously described problems of vehicle and pedestrian delay, yet poor geometric design may be the overriding factor.
- (2) The following information can be used to further define a crash problem:
 - (a) Hourly approach volumes and pedestrian volumes – from the turning movement count (Chapter 4) – for the highest 8 hours of an average day, as required for *MUTCD* Warrants 1 – 5 and 7 – 9
 - (b) Crash records/rates as required for *MUTCD* Warrant 7
 - (c) Collision diagram (Chapter 7)
 - (d) Speed study (Chapter 13) may be required for *MUTCD* Warrants 1-4 and 7
 - (e) Intersection sight distances (Chapter 6)
 - (f) Geometrics: vertical and horizontal
 - (g) Pavement condition for skid resistance
 - (h) Roadside hazards
 - (i) Existing positive guidance through signing and marking
 - (j) Existing highway lighting
 - (k) Traffic conflict investigation and analysis
- (3) This list of data to be collected for each of the three basic areas of concern is neither all inclusive nor suggested as a minimum effort. Keep in mind that data is required for justification (warrant analysis) and other data is required for design and operation. Data for justification; however, is not mutually exclusive of the data required for design and operation.
- (4) The engineer should not attempt to collect any of the data elements listed unless he is certain it will ultimately be required for the study. In fact, certain elements should not be collected until others have been reviewed. For example, hourly approach volumes (preferably fifteen minute volumes) should be counted for analysis of traffic signal warrants, which is generally necessary for each of the three areas of concern. Once the warrant analysis has been completed and the problem(s) has been identified (and before any turning volumes are counted), the machine counts should also be examined carefully to determine the control periods of interest. These periods of interest are the peak and off-peak periods for which the various signal operation plans will be designed.

2.5 DATA COLLECTION, REDUCTION AND SUMMARIZATION

Conducting the previously mentioned studies generates a large volume of data. The study sheets and techniques available in this manual are designed to allow for use as field collection sheets, reduction sheets, and summary sheets, thus reducing the amount of paperwork and time required to finalize field work (A convenient manner in which to summarize and thus facilitate interpretation of the data required for the *MUTCD* signal warrants is to complete the Traffic Signal Warrants worksheet, Form TR-01, in Chapter 3). For more information regarding data collection, reduction, and summarization see the individual chapters contained herein.

2.6 DATA ANALYSIS AND INTERPRETATION

- (1) Once the appropriate data for the warrant analysis has been collected, it is the traffic engineer's responsibility to analyze and interpret it.
- (2) Application of the Traffic Signal Warrants worksheet can be made in a straightforward manner and provides the traffic engineer with information concerning the minimum conditions for justifying signal installation. Instructions for use of the Traffic Signal Warrants worksheet (Form TR-01) are included in Chapter 3.
- (3) Further explanation of the individual warrants can be found in Part 4 of the *MUTCD*.
- (4) Engineering judgment plays an important role in the decision to signalize an intersection. The traffic engineers need a thorough knowledge and understanding of any local conditions which may or may not support the need for signalization. Situations may arise when a traffic signal is best not installed even though one of the eight warrants may be met. Such a condition may exist when minimum traffic volumes are present at a location, but signalization would severely interrupt mainline movement to serve a relatively small side street movement. Some additional considerations should be made by the engineer when minimum warrants have been met to insure that installation of a signal does not create a greater problem. These considerations include, but are not limited to the following:
 - (a) Development of excessive queues on the major street
 - (b) Queue dissipation rates
 - (c) Spacing between adjacent signalized intersections
 - (d) Highway and intersection geometry (turn lanes)
 - (e) Distance to pedestrian crossings and distance pedestrians have to cross
- (5) Conversely, local conditions may, on rare occasions, dictate installation of a signal when the minimum volume warrants are not met for the required eight hours. An example of this situation is the entrance to a plant or office complex which generates sufficient traffic such as work trips, to meet volume warrant criteria for several hours of the day (but less than the full eight hours) for at least each weekday. These locations should be designed with an operation plan which may include flashing operation during hours when full signal control is not justified. See Warrants 2 and 3 (Sections 3.9 and 3.10) in Chapter 3.
- (6) It is very important to note that even when a traffic signal is justified (e.g., it satisfies one or more warrants), it may not contribute to the safety and efficiency of the roadway. Closely spaced intersections in high volume corridors could all meet volume warrants, but signals are not desirable at every cross street. Signals can be poorly designed, ineffectively placed, improperly operated, and poorly maintained. Any of these conditions can negate the benefits intended by the traffic signal installation. The traffic engineer should also be increasingly aware of energy conservation and include these thoughts when signalization is considered.

2.7 PREPARATION AND APPROVAL OF STUDY REPORT

- (1) Proper documentation of all activities that have taken place from the initial allegation of a problem through the warrant analysis is extremely important. A traffic signal study report which includes the following elements (as needed) should be prepared:
 - (a) Cover/Title page that is signed and sealed
 - (b) Description and map of intersection being considered
 - (c) Existing conditions and a diagram (sketch) – see Chapter 5
 - (d) Crash analysis and Collision Diagram – see Chapter 7

- (e) Warrant analysis – see Chapter 3
 - Statement of use of 70 or 100 percent requirements
 - Discussion of number of approach lanes used in the analysis
 - Discussion of how right turns are considered in the analysis
 - Analysis discussion of Warrants 1-9 (only those applicable)
 - Discussion of delay study
 - Discussion of capacity analysis with Synchro or HCS+
- (f) Recommendations (including sketch if applicable)
- (g) Supplemental information or data to be submitted (as appropriate)
 - Completed Traffic Signal Warrants worksheets (Form TR-01)
 - Turning movement counts for the existing intersection (8 hour - A.M., Noon and P.M. peaks)
 - Projected turning movement counts for the proposed intersection (A.M., Noon and P.M. peaks) (if applicable)
 - 24-hour machine counts
 - Pedestrian counts (8 hours)
 - Color photos of each approach
 - Projected traffic data for new intersection (if applicable)
 - Pertinent supplemental information if needed
 - Computer program outputs
- (2) Guidelines for the content and format of this report are necessary to insure uniform report preparation procedures and to expedite report review time.
- (3) The traffic signal study report should conclude one of the following: (1) no problem exists and therefore no traffic signal is warranted; (2) a problem exists, but the solution is not a traffic signal; (3) a problem exists and a traffic signal will correct or reduce the problem; or (4) a problem exists and a traffic signal in conjunction with other improvements will correct or reduce the problem.
- (4) In the first case, the traffic signal study should be terminated and the party initiating the request should be notified. It may also be beneficial to disseminate further information explaining the basis of the decision. In the second case, the traffic signal study should also be terminated, another study (non-signal related) should be initiated to resolve the problem, and proper notification should be given. In the third or fourth case, the study should be initiated to resolve the problem, and proper notification should be given, also the study should be handed over to the engineer(s) responsible for design. It is again advisable at this point to notify the party initiating the request so that they are kept informed of the progress of the study.

2.8 DEVELOPMENT OF NEW TRAFFIC SIGNAL DESIGN

- (1) The design stage includes all activities that take place after justification of a new traffic signal installation has been made or the modification of the operation of the existing signal is required. These activities, which lead up to the traffic signal design reconnaissance report, include the following:
 - (a) Collect additional data (if needed)
 - (b) Develop alternatives
 - (c) Evaluate alternatives
 - (d) Select “Best” alternative
 - (e) Design improvement

- (2) For the installation of a new traffic signal the additional data collection will generally be limited to the turning volume counts for 15-minute time periods required for developing the signal operating plan and controller timings. Data collected for the signal warrants are of course available if needed. For modification of an existing signal the data available is often dated, so it may also be necessary to collect some of the data elements outlined previously in addition to the turning volumes. In any event it is advisable to develop alternative concepts prior to the collection of additional data.
- (3) The alternative development, evaluation, and selection steps are significant steps in themselves and are, therefore, only addressed in general terms in this manual. However, the basic approach is presented in order to provide the user with guidelines necessary to properly conduct the traffic signal study.
- (4) All reasonable alternative concepts should be considered by the engineer. These concepts should then be screened based on any known constraints such as funding, future programmed construction, etc. All of the alternatives determined to be feasible by the engineer should then be evaluated using the optimization and simulation computer programs.
- (5) The first step is an isolated intersection analysis. Synchro is a valuable program with a Highway Capacity Manual interface that can be used for design, analysis, and evaluation of isolated intersections. By specifying appropriate commands and parameters, this program can select optimal phase patterns and timings (cycle lengths and splits). Each alternative can be analyzed by the measures of effectiveness included in the output reports. Several alternatives can also be evaluated by comparative analysis to determine the best alternative. The Engineer of Record should be responsible for any model result.
 - (a) When modeling intersections using Synchro or HCS+, it is imperative that the factors used in the analysis reflect actual Wyoming driving conditions. For example, the default saturation flow rate should be set to 1600 vehicles per lane per hour of green. Field observation of the traffic characteristics may be used to justify increasing the saturation flow rate to 1700 where conditions indicate that driver behavior at the intersection is more aggressive than the typical Wyoming intersection.
 - (b) With the majority of intersections in Wyoming being located in relatively sparsely populated areas, the traffic volumes can tend to fluctuate excessively throughout the day and throughout the peak periods of the day. Therefore, when modeling intersections using Synchro or HCS+, the actual peak hour factor for each movement should be used for the analysis, rather than relying on the software's default peak hour factors.
- (6) If the intersection is included in a linear arterial highway under study for progression, is part of a grid network, or is part of an interchange with coordinated signals at each ramp terminal, a Synchro analysis should be conducted. Synchro optimizes signal progression and is capable of design and analysis of multiphase, actuated, as well as two phase, fixed time signal control.
- (7) It is advisable to examine all legitimate phasing patterns and determine the optimal cycle length for an intersection regardless of whether it is isolated or part of a network. This may result in significant time savings, because model output can be used to determine input values and ranges necessary to run Synchro more effectively and more efficiently.
- (8) An economic analysis (cost effectiveness) should be conducted in conjunction with the computer analyses and before proceeding to the implementation stage. Unfortunately, constraints beyond the engineer's control may sometimes not permit implementation of the best alternative.
- (9) Although input from the local agency is usually received through the traffic signal request, in all cases the conceptual design should reflect any special needs or conditions the local agency requires.

2.9 TRAFFIC SIGNAL RECONNAISSANCE REPORT

- (1)** Upon completion of the conceptual traffic signal design process, a design reconnaissance report should be prepared. This report should include the following elements as a minimum:
 - (a)** All elements of the traffic signal study report (show report in the Appendix)
 - (b)** Additional data collected, if any
 - (c)** Description of alternatives
 - (d)** Description of analyses (including appropriate output from Synchro, SIDRA, VisSim or HCS+)
 - (e)** Recommendations of engineer
 - (f)** Work to be performed
 - (g)** Approval of recommended concept
- (2)** This report should be distributed to the State Traffic Engineer, both Assistant State Traffic Engineers, Traffic Studies Engineer, District Traffic Engineer and Electrical Operations Engineer. If the project involves geometric changes, such as ADA modifications, corner radii improvements or the addition of turn lanes, the Highway Development Engineer should be included in the distribution because Project Development will need to be involved with the geometric project design and administration.

2.10 IMPLEMENTATION

- (1)** Actual implementation of the improvement should take place as soon as possible after the traffic signal study report and design reconnaissance report stages. Conditions change with time, and if too much time lapses before implementation it may be necessary to repeat the entire traffic signal study procedure. For this reason it is wise to plan traffic signal studies in close conjunction with the State Transportation Improvement Program (STIP). If this is not done the result may be an improvement that does not match the conditions at the site.
- (2)** Following implementation, the engineer should always visit the site to determine if the traffic signal is operating as designed. As a minimum, he should observe the operation during each critical time period, keeping in mind the original concern and/or any other concerns identified in the Traffic Signal Study Report. It is always a good idea to drive through the intersection from all approaches and to make any critical turning maneuvers. The Operational Review Signalized Intersection Checklist (Form TR-18) provides a convenient form on which to check each of the signal components and note any concerns or deficiencies (see Chapter 10).
- (3)** In some cases, data collection may be necessary to determine if and how well the improvement is operating. This is particularly true for the after condition of a before and after study, where crash data (Chapter 7), travel time and delay data (Chapter 14), etc., are required.
- (4)** It is also advisable to follow through on the implementation of a traffic signal with an educational program, preferably before any ground is broken, to increase public awareness of the change. This should result in improved safety and efficiency during the transition, and it draws attention to the traffic engineering activities, particularly safety and energy efficiency, that benefit the area.

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CHAPTER 3 – TRAFFIC SIGNAL WARRANT ANALYSIS

3.1 **PURPOSE**

- (1) Section 4C.01 of the *MUTCD* requires that an engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location.
- (2) This chapter provides a procedure to determine input into the decision of whether or not conditions warrant the installation or the continued operation of a traffic signal.

3.2 **TRAFFIC SIGNAL WARRANT ANALYSIS**

- (1) The *MUTCD* requires that the investigation of the need for a traffic control signal shall include an analysis of factors related to the existing operation and safety at the study location and the potential to improve these conditions, and the applicable factors contained in the following traffic signal warrants:
 - Warrant 1, Eight-Hour Vehicular Volume
 - Warrant 2, Four-Hour Vehicular Volume
 - Warrant 3, Peak Hour
 - Warrant 4, Pedestrian Volume
 - Warrant 5, School Crossing
 - Warrant 6, Coordinated Signal System
 - Warrant 7, Crash Experience
 - Warrant 8, Roadway Network
 - Warrant 9, Intersection Near a Grade Crossing
- (2) Traffic signals should not be installed unless one or more of these nine warrants are satisfied. Because these are minimum requirements, satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a traffic control signal. Delay, congestion, crash experience, confusion, or other evidence of the need for right-of-way assignment must be shown. Geometric changes which may eliminate the need for a signal should be considered.
- (3) A warrant is a set of criteria which can be used to define the relative need for, and appropriateness of, a particular traffic control device (i.e., STOP or YIELD sign, traffic signal, etc.). Warrants are usually expressed in the form of numerical requirements such as the volume of vehicular or pedestrian traffic. A warrant normally carries with it a means of assigning priorities among several alternative choices. There are two fundamental concepts involved in this determination:
 - (a) The most effective traffic control device is that which is the least restrictive while still accomplishing the intended purpose. For instance, geometric changes alone may negate the need for a traffic signal.
 - (b) Driver response to the influences of a traffic control device has been previously identified by observation, field experience, and laboratory tests under a variety of traffic and driver conditions.
- (4) Warrants should be viewed as guidelines, not as absolute values. Satisfaction of a warrant is not a guarantee that the device is needed. The warrant analysis process is just one of the tools to be used in determining if a traffic signal is warranted.
- (5) The application of warrants is effective only when combined with comprehensive analysis and evaluation of available pertinent information, and the application of appropriate principles, provisions, and practices as contained in the *MUTCD* and other sources, for the purpose of deciding upon the applicability, design, operation, or installation of a traffic control device as

noted in the definition of Engineering Study in Section 1A.13 of the *MUTCD*. In all cases, at least one or more warrants must be fully met before a traffic signal installation is considered.

- (6) Most of the warrants have criteria associated with the number of approach lanes and reduced criteria for rural and/or higher speed locations. Each traffic signal warrant analysis must determine which criteria apply based on the number of lanes and whether or not the reduced warrant criteria apply. Engineering judgment must be used to determine when to apply the reduced criteria and the appropriate number of lanes to use for the warrant analysis.

3.3 APPLICATION OF REDUCED (70%) WARRANT CRITERIA

- (1) The *MUTCD* allows for the application of reduced (70%) traffic signal warrant criteria at certain rural and/or higher speed locations. The application of the 70% criteria is applicable for intersections that lie within the built-up area of an isolated community having a population of less than 10,000, or where the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 40 mph.
- (2) The application of the 70% criteria based on population only applies to communities in Wyoming that do not currently have a signalized intersection (reduction based on speed may still apply). It also does not apply to intersections lying outside the incorporated limits of a community, but within the urban planning boundaries (typically within 3 miles, or otherwise as determined by the Planning Program).
- (3) The application of the reduced warrant criteria based on speeds will be based on the posted speed limit. If the speed limit is posted less than 40 mph, the reduced criteria do not apply based on speeds (reduction based on population may still apply). If the posted speed limit is 45 mph or greater, the reduced criteria applies. If the speed limit is posted at 40 mph, a spot speed study (see Chapter 13) should be conducted at the intersection to determine whether or not the 85th-percentile speed is greater than 40 mph.

3.4 APPROACH LANES

- (1) Engineering judgment must be exercised in applying various traffic signal warrants to cases where approaches consist of one lane plus one right or one left-turn lane. The site specific traffic characteristics will dictate whether an approach should be considered as a one-lane approach or a two-lane approach.
- (2) For a minor street approach with one lane plus a left-turn lane, engineering judgment would indicate that it should be considered a one-lane approach if the traffic using the left-turn lane is minor. In such a case, the total traffic volume approaching the intersection should be applied against the signal warrants as a one-lane approach. The approach should be considered two lanes if approximately half of the traffic on the approach turns left and the left-turn lane is of sufficient length to accommodate all left-turn vehicles.
- (3) Similar engineering judgment and rationale should be applied to a street approach with one-lane plus a right-turn lane. In the case of a right-turn lane, engineering judgment must also be exercised relative to the degree of conflict of minor street right-turn traffic with traffic on the major street. Thus, right-turn traffic should not be included in the minor street volume if the movement enters the major street with minimal conflict. In such cases, the approach would be evaluated as a one-lane approach and only the traffic in the through/left-turn lane considered.
- (4) In some cases the minor street approach may not be striped with multiple lanes, but may be of sufficient width (typically 18 feet or more) to allow right-turning traffic to pass to the right of any left-turn or through traffic and complete their turn with little delay. In this case, the approach should be considered a single lane approach, but the right turn volumes from the minor street should not be included in the warrant analysis.

- (5) Minor street approaches having a single left-turn/through lane and a free flow right-turn lane should be considered a single lane approach, and the right turn volumes from the minor street should not be included in the warrant analysis.
- (6) Major street approaches having single through lanes with separate left or right-turn lanes are typically considered one-lane approaches for the warrant analysis.

3.5 VOLUMES

- (1) The volumes of traffic used in a full signal warrant analysis should be the actual turning movement count (see Chapter 4) taken for the highest 8 to 12 hours in an average day (a weekday representing traffic volumes normally and repeatedly found at the location).
- (2) A review of the latest machine counts should be conducted first in order to determine:
 - (a) The need for a turning movement count (i.e., if the volumes are too low then 8 to 12 hours of manual count are not needed and the warrant analysis may be completed based on the machine counts only); and
 - (b) The appropriate time periods for conducting the turning movement count.
- (3) In all of the warrants where hourly volumes are to be entered, any hourly period may begin on any quarter hour (7:15, 7:30, 7:45 etc.), as long as there is no overlap among warranted hours.
- (4) An engineering study should consider the effects of the right-turn vehicles from the minor-street approaches. Engineering judgment should be used to determine what, if any, portion of the right-turn traffic is subtracted from the minor street traffic count when evaluating the count against the signal warrants.
- (5) The following factors should be considered when applying engineering judgment to determine the portion of right-turn volumes included in the minor street volume:
 - (a) Number of lanes on the minor street approach
 - (b) Presence or absence of exclusive right-turn lane
 - (c) Presence or absence of free flow right-turn lane
 - (d) Availability of gaps in major street traffic
 - (e) Sight distance available to right-turning vehicles
 - (f) Percentage of minor street traffic which turns right
 - (g) Pedestrian volumes
- (6) Section 3.4 includes several instances where right turn volumes would not be included in the warrant analysis.
- (7) If free flow right-turn lanes are present, the right turn volumes should not be included in the warrant analysis. This includes both free flow right-turns from the major street (right turn volumes deducted from the major street volumes), and from the minor street (right turn volumes deducted from the minor street approach volumes).
- (8) When a minor street approach consists of a single lane, but right-turn volumes exceed 50% of the total traffic on the approach, some of the right-turn traffic can proceed with little delay, but some will be impeded by through or left-turn traffic. Also, the presence of the right turn traffic, though it may be able to turn with little delay adds delay to the through and left-turn traffic. In this case, all of the left-turn and through volume plus 50% of the right turn volume should be considered in the warrant analysis and the single lane approach criteria should be used.

3.6 PRELIMINARY SCREENING

- (1) Prior to conducting a full traffic signal warrant analysis, existing two-way average daily traffic (ADT) volume data should be reviewed to determine if the intersection experiences enough traffic to possibly meet any traffic signal warrants. The ADT volumes for all state highway routes are available in the latest Vehicle Miles Book published by the Department's Planning Program each year. The ADT volumes for most major city streets are also available from the Department's Planning Program. Table 3-1 shows the minimum ADT volumes below which it is impossible to meet the 8-hour traffic signal warrant criteria.
- (2) The Equivalent ADT volumes indicated in the table are the minimum hourly volumes required to meet the 8-hour warrant criteria multiplied by 8 (the number of hours that must meet the minimum volume criteria). If either street at the intersection experiences traffic volumes below the equivalent ADT for the applicable number of lanes and application of the full (100%) or reduced (70%) criteria, it can be concluded that the intersection will not warrant the installation of a traffic control signal, and the signal warrant study can be terminated. The requestor should be notified of these findings per Chapter 2.

Table 3-1 ADT Volumes below which MUTCD Signal Warrants Cannot be Met

	Number of Lanes for Moving Traffic on Each Approach		Vehicles Per Hour on Major Street (Total of Both Approaches)		Equivalent ADT		Vehicles Per Hour on Higher Volume Minor Street Approach (One Direction Only)		Equivalent ADT	
	Major St.	Minor St.	100%	70%	100%	70%	100%	70%	100%	70%
Warrant 1 Condition A	1	1	500	350	4,000	2,800	150	105	2,400	1,680
	2 or more	1	600	420	4,800	3,360	150	105	2,400	1,680
	2 or more	2 or more	600	420	4,800	3,360	200	140	3,200	2,240
	1	2 or more	500	350	4,000	2,800	200	140	3,200	2,240
Warrant 1 Condition B	1	1	750	525	6,000	4,200	75	53	1,200	848
	2 or more	1	900	630	7,200	5,040	75	53	1,200	848
	2 or more	2 or more	900	630	7,200	5,040	100	70	1,600	1,120
	1	2 or more	750	525	6,000	4,200	100	70	1,600	1,120
Combination of Warrants 1A & 1B	1	1	600	420	4,800	3,360	120	84	1,920	1,344
	2 or more	1	720	504	5,760	4,032	120	84	1,920	1,344
	2 or more	2 or more	720	504	5,760	4,032	160	112	2,560	1,792
	1	2 or more	600	420	4,800	3,360	160	112	2,560	1,792

- (3) For the volumes in Table 3-1 to meet the 8-hour warrant criteria, all traffic during the day would have to be concentrated into an 8-hour period, with no other traffic during the remaining 16 hours of the day. Based on the normal distribution of traffic volumes throughout the day, the actual two-way ADT volumes needed to meet the 8-hour warrant criteria is significantly higher than those indicated in Table 3-1. Normal daily traffic distribution was analyzed to determine the typical 24-hour traffic volumes that would be likely to meet the 8-hour warrant criteria. Table 3-2 shows the results of that analysis. If the roadway volumes on both approaches meet or exceed the traffic volumes shown on Table 3-2 for the applicable number of lanes and application of the full (100%) or reduced (70%) criteria, it does not necessarily mean that a traffic signal is warranted and should be installed, but indicates that the intersection should be further analyzed for possible signal warrants (a full warrant analysis should be conducted per the remainder of this chapter). If the two-way ADT volumes on the approaches are less than those shown on Table 3-2, engineering judgment should be used to decide whether the traffic volumes are close enough to need full warrant analysis or the volumes are too low to meet the warrant criteria.

Table 3-2 ADT Volumes above which MUTCD Signal Warrants are Likely to be Met

	Number of Lanes for Moving Traffic on Each Approach		Vehicles Per Hour on Major Street (Total of Both Approaches)		Equivalent ADT *		Vehicles Per Hour on Higher Volume Minor Street Approach (One Direction Only)		Equivalent ADT *	
	Major St.	Minor St.	100%	70%	100%	70%	100%	70%	100%	70%
warrant 1 condition a	1	1	500	350	8,300	5,810	150	105	4,600	3,220
	2 or more	1	600	420	10,000	7,000	150	105	4,600	3,220
	2 or more	2 or more	600	420	10,000	7,000	200	140	6,000	4,200
	1	2 or more	500	350	8,300	5,810	200	140	6,000	4,200
Warrant 1 Condition B	1	1	750	525	12,500	8,750	75	53	2,300	1,610
	2 or more	1	900	630	15,000	10,500	75	53	2,300	1,610
	2 or more	2 or more	900	630	15,000	10,500	100	70	3,100	2,170
	1	2 or more	750	525	12,500	8,750	100	70	3,100	2,170
Combination of Warrants 1A & 1B	1	1	600	420	10,000	7,000	120	84	3,680	2,576
	2 or more	1	720	504	12,000	8,400	120	84	3,680	2,576
	2 or more	2 or more	720	504	12,000	8,400	160	112	4,800	3,360
	1	2 or more	600	420	10,000	7,000	160	112	4,800	3,360

* Box, P. "Warrants for Traffic Control Signals," *Traffic Engineering*, November 1967

3.7 TRAFFIC SIGNAL WARRANTS WORKSHEET

- (1) The Traffic Signal Warrants worksheet is an Excel spreadsheet that has been developed to simplify the traffic signal warrant analysis procedure. It is designed for the easy input of the volume data and pertinent intersection conditions and to compile the results in a clear and understandable format for use in justifying the installation of a new signal or the removal of an existing signal.
- (2) This form summarizes data previously collected at the intersection. This data is drawn from a larger set of data which can later be used to determine the proper design and operation should signalization be warranted.
- (3) Most of the data entry for the Traffic Signal Warrants worksheet takes place on the "Input Sheet". All fields should be filled in as applicable. Figure 3-1 gives an example of the "Input Sheet".
 - (a) It is important that the city name be entered and spelled correctly because the spreadsheet determines whether or not to apply the reduced warrant criteria based on the name of the city. If the intersection is within the urban area boundary of an incorporated city, even though it may be outside of the actual corporate limits, the city's name should be used.
 - (b) Enter the names and information for each of the approaches. Select "Yes" or "No" from the dropdown lists in each of the blanks after a question.
 - (c) The posted speed limit on the major street must be input for proper application of the speed-based warrant reductions. If the speed limit is posted at 40 mph, the spreadsheet will ask if the 85th-percentile speed exceeds 40 mph. This should be determined by a spot speed study (see Chapter 13). Select "Yes" if the 85th percentile speed is greater than 40 mph, or "No" if it is 40 mph or less, from the dropdown list next to the question that is highlighted in red text.
 - (d) The number of lanes per approach should be determined per Sections 3.4 and 3.5.

Figure 3-1 Traffic Signal Warrants Input Sheet

Form TR-21
Revised 01/17/10

TRAFFIC SIGNAL WARRANTS INPUT SHEET

CALC by _____
 CHK by _____

CALC DATE _____
 COUNT DATE _____

CITY _____
 DIST _____
 CO _____
 M.P. _____

North-South Street _____ Posted Approach Speed _____ mph Lanes: _____

Is street part of the street or highway system that serves as the principal roadway network for through traffic flow? _____

Does street include rural or suburban highways outside, entering, or traversing a city? _____

Does street appear as a major route on an official street plan? _____

Distance to nearest signal: North _____ ft South _____ ft

Will a signal at this location provide the necessary degree of platooning and progression between the adjacent signals? _____

East-West Street _____ Posted Approach Speed _____ mph Lanes: _____

Is street part of the street or highway system that serves as the principal roadway network for through traffic flow? _____

Does street include rural or suburban highways outside, entering, or traversing a city? _____

Does street appear as a major route on an official street plan? _____

Distance to nearest signal: East _____ ft West _____ ft

Will a signal at this location provide the necessary degree of platooning and progression between the adjacent signals? _____

Is there an engineering study that has 5-year projected volumes at this intersection that meet one or more of Warrants 1, 2, or 3 during an average weekday? _____

Do traffic volumes on a Saturday or Sunday meet or exceed 1000 veh/hr for at least 5 hours? _____

Is there a designated school crossing across the uncontrolled roadway at this intersection? _____

Is there a railroad grade crossing within 140 feet of the intersection on a STOP controlled approach? _____

Volume Input Table

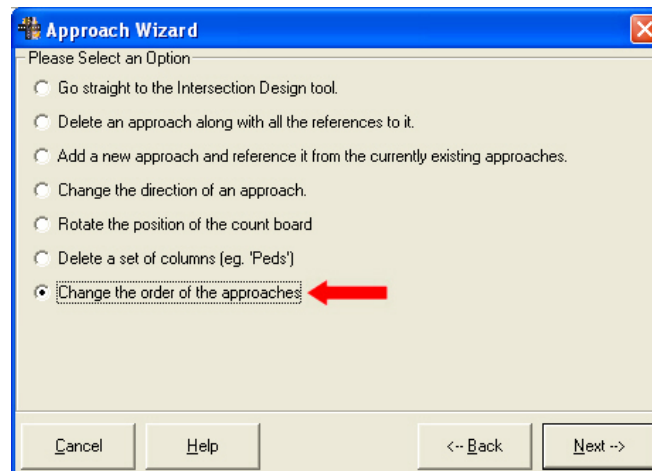
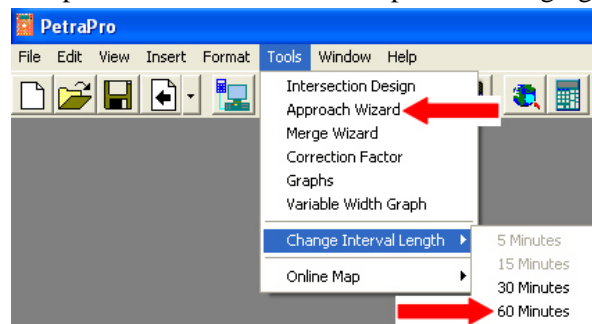
	NORTHBOUND				SOUTHBOUND				EASTBOUND				WESTBOUND			
	Lt	Thru	Rt	Peds	Lt	Thru	Rt	Peds	Lt	Thru	Rt	Peds	Lt	Thru	Rt	Peds
6:00-7:00 am																
7:00-8:00 am																
8:00-9:00 am																
9:00-10:00 am																
10:00-11:00 am																
11:00-12:00 n																
12:00-1:00 pm																
1:00-2:00 pm																
2:00-3:00 pm																
3:00-4:00 pm																
4:00-5:00 pm																
5:00-6:00 pm																
6:00-7:00 pm																

DELAY INPUT TABLE

AVERAGE STOPPED TIME BY APPROACH

	NB	SB
6:00-7:00 am		
7:00-8:00 am		
8:00-9:00 am		
9:00-10:00 am		
10:00-11:00 am		
11:00-12:00 n		
12:00-1:00 pm		
1:00-2:00 pm		
2:00-3:00 pm		
3:00-4:00 pm		
4:00-5:00 pm		
5:00-6:00 pm		
6:00-7:00 pm		

- (e) If “Yes” is selected for the question, “Is there a designated school crossing across the uncontrolled roadway at this intersection?”, then a pedestrian gap study (see Chapter 9) should be performed and the results tabulated on the Pedestrian Gap Study form (Form TR-12) and the School Crossing Warrant Sheet (Form TR-01a) should be completed, which can be found under the “Wrnt 5” tab of the Traffic Signal Warrants worksheet.
- (f) If “Yes” is selected for the question “Is there a railroad grade crossing within 140 feet of the intersection on a STOP controlled approach?”, then the Intersection Near a Grade Crossing Warrant Sheet (Form TR-01b) should be completed, and which can be found under the “Wrnt 9 Input”, “Fig 4C-9” and “Fig 4C-10” tabs of the Traffic Signal Warrants worksheet.
- (g) The traffic volumes can be input manually, but the recommended method is to copy the volumes directly from the PetraPro software program. To prepare the count data, first arrange the approaches in the order of Northbound, Southbound, Eastbound and Westbound using the approach wizard tool. Then, if all of the count intervals start on the hour (i.e., XX:00), change the interval length to 60 minutes using the “Tools” dropdown menu in PetraPro, then selecting “Change Interval Length” and “60 minutes”. If any of the count intervals were started on the quarter hour (i.e., XX:15, XX:30 or XX:45), the count data will need to be moved to where it starts on the hour in order for the PetraPro software to process the count data into full one-hour blocks. Also, any count intervals that form incomplete hours must be deleted prior to changing the interval length.



- (4) Once all of the data is entered on the “Input Sheet”, additional data for the Crash Experience warrant must be entered on “Pg 3” of the worksheet.
- (a) Under sub-section A, select “X” if adequate trial of alternatives to reduce crashes has failed to reduce the crash experience at the intersection.

WARRANT 7 - Crash Experience

				SATISFIED	YES	<input type="checkbox"/>	NO	<input checked="" type="checkbox"/>		
A. ADEQUATE TRIAL OF ALTERNATIVES WITH SATISFACTORY OBSERVANCE AND ENFORCEMENT HAS FAILED TO REDUCE THE CRASH FREQUENCY;				AND	Yes	<input type="checkbox"/>	No	<input checked="" type="checkbox"/>		
B. MINIMUM REQUIREMENT		NUMBER OF CRASHES								
5 OR MORE CRASHES IN 12 MONTHS		0 Crashes		AND	Yes	<input type="checkbox"/>	No	<input checked="" type="checkbox"/>		
C. ONE WARRANT		WARRANT 1A - MINIMUM VEHICULAR VOLUME			Yes	Select "X" if alternative measures have been tried without a satisfactory reduction in crashes.				
SATISFIED AT		WARRANT 1B - INTERRUPTION OF CONTINUOUS TRAFFIC			Yes				No	<input checked="" type="checkbox"/>
80%		WARRANT 4 - PEDESTRIAN VOLUME			Yes				No	<input checked="" type="checkbox"/>

- (b) Under sub-section B, enter the number of correctable crashes that have occurred at the intersection each year, and select "X" if there have been more than five correctable crashes in a 12 month period. Crashes that are considered susceptible to correction are typically crashes involving either crossing or left-turning vehicles from the minor street being struck by through vehicles on the major street. See Chapter 7 regarding crash studies.

WARRANT 7 - Crash Experience

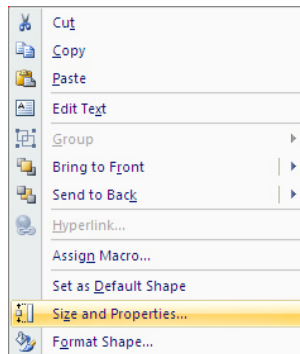
				SATISFIED	YES	<input type="checkbox"/>	NO	<input checked="" type="checkbox"/>		
A. ADEQUATE TRIAL OF ALTERNATIVES WITH SATISFACTORY OBSERVANCE AND ENFORCEMENT HAS FAILED TO REDUCE THE CRASH FREQUENCY;				AND	Yes	<input type="checkbox"/>	No	<input checked="" type="checkbox"/>		
B. MINIMUM REQUIREMENT		NUMBER OF CRASHES								
5 OR MORE CRASHES IN 12 MONTHS		3 crashes 2007, 4 crashes 2008, 7 crashes 2009		AND	Yes	<input type="checkbox"/>	No	<input checked="" type="checkbox"/>		
C. ONE WARRANT		WARRANT 1A - MINIMUM VEHICULAR VOLUME			Yes	Select "X" if there have been 5 or more correctable crashes in a 12 month period.				
SATISFIED AT		WARRANT 1B - INTERRUPTION OF CONTINUOUS TRAFFIC			Yes				No	<input checked="" type="checkbox"/>
80%		WARRANT 4 - PEDESTRIAN VOLUME			Yes				No	<input checked="" type="checkbox"/>

- (5) The peak four-hour volumes must be plotted on Figure 4C-1 if the full warrant criteria is used, or Figure 4C-2 if the reduced (70%) criteria is used. The peak one-hour volumes must be plotted on Figure 4C-3 if the full warrant criteria is used, or Figure 4C-4 if the reduced (70%) criteria is used. These figures can be found under the "Pg 5 Full" or "Pg 5 70%" tabs in the Traffic Signal Warrants worksheet. Figures 4C-1 and 4C-3 are included on the "Pg 5 Full" sheet for studies that use the full warrant criteria, and Figures 4C-2 and 4C-4 are included on the "Pg 5 70%" sheet for studies that use the reduced (70%) warrant criteria.

- (a) First, determine which sheet applies and select the respective tab.
- (b) On the blank worksheet, each figure contains green horizontal lines underlining each of the possible lane configurations. Delete the lines that do not apply, leaving the applicable lane configuration used for the analysis underlined in green.
- (c) On the blank worksheet, Figures 4C-1 and 4C-2 include four horizontal and four vertical lines each of red, blue and green colors which are to be used to plot the appropriate points for analysis. Figures 4C-3 and 4C-4 include one horizontal and one vertical line each of red, blue and green colors. The lines are color coded to mean:
- Red = warrant criteria is met
 - Blue = warrant criteria is close to being met (i.e., the point fall on or just below the curve)
 - Green = warrant criteria is not met.
- (d) To the right of each of the figures, a table of data indicates the peak eight hours of data analyzed in the worksheet, including how much above or below the curve the point falls for each hour. Positive numbers typically fall above the curve, while negative numbers typically fall below the curve. This data is color coded as previously discussed to

indicate the appropriate color of line to use to plot that hour's data. Due to the scale of the figure and inherent errors in plotting the points, some positive numbers will show as blue to indicate that the point is on, or nearly on, the curve, but not above the curve as required for the warrant to be met. The table also indicates how long the associated horizontal and vertical lines need to be to accurately represent the respective volumes on the figures.

- (e) Determine the four highest points to be plotted on the Four-Hour Warrant curves from the four highest numbers under the "Volume Above/Below Criteria" heading. The color coding will indicate how many points will be plotted in each color. Delete the extra horizontal and vertical lines leaving just four horizontal and four vertical lines of the appropriate colors.
- (f) Set the length of each of the lines by right-clicking on the line, selecting Size and Properties, and entering the length of the line from the table to the right of the figure. Set the length of line for horizontal lines in the Width field, and for vertical lines in the Height field.



- (g) Move each of the horizontal and respective vertical lines into their appropriate locations on the figure to accurately represent each of the plotted points.
- (6) If the School Crossing warrant applies, complete the School Crossing Signal Warrant Sheet (Form TR-01a) under the "Wrnt 5" tab. This first requires the completion of a pedestrian gap study (see Chapter 9).
- (7) If the Intersection Near a Grade Crossing warrant applies, complete the Intersection Near a Grade Crossing Warrant worksheet (Form TR-01b). Enter the pertinent information on the "Wrnt 9 Input" sheet, then plot the highest point on the applicable figure (i.e., Figure 4C-9 for a single lane over the crossing or Figure 4C-10 for multiple lanes over the crossing).
- (8) Figure 3-2, consisting of 6 pages, gives an example of a completed traffic signal warrant analysis using the Traffic Signal Warrants worksheet.
- (9) Figure 3-3 gives an example of a completed School Crossing Signal Warrant Sheet.
- (10) Figure 3-4 gives an example of a completed Intersection near a Grade Crossing Warrant Sheet.

Figure 3-2 Example Traffic Signal Warrants Worksheet (Page 1 of 6)

Form TR-01, Revised 9/11/10 Page 1 of 6

WYOMING DEPARTMENT OF TRANSPORTATION TRAFFIC SIGNAL WARRANTS

Calc by JDT Calc Date 09/17/10
 Chk by LJR Count Date 6/31/10

Jackson CITY 3 DIST Teton CO

Major Street Broadway Posted Approach Speed 35 mph Lanes: 2
 Minor Street Gill Street Posted Approach Speed 30 mph Lanes: 1

Critical speed of major street traffic > 40 mph ----- ☐ OR
 In built up area of isolated community of <= 10,000 pop. with no existing signals ----- ☐

WARRANT 1 - Eight-Hour Vehicular Volume

Condition A - Minimum Vehicular Volume

WARRANT SATISFIED YES ☐ NO ☒

	APPROACH LANES	WARRANT VOLUME	7 AM	8 AM	11 AM	12 PM	1 PM	3 PM	4 PM	5 PM
Both Approaches Major Street	2	600	745	725	1004	1147	1026	1000	1272	1530
Highest Approach Minor Street	1	150	72	67	93	109	100	122	201	185
Warrant Volume Met?			No	No	No	No	No	No	Yes	Yes

Condition B - Interruption of Continuous Traffic

WARRANT SATISFIED YES ☐ NO ☒

	APPROACH LANES	WARRANT VOLUME	7 AM	8 AM	11 AM	12 PM	1 PM	3 PM	4 PM	5 PM
Both Approaches Major Street	2	900	745	725	1004	1147	1026	1000	1272	1530
Highest Approach Minor Street	1	75	72	67	93	109	100	122	201	185
Warrant Volume Met?			No	No	Yes	Yes	Yes	Yes	Yes	Yes

Combination of Conditions "A" and "B"

BOTH SATISFIED YES ☐ NO ☒

Condition "A"

A" SATISFIED YES ☐ NO ☒

	APPROACH LANES	WARRANT VOLUME	7 AM	8 AM	11 AM	12 PM	1 PM	3 PM	4 PM	5 PM
Both Approaches Major Street	2	480	745	725	1004	1147	1026	1000	1272	1530
Highest Approach Minor Street	1	120	72	67	93	109	100	122	201	185
Warrant Volume Met?			No	No	No	No	No	Yes	Yes	Yes

Condition "B"

B" SATISFIED YES ☒ NO ☐

	APPROACH LANES	WARRANT VOLUME	7 AM	8 AM	11 AM	12 PM	1 PM	3 PM	4 PM	5 PM
Both Approaches Major Street	2	720	745	725	1004	1147	1026	1000	1272	1530
Highest Approach Minor Street	1	60	72	67	93	109	100	122	201	185
Warrant Volume Met?			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Figure 3-2 Example Traffic Signal Warrants Worksheet (Page 2 of 6)

Form TR-01, Revised 5/17/10

Page 2 of 6

WYOMING DEPARTMENT OF TRANSPORTATION TRAFFIC SIGNAL WARRANTS

WARRANT 2 - Four-Hour Vehicular Volume

SATISFIED* YES ☐ NO ☒

Approach Lanes		7 AM	8 AM	11 AM	12 PM	1 PM	3 PM	4 PM	5 PM
A - Two or more	A Both Approaches - Major Street	745	725	1004	1147	1026	1000	1272	1530
B - One	B Highest Approach - Minor Street	72	67	93	109	100	122	201	185
Does plotted point fall above curve on Figure 4C-1?		No	No	No	Close	No	No	Yes	Yes

*Refer to MUTCD Figure 4C-1 to determine if this warrant is satisfied

WARRANT 3 - Peak Hour

Condition "A" (for the same 1 hour of an average day)

SATISFIED* YES ☐ NO ☒

1. The total STOPPED delay experienced on one minor street approach controlled by a STOP sign equals or exceeds: 4 veh/hrs for a 1-lane approach; or 5 veh/hrs for a 2-lane approach, Ave Delay/Veh 20.49 Ave Delay/Veh 20.18 Ave Delay/Veh 17.5 AND						FULFILLED			
						Yes	<input type="checkbox"/>	No	<input checked="" type="checkbox"/>
2. The volume on the same minor street approach equals or exceeds 100 vph for one moving lane of traffic or 150 vph for two moving lanes. (Actual volume 185, Hour Beginning 5 PM) AND						Yes	<input checked="" type="checkbox"/>	No	<input type="checkbox"/>
3. The total entering volume serviced during the hour equals or exceeds 650 vph for intersections with three approaches or 800 vph for intersections with four or more approaches. (Actual volume 1834)						Yes	<input checked="" type="checkbox"/>	No	<input type="checkbox"/>

Condition "B"

SATISFIED* YES ☒ NO ☐

Approach Lanes		7 AM	8 AM	11 AM	12 PM	1 PM	3 PM	4 PM	5 PM
A - Two or more	A Both Approaches - Major Street	745	725	1004	1147	1026	1000	1272	1530
B - One	B Highest Approach - Minor Street	72	67	93	109	100	122	201	185
Does plotted point fall above curve on Figure 4C-3?		No	No	No	No	No	No	Close	Yes

*Refer to MUTCD Figure 4C-3 to determine if this warrant is satisfied

WARRANT 4 - Pedestrian Volume

Posted speed of major street traffic > 35 mph? ☒ No

4-HOUR WARRANT SATISFIED YES ☐ NO ☒

1-HOUR WARRANT SATISFIED YES ☒ NO ☐

	7 AM	8 AM	11 AM	12 PM	1 PM	3 PM	4 PM	5 PM
Vehicular Volume, Major Street - Total Both Approaches*	745	725	1004	1147	1026	1000	1272	1530
Total Pedestrians Crossing Major Street	128	179	101	87	91	270	221	103
Does plotted point fall above curve on Figure 4C-5?	No	No	No	No	No	Yes	Yes	Close
Does plotted point fall above curve on Figure 4C-7?	No	No	No	No	No	Close	Yes	No

* Where there is a divided street having a median of sufficient width for pedestrians to wait, the requirement applies separately to each direction of vehicular traffic.

NOTE: This warrant shall not be applied at locations where the distance to the nearest traffic control signal along the major street is less than 300 ft., unless the proposed traffic control signal will not restrict the progressive movement of traffic.

WARRANT 5 - School Crossing

Not Applicable ☒

See School Crossing Warrant Sheet ☐

Figure 3-2 Example Traffic Signal Warrants Worksheet (Page 3 of 6)

Form TR-01, Revised 9/17/10		Page 3 of 6	
WYOMING DEPARTMENT OF TRANSPORTATION TRAFFIC SIGNAL WARRANTS			
WARRANT 6 - Coordinated Signal System			
		SATISFIED	YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>
MINIMUM REQUIREMENT	DISTANCE TO NEAREST SIGNAL		FULFILLED
Greater than 1000 ft	N _____ ft	S _____ ft	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
A. ON A ONE-WAY STREET OR A STREET THAT HAS TRAFFIC PREDOMINANTLY IN ONE DIRECTION, THE ADJACENT TRAFFIC CONTROL SIGNALS ARE SO FAR APART THAT THEY DO NOT PROVIDE THE NECESSARY DEGREE OF VEHICULAR PLATOONING;			OR
			Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
B. ON A TWO-WAY STREET, ADJACENT TRAFFIC CONTROL SIGNALS DO NOT PROVIDE THE NECESSARY DEGREE OF VEHICULAR PLATOONING AND THE PROPOSED AND ADJACENT TRAFFIC CONTROL SIGNALS WILL COLLECTIVELY PROVIDE A PROGRESSIVE OPERATION.			Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
WARRANT 7 - Crash Experience			
		SATISFIED	YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>
A. ADEQUATE TRIAL OF ALTERNATIVES WITH SATISFACTORY OBSERVANCE AND ENFORCEMENT HAS FAILED TO REDUCE THE CRASH FREQUENCY;		AND	FULFILLED
			Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
B. MINIMUM REQUIREMENT		NUMBER OF CRASHES	
5 OR MORE CRASHES IN 12 MONTHS	3 in 2007, 1 in 2008, 4 in 2009		AND
			Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
C. ONE WARRANT SATISFIED AT 80%		WARRANT 1A - MINIMUM VEHICULAR VOLUME WARRANT 1B - INTERRUPTION OF CONTINUOUS TRAFFIC WARRANT 4 - PEDESTRIAN VOLUME	
		Yes	No
		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
WARRANT 8 - Roadway Network			
		SATISFIED	YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>
MINIMUM REQUIREMENT		FULFILLED	
Total entering volume equals 1000 vehicles or more per/hr			
A. DURING TYPICAL WEEKDAY PEAK HOUR 1834 VEH/HOUR HAS 5-YEAR PROJECTED VOLUMES, BASED ON AN ENGINEERING STUDY, THAT MEET ONE OR MORE OF WARRANTS 1, 2, AND 3 DURING AN AVERAGE WEEKDAY;		AND	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
		OR	
B. DURING EACH OF ANY 5 HRS OF A SATURDAY OR SUNDAY EXCEED 1,000 VEH/HOUR			Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
CHARACTERISTICS OF MAJOR ROUTES		MAJOR	MINOR
A. IT IS PART OF THE STREET OR HIGHWAY SYSTEM THAT SERVES AS THE PRINCIPAL ROADWAY NETWORK FOR THROUGH TRAFFIC FLOW;		<input checked="" type="checkbox"/>	<input type="checkbox"/>
OR			
B. IT INCLUDES RURAL OR SUBURBAN HIGHWAYS OUTSIDE, ENTERING, OR TRAVERSING A CITY		<input checked="" type="checkbox"/>	<input type="checkbox"/>
OR			
C. IT APPEARS AS A MAJOR ROUTE ON AN OFFICIAL PLAN, SUCH AS A MAJOR STREET PLAN IN AN URBAN AREA TRAFFIC AND TRANSPORTATION STUDY.		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
ANY MAJOR ROUTE CHARACTERISTICS MET FOR BOTH STREETS Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>			
WARRANT 9 - Intersection Near a Grade Crossing			
		Not Applicable <input checked="" type="checkbox"/>	
		See Intersection Near a Grade Crossing Warrant Sheet <input type="checkbox"/>	

Figure 3-2 Example Traffic Signal Warrants Worksheet (Page 4 of 6)

Form TR-01, Revised 9/17/10

Page 4 of 6

Volumes Used for This Signal Warrant Study

	Major Street Totals (Both Approaches)	Minor Street Totals (Highest Approach)	Pedestrians Across Major Street
6:00-7:00 am			
7:00-8:00 am	745	72	128
8:00-9:00 am	725	67	179
9:00-10:00 am			
10:00-11:00 am			
11:00-12:00 n	1004	93	101
12:00-1:00 pm	1147	109	87
1:00-2:00 pm	1026	100	91
2:00-3:00 pm			
3:00-4:00 pm	1000	122	270
4:00-5:00 pm	1272	201	221
5:00-6:00 pm	1530	185	103
6:00-7:00 pm			

**AVERAGE STOPPED TIME BY
APPROACH FOR MINOR STREET**

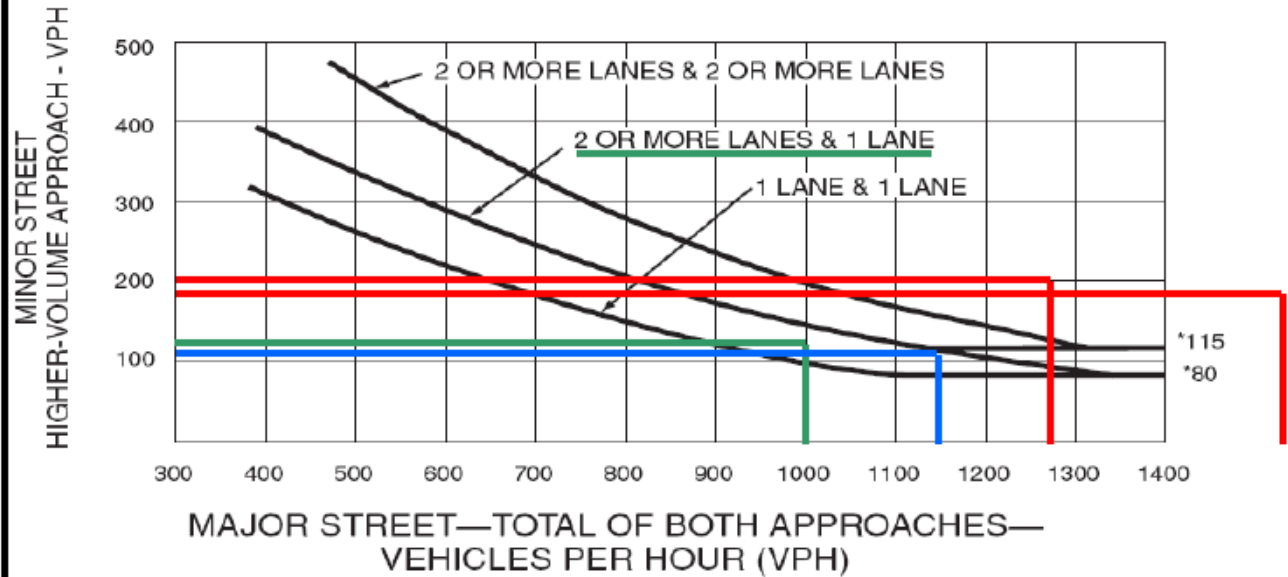
	NB	SB
6:00-7:00 am		
7:00-8:00 am	12.13	11.28
8:00-9:00 am	8.33	12.08
9:00-10:00 am		
10:00-11:00 am		
11:00-12:00 n	17.5	13.01
12:00-1:00 pm	19.18	20.18
1:00-2:00 pm		
2:00-3:00 pm		
3:00-4:00 pm	14.53	16.65
4:00-5:00 pm	20.49	17.95
5:00-6:00 pm		
6:00-7:00 pm		

Figure 3-2 Example Traffic Signal Warrants Worksheet (Page 5 of 6)

Form TR-01, Revised 9/17/10

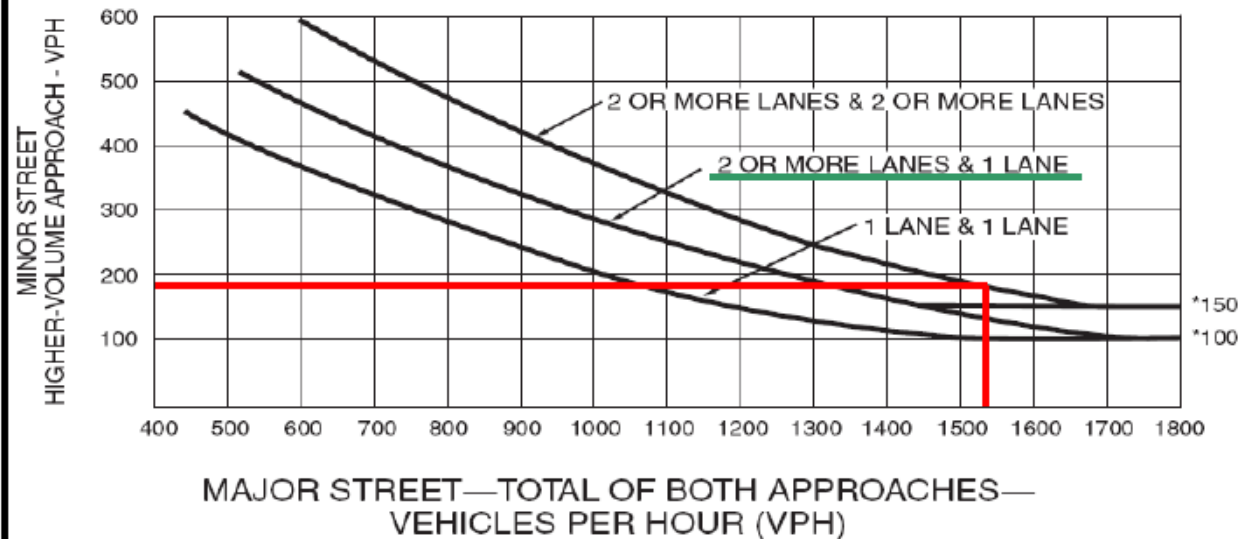
Page 5 of 6

Figure 4C-1. Warrant 2, Four-Hour Vehicular Volume



*Note: 115 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 80 vph applies as the lower threshold volume for a minor-street approach with one lane.

Figure 4C-3. Warrant 3, Peak Hour



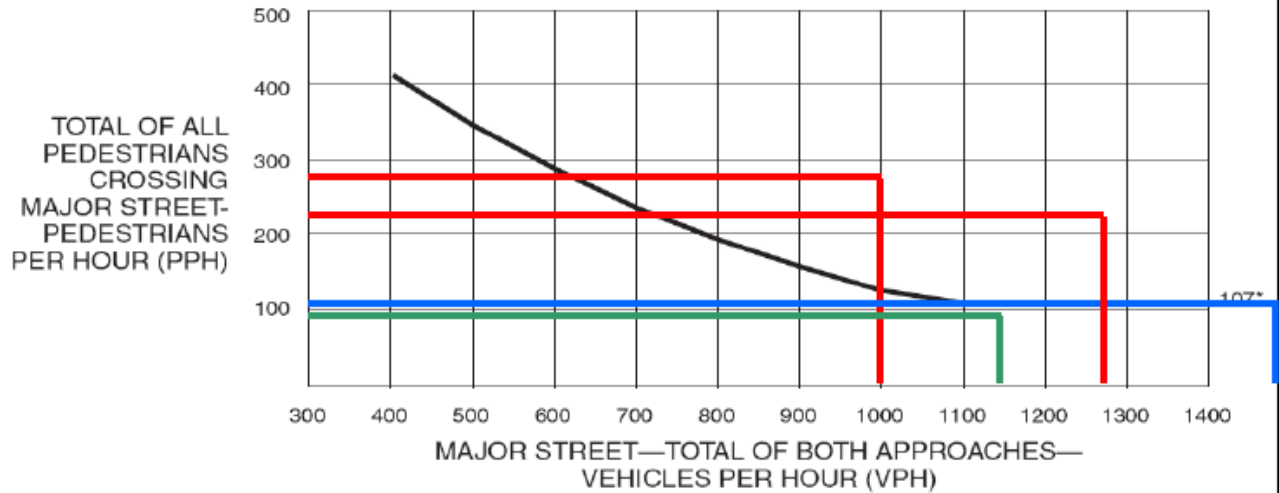
*Note: 150 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 100 vph applies as the lower threshold volume for a minor-street approach with one lane.

Figure 3-2 Example Traffic Signal Warrants Worksheet (Page 6 of 6)

Form TR-01, Revised 9/17/10

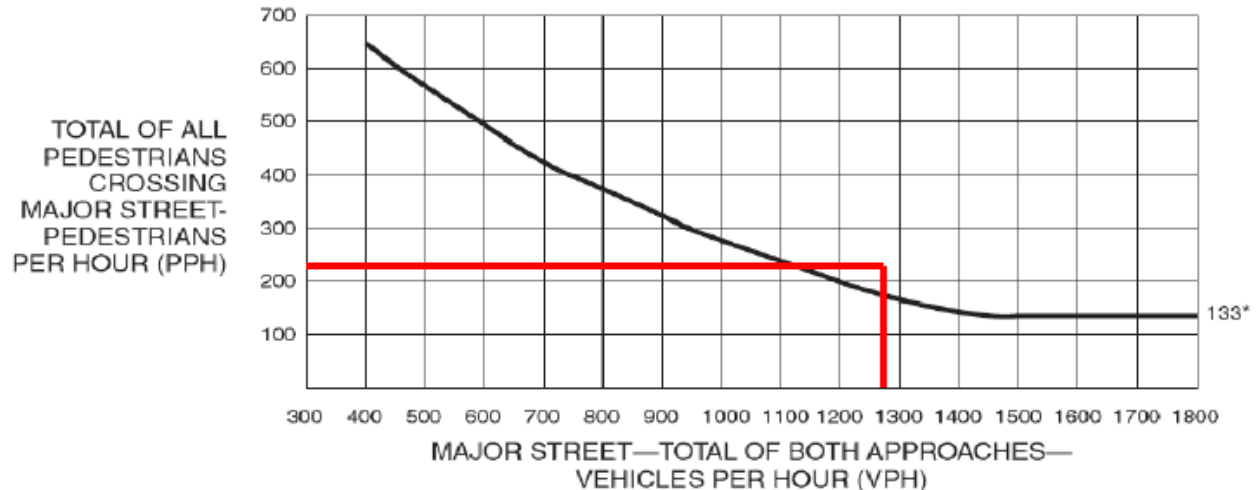
Page 6 of 6

Figure 4C-5. Warrant 4, Pedestrian Four-Hour Volume



*Note: 107 pph applies as the lower threshold volume.

Figure 4C-7. Warrant 4, Pedestrian Peak Hour



*Note: 133 pph applies as the lower threshold volume.

Figure 3-3 Example School Crossing Signal Warrant Sheet

Form TR-51a, Revised 9/17/10		Page 1 of 1	
WYOMING DEPARTMENT OF TRANSPORTATION TRAFFIC SIGNAL WARRANTS SCHOOL CROSSING SIGNAL WARRANT SHEET			
Dubois City	5 Dist	Fremont County	JDT Observer
			4/31/10 Study Date
Major Street	Main Street	Minor Street	D Street
Start Time	3:30 PM	End Time	4:30 PM
		Duration	60 minutes
Width of Major Street (W)	60 ft.	Minimum Acceptable Gap to Cross (G)	20.1 seconds
(curb-to-curb width)		(Assuming 3.5 ft/sec walking speed and 3 sec. startup; $G = W/3.5 + 3$)	
Number of students crossing during highest crossing hour		36	(From Pedestrian Gap Study)
Number of gaps exceeding 20.1 (G) seconds		63	(From Pedestrian Gap Study)
Number of gaps exceeding 40.3 (i.e., $2 \times G$) seconds		0	(From Pedestrian Gap Study)
Is there an existing traffic signal along the major street that is less than 300 feet away? No			
Will a traffic signal at this location restrict the progressive movement of traffic? Yes			
WARRANT 5 - School Crossing			
APPLICABLE		YES <input checked="" type="checkbox"/>	NO <input type="checkbox"/>
SATISFIED		YES <input type="checkbox"/>	NO <input checked="" type="checkbox"/>
		FULFILLED	
1. There are a minimum of 20 students crossing during the highest crossing hour.		AND	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>
2. There are fewer adequate gaps in the major road traffic stream during the period when the children are using the crossing than the number of minutes in the same period. Effective total number of gaps available = 63		AND	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
3. The nearest traffic signal along the major road is located more than 300 feet away. Or, the nearest traffic signal is within 300 feet, but the proposed traffic signal will not restrict progressive movement of traffic.		Dist. to Nearest Signal	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>
		E _____ ft W _____ ft	
NOTE: Before a decision is made to install a traffic control signal on the basis of this warrant, consideration shall first be given to the implementation of other remedial measures, such as warning signs and flashers, school speed zones, school crossing guards, or a grade-separated crossing.			

Figure 3-4 Example Intersection near a Grade Crossing Warrant Sheet

Form TR-01b, Revised 9/17/10

Page 1 of 1

**WYOMING DEPARTMENT OF TRANSPORTATION
TRAFFIC SIGNAL WARRANTS
INTERSECTION NEAR A GRADE CROSSING WARRANT SHEET**

Calc by <u>JDT</u> Calc Date <u>09/17/10</u>		
Chk by <u>LJR</u> Count Date <u>6/31/10</u>		
CITY <u>Torrington</u>	DIST <u>2</u>	CO <u>Goshen</u>
Major Street <u>E. Valley Rd (US 26)</u>	Minor Street <u>E. F Street</u>	Number of Lanes <u>1</u> at Track Crossing
Number of Trains Per Day <u>47</u>	Clear Storage Distance (D) <u>85</u>	
% of High-Occupancy Buses on Minor Street Approach <u>2</u>		
% of Tractor-Trailer Trucks on Minor Street Approach <u>6</u>		

Adjustment Factors:

Adjustment Factor for Daily Frequency of Rail Traffic 1.33 (From MUTCD Table 4C-2, based on 47 trains per day)

Adjustment Factor for Percentage of High-Occupancy Buses 1.09 (From MUTCD Table 4C-3, based on 2% buses)

Adjustment Factor for Percentage of Tractor-Trailer Trucks 0.75 (From MUTCD Table 4C-4, based on 6% trucks and 85 ft. clear storage distance)

WARRANT 9 - Intersection Near a Grade Crossing

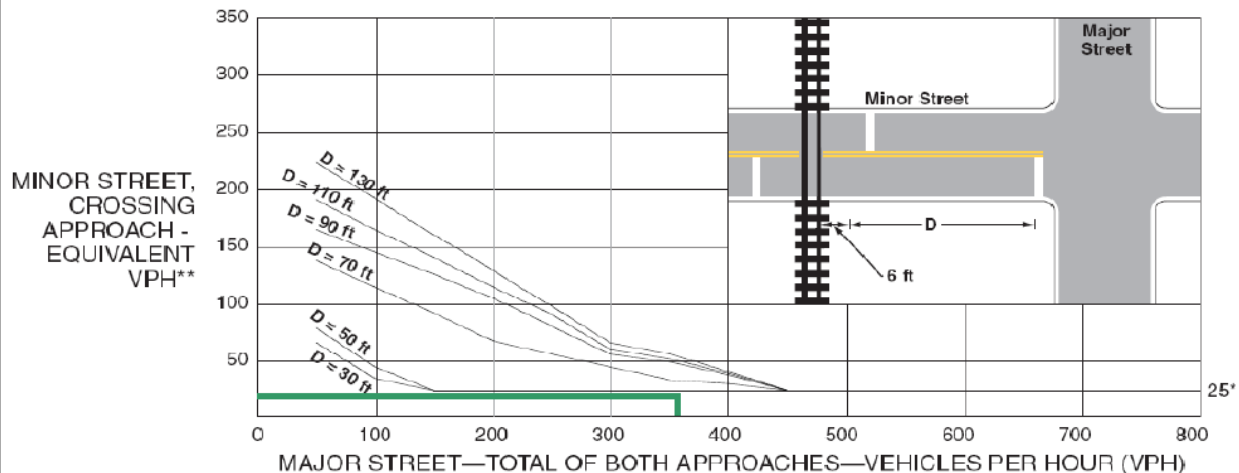
SATISFIED* YES ☐ NO ☒

	7 AM	8 AM	11 AM	12 PM	1 PM	3 PM	4 PM	5 PM
Major Street Total of Both Approaches - VPH	264	216	250	287	246	341	358	313
Minor Street Crossing Approach - Equivalent VPH **	26	8	14	11	11	13	16	15
Does plotted point fall above curve on Figure 4C-9?	No	No	No	No	No	No	No	No

*Refer to MUTCD Figure 4C-9 to determine if this warrant is satisfied

**VPH after applying the adjustment factors in Tables 4C-2, 4C-3, and/or 4C-4, if appropriate

**Figure 4C-9. Warrant 9, Intersection Near a Grade Crossing
(One Approach Lane at the Track Crossing)**



* 25 vph applies as the lower threshold volume

** VPH after applying the adjustment factors in Tables 4C-2, 4C-3, and/or 4C-4, if appropriate

3.8 WARRANT 1, EIGHT HOUR VEHICULAR VOLUME

The Eight Hour Vehicular Volume signal warrant is broken into three conditions that are detailed in Section 4C.02 of the *MUTCD*.

The Minimum Vehicular Volume, Condition A, is intended for application at locations where a large volume of intersecting traffic is the principal reason to consider installing a traffic control signal.

The Interruption of Continuous Traffic, Condition B, is intended for application at locations where Condition A is not satisfied and where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or conflict in entering or crossing the major street.

The combination of Conditions A and B is intended for application at locations where Condition A is not satisfied and Condition B is not satisfied and should be applied only after an adequate trial of other alternatives that could cause less delay and inconvenience to traffic has failed to solve the traffic problems.

3.9 WARRANT 2, FOUR-HOUR VEHICULAR VOLUMES

The Four-Hour Vehicular Volume signal warrant is intended to be applied where the volume of intersecting traffic is the principal reason to consider installing a traffic control signal. The warrant conditions are detailed in Section 4C.03 of the *MUTCD*.

3.10 WARRANT 3, PEAK HOUR

The Peak Hour signal warrant is intended for use at a location where traffic conditions are such that for a minimum of 1 hour of an average day, the minor street traffic suffers undue delay when entering or crossing the major street. The warrant conditions are detailed in Section 4C.04 of the *MUTCD*.

This signal warrant shall be applied only in unusual cases, such as office complexes, manufacturing plants, industrial complexes, or high-occupancy vehicle facilities that attract or discharge large numbers of vehicles over a short time.

3.11 WARRANT 4, PEDESTRIAN VOLUME

The Pedestrian Volume signal warrant is intended where the traffic volumes on a major street are so heavy that pedestrians experience excessive delays in crossing the major street. The warrant conditions are detailed in Section 4C.05 of the *MUTCD*.

3.12 WARRANT 5, SCHOOL CROSSING

The School Crossing signal warrant is intended for application where the fact that school children cross the major street is the principal reason to consider installing a traffic control signal. The warrant conditions are detailed in Section 4C.06 of the *MUTCD*.

Before a decision is made to install a traffic control signal, consideration shall be given to the implementation of other remedial measures, such as warning signs and flashers, school speed zones, school crossing guards, or a grade-separated crossing.

3.13 WARRANT 6, COORDINATED SIGNAL SYSTEM

Progressive movement in a coordinated signal system sometimes necessitates installing traffic signal at intersections where they would not otherwise be needed in order to maintain proper platooning of vehicles. The warrant conditions for this warrant are detailed in Section 4C.07 of the *MUTCD*.

In order for this warrant to apply, there must be a signalized intersection more than 1,000 feet away in each direction along the coordinated signal corridor.

3.14 WARRANT 7, CRASH EXPERIENCE

The Crash Experience signal warrant conditions are intended for applications where the severity and frequency of crashes are the principal reasons to consider installing a traffic control signal. The warrant conditions for this warrant are detailed in Section 4C.08 of the *MUTCD*.

3.15 WARRANT 8, ROADWAY NETWORK

Installing a traffic signal at some intersections might be justified to encourage concentration and organization of traffic flow on a roadway network. The warrant conditions for this warrant are detailed in Section 4C.09 of the *MUTCD*.

3.16 WARRANT 9, INTERSECTION NEAR A GRADE CROSSING

The Intersection Near a Grade Crossing signal warrant is intended for use at a location where none of the conditions described in the other eight traffic signal warrants are met, but the proximity to the intersection of a grade crossing on an intersection approach controlled by a STOP or YIELD sign is the principal reason to consider installing a traffic control signal. The warrant conditions for this warrant are detailed in Section 4C.10 of the *MUTCD*.

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CHAPTER 4 – TURNING MOVEMENT COUNT

4.1 PURPOSE

The purpose of a turning movement count (TCM) is to summarize the counts of vehicle movements through an intersection during certain time periods. This type of volume summary is used in making decisions regarding the geometric design of the roadway, sign and signal installation, signal timing, pavement marking, traffic circulation patterns, capacity analysis, parking and loading zones, and vehicle classification.

4.2 MANUAL TURNING MOVEMENT COUNT

- (1) Manual turning movement counts should be collected using an electronic count board such as a JAMAR Technologies DB-400, TDC-8 or TDC-12 traffic data collector, and processed through JAMAR's PetraPro software.
- (2) The count header on the turning movement count should be filled in completely. Enter the Street Name of each roadway and orient the intersection by indicating the approach direction of each approach (i.e., Northbound, Southbound, Eastbound and Westbound).
- (3) For turning movement counts that will be used for signal warrant analysis, the approaches should be in order of Northbound, Southbound, Eastbound and Westbound from left to right.
- (4) Briefly describe the Weather Conditions and include any Comments that may influence the results of the data being collected. For example, a stalled vehicle that may temporarily restrict a vehicle movement during a time period should be noted.
- (5) Figure 4-1 gives an example of a turning movement count that was completed using a TDC-8 count board and processed through the PetraPro software.

4.3 AUTOMATED TURNING MOVEMENT COUNT

Automated turning movement counts are collected using Miovision Technologies Polemount Video Collection Units (VCUs), and the data is processed and retrieved on Miovision's Traffic Data Online (TDO) servers.

Figure 4-1 Example Turning Movement Count
Wyoming Department of Transportation
Traffic Program
Safety & Studies Section
Cheyenne, WY

Intersection: Main & 5th St
 Counted By: AA
 Weather: Rainy
 Comments:

File Name: N Main & 5th St
 Site Code: 00000005
 Start Date: 6/5/2008
 Page No: 1

Groups Printed- All Vehicles

Start Time	N Main Northbound				N Main Southbound				5th St Eastbound				5th St Westbound				Int. Total
	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	Left	Thru	Right	Peds	
07:00 AM	12	73	6	0	31	57	4	0	15	37	11	0	10	14	29	0	299
07:15 AM	19	48	6	0	31	51	12	1	9	40	24	1	15	27	44	0	328
07:30 AM	17	53	11	0	44	76	16	0	13	46	22	1	11	42	19	1	372
07:45 AM	21	77	10	0	67	103	18	0	18	74	29	1	12	40	30	1	501
Total	69	251	33	0	173	287	50	1	55	197	86	3	48	123	122	2	1500
08:00 AM	24	65	13	0	50	78	15	0	11	46	20	1	15	22	25	0	385
08:15 AM	14	59	3	0	28	63	9	0	11	38	25	1	9	34	21	0	315
08:30 AM	12	43	10	0	39	64	13	0	10	37	19	0	9	13	23	0	292
08:45 AM	18	50	10	0	31	57	9	0	9	44	16	0	13	24	32	0	313
Total	68	217	36	0	148	262	46	0	41	165	80	2	46	93	101	0	1305
11:00 AM	23	67	10	0	39	81	11	0	15	42	19	0	15	31	39	0	392
11:15 AM	21	77	7	0	33	69	8	0	13	49	26	0	22	31	32	0	388
11:30 AM	23	86	15	0	45	82	10	1	15	45	22	1	12	32	46	0	435
11:45 AM	30	82	15	0	42	75	11	0	8	43	31	0	17	46	39	0	439
Total	97	312	47	0	159	307	40	1	51	179	98	1	66	140	156	0	1654
12:00 PM	26	101	11	0	36	90	15	0	18	60	25	0	20	47	48	3	500
12:15 PM	17	95	14	2	30	92	9	1	10	28	14	0	17	38	36	1	404
12:30 PM	33	87	14	0	46	84	11	0	25	38	25	0	16	44	27	1	451
12:45 PM	31	88	17	1	46	74	13	0	16	46	19	1	17	35	49	1	454
Total	107	371	56	3	158	340	48	1	69	172	83	1	70	164	160	6	1809
03:30 PM	27	78	12	0	51	91	7	0	15	34	21	0	16	29	26	2	409
03:45 PM	44	104	17	0	50	98	24	0	11	24	35	0	6	15	24	1	453
Total	71	182	29	0	101	189	31	0	26	58	56	0	22	44	50	3	862
04:00 PM	29	109	10	0	72	140	14	0	17	57	17	1	22	43	50	0	581
04:15 PM	40	79	11	0	59	92	17	3	15	41	25	3	25	35	46	0	491
04:30 PM	52	91	5	0	49	97	18	2	19	53	25	4	21	49	45	0	530
04:45 PM	44	108	8	0	62	89	21	0	17	41	19	1	21	39	43	0	513
Total	165	387	34	0	242	418	70	5	68	192	86	9	89	166	184	0	2115
05:00 PM	58	131	11	0	54	93	15	0	26	66	22	0	28	63	52	0	619
05:15 PM	48	109	15	0	42	85	12	0	14	58	21	2	18	39	42	0	505
Grand	683	1960	261	3	1077	1981	312	8	350	1087	532	18	387	832	867	11	10369
Apprch %	23.5	67.4	9	0.1	31.9	58.6	9.2	0.2	17.6	54.7	26.8	0.9	18.5	39.7	41.3	0.5	
Total %	6.6	18.9	2.5	0	10.4	19.1	3	0.1	3.4	10.5	5.1	0.2	3.7	8	8.4	0.1	

CHAPTER 5 – CONDITION DIAGRAM

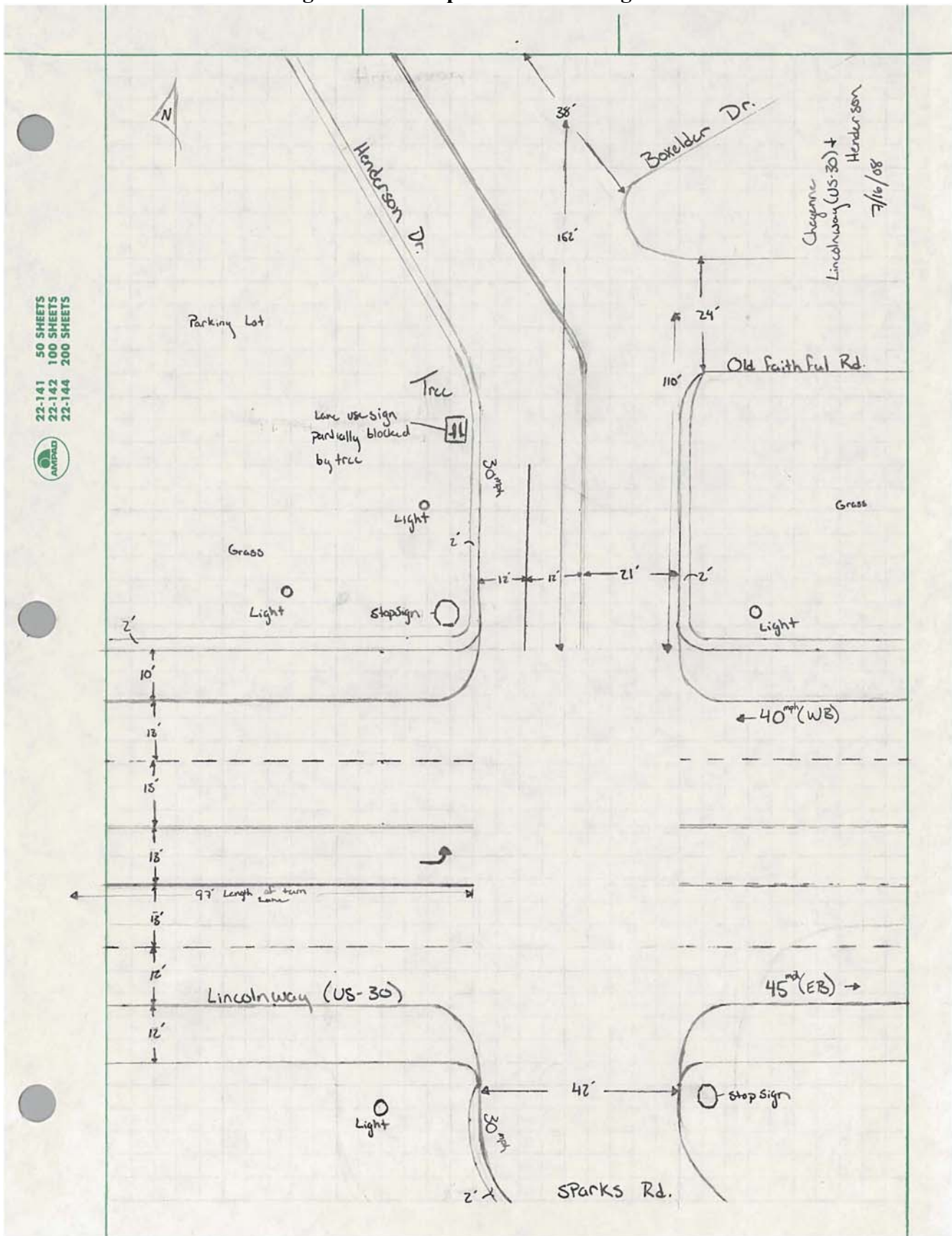
5.1 *PURPOSE*

- (1) The purpose of the condition diagram is to show the intersection and the conditions within the surrounding area as it exists. The diagram should include the intersection alignment, items such as buildings, sidewalks, trees, light poles, fire hydrants, stop signs, number of lanes, lane use if required, approach speed limits, and distance to the next signal in each direction (if applicable), associated with the streets forming the intersection. The condition diagram should show the length of all exclusive lanes and associated tapers.
- (2) The condition diagram provides the engineer with details of field conditions and helps investigate the need for changes to existing traffic control devices. The diagram should also be part of an intersection crash analysis.

5.2 *COMPLETING THE CONDITION DIAGRAM*

- (1) The location information should be entered so that the intersection is thoroughly identified. The state, U.S., or county route numbers and street names for both streets should be included if applicable, as well as the County, City, Date, and Person(s) preparing the diagram. Orient the intersection by indicating north with a north arrow.
- (2) All items associated with the streets should be drawn using representative symbols. The diagram should also include the width and surface type of the streets, the grades (if 5 percent or more), and traffic control devices. All measurements should be as accurate as possible and indicated on the diagram. The usual distance measured from the intersection is 80 to 100 feet; however, in those cases where pertinent signing or pavement markings concerning the intersection (such as 'Stop Ahead') occur in advance of the intersection in question, those conditions should be diagrammed and distances indicated with a "broken arrow." Reasonable judgment should be used to decide the distance away from the intersection to include elements in the condition diagram.
- (3) Show all lanes and the movements allowed/required from each lane. Include lane widths, full-width turn bay lengths and turn bay taper lengths.
- (4) Note the posted speed limit on all approaches and the distance to the next traffic signal in each direction (if applicable).
- (5) Figure 5-1 gives an example of a completed condition diagram.

Figure 5-1 Example Condition Diagram



CHAPTER 6 –SIGHT DISTANCE STUDIES

6.1 PURPOSE

- (1) Sight distance is the length of roadway visible to a driver. The three types of sight distance common in roadway design are intersection sight distance, stopping sight distance, and passing sight distance. This chapter will discuss intersection sight distance and stopping sight distance. Information on passing sight distance can be found in Chapter 12 of this manual and in Chapter 3 of the AASHTO *A Policy on Geometric Design of Highways and Streets* (Green Book).
- (2) A sight distance study at an intersection includes four key steps:
 - Determine the minimum recommended sight distance.
 - Obtain or construct sighting and target rods.
 - Measure current sight distances and record observations.
 - Perform sight distance analysis.

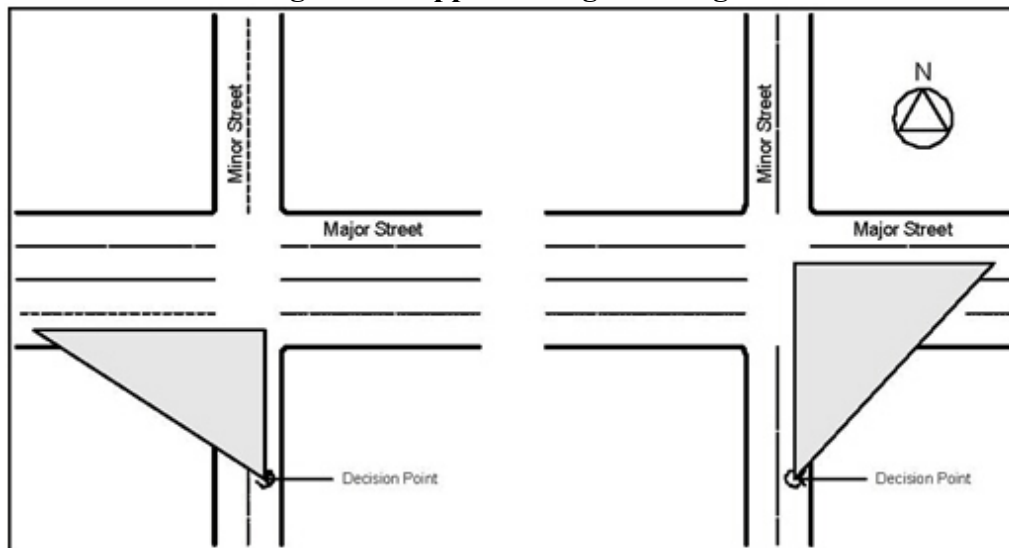
6.2 INTERSECTION SIGHT DISTANCE

- (1) The driver of a vehicle approaching or departing from an intersection should have an unobstructed view of the intersection, including any traffic control devices, and sufficient lengths along the intersecting highway to permit the driver to anticipate and avoid potential collisions (Maze and Plazak 2000). These unobstructed views form triangular areas known as sight triangles.
- (2) A typical intersection is divided into areas between each leg known as quadrants. Sight triangles are the specified areas along an intersection's approach legs and across the included corners (see Figures 6-1 and 6-2 for an illustration). These areas should be clear of obstructions that might block a driver's view of conflicting vehicles or pedestrians. The two types of sight triangles are approach sight triangles and departure sight triangles (AASHTO, *Green Book*, 2004).

6.2.1 APPROACH SIGHT TRIANGLES

Approach sight triangles provide the driver of a vehicle approaching an intersection an unobstructed view of any conflicting vehicles or pedestrians. These triangular areas should be large enough that drivers can see approaching vehicles and pedestrians in sufficient time to slow or stop and avoid a crash. Approach sight triangles are illustrated in Figure 6-1.

Figure 6-1 Approach Sight Triangles

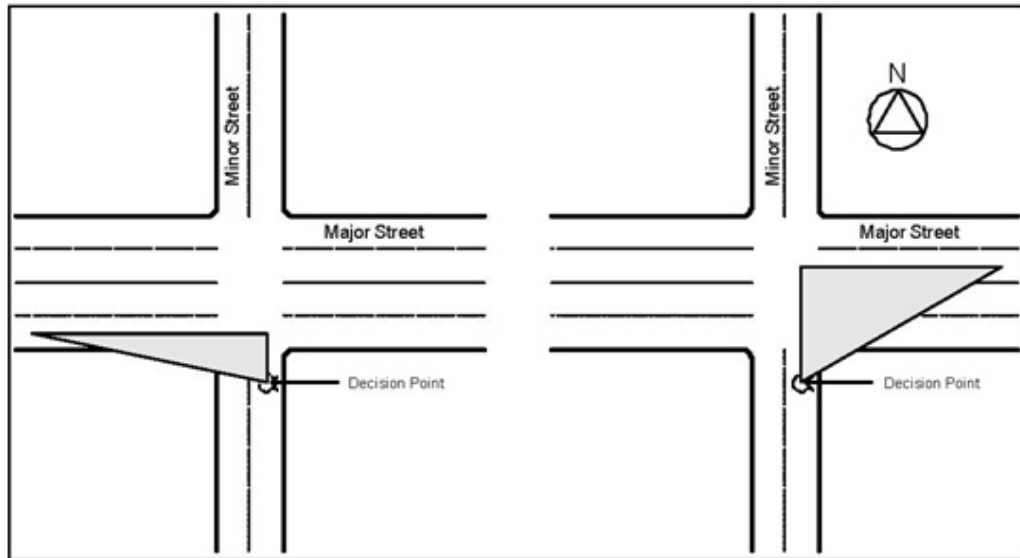


(Source: CTRE)

6.2.2 DEPARTURE SIGHT TRIANGLES

Appropriate departure sight triangles provide adequate sight distance for a stopped driver on a minor roadway to depart from the intersection and enter or cross the major roadway. These sight triangles should be provided in each quadrant of a controlled intersection. Departure sight triangles are illustrated in Figure 6-2.

Figure 6-2 Departure Sight Triangles

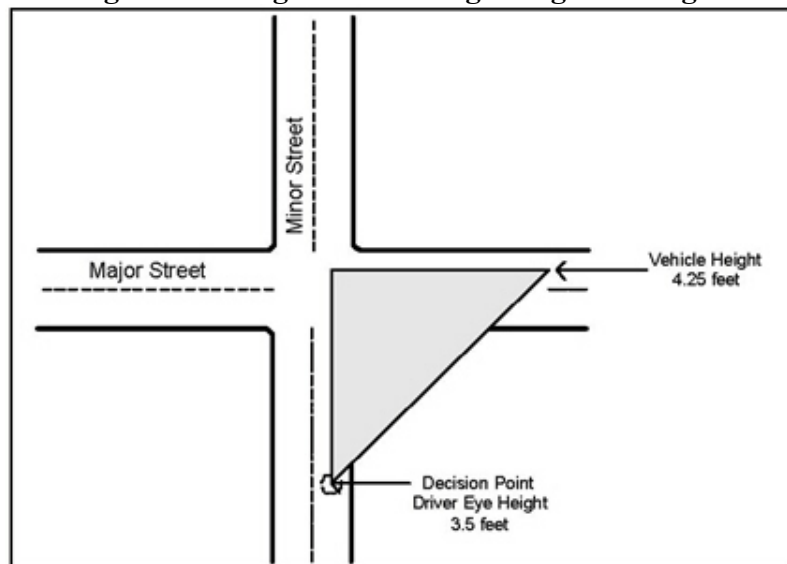


(Source: CTRE)

6.2.3 OBSTRUCTIONS WITHIN SIGHT TRIANGLES

- (I) To determine whether an object is a sight obstruction, consider both the horizontal and vertical alignment of both roadways, as well as the height and position of the object (AASHTO *Green Book*). For passenger vehicles, it is assumed that the driver's eye height is 3.5 feet and the height of an approaching vehicle is 4.25 feet above the roadway surface, as illustrated in Figure 6-3. At the decision point, the driver's eye height is used for the measurement. Sometimes a higher driver's eye height should be considered for drivers of trucks to see underneath the tree canopy.

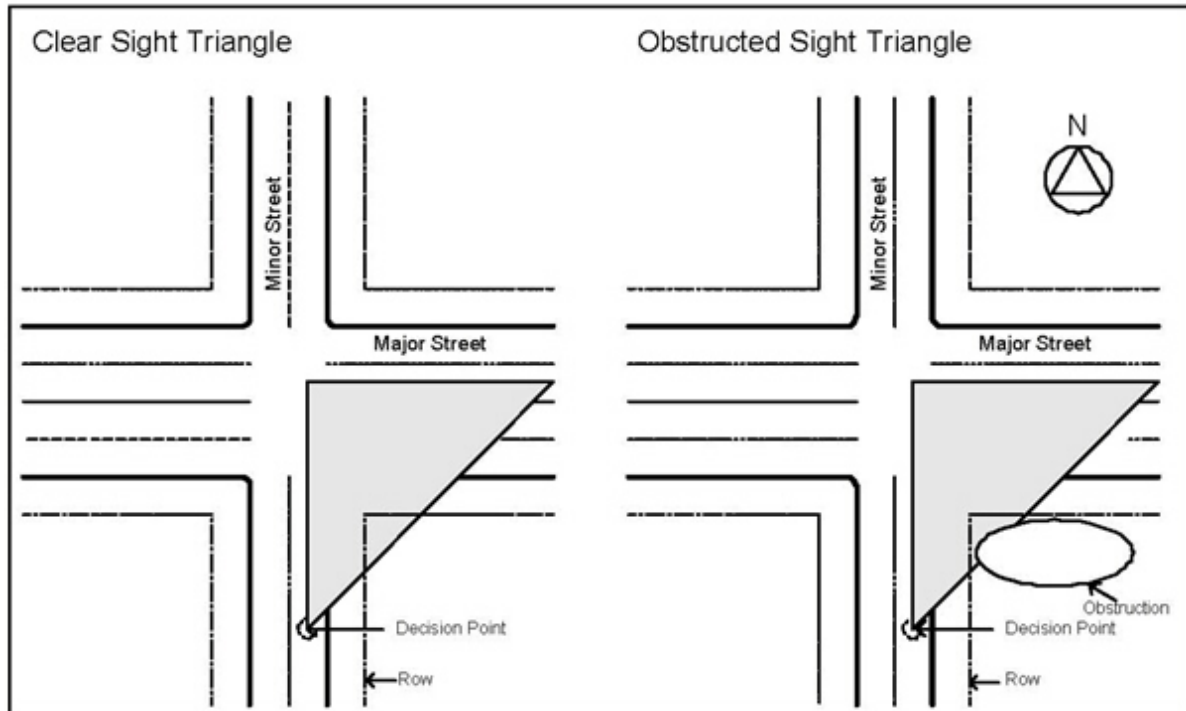
Figure 6-3 Heights Pertaining to Sight Triangles



(Source: CTRE)

- (2) Any object within the sight triangle that would obstruct the driver's view of an approaching vehicle (4.25 feet in height) should be removed or modified or appropriate traffic control devices should be installed as per the *MUTCD*. Obstructions within sight triangles could be buildings, parked vehicles, hedges, trees, bushes, tall crops, walls, fences, etc. Figure 6-4 shows a clear sight triangle and an obstructed sight triangle.

Figure 6-4 Clear Versus Obstructed Sight Triangles



(Source: CTRE)

6.3 ***SIGHT DISTANCE STUDY METHODS***

- (1) Different types of traffic control require different sight distances. For example, intersections with no control require adequate distance for the approaching vehicle to identify any conflicts in or approaching the intersection before entering. An approach sight triangle is used for this analysis. However, intersections with stop control require drivers to stop at the intersection, check for approaching vehicles in the intersection, and then depart. A departure sight triangle is used for this analysis.
- (2) Example sighting and target rods are illustrated in Figure 6-5. The target rod can be constructed out of normal 1x2 dimensional lumber. The target rod should be 4.25 feet tall to represent the vehicle height and be painted fluorescent orange on both the top portion and bottom 2 feet of the rod. The bottom 2-foot portion represents the object height for measuring stopping sight distance (this will be further explained later in Section 6.3.3). The sighting rod should be 3.5 feet tall to represent the driver's eye height. The sighting rod can be constructed out of the same type of wood but should be painted flat black. The sighting rod and target rod are used in measuring sight distance.
- (3) The methods to measure and analyze the approach sight distance for uncontrolled intersection, intersection sight distance for STOP controlled intersections and stopping sight distance are described below.

Figure 6-5 Example Sighting Rod (left) and Target Rod (right)



(Source: CTRE)

6.3.1 UNCONTROLLED INTERSECTIONS

- (1) For uncontrolled intersections, the drivers of both approaching vehicles should be able to see conflicting vehicles in adequate time to stop or slow to avoid a crash. The required sight distance for safe operation at an uncontrolled intersection is directly related to the vehicle speeds and the distances traveled during perception, reaction, and braking time. Table 6-1 lists the minimum recommended sight distances for specific design speeds. For example, for a speed limit of 30 mph, 140 feet is the minimum recommended sight distance along that approach leg.

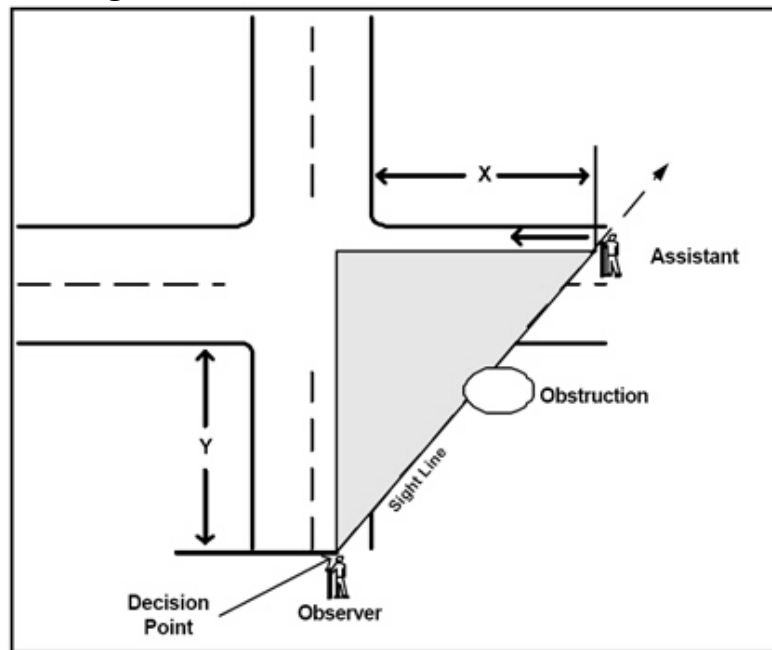
Table 6-1 Length of Sight Triangle Leg (No Traffic Control)

Posted Speed (mph)	Length of Leg (X or Y) (feet)
20	90
25	115
30	140
35	165
40	195
45	220
50	245
55	285
60	325
65	365

(Source: AASHTO *Green Book*, 2004)

- (2) Determine the minimum sight distance for the posted speed on each approach to the intersection per Table 6-1.
- (3) Sight distance measurements should be gathered for all legs of the uncontrolled intersection. Traffic approaching from both the left and right should be considered for measurements. The observer records the date and time, posted or operating speed, site location, and weather conditions on the sight distance diagram. The measuring process is represented in Figure 6-6 and described below.

Figure 6-6 Sight Distance Measurement at Uncontrolled Intersection



(Source: CTRE)

- (4) The observer holds the sighting rod, and the assistant holds the target rod. They position themselves on two intersecting approaches at the appropriate stopping sight distances taken from Table 6-1. These are the X and Y dimensions. The observer represents the approaching vehicle and is located at the decision point. The observer uses the 3.5-foot sighting rod, which represents the driver's eye height. The assistant represents the intersecting vehicle. The assistant uses the 4.25-foot target rod, which represents the height of the approaching vehicle. The observer sights from the top of the sighting rod to the target rod.
- (5) If the target rod is visible, the approach sight triangle for the intersection is appropriate. If the top of the target rod is not visible, the assistant holding the target rod should walk toward the intersection along the centerline of the intersecting lane until the observer can see the target rod. When the target rod is visible, the position should be marked and the distance to the intersection should be measured along the centerline of the roadway. This is the X dimension.
- (6) The analysis of intersection sight distance consists of comparing the recommended sight distance to the measured sight distance. The measured sight distance should be equal to or greater than the recommended stopping sight distance. If the measured sight distance is less than the recommended sight distance, some mitigation may be required. Some mitigation measures are as follows:
 - (a) Remove/modify obstruction.
 - (b) Reduce speeds (Note: posting lower speed limits alone is seldom effective).
 - (c) Install traffic control devices (if warranted by the MUTCD).

6.3.2 INTERSECTIONS CONTROLLED WITH STOP SIGNS

- (1) Vehicles stopped at an intersection must have sufficient sight distance to permit a safe departure. At intersections with stop sign control, close attention should be given to departure sight triangles.
- (2) Three maneuvers can be completed by vehicles stopped at an intersection: crossing maneuver, left-turn maneuver, and right-turn maneuver.
- (3) When a driver is completing a crossing maneuver, there must be sufficient sight distance in both directions available to cross the intersecting roadway and avoid approaching traffic. The sight distance required for this maneuver is based on the distance approaching vehicles will travel on the major road during the time it takes a stopped vehicle to clear the intersection. Table 6-2 lists the recommended sight distances for this maneuver based on design speeds.
- (4) The left-turn maneuver requires first clearing the traffic on the left, then entering the traffic stream from the right. The required sight distance for this maneuver is affected by the amount of time it takes the stopped vehicle to turn left, clearing traffic from the left and reach average running speed without affecting the speed of an approaching vehicle from the right. Table 6-2 lists the recommended sight distances for this maneuver based on design speeds.
- (5) The right turn maneuver must have sufficient sight distance to permit entrance onto the intersecting roadway and then accelerate to the posted speed limit without being overtaken by approaching vehicles from the left. Table 6-2 lists the recommended sight distances for this maneuver based on design speeds.

Table 6-2 Intersection Sight Distance (STOP Controlled)

Posted Speed (mph)	Sight Distance for Left-Turn Maneuver (feet)	Sight Distance for Crossover and Right-Turn Maneuvers (feet)
20	225	195
25	280	240
30	335	290
35	390	335
40	445	385
45	500	430
50	555	480
55	610	530
60	665	575
65	720	625
70	775	670

(Source: AASHTO Green Book, 2004)

- (6) To measure the intersection sight distance, first determine the minimum sight distance for each maneuver and speed (see Table 6-2).
- (7) The observer records the date and time, posted or operating speed, site location, and weather conditions on the sight distance diagram.
- (8) The sight distance should be measured in each direction from each minor street approach. The line of sight should be from the driver's eye position where traffic would normally be expected to stop and look for gaps in approaching traffic (a typical rule of thumb is 15 feet from the near edge

of the major street traveled way). Observation of traffic behavior at the intersection should be used to determine the point at which the majority of drivers stop to look for gaps in traffic without encroaching on the through lanes. Measure the intersection sight distance from that point.

- (9) The observer with the sighting rod stands at the center of the approaching lane at the point determined above. The observer's eyes should be at the top of the sighting rod. The assistant walks away from the observer along the intersecting roadway toward approaching traffic. The assistant should stop periodically and place the target rod on the pavement for sighting by the observer. This process should continue until the top of the target rod can no longer be seen. The point where the target rod disappears is the maximum sight distance along that leg. The position should be marked and the distance to the intersection should be measured along the centerline of the roadway.
- (10) The analysis of intersection sight distance consists of comparing the recommended sight distance to the measured available sight distance. The comparison of the actual distances should be performed with consideration to posted speed limit. If the measured sight distance is less than the recommended sight distance some mitigation may be required. Some mitigation measures are as follows:
 - (a) Remove/modify obstruction.
 - (b) Post a reduced advisory speed.
 - (c) Install additional traffic control devices (if warranted by the MUTCD).

6.3.3 STOPPING SIGHT DISTANCE

- (1) The available sight distance on a roadway should be sufficiently long to enable a vehicle traveling at the posted speed to stop before reaching a stationary object in its path. Although greater lengths of visible roadway are desirable, the sight distance at every point along a roadway should be at least that needed for a below-average driver or vehicle to stop (*AASHTO Green Book*). Stopping sight distance is defined as the sum of two distances:
 - (a) Brake reaction distance – the distance traveled by the vehicle from the instant the driver sees an object necessitating a stop to the instant the brakes are applied; plus
 - (b) Braking distance – the distance needed to stop the vehicle from the instant brake application begins.
- (2) The reaction distance is based on the reaction time of the driver and the speed of the vehicle. The braking distance is dependent upon the vehicle speed and the coefficient of friction between the tires and roadway.
- (3) Table 6-3 lists minimum recommended stopping sight distances based on design speed and the sum of reaction distance and braking distance rounded to the nearest 5 feet for ease of application. At 55 mph, for example, the recommended stopping sight distance is 495 feet.
- (4) For stopping distance calculations, the height of the driver's eye is 3.5 feet above the roadway and the object height is 2 feet above the roadway surface, as illustrated in Figure 6-7. The 2-foot object height represents an object that the driver of an approaching vehicle would want to avoid.
- (5) One element to consider for stopping sight distance is vertical curvature of the roadway. On straight roadway sections, the obstruction that blocks the driver's vision of the roadway ahead is the vertical curvature of the road surface. As the vertical curvature increases, stopping sight distance also increases.
- (6) Determine the minimum stopping sight distance for the posted speed limit (see Table 6-3).
- (7) The observer records the date and time, posted or operating speed, site location, and weather conditions on the sight distance diagram.

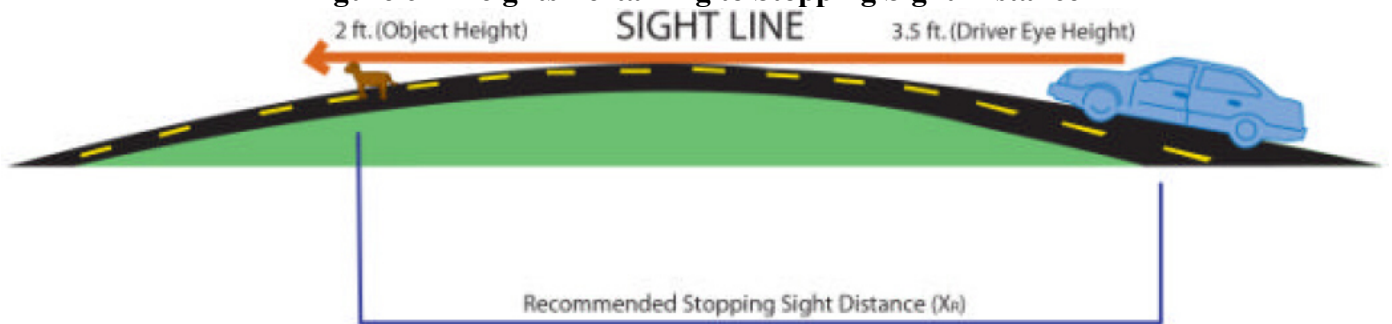
- (8) Standing at a pre-determined location along the road, the observer should sight from the top of the sighting rod while the assistant moves away in the direction of travel. The assistant stops when the bottom 2-foot portion of the target rod is no longer visible. This is the distance at which a 2-foot tall object can no longer be seen by an approaching driver. The distance from the disappearing point to the observer is measured and recorded.

Table 6-3 Stopping Sight Distance

Design Speed (mph)	Stopping Sight Distance (feet)
20	115
25	155
30	200
35	250
40	305
45	360
50	425
55	495
60	570
65	645
70	730
75	820
80	910

(Source: AASHTO Green Book, 2004)

Figure 6-7 Heights Pertaining to Stopping Sight Distance



(Source: CTRE)

- (9) The analysis of stopping sight distance consists of comparing the recommended sight distance to the measured sight distance. The measured stopping sight distance should be greater than the recommended stopping distance. On a horizontal curved roadway, a sight obstruction may be due to the curve or to physical features outside of the roadway. On a straight roadway, the sight obstruction will be due to the vertical curvature of the roadway.

CHAPTER 7 – CRASH STUDY

7.1 PURPOSE

- (1) The purpose of a Crash Study is to review the crash history associated with the study intersection. The crash analysis should include the latest five years of available crash data. This data is used to identify any crash patterns or trends that may be occurring at the intersection.
- (2) WYDOT has several tools for the retrieval and analysis of crash data:
 - (a) Individual crash reports are contained on the ReportBeam website. Users must obtain a username and password from the Highway Safety Program in order to access the online crash data.
 - (b) The Wyoming Electronic Crash Reporting System (WECRS) crash database can be queried using Crystal Reports to get a list of crashes at a specific intersection or along a specific corridor.
 - (c) The WECRS crash data is periodically (typically quarterly) processed through the Critical Analysis Reporting Environment (CARE), which can be used to locate and analyze crash data in a number of ways such as pin maps, hotspot analysis, etc.

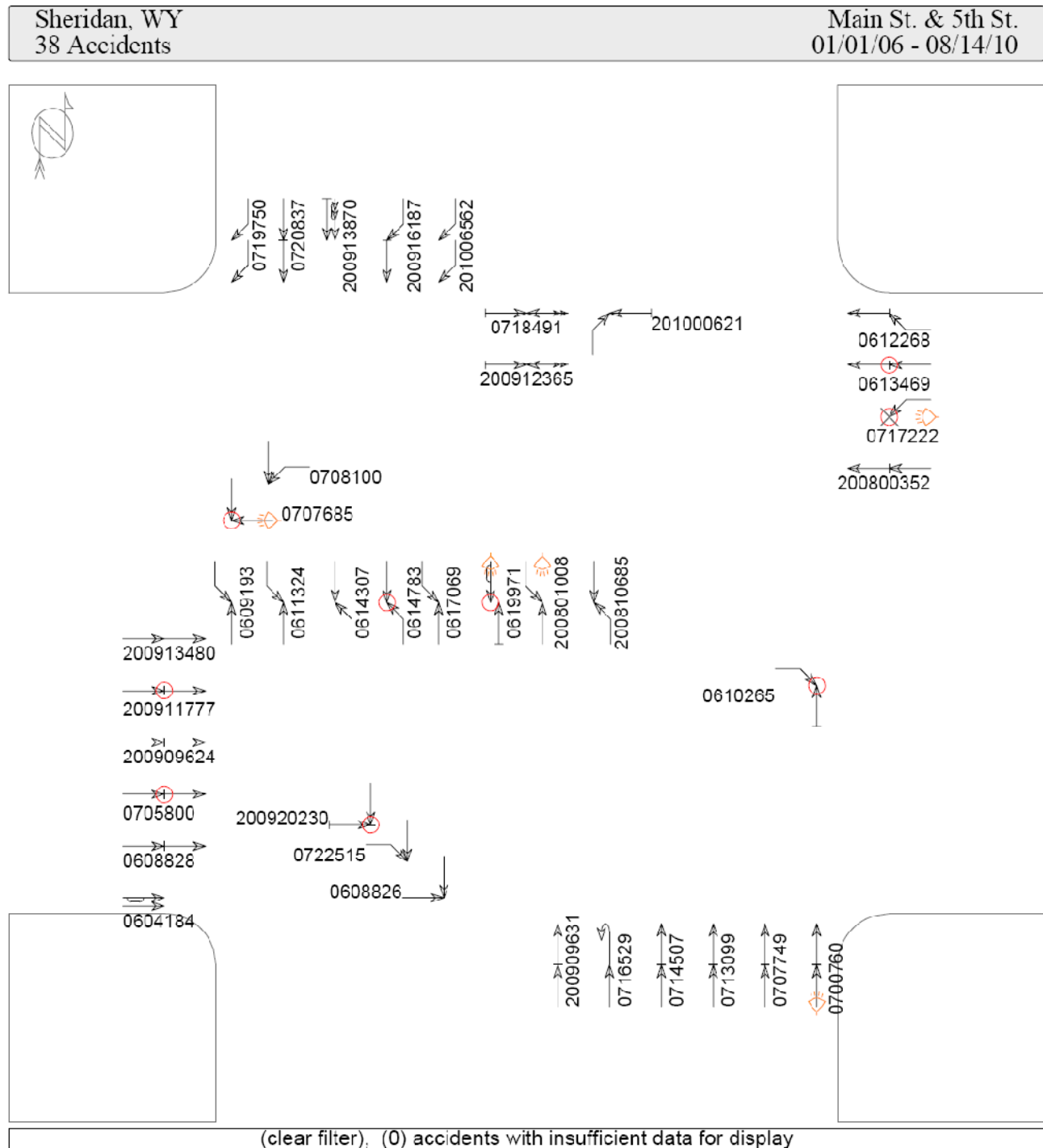
7.2 COLLISION DIAGRAM

- (1) The collision diagram is used to pictorially represent different types of crashes that have occurred at a particular intersection. Figure 7-1 is an example of a collision diagram. Collision diagrams are typically generated by Intersection Magic for the referenced intersection.
- (2) All intersection related crashes should be shown on the diagram with their respective Crash ID numbers. The primary graphic consideration is to properly show the direction of original travel, coupled with a curve in the approach line representing the beginning of the path the vehicle would have followed, if turning. If a pedestrian is struck, the general location by crosswalk and direction of travel should be diagrammed. Similarly, a fixed object crash should be shown in the correct quadrant of the intersection.

7.3 CRASH LISTING

- (1) The crash listing is a detailed summary of the crash information represented in the collision diagram. Figure 7-2 is an example of a crash listing. Crash listings are typically generated by Intersection Magic for the referenced intersection.
- (2) In reviewing the summary of the crash information, the following factors are important. The day of the week can be significant because certain parking and turning restrictions may apply only on weekends. The date is necessary to allow the separation of crashes which may have occurred before or after a change in control, improvement, or increased traffic volume. The time of occurrence is important for developing crash rates as a function of traffic volume during certain time periods, for performing violation or other observance studies, and for possibly limiting applications of certain regulations during specific hours of the day.

Figure 7-1 Example Collision Diagram




← Straight	 Parked	× Pedestrian	Fixed objects:	
← Stopped	← Erratic	⊗ Bicycle	□ General	▣ Pole
← Unknown	← Out of control	○ Injury	▣ Signal	▣ Curb
↔ Backing	↗ Right turn	⊙ Fatality	▣ Tree	⊗ Animal
↔ Overtaking	↖ Left turn	🌙 Nighttime	◀ 3rd vehicle	
↔ Sideswipe	↻ U-turn	🚔 DUI	✱ Extra data	

Figure 7-2 Example Intersection Magic Crash List

Intersection Magic VER 6.714
State of Wyoming DOT, WY 02/15/2011

Accident listing
01/01/2006 - 08/14/2010
Main St. & 5th St.
Sheridan, WY
Sorted by <DATE;TIME;ACC#>

CASE ID	STREET 1	DATE	TIME	DAY	INJ	FAT	V1 DIR	V1 MANEUV	V2 DIR	V2 MANEUV	1ST HARMF	COLL TYPE	LIGHTING	ROAD COND	DUI
0604184	ML302B	03/04/2006	11:00	Sat	No	No	East	Straight	East	Straight	Motor Veh	Sideswipe	Daylight	Dry	Nul
0608826	ML302B	05/31/2006	15:00	Wed	No	No	South	Straight	East	Straight	Motor Veh	Angle Dir	Daylight	Dry	Nul
0608828	ML330B	06/01/2006	17:00	Thu	No	No	East	Straight	East	Straight	Motor Veh	Rear End	Daylight	Dry	Nul
0609193	ML302B	06/02/2006	15:00	Fri	No	No	South	Turning L	North	Straight	Motor Veh	Other	Daylight	Dry	Nul
0610265	ML302B	06/22/2006	12:00	Thu	1 I	No	East	Turning R	North	Stopped i	Motor Veh	Other	Daylight	Dry	Nul
0611324	ML302B	07/08/2006	9:00	Sat	No	No	South	Turning L	North	Straight	Motor Veh	Other	Daylight	Dry	Nul
0614307	ML302B	07/23/2006	12:00	Sun	No	No	North	Turning L	South	Straight	Motor Veh	Other	Daylight	Dry	Nul
0612268	ML1704B	07/26/2006	18:00	Wed	No	No	West	Turning R	West	Stopped i	Motor Veh	Other	Daylight	Dry	Nul
0613469	ML1704B	08/15/2006	12:00	Tue	1 I	No	West	Straight	West	Stopped i	Motor Veh	Rear End	Daylight	Dry	Nul
0614783	ML302B	09/06/2006	13:00	Wed	1 I	No	North	Turning L	South	Straight	Motor Veh	Other	Daylight	Dry	Nul
0617069	ML302B	10/09/2006	8:00	Mon	No	No	South	Turning L	North	Straight	Motor Veh	Other	Daylight	Wet	Nul
0619971	ML302B	11/22/2006	21:00	Wed	1 I	No	South	Straight	North	Stopped i	Motor Veh	Sideswipe	Darkness	Dry	Nul
0700760	ML302B	01/21/2007	25:00	Sun	No	No	North	Straight	North	Stopped i	Motor Veh	Rear End	Darkness	Ice/Frost	Nul
0705800	ML330B	03/18/2007	11:00	Sun	1 I	No	East	Straight	East	Stopped i	Motor Veh	Rear End	Daylight	Dry	Nul
0707685	ML302B	04/26/2007	23:00	Thu	1 I	No	West	Straight	South	Straight	Motor Veh	Angle Dir	Darkness	Dry	Nul
0707749	ML302B	04/29/2007	15:00	Sun	No	No	North	Straight	North	Stopped i	Motor Veh	Rear End	Daylight	Dry	Nul
0708100	ML302B	05/01/2007	17:00	Tue	No	No	West	Turning L	South	Straight	Motor Veh	Other	Daylight	Dry	Nul
0713099	ML302B	07/26/2007	17:00	Thu	No	No	North	Straight	North	Stopped i	Motor Veh	Rear End	Daylight	Dry	Nul
0714507	ML302B	08/20/2007	18:00	Mon	No	No	North	Straight	North	Stopped i	Motor Veh	Rear End	Daylight	Dry	Nul
0717222	ML330B	09/23/2007	21:00	Sun	1 I	No	West	Turning L	10	Non-motor	Pedestria	Unknown	Darkness	Dry	Nul
0716529	ML302B	09/25/2007	16:00	Tue	No	No	North	Make U-Tu	North	Straight	Motor Veh	Angle Dir	Daylight	Dry	Nul
0718491	ML330B	10/12/2007	13:00	Fri	No	No	West	Backing	East	Stopped i	Motor Veh	Head On	Daylight	Dry	Nul
0719750	ML302B	11/13/2007	15:00	Tue	No	No	South	Turning R	South	Turning R	Motor Veh	Other	Daylight	Dry	Nul
0720837	ML302B	12/01/2007	16:00	Sat	No	No	South	Straight	South	Stopped i	Motor Veh	Rear End	Dusk	Snow	Nul
0722515	ML302B	12/13/2007	8:00	Thu	No	No	South	Straight	East	Turning R	Motor Veh	Other	Daylight	Unknown	Nul
200800352	ML330B	01/08/2008	16:00	Tue	No	No	West	Straight	West	Stopped i	Motor Veh	Rear End	Dusk	Dry	Nul
200801008	ML60B	01/28/2008	16:00	Mon	No	No	Southe	Turning L	North	Straight	Motor Veh	Angle Rig	Darkness	Snow	Nul
200810685	ML60B	07/27/2008	12:00	Sun	No	No	Northw	Turning L	South	Straight	Motor Veh	Angle (Fr	Daylight	Dry	Nul
200909631	ML60B	07/09/2009	16:00	Thu	No	No	North	Straight	North	Straight	Motor Veh	Rear End	Daylight	Dry	Nul
200909624	ML1704B	07/10/2009	8:00	Fri	No	No	East	Straight	East	Stopped i	Motor Veh	Rear End	Daylight	Dry	Nul
200911777	ML330B	07/13/2009	15:00	Mon	1 I	No	East	Straight	East	Stopped i	Motor Veh	Rear End	Daylight	Dry	Nul
200912365	ML330B	08/14/2009	11:00	Fri	No	No	West	Backing	East	Stopped i	Motor Veh	Rear to F	Daylight	Dry	Nul
200913480	ML1704B	09/12/2009	12:00	Sat	No	No	East	Straight	East	Straight	Motor Veh	Angle Rig	Daylight	Dry	Nul
200913870	ML60B	09/15/2009	11:00	Tue	No	No	South	Overtakin	South	Stopped i	Motor Veh	Sideswipe	Daylight	Dry	Nul
200916187	ML60B	10/30/2009	8:00	Fri	No	No	South	Stopped i	South	Turning R	Motor Veh	Angle (Fr	Daylight	Dry	Nul
200920230	ML330B	12/06/2009	11:00	Sun	1 I	No	South	Straight	East	Stopped i	Motor Veh	Rear End	Daylight	Wet	Nul
201000621	ML60B	01/06/2010	14:00	Wed	No	No	North	Turning R	West	Stopped i	Motor Veh	Angle Sam	Daylight	Snow	Nul
201006562	ML60B	05/28/2010	10:00	Fri	No	No	South	Turning R	South	Turning R	Motor Veh	Angle Dir	Daylight	Dry	Nul

Figure 7-3 Example Crystal Reports Crash List
CRASH HISTORY FOR SHERIDAN AT THE INTERSECTION OF
MAIN ST & 5TH ST
FOR THE PERIOD JAN 1, 2009 THROUGH JAN 31, 2011

DATE	TIME	REPORT NUMBER	CRASH LOCATION	NUM INJ	NUM KIL	JUNCTION RELATION	MANNER OF COLLISION	DIRECTION	ACTIVITY PRIOR	FIRST HARMFUL EVENT	LIGHT COND	ROAD COND	DRIVER ACTION
2009													
07/09/2009	1635	200909631	N MAIN ST 5TH ST/WY 336	0	0	Intersection Related	Rear End (Front to Rear)	North	Straight Ahead	Motor Vehicle In Transport on Roadway	Daylight	Dry	Following too Close
07/10/2009	800	200909624	5TH ST/WY 336 N MAIN ST	0	0	Intersection	Rear End (Front to Rear)	East	Straight Ahead	Motor Vehicle In Transport on Roadway	Daylight	Dry	Following too Close
07/13/2009	1535	200911777	5TH ST/WY 330 MAIN ST	1	0	Intersection Related	Rear End (Front to Rear)	East	Straight Ahead	Motor Vehicle In Transport on Roadway	Daylight	Dry	Following too Close
08/14/2009	1109	200912365	5TH ST/WY 330 MAIN ST	0	0	Intersection Related	Rear to Front (Normally Backing)	West	Backing	Motor Vehicle In Transport on Roadway	Daylight	Dry	Unknown
09/12/2009	1202	200913480	5TH ST/WY 336 MAIN ST	0	0	Intersection	Angle Right (Front to Side, Includes Broadside)	East	Straight Ahead	Motor Vehicle In Transport on Roadway	Daylight	Dry	Ran Red Light
09/15/2009	1129	200913870	N MAIN ST 5TH ST/WY 330	0	0	Intersection Related	Sideswipe Same Direction (Passing)	South	Overtaking/Passing	Motor Vehicle In Transport on Roadway	Daylight	Dry	Improper Passing
10/30/2009	823	200916187	MAIN ST 5TH ST/WY 330	0	0	Intersection	Angle (Front to Side), Opposing Direction	South	Stopped in Traffic	Motor Vehicle In Transport on Roadway	Daylight	Dry	Other Improper Action
12/06/2009	1104	200920230	5TH ST/WY 330 N MAIN ST	1	0	Intersection Related	Rear End (Front to Rear)	South	Straight Ahead	Motor Vehicle In Transport on Roadway	Daylight	Wet	Following too Close
								East	Stopped in Traffic	Motor Vehicle In Transport on Roadway			No Improper Driving
2010													
01/06/2010	1443	201000621	MAIN ST 5TH ST/WY 336	0	0	Intersection	Angle Same Direction (Front to Side)	North	Turning Right	Motor Vehicle In Transport on Roadway	Daylight	Snow	Improper Turn or No Signal
05/28/2010	1038	201006562	N MAIN ST 5TH ST/WY 330	0	0	Intersection Related	Angle Direction not Specified	South	Turning Right	Motor Vehicle In Transport on Roadway	Daylight	Dry	Improper Turn or No Signal
12/15/2010	930	201018458	5TH ST/WY 330 N MAIN ST	0	0	Intersection Related	Rear End (Front to Rear)	East	Straight Ahead	Motor Vehicle In Transport on Roadway	Daylight	Wet	Following too Close
								East	Slowing	Motor Vehicle In Transport on Roadway			No Improper Driving
2011													
01/19/2011	850	201100896	5TH ST N MAIN ST	0	0	Intersection	Rear End (Front to Rear)	South	Turning Right	Motor Vehicle In Transport on Roadway	Daylight	Snow	Drove too Fast for Conditions
								West	Turning Left	Motor Vehicle In Transport on Roadway		Ice/Frost	No Improper Driving

TOTAL CRASHES IN THIS REPORT 12

PDO CRASHES 10
 INJURY CRASHES 2
 FATAL CRASHES 0

TOTAL PERSONS INJURED 2
 TOTAL PERSONS KILLED 0

	NUMBER PERSONS INJURED	NUMBER PERSONS KILLED	PDO* CRASHES	INJURY CRASHES	FATAL CRASHES	TOTAL CRASHES
2009	2	0	6	2	0	8
2010	0	0	3	0	0	3
TOTAL	2	0	9	2	0	11

*PDO = Property Damage Only Crashes; No Injuries, No Fatalities

CHAPTER 8 – STOP SIGN DELAY STUDY

8.1 PURPOSE

The stop sign delay study is used to evaluate the performance of stop-controlled intersections in allowing traffic to enter and pass through, or to enter and turn onto another route. This study will effectively provide a detailed evaluation of stopped time delay at the intersection. This study is generally used in conjunction with Warrant 2 (Interruption of Continuous Traffic) and Warrant 3 (Peak Hour Delay).

8.2 STOP SIGN DELAY STUDY

- (1) The stop sign delay study should be collected using an electronic traffic data collector such as a JAMAR Technologies TDC-8 or TDC-12.
- (2) The stop sign delay study is designed to measure the traffic characteristics at an intersection controlled by a STOP sign. Although it primarily measures delay, it also provides information about the queue length and traffic volume on an approach. The study procedure is detailed in the respective User's Manual for the TDC-8 or TDC-12. Figure 8-1 is an example of the stop sign delay study output with 15-minute intervals and hourly summaries.
- (3) A stop sign delay study should be used to measure delays during the highest peak hour of each of the three peak periods (i.e., AM, Noon and PM). The correct hours to study can be determined by first completing a turning movement count (Chapter 4) at the intersection.

8.3 FIELD OBSERVATION

- (1) Stop sign delay studies are normally done at one approach to an intersection. Typically, the approach with the highest volume would be studied, since that approach would likely have the longest delays and would experience the greatest overall delay. One or two lanes can be measured at once.
- (2) If the study is interested in knowing the queue lengths or specific details about the length of delay experienced by individual vehicles, then delays on each lane of the approach must be measured separately.
- (3) If the study is being used only to determine the average stopped delay for the entire approach (not necessarily by lane) and the reviewer is not necessarily concerned with vehicle queues, multiple lanes can be measured simultaneously by using only one set of "stop" and "go" buttons on the board. This method will not accurately measure queues or individual vehicle delays, but can be used as a quick check to determine total approach delay and average delay per vehicle for the entire approach. Using this method allows the data collector to also measure the total stopped delay and average stopped delay per vehicle on the opposing STOP controlled approach by using the second set of "stop" and "go" buttons for the opposing approach.

Figure 8-1 Example Stop Sign Delay Study
Wyoming Department of Transportation
Traffic Program
Safety & Studies Section
Cheyenne, WY

Intersection: Pine & Tyler
 Counted By: Auzqui & Nelson
 Weather:
 Comments:

File Name : Pine&TylerPM
 Site Code : 00000003
 Start Date : 6/29/2004
 Page No : 1

Summary Information:

3:00:00 PM - 4:00:00 PM	Southbound
Total Vehicle Count:	50
Delayed Vehicle Count:	50
Through Vehicle Count:	0
Average Stopped Time:	13.48
Maximum Stopped Time:	51
Min. Secs. for Delay:	0
Average Queue:	0.19
Queue Density:	1.16
Maximum Queue:	2
Delay in Vehicle Hour:	0.19
Total Delay:	674

Summary Information:

4:00:00 PM - 5:00:00 PM	Southbound
Total Vehicle Count:	39
Delayed Vehicle Count:	39
Through Vehicle Count:	0
Average Stopped Time:	11.97
Maximum Stopped Time:	55
Min. Secs. for Delay:	0
Average Queue:	0.13
Queue Density:	1.08
Maximum Queue:	2
Delay in Vehicle Hour:	0.13
Total Delay:	467

Summary Information:

3:00:00 PM - 5:00:00 PM	Southbound
Total Vehicle Count:	89
Delayed Vehicle Count:	89
Through Vehicle Count:	0
Average Stopped Time:	12.82
Maximum Stopped Time:	55
Min. Secs. for Delay:	0
Average Queue:	0.16
Queue Density:	1.13
Maximum Queue:	2
Delay in Vehicle Hour:	0.16
Total Delay:	1141

CHAPTER 9 – PEDESTRIAN GAP STUDY

9.1 *PURPOSE*

- (1) The gap study is used to determine the size and the number of gaps in the vehicular traffic stream that are of adequate length to permit pedestrians to cross.
- (2) A gap is normally defined as the amount of time, in seconds, between when the end of one vehicle passes a point on the roadway and when the front of the next vehicle passes the same point.
- (3) You can measure gaps on the entire road, with several lanes of traffic going in different directions, or you can measure gaps on individual lanes. It depends on the data that is required.
- (4) A pedestrian gap study consists of measuring the predominant pedestrian group size, determining the length of minimum adequate gap, measuring the gap sizes in the traffic stream, and determining the sufficiency of adequate gaps.
- (5) The principal application of the study results is in analyzing roadway crossings by pedestrians to determine appropriate traffic controls and safety improvements. The results of gap studies are used in pedestrian and school crossing studies and in traffic signal warrant analyses.

9.2 *PEDESTRIAN GAP STUDY FORM*

- (1) The Pedestrian Gap Study form (Form TR-12) is used to determine the pedestrian group size, minimum adequate gap length and to determine the frequency and duration of adequate gaps available at the crossing location. A blank form can be printed for use in the field to gather the data, and then the .PDF form can be completed in-house for a clean presentation of the data and calculations.
- (2) In order to accurately analyze the data, the top portion of the Pedestrian Gap Study form should be filled in as completely as possible. Enter the location so that the study location is thoroughly identified. The U.S. route numbers, state route numbers, and county road or street names should be included if applicable.
- (3) Enter the county, city, date, time of study, and the observer making the study. Identify the street associated with the crosswalk. Enter the width of the street from edge to edge or from curb to curb. If the roadway has a raised median, indicate by circling YES; if not, circle NO. If divided, indicate the width of the median. Also include any remarks that may affect the data being collected.

9.3 *PEDESTRIAN GROUP SIZE SURVEY*

- (1) The purpose of the pedestrian group size survey is to determine the 85th-percentile group size of pedestrians that cross the street at the pedestrian gap study location.
- (2) Pedestrians waiting to cross a roadway will generally arrange themselves in rows one behind the other. Group size is comprised of row width and number of rows. When the group starts to cross, they enter the roadway (step off the curb) with approximately 2 seconds of headway between rows. Since the factor of interest is the amount of time it takes the entire group to enter the crossing, it is only necessary to determine the predominant number of rows entering the crossing. The width of the rows and the total number of pedestrians in the group are inconsequential.
- (3) Distinguishing distinct rows may be somewhat difficult at first. With some training and experience, however, observers manage easily. A sample of 30 to 50 groups is usually sufficient to establish the group size (i.e., number of rows per group). This measurement should be made

during the time and under the conditions of interest for the gap study. The observer should be positioned unobtrusively perpendicular to the crossing and parallel to the roadway with a clear view of the crossing point with the heaviest concentration of pedestrians.

- (4) Observe each group as they enter the crossing. Place a tick mark in the tally column corresponding to the number of rows in the group. Stragglers are not included. Groups will form naturally when gaps are inadequate to accommodate random arrivals. When the sampling period is complete, count the tally marks and record the frequency of each corresponding group size in the total column. The sum of the total column will be the total number of groups sampled.
- (5) The remainder of the pedestrian group size survey portion of the form is completed by multiplying the total number of groups by 0.85 to obtain the number of groups at or below the 85th-percentile group size. The 85th-percentile group size is the group size that contains that value.
- (6) Figure 9-1 gives an example of a completed pedestrian group size study.

9.4 MINIMUM ADEQUATE GAP

- (1) Having calculated the 85th-percentile group size, the minimum adequate gap time (G) required for crossing the street can be found by using the following equation:

$$\text{Equation 9-1}$$

$$G = \frac{W}{S} + 2(N - 1) + 3$$

Where:

G	=	Minimum adequate gap time (seconds)
W	=	Width of roadway in feet
S	=	Assumed walking speed in feet/second (use 3.5 for students and 4.0 for normal pedestrian traffic)
$2(N - 1)$	=	Pedestrian clearance time
N	=	Number of rows in 85th-percentile group size
2	=	Time interval between rows (Headway) in seconds
3	=	Perception and reaction (Start-up) time in seconds

- (2) This value is the minimum length in seconds of a gap in traffic which will permit an 85th-percentile group of pedestrians to cross a roadway of specified width from a point of relative safety on one side to a point of relative safety on the other side without a vehicle crossing their path.
- (3) To determine the impacts of traffic on the calculated minimum adequate gap time, the vehicle gap size should be analyzed as shown in the available gap survey portion of the pedestrian gap study form (see Figure 9-1). The results of both pedestrian group size survey and available gap survey (see Section 9.5) will determine if controls are warranted.

Figure 9-1 Example of Pedestrian Gap Study Form

FORM TR-12		WYOMING DEPARTMENT OF TRANSPORTATION		REV: 9/17/2010	
PEDESTRIAN GAP STUDY					
PEDESTRIAN GROUP SIZE SURVEY		LOCATION: Main St. & D St.			
COUNTY: Fremont		CITY: Dubois			
STUDY DATE: 4/31/10		TIME FROM: 3:30 PM		TO: 4:30 PM	
OBSERVER: JDT					
CROSSWALK ACROSS: Main St.		CURB TO CURB DISTANCE (W): 60 ft.			
RAISED MEDIAN? No		WIDTH OF MEDIAN: N/A ft.			
REMARKS:					
GROUP SIZE	NO. OF ROWS (N)	NUMBER OF GROUPS		CUMULATIVE TOTAL	COMPUTATIONS
		TALLY	TOTAL		
3 or less	1		27	27	<---- Contains 26.4
4-6	2		3	30	
7-9	3	/	1	31	
10-12	4				
13-15	5				
16-18	6				
19-21	7				
22-24	8				
25-27	9				
27-30	10				
Total Number of Groups			31	x 0.85 = 26.4	N = 1
MINIMUM ACCEPTABLE GAP, $G = W/S + 2(N - 1) + 3 = 60 / 3.5 + 2(1 - 1) + 3 = 21$ seconds					

AVAILABLE GAP SURVEY		DATE: 4/31/10	TIME FROM: 3:30 PM	TO: 4:30 PM	DURATION 60 MIN.
GAP (seconds)	NUMBER OF GAPS		MULTIPLY BY GAP SIZE	COMPUTATIONS	
	TALLY	TOTAL			
10				Pedestrian Delay (D): $T = \text{Duration} \times 60$ $= 60 \times 60$ $= 3600 \text{ sec.}$ $D = \frac{(T - t) \times 100}{T}$ $D = \frac{(3600 - 1590) \times 100}{3600}$ Ped. Delay = 56 % Average No. of Adequate Gaps / Five-min. Period (P) $P = \frac{A}{\text{Duration} / 5}$ $= \frac{63}{60 / 5}$ $= 5 \text{ Adequate gaps 5-min. period}$	
11					
12					
13					
14					
15					
16					
17					
18	/				
19					
20	/	<Ignore gaps	less than 21 sec.		
21		22	462		
22		5	110		
23		5	115		
24		3	72		
25		4	100		
26		4	104		
27					
28		4	112		
29		2	58		
30	/	1	30		
31		4	124		
32	/	1	32		
33		5	165		
34	/	1	34		
35					
36		2	72		
37					
38					
39					
40					
Total Adequate Gaps (A)		63	1590 sec.	<Total Time Of All Gaps (t) ≥ G	

9.5 MEASURING GAP SIZES

- (1) The next part of the field study is to measure the time lengths of the gaps in traffic.
- (2) Gap studies can be broken into two types of studies – multi-direction gap studies or total (combined direction) gap studies. Multi-direction gap studies (see Section 9.5.1) measure the gaps in each direction as well as the distribution of gaps across both directions. Typically this is used at an unsignalized intersection or mid-block crossing location to determine if the addition of a raised median to provide a pedestrian refuge island will provide adequate crossing opportunities for pedestrians. The total (combined direction) gap study (see Section 9.5.2) measures the duration of gaps across both directions of vehicular travel. This is typically used for pedestrian crossings without median refuge islands.

9.5.1 MULTI-DIRECTION GAP STUDY

- (1) The standard Gap Study procedure provided in the electronic traffic data collectors such as the JAMAR Technologies TDC-8 or TDC-12 traffic data collectors must be used to perform multi-direction Gap Studies. The multi-direction Gap Study procedure is detailed in the respective User's Manual for the TDC-8 or TDC-12 electronic traffic data collector.
- (2) Preferably, the study interval should be set to 5 minutes at the beginning of the study to better facilitate the determination of adequate gaps per 5-minute period (per the WYDOT Pedestrian and School Crossing Traffic Control Manual, 2003). If the study is performed with shorter intervals, the final analysis can use longer intervals. On the other hand, the final analysis cannot be performed on intervals less than those set during the initial study. When printing the study data, only one direction at a time or the combined direction can be selected in the Gap Print Setup screen or the results will be added together resulting in numbers that are higher than actuality.

Gap Print Setup

General | Peak | Comments | Factor | Page | Headings

Select Interval Length

☐ No Data

☐ 1 Minute

☐ 5 Minutes

☒ 15 Minutes

☐ 30 Minutes

☐ 60 Minutes

☐ Grand Total

Empty Intervals

☒ Hide Empty Intervals

Wording:

From - To

First Interval: 15:00 2/25

Last Interval: 15:45 2/25

Options

☒ Print Comments

☐ Print Peaks

☐ Intersection Drawing

☐ Intersection Photo

☐ Do NOT Print Headings

☐ Hide Header Information

Combine Groups

☒ SB 4th St

☐ NB 4th St

☐ Combined

☐ Not Used

☐ Not Used

☐ Not Used

☐ Not Used

☐ Not Used

☐ Not Used

☐ Not Used

☐ Not Used

☐ Not Used

☐ Not Used

☐ Not Used

Preview | Print | Save Print Defaults | Close | Help

- (3) Figure 9-2 gives an example of the output from a multi-direction gap study, showing the gaps for each direction as well as the total (combined direction) gaps.
- (4) For divided roadways with sufficient median width for storage to accommodate two separate crossings, a multi-direction gap study should be performed so the gap size can be determined for each direction of vehicular travel.

Figure 9-2 Example Multi-Direction Gap Study Output
Wyoming Department of Transportation
 Traffic Program
 Safety & Studies Section
 Cheyenne, WY

Intersection: 4th & Hamilton
 Counted by: LR
 Weather: Cool
 Comments: Signal Turned Off

File Name: hamiltongap
 Site Code: 00021304
 Start Date: 4/31/2009
 Page No: 1

Direction: NB 4th St

Start Time	Volume	2 - 3	4 - 5	6 - 7	8 - 9	10 - 11	12 - 13	14 - 15	16 - 17	18 - 19	20 - 21	22 - 23	24 - 25	26 - 27	28 - 29	>29	Int. Total	Average
Factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
03:00 PM	85	7	7	7	5	4	3	6	0	2	3	1	1	0	2	2	50	8 - 9
03:15 PM	92	9	11	6	7	11	2	3	3	3	1	2	0	1	1	2	62	8 - 9
03:30 PM	123	13	14	10	9	5	1	3	3	1	1	0	1	1	0	3	65	6 - 7
03:45 PM	104	6	10	6	0	6	5	5	1	1	1	2	2	1	2	3	51	10 - 11
Total	404	35	42	29	21	26	11	17	7	7	6	5	4	3	5	10	228	8 - 9
Grand Total	404	35	42	29	21	26	11	17	7	7	6	5	4	3	5	10	228	8 - 9
Total %		15.4	18.4	12.7	9.2	11.4	4.8	7.5	3.1	3.1	2.6	2.2	1.8	1.3	2.2	4.4		

Direction: SB 4th St

Start Time	Volume	2 - 3	4 - 5	6 - 7	8 - 9	10 - 11	12 - 13	14 - 15	16 - 17	18 - 19	20 - 21	22 - 23	24 - 25	26 - 27	28 - 29	>29	Int. Total	Average
Factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
03:00 PM	73	1	7	9	6	5	0	3	2	0	2	0	1	0	1	7	44	8 - 9
03:15 PM	67	1	7	4	10	3	4	2	5	4	2	0	1	0	2	3	48	10 - 11
03:30 PM	103	2	11	7	6	3	8	4	3	2	3	0	2	0	0	2	53	10 - 11
03:45 PM	78	3	6	7	5	3	6	5	3	1	1	2	0	1	1	5	49	12 - 13
Total	321	7	31	27	27	14	18	14	13	7	8	2	4	1	4	17	194	10 - 11
Grand Total	321	7	31	27	27	14	18	14	13	7	8	2	4	1	4	17	194	10 - 11
Total %		3.6	16.0	13.9	13.9	7.2	9.3	7.2	6.7	3.6	4.1	1.0	2.1	0.5	2.1	8.8		

Direction: Combined

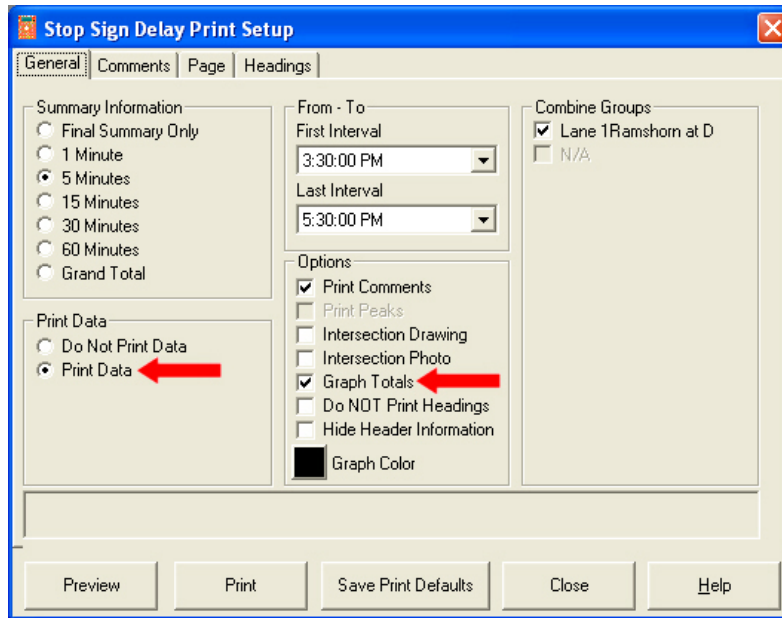
Start Time	Volume	2 - 3	4 - 5	6 - 7	8 - 9	10 - 11	12 - 13	14 - 15	16 - 17	18 - 19	20 - 21	22 - 23	24 - 25	26 - 27	28 - 29	>29	Int. Total	Average
Factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
03:00 PM	158	11	11	11	11	6	4	2	1	1	0	1	1	0	1	0	61	6 - 7
03:15 PM	159	12	19	11	7	10	6	1	3	1	1	1	0	1	0	1	74	6 - 7
03:30 PM	226	22	22	10	6	2	0	3	2	2	0	0	0	0	0	1	70	4 - 5
03:45 PM	182	11	18	15	4	8	3	3	1	1	0	2	2	1	0	1	70	6 - 7
Total	725	56	70	47	28	26	13	9	7	5	1	4	3	2	1	3	275	6 - 7
Grand Total	725	56	70	47	28	26	13	9	7	5	1	4	3	2	1	3	275	6 - 7
Total %		20.4	25.5	17.1	10.2	9.5	4.7	3.3	2.5	1.8	0.4	1.5	1.1	0.7	0.4	1.1		

9.5.2 TOTAL (COMBINED DIRECTION) GAP STUDY

- (1) A total (combined direction) gap study can be performed with either a conventional stop watch or with an electronic traffic data collector such as a JAMAR Technologies TDC-8 or TDC-12.
- (2) There are two acceptable ways to measure the length of gaps using JAMAR Technologies TDC-8 or TDC-12 traffic data collectors. They can be used to perform multi-direction gap studies or total (combined direction) gap studies. If the total gap is the only gap data needed, the traffic data collector's standard gap study procedure can be used or the stop sign delay study can be adapted to measure the available gaps.
- (3) A total (combined direction) gap study can be conducted using the standard gap study procedure on the electronic traffic data collector by combining the multi-direction data together. This is accomplished through the PetraPro software analysis program by checking the combined tab under Combine Groups in the Gap Print Setup window.

The screenshot shows the 'Gap Print Setup' dialog box. The 'General' tab is selected. Under 'Select Interval Length', '15 Minutes' is chosen. Under 'Empty Intervals', 'Hide Empty Intervals' is checked. The 'From - To' section shows 'First Interval' as '15:00 2/25' and 'Last Interval' as '15:45 2/25'. In the 'Options' section, 'Print Comments' is checked. In the 'Combine Groups' section, the 'Combined' checkbox is checked and highlighted with a red arrow. The bottom of the window features buttons for 'Preview', 'Print', 'Save Print Defaults', 'Close', and 'Help'.

- (4) The total number of gaps of each size from the combined groups of the multi-direction study can then be entered directly into the Total column in the available gap survey portion of the pedestrian gap study form.
- (5) The stop sign delay study procedure can be adapted to measure and document the length of each gap over an extended period of time. This is accomplished by marking the beginning of each gap in traffic by pushing the "Vehicle Stops" button and then pushing the "Vehicle Goes" button at the end of the gap. This effectively documents the time and duration of each gap measured. The stop sign delay study procedure is detailed in the respective user's manual for the TDC-8 or TDC-12. When the stop sign delay study (used for measuring gaps) is processed through the PetraPro analysis software, the individual gaps can be displayed, printed and/or exported to a spreadsheet for transfer to the available gap survey portion of the pedestrian gap study form. To print the study displaying the individual gaps, make sure the Print Data toggle on the Stop Sign Delay Print Setup screen is set to Print Data.



- (6) Since the software is set up to display information concerning stop delays, the output data from the stop sign delay study must be reinterpreted for use as a gap study as follows:
- (a) Joined Queue is the time at the beginning of the gap measured
 - (b) Released from Queue is the time at the end of the gap measured
 - (c) Delay is the length of gap (gap size) in seconds
 - (d) Total Vehicle Count and Delayed Vehicle Count should match and is the total number of gaps measured
 - (e) Average Stopped Time is the average gap size
 - (f) Maximum Stopped Time is the maximum gap size measured
 - (g) Average Queue is a relative indicator of the amount of platooning - the lower the value, the more platooning (individual gaps are not usually measured between successive vehicles in platoons)
- (7) Figure 9-3 gives an example of a gap study that was performed using the stop sign delay study procedure.

Figure 9-3 Example of Gap Study Using Stop Sign Delay Procedure
Wyoming Department of Transportation
Traffic Program
Safety & Studies Section
Cheyenne, WY

Intersection: Main St & D St
 Counted by: JDT
 Weather:
 Comments: Gaps on Main St @ D St

File Name: US26Dstgap
 Site Code: 00051000
 Start Date: 4/31/2010
 Page No: 1

		<i>(Beginning of Gap)</i>	<i>(End of Gap)</i>	<i>(Gap Size)</i>	
L	No.	Joined Queue	Released From Queue	Delay	
1	1	3:30:00 PM	3:30:12 PM	12	
1	2	3:30:12 PM	3:30:17 PM	5	
1	3	3:30:18 PM	3:30:22 PM	4	
1	4	3:30:22 PM	3:30:34 PM	12	
1	5	3:30:35 PM	3:30:43 PM	8	
1	6	3:30:44 PM	3:30:52 PM	8	
1	7	3:30:53 PM	3:31:05 PM	12	
1	8	3:31:06 PM	3:31:11 PM	5	
1	9	3:31:11 PM	3:31:16 PM	5	
1	10	3:31:16 PM	3:31:21 PM	5	
1	11	3:31:21 PM	3:31:22 PM	1	
1	12	3:31:22 PM	3:31:24 PM	2	
1	13	3:31:24 PM	3:31:26 PM	2	
1	14	3:31:26 PM	3:31:37 PM	11	
1	15	3:31:37 PM	3:31:49 PM	12	
1	16	3:31:49 PM	3:31:51 PM	2	
1	17	3:31:51 PM	3:31:53 PM	2	
1	18	3:31:53 PM	3:32:01 PM	8	
1	19	3:32:01 PM	3:32:06 PM	5	
1	20	3:32:06 PM	3:32:26 PM	20	
1	21	3:32:26 PM	3:32:36 PM	10	
1	22	3:32:40 PM	3:32:43 PM	3	
1	23	3:32:44 PM	3:32:46 PM	2	
1	24	3:32:47 PM	3:32:53 PM	6	
1	25	3:32:54 PM	3:32:55 PM	1	
1	26	3:32:55 PM	3:33:13 PM	18	
1	27	3:33:16 PM	3:33:27 PM	11	
1	28	3:33:27 PM	3:33:32 PM	5	
1	29	3:33:32 PM	3:33:58 PM	26	
1	30	3:33:58 PM	3:34:02 PM	4	
1	31	3:34:03 PM	3:34:16 PM	13	
1	32	3:34:16 PM	3:34:47 PM	31	
1	33	3:34:47 PM	3:34:50 PM	3	
1	34	3:34:55 PM	3:35:01 PM	6	

Summary Information:

3:30:00 PM - 3:35:00 PM	Lane 1 Main at D
Total Vehicle Count: <i>(Total Gaps Measured)</i>	34
Delayed Vehicle Count: <i>(Total Gaps Measured)</i>	34
Through Vehicle Count:	0
Average Stopped Time: <i>(Average Gap Size)</i>	8.24
Maximum Stopped Time: <i>(Maximum Gap Measured)</i>	31
Min. Secs. for Delay:	0
Average Queue: <i>(An indication of amount of platooning)</i>	0.93
Queue Density:	1.00
Maximum Queue:	1
Delay in Vehicle Hour:	0.93
Total Delay:	280

9.5.3 AVAILABLE GAP SURVEY

- (1) The number of adequate gaps for pedestrians to cross the roadway can be determined based on the calculation of the minimum adequate gap (see Section 9.4) and the measurement of actual gaps available for the crossing location being studied.
- (2) To complete the available gap survey portion of the pedestrian gap study form, note the beginning and ending times and total duration of the study in minutes.
- (3) Place a tick mark in the tally column corresponding to the length of gap measured. Gaps measured by a stop watch are entered directly into the form as they are measured. Gaps measured by an electronic traffic data collector must be downloaded and then transferred to the form.
- (4) Gaps less than the minimum adequate gap do not need to be included on the form; however, documentation of the availability of gaps that are within a few seconds of the minimum adequate gap can be used for the consideration of possible roadway geometric changes that would reduce the crossing distance (e.g., bulb-out curb extensions or narrower lanes) or other measures to reduce the minimum adequate gap time needed for a pedestrian to cross the roadway.
- (5) Gaps that are more than twice as long as the minimum adequate gap can be counted as two or more gaps that are longer than the minimum adequate gap. For example, if the minimum adequate gap is 20 seconds, a gap of 43 seconds can be broken into one 20-second gap and one 23-second gap for purposes of the available gap survey.
- (6) The tally marks are then totaled for each gap size greater than the minimum acceptable gap. The sum of these totals is the number of gaps of sufficient length to accommodate the crossing of 85% of the pedestrian groups using the crossing at a day and time and under the conditions similar to those of the study.
- (7) The total time of all adequate gaps is then determined by multiplying the gap size by the total number of gaps of that size. The sum of these totals is the total amount of time available (t) for pedestrians to cross the roadway.
- (8) Pedestrian Delay can be calculated using the following equation:

$$\text{Equation 9-2}$$
$$D = \frac{(T - t) \times 100}{T}$$

Where:

D	=	Pedestrian Delay (expressed as % delayed)
T	=	Total time of study, in seconds (Duration x 60)
t	=	Total time of all Adequate Gaps, in seconds

- (9) The average number of adequate gaps per five-minute period is used in determining the possible need for various pedestrian and school crossing traffic controls. It can be calculated using the following equation:

$$\text{Equation 9-3}$$
$$P = \frac{A}{\text{Duration}/5}$$

Where:

P	=	Number of Adequate Gaps per 5-minute period
Duration	=	Total time of study, in minutes

- (10) Figure 9-1 gives an example of a completed pedestrian gap study form, showing the completed available gap survey with the total adequate gaps, percent pedestrian delay and average number of gaps per 5-minute period.

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CHAPTER 10 – SIGNAL OPERATIONS STUDIES

10.1 PURPOSE

Once an engineering study has been performed and the installation of a traffic control signal has been determined to be justified, many decisions must be made for its proper design and operation. The proper design and operation of a traffic control signal is crucial to the safety and efficiency of the intersection once it is installed. The operational parameters of the signal should be determined prior to the design of the signal, and should be included in the Traffic Signal Reconnaissance Report. The primary operational parameters of an intersection traffic control signal consist of:

- Controller phasing including provisions for pedestrians
- Pretimed versus actuated control
- Local detection alternatives
- Isolated versus system operation (coordination)
- Use of flashing operations

10.2 CONTROLLER PHASING

- (1) The phasing selected for implementation at a given intersection should consider the roadway volumes, amount of turning traffic, pedestrian activity and geometric conditions. Phase sequence plans range from relatively simple two-phase to phasing plans utilizing one or more left-turn and/or right-turn movements to phasing plans utilizing exclusive vehicle and/or pedestrian phases.
- (2) As a general rule, the number of phases should be held to a minimum.
- (3) When determining the phasing to be used at a traffic control signal, both vehicular and pedestrian movements must be considered. For pedestrian movements, whether or not to provide pedestrian indications at the intersection is the first decision. If no pedestrian indications are provided, any permitted pedestrian movements are controlled by the vehicular signal indications.
- (4) For vehicular movements, whether or not to provide separate left-turn or right-turn phases is the first decision. If left-turn and/or right-turn phases are to be provided, decisions concerning the specific operation must follow. These include deciding which approaches will have turn phases, whether the phases will operate as protected-only mode, protected/permissive mode or variable mode and whether the turn phases will be operated as leading or lagging.
- (5) The simplest traffic control signal phase operation is commonly called two-phase operation. In this operation, traffic on one street is assigned the right-of-way during one of the phases and traffic on the other street is assigned the right-of-way during the second phase. If pedestrian signal heads are provided at the intersection, Walk and flashing Don't Walk indications for pedestrians crossing a street are simultaneously displayed with the adjacent vehicular indications. Drivers making left turns may do so but must first wait for an adequate gap in oncoming traffic and also must yield to any pedestrians in the crosswalk which they will be turning across (all left turns are made in the permissive only mode).
- (6) Two-phase operation may be used where separate turn lanes exist or where turning and through movements are made from a share-use lane. Two-phase operation functions most effectively when there are relatively few left turns, where there are sufficient adequate gaps in oncoming traffic and adjacent pedestrian movements to accommodate the volume of left turns being made, and where there are minimal conflicts between pedestrians and turning vehicles.

10.3 LEFT-TURN OPERATION

Left turns at signalized intersections can be operated in one of several modes:

- (1) **Permissive only.** When permissive only left-turn mode is used, no left-turn arrows are provided. Left turns are made during the circular green indication when gaps in opposing traffic permit.
- (2) **Protected only left-turn phasing.** Protected-only left-turn phasing is a left-turn operation in which a protected (green arrow) interval is provided and left turns may be made only when the green arrow is displayed. Since no left-turn demand is accommodated during the through-green interval, protected-only mode left-turn phasing requires longer left turn phases, thus increasing delays to the left-turning vehicles (there are fewer opportunities to turn left) as well as the conflicting through phases (through traffic has to wait longer for the left turn movements to clear), and that drives up the minimum cycle length needed to serve all of the traffic movements at the intersection. This type of left-turn phasing is the most restrictive and causes the most over-all delays and should be limited to intersections where geometric conditions or extremely high opposing volumes do not allow permissive left-turn movements to be made safely. It is typically reserved for intersections that have opposing dual left-turn lanes without sufficient positive offset for drivers of left-turning vehicles to see past vehicles in the opposing left turn lanes, or to locations where there has been a documented high crash rate associated with left turn crashes involving left turns being made during the permissive mode. Protected-only left turn phasing should not be used for approaches with a shared-use left-turn and through movement lane unless the left-turn and through movement operate simultaneously.
- (3) **Protected/permissive left-turn phasing.** Protected/permissive left-turn phasing is a left-turn operation in which both a protected (green arrow) interval and a permissive (circular green or flashing yellow arrow) interval is provided. This operation is the preferred mode of left-turn phasing when left-turn phasing is warranted.

10.4 LEFT-TURN PHASING CRITERIA

The following criteria should be followed when deciding where separate left-turn phasing should be used:

- (1) **Volumes:**
 - (a) The volumes considered include the number of vehicles per hour make the left turn movement and the number of opposing (conflicting) through and right-turn movements during the same hour. Left-turn phasing may be warranted if:
 - (b) There are at least 100 left turns during the peak hour; **and**
 - (c) The number of left turns multiplied by the number of opposing through and right turns during the peak hour exceeds 100,000 on a 4-lane street, or 50,000 on a 2-lane street; **and**
 - (d) There are more than two left-turn vehicles per cycle per approach at the end of the through movement green during the peak hour.
- (2) **Delay:**
 - (a) Excessive delays experienced by left-turning vehicles may warrant left-turn phasing. Left-turn phasing may be warranted if:
 - (b) There is at least 2.0 vehicle-hours of left-turn delay during the peak hour on the approach; **and**
 - (c) There are at least two left turns per cycle during the peak hour; **and**
 - (d) The average delay per left-turning vehicle exceeds 35 seconds.

(3) Crashes:

- (a)** A high frequency of crashes between left-turning vehicles and opposing through or right-turning vehicles may warrant left-turn phasing. Left-turn phasing may be warranted if:
- (b)** On one approach there have been 4 left-turn crashes in 1 year or 6 left-turn crashes in 2 years.
- (c)** On both (opposing) approaches there have been 6 left-turn crashes in 1 year or 9 left-turn crashes in 2 years.

10.5 PROTECTED/PERMISSIVE LEFT-TURN PHASE CONTROL

- (1)** Left turns that are provided with protected/permmissive left-turn phasing can be controlled by either 5-section (doghouse) left-turn signal faces, or with 4-section all-arrow signal faces.
- (2)** All new installations of protected/permmissive left turn phasing where separate left turn lanes are provided will utilize the 4-section all-arrow signal faces.
- (3)** All protected/permmissive left-turn phasing where the left turns are being made from a shared-use left-turn and through lane will utilize the 5-section left-turn signal faces.
- (4)** All protected/permmissive left turn phases controlled with 4-section all-arrow signal faces will be lagging phases unless the adjacent through phases are coordinated with other signals on the highway corridor and leading one or both of the left-turn phases improves the two-way progression of traffic from one signal to the next.
- (5)** All protected/permmissive left turn phases controlled with 5-section left-turn signal faces will be leading phases unless there is no opposing left turn movement (e.g., at a T-intersection or at the intersection with a one-way street) and the adjacent through phases are coordinated with other signals on the highway corridor and lagging the left-turn phase improves the two-way progression of traffic from one signal to the next.

10.6 PEDESTRIAN PHASES

For pedestrian phases, the first decision is whether or not to provide pedestrian indications at the intersection, and which (if any) potential pedestrian crossings will be controlled with pedestrian indications.

- (1)** All traffic signals in central business districts shall be equipped with pedestrian indications.
- (2)** Any traffic signal that was installed based on the Pedestrian Volume warrant (Warrant 4) or the School Crossing warrant (Warrant 5) shall be equipped with pedestrian indications.
- (3)** Any traffic signal that is located on a designated school walk route shall be equipped with pedestrian indications to control the crossing of any approach leg(s) that include the school walk route.
- (4)** Signalized intersections that have pedestrian facilities (sidewalks and ADA ramps) provided on both sides of the intersection, to allow for the continuation of the pedestrian walkway, should be equipped with pedestrian indications unless a pedestrian study indicates that there are less than 5 pedestrians using the crossing per hour during the peak hour of pedestrian crossing activity.
- (5)** Appropriate pedestrian phase timings and operation are outlined in Chapter VI of the *WYDOT Electrical Traffic Control Manual*, 2006.

10.7 PEDESTRIAN CROSSING DISTANCE MEASUREMENT

- (1)** The pedestrian clearance time at all traffic signals must be sufficient to clear the pedestrian to the far side of the traveled way. The measurement of the crossing distance is critical to the proper

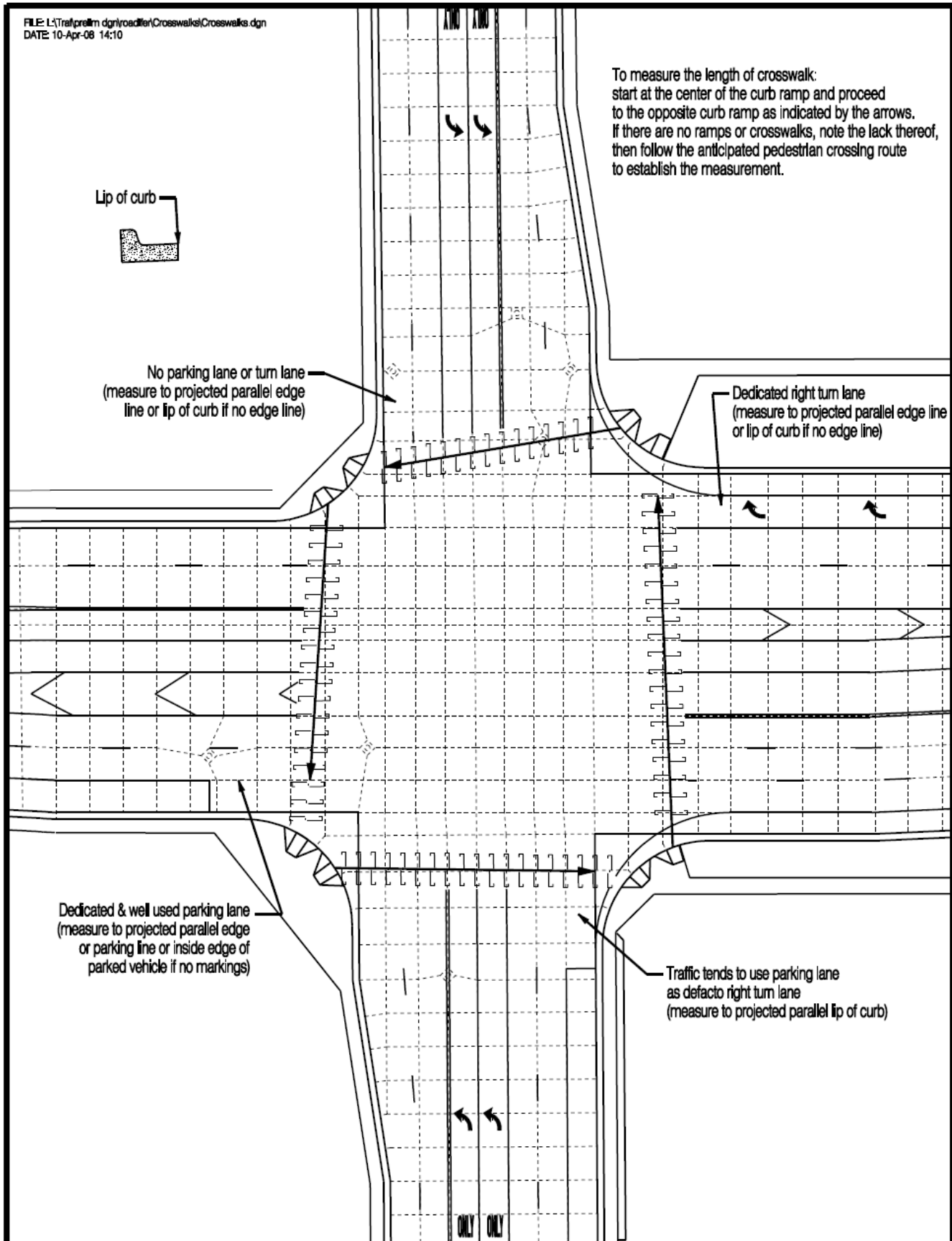
timing of the pedestrian clearance time. The crosswalk distance can vary greatly considering the many variables that might be present at the intersection, such as turn lanes, parking lanes and corner radii. There are essentially four conditions that will be encountered when measuring the crosswalk. They are:

- (a) There is no parking lane or right turn lane. In this case, measure to the projected parallel edge line or lip of curb if no edge line.
 - (b) There is a dedicated and well used parking lane. In this case, measure to the projected parallel parking or edge line or to the inside edge of the parked vehicles if no markings exist.
 - (c) There is an area provided for parking, but due to minimal parking activity, that area is typically used by vehicles as a de facto right turn lane. In this case, measure to the projected parallel lip of curb
 - (d) There is a dedicated right turn lane. Measure to the projected parallel edge line or lip of curb if no edge line.
- (2) Figure 10-1 is an intersection diagram that was developed to help simplify/standardize the process used to measure the crosswalk length. The diagram shows how to measure the crosswalk length for each of the above conditions. The measurement should start in the center of the pedestrian ramp (or anticipated beginning point if no ramp) at the lip of curb and proceed in a counterclockwise direction to the opposite corner, stopping at the point indicated above.

10.8 PRETIMED VERSUS ACTUATED CONTROL

- (1) There are many factors that influence the decision concerning whether a traffic control signal should operate on a pretimed, semi-actuated or fully-actuated basis. Those factors include:
- (a) Equipment availability
 - (b) Traffic patterns
 - (c) Proximity to other traffic control signals
 - (d) Availability of funds
- (2) Pretimed signals provide a consistent and regularly repeated sequence of signal indications to traffic, while actuated signals provide at least some signal intervals that fluctuate with traffic demands. The duration of some but not all phases of semi-actuated signals will fluctuate with traffic demands, while the duration of all phases of fully-actuated signals will fluctuate with traffic demands. Pretimed traffic signals are cheaper to install and maintain, but are relatively inefficient where traffic volumes fluctuate widely and irregularly. Actuated signals are generally more expensive to install and maintain, but are more efficient because they can respond to greater variations in traffic. The reduction in motor-vehicle operating costs and possible reduction in crashes associated with more efficient traffic signal operations will normally offset the added installation and maintenance costs associated with maximizing the efficiency of the intersection controls.
- (3) Overall, there are valid considerations for using each of the various control types.

Figure 10-1 Measuring Pedestrian Crosswalk Lengths



10.8.1 PRETIMED CONTROL

Pretimed control is best suited to intersections where traffic patterns are either relatively stable or predictable such that the variations in traffic that do occur can be accommodated by predetermined timing plans without contributing to unreasonable delays or congestion. Pretimed control may be justified in the following conditions:

- (1) Two-phase operation at intersections in the central business district of larger cities
- (2) When intersection spacing and traffic speeds are favorable and pretimed signals will provide for coordinated traffic flow on the street
- (3) When coordination is needed with adjacent signals on two or more intersecting streets such as on a grid system
- (4) Where there are large and relatively consistent pedestrian volumes present

10.8.2 SEMI-ACTUATED CONTROL

Semi-actuated control is best suited to signalized intersections along a major roadway with relatively minor cross streets and where the signals are coordinated throughout the day. Semi-actuated control is also advantageous when intersections are unfavorably located within a progressive pretimed system or where interruption of the major street traffic is undesirable and must be held to a minimum in frequency and duration.

10.8.3 FULLY-ACTUATED CONTROL

Fully-actuated control is best suited to isolated signalized intersections that will operate in a free or isolated (not coordinated with adjacent signals) mode and where approach speeds are greater than 35 mph. It is also appropriate for complex intersections where one or more movements are sporadic or subject to variations in volume.

10.9 ISOLATED VERSUS SYSTEM OPERATION

- (1) Whether a traffic signal will be operated as part of a system or isolated depends on whether coordination with other traffic control signals is needed. An isolated traffic control signal is one in which the signal intervals and/or timing plans operate independently of any other traffic control signals. System operation is when there is some form of communications system between groups of traffic control signals used to coordinate the signal intervals.
- (2) The *MUTCD* recommends that traffic control signals that are within 0.5 miles of one another along a major route or in a network of intersecting major routes should be coordinated. Although the *MUTCD* references a 0.5 mile separation, effective coordination can occur where signals exceed a mile apart. Such coordination is especially effective where roadside friction is minimal, speeds are fairly high and the traffic control signals are visible for some distance in advance of the intersection.
- (3) Even if it is not possible to identify a platoon at a downstream intersection, it is desirable to attempt to coordinate signalized intersections whenever possible.

10.10 USE OF FLASHING OPERATION

- (1) There are a number of situations when it may be appropriate to operate a traffic signal in the flashing mode. Both pretimed and actuated signals may be operated in the flashing mode. A common use of planned flashing operation is at night or other times during periods of low traffic volumes. Flashing operation based on low traffic volumes typically occurs on a daily or repetitive basis. Operating a traffic control signal in the flashing mode when traffic volumes are low offers a number of potential benefits to the agency and to motorists including:
 - (a) Reduced stops and delay to major-street traffic

- (b) Reduced delay to cross-street traffic
 - (c) Reduction in fuel consumption due to the reduced delay
 - (d) Reduction in electrical consumption by the traffic control signal equipment
- (2) When operated in flashing mode, flashing yellow indications should be used for the major-street and flashing red indications should be used for the minor-street, provided that minor-street drivers have an adequate view of approaching major-street traffic.
 - (3) All-red flashing operation may be appropriate at multi-legged intersections, intersections with low but balanced traffic volumes and intersections in which drivers' views of approaching traffic are limited.
 - (4) When a traffic control signal is operated in the flashing mode as part of the planned signal operation, the crash patterns should be monitored. Signal operation should be changed to stop-and-go operation if the crash pattern or severity increases. The following criteria can justify eliminating the flashing operation:
 - (a) 3 or more right-angle crashes in one year that occur during flashing operation
 - (b) 5 or more right-angle crashes in two years that occur during flashing operations
 - (5) Fully-actuated signals that have protected-only left turn phasing should not be operated in time-of-day flash.

10.11 OPERATIONAL REVIEWS

Whenever a new traffic control signal is installed, or an existing signal is significantly modified, an operational review should be performed on the signal to verify that it is operating as intended. The operational review should be conducted by the District Traffic Engineer or Safety and Studies Section personnel as soon after all work is completed as possible (normally within 30 days).

10.11.1 SIGNALIZED INTERSECTION CHECKLIST

An operational review consists of verifying that the traffic signal controls traffic as intended, that all of the signal equipment is functioning properly, and that all associated signs and markings are installed properly. An Operational Review Signalized Intersection Checklist (Form TR-18) has been developed to assist with the performance of operational reviews on new or significantly modified traffic control signals. Figure 10-2 gives an example of a completed operational review checklist.

10.11.2 LEFT-TURN PHASE OPERATIONAL REVIEW

Whenever protected/permissive left turn phasing using 4-section all-arrow left turn signal faces is installed at an intersection, either in a new signal installation or as a retrofit to an existing signal, a left turn operational review should be conducted to verify the proper operation of the left-turn phases. The detector settings and phase timings should be set to minimize the unnecessary activation of the left-turn phases while still adequately serving all left-turning vehicles. A Left-Turn Operational Review form (Form TR-19) has been developed to assist with the performance of left-turn operational reviews. Figure 10-3 gives an example of a completed left turn operational review.

Figure 10-2 Example of an Operational Review Checklist
Operational Review

Signalized Intersection Check List

Town: _____ Reviewed By: _____ Date: _____

Intersection: _____

	OK	NO	COMMENTS
Overall Intersection Operation	_____	_____	_____
Signal Phasing	_____	_____	_____
No Loaded Cycles	_____	_____	_____
Clearance Intervals	_____	_____	_____
No Skidmarks Evident	_____	_____	_____
No Signal Violations (Red Light Running)	_____	_____	_____
Vehicle Detection Works	_____	_____	_____
Vehicle Detectors Located Correctly	_____	_____	_____
Vehicle Detectors Call/Extend Correct Phase(s)	_____	_____	_____
Detector Extension/Delay Appropriate	_____	_____	_____
Special Turning Movement Operation	_____	_____	_____
4 or 5 Section Heads	_____	_____	_____
Head Alignment	_____	_____	_____
Signal Faces	_____	_____	_____
Backplates	_____	_____	_____
Visors	_____	_____	_____
No Adverse Background Lighting	_____	_____	_____
Pedestrian Indications	_____	_____	_____
Pedestrian Timing	_____	_____	_____
Rest in Walk on Mainline	_____	_____	_____
Pedestrian Buttons Work	_____	_____	_____
Pedestrian Buttons Oriented Correctly	_____	_____	_____
Pedestrian Signs	_____	_____	_____
No Arrow Across Pedestrian Movement	_____	_____	_____
Stop Bar Location and Condition	_____	_____	_____
Channelization	_____	_____	_____
Lane Control Pavement Markings	_____	_____	_____
Auxiliary Turn Lanes Long Enough to Avoid Spillback	_____	_____	_____
Turning Radii	_____	_____	_____
Left Turn Only Sign on Mast Arm (if no left turn phase)	_____	_____	_____
Painting/Galvanization	_____	_____	_____
Overhead Street Name Signs on Mast Arms	_____	_____	_____
Advance Warning Signs Appropriate for the Situation	_____	_____	_____

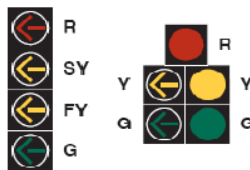


Figure 10-3 Example of a Left Turn Operational Review

20								
19								
18								
17								East/West Street
16								
15								
14								
13								North/South Street
12								
11								
10								
9								Analyst
8								
7								
6								
5								Date
4								
3								
2								
1								Time Period
	Skipped - No Demand	Skipped - Demand but Not Served	Veh Turned on FYA w/opposing Grn Arrow	False Call - No Vehicle	False Call - Vehicle Gone	Only 1 Vehicle	More than 1 Vehicle	
	bound Left Turn Phase							

Left Turn Phase Operational Review

	bound Left Turn Phase						
	Skipped - No Demand	Skipped - Demand but Not Served	Veh Turned on FYA w/opposing Grn Arrow	False Call - No Vehicle	False Call - Vehicle Gone	Only 1 Vehicle	More than 1 Vehicle
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

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CHAPTER 11 – CURVE ADVISORY SPEED STUDY

11.1 PURPOSE

- (1) The average crash rate for horizontal curves is about three times the average crash rate for highway tangents (Glennon et al., 1985). The most prevalent types of crashes that occur on horizontal curves are lane departure-type crashes including run-off-road, side-swipe meeting and head-on crashes. The potential for crashes is significantly increased when the safe and comfortable travel speed along a curve is below the posted speed along a tangent segment of the highway. This potential tends to increase as the distance upstream of the curve to a previous curve of equal or lower safe and comfortable travel speed increases.
- (2) The primary strategy used by traffic engineers to minimize crashes on horizontal curves is to provide advance warning of unexpected changes in horizontal alignment. Motorists are normally advised of maximum recommended speeds along curves through the use of Horizontal Alignment signs and Advisory Speed plaques.
- (3) According to the *MUTCD*, the advisory speed shall be determined by an engineering study. Therefore, the establishment of advisory speeds on Wyoming state highways must follow the standard procedures developed and adopted by WYDOT. All field work used for determining the advisory speeds must be performed under the supervision of an engineer.
- (4) This chapter sets forth the procedures to be used to establish the advisory speed on horizontal curves in Wyoming. The established advisory speed must be both realistic and safe, meeting drivers' expectations for a given set of geometric, operational, and environmental conditions. The posted advisory speed shall be a multiple of 5 mph.
- (5) There are two acceptable methods for determining the advisory speed on an existing horizontal curve: use of the design speed equation and the ball-bank indicator method. The most common method is the ball-bank indicator method, but for newer roadways where the curve radius and super elevation are known, the design speed equation can be used effectively.
- (6) Table 11-1 shows the maximum ball-bank reading and lateral acceleration to be used when determining the advisory speed on curves. These readings are the usually accepted limits beyond which riding discomfort will be excessive and loss of vehicle control might occur. The ball-bank readings are read directly from the ball-bank indicator while traveling the curve at a set speed. The lateral acceleration is the same value that is used in the design speed equation (see Equation 11-1).

Table 11-1 Recommended Criteria for Curve Advisory Speed Determination

Speeds (mph)	Ball Bank Reading	Lateral Acceleration (g)
≤ 25	12°	0.21
> 25	10°	0.17

(Source: Adapted from Carlson and Mason, 1999)

- (7) It is important to note that the advisory speed criteria are based on driver comfort more than safety. A sufficiently skillful driver may be able to traverse a curve on dry pavement at a speed considerably higher than the advisory speed without exceeding the friction capabilities of the pavement. However, most drivers would choose not to drive at a higher speed because they would experience uncomfortable levels of lateral acceleration.

11.2 USE OF THE DESIGN SPEED EQUATION

- (1) The design of highway curves is based on the relationship between design speed, radius of curvature, superelevation, and side friction (centripetal acceleration). The design speed equation can be used to calculate the advisory speed for a curve if the curve radius and superelevation are known. The side friction factor is the same as lateral acceleration (measured in “g’s”), and is based on driver comfort. For the establishment of advisory speeds on curves, the lateral acceleration rates contained in Table 11-1 should be used. The mathematical relationship between these variables is given by the equation:

Equation 11-1

$$V = \sqrt{15R(0.01e + f)}$$

Where:

V	=	Design speed (mph)
R	=	Curve radius (feet)
e	=	Superelevation (%)
f	=	Side friction factor

- (2) The rounded advisory speeds calculated for various combinations of superelevation and curve radius are shown in Table 11-2.

Table 11-2 Rounded Passenger Car Advisory Speeds (mph)

Radius (ft)	Superelevation (%)				
	-2	2	4	6	8
100	15	20	20	20	20
200	25	25	25	25	25
400	30	35	35	35	40
600	35	40	45	45	45
800	40	50	50	55	55
1000	45	55	55	60	60
1200	50	60	60	65	65
1400	55	65	65	70	70

Based on Design Speed Equation and Table 11-2 Side Friction Factors

- (3) In some cases, the curve radius and superelevation can be taken from as-built plans for a roadway that has been constructed fairly recently. However, it must be considered that a roadway that has been in service for many years may have been resurfaced one or more times since original construction. As a result of resurfacing, the superelevation of the curve may have changed, and the original plans may no longer be representative of field conditions. In other cases, the original plans may no longer be available.
- (4) The WYDOT Highway Features File (HFF) contains horizontal alignment data, as taken from as-built plans, for all State Highways in Wyoming. The HFF data includes the reference marker of the middle of the curve (PI), the curve length and the change in direction or delta of the curve. The radius of the curve can be calculated from the curve length and delta using the following equation:

Equation 11-2

$$R = \frac{180L}{\Delta\pi}$$

Where:

R	=	Curve radius (feet)
L	=	Curve length (feet)
Δ	=	Change in direction (degrees)
π	=	Pi (approximately 3.14)

- (5) WYDOT's Pavement Management System (PMS) uses Pathways Services, Inc. and Pathview II software to gather and maintain state of the art pavement condition data and video images of the State Highway System. The Pathview II data contains multiple sensor readings along the roadway including the cross slope of the roadway, recorded in decimal degrees, throughout the roadway system. The superelevation on a given curve can be determined by Equation 11-3.

Equation 11-3

$$e = (\tan CS) \times 100\%$$

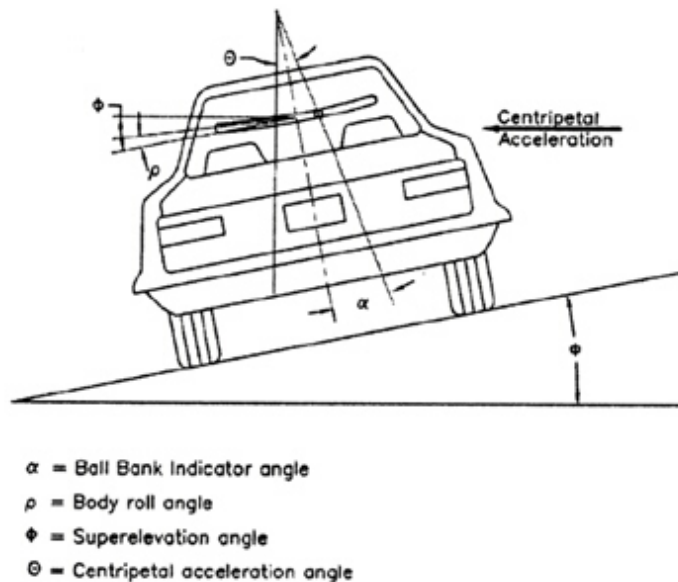
Where:

e	=	Superelevation (%)
CS	=	Cross slope on subject curve from Pathview II

11.3 BALL-BANK INDICATOR METHOD

- (1) The ball-bank indicator method is the most common and practical way of determining advisory speeds on older existing curves. The ball-bank indicator consists of a curved glass tube which is filled with a liquid. A weighted ball floats in the glass tube. The ball-bank indicator is mounted in a vehicle, and as the vehicle travels around a curve the ball floats outward in the curved glass tube. The movement of the ball is measured in degrees of deflection, and this reading is indicative of the combined effect of superelevation, lateral (centripetal) acceleration, and vehicle body roll as shown in Figure 11-1. The amount of body roll varies somewhat for different types of vehicles, and may affect the ball-bank reading by up to 1°, but generally is insignificant if a standard passenger car is used for the test. During testing, the device is mounted in a vehicle and ball-bank readings are taken at different speeds along a curve to determine the comfortable traveling speed.

Figure 11-1 Factors Affecting Ball Bank Indicator Reading



- (2) In order to negate any errors caused by vehicle body roll, when using this technique, it is best to use a typical passenger car rather than a pickup truck, van, or sports utility vehicle.
- (3) The equipment and personnel needed to perform a curve advisory speed study using the ball-bank indicator method consists of a test vehicle (intermediate size), driver, observer (if necessary), ball bank indicator (Slope Meter safe curve indicator), Distance Measuring Instrument (DMI), and the Curve Advisory Speed Study form (Form TR-16) to input data. Figure 11-2 is an example of how the test vehicle is equipped to perform a curve advisory speed study.

Figure 11-2 Example of Equipment Used for the Ball-bank Indicator Method

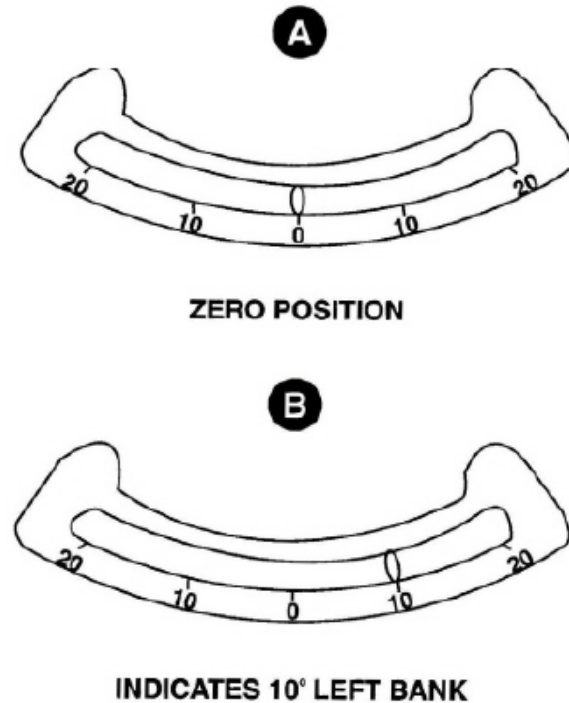


(Source: Stephen Ford, MCDOT)

- (4) To ensure proper results, it is critical that the following steps be taken before starting test runs with the ball-bank indicator:
 - (a) Inflate all tires to uniform pressure as recommended by the vehicle manufacturer
 - (b) Calibrate the test vehicle's DMI
 - (c) Zero the ball-bank indicator
- (5) The vehicle's DMI should be calibrated to the manufacture's recommendations to ensure accurate test results. If the DMI used cannot display both speed and distance simultaneously, once the DMI is properly calibrated, the vehicle's speedometer should be correlated to the DMI speed readings at each of the test speeds (i.e., every five mph increment over 20 mph). If there are any discrepancies, note the discrepancies so the driver can drive the vehicle at the correct speeds when doing the study (e.g., if the speedometer reads 48 mph when the DMI reads 50 mph, then drive the vehicle at 48 mph according to its speedometer when testing the curve for ride comfort at 50 mph).
- (6) The ball-bank indicator must be mounted in the vehicle so that it displays a 0° reading when the vehicle is stopped on a level surface. The positioning of the ball-bank indicator should be checked before starting any test. This can be done by stopping the car so that its wheels straddle the centerline of a two-lane highway on a tangent alignment. In this position, the vehicle should be essentially level, and the ball-bank indicator should give a reading of 0°. It is essential that the driver and recorder be in the same position in the vehicle when the ball-bank indicator is set to a 0° reading as they will be when the test runs are made because a shift in the load in the vehicle can affect the ball-bank indicator reading.

- (7) The ball-bank indicator method is normally a two-person operation, with one person to drive and the other to record curve data and the ball-bank readings, especially if advisory speeds are being determined for a series of curves.
- (8) Vehicle movement around a curve causes the ball to swing from the zero position (e.g., vehicle movement to the left causes the ball to swing to the right). The faster the vehicle moves around the curve or the sharper the curve, the greater the distance the ball swings away from the zero degree position. Superelevation, however, tends to bring the ball back to the zero position. The net result is the indicator reading in degrees of deflection (see Figure 11-3).

Figure 11-3 Example Ball Bank Indicator Readings



(Source: FDOT, Manual on Uniform Traffic Studies)

- (9) Testing should start well in advance of the curve being evaluated so the driver can reach the test speed at a distance of at least 1/4 mile in advance of the beginning of the curve. The first trial run should be made at a speed (multiple of 5 mph) somewhat below the anticipated advisory speed. The driver should enter the curve at the predetermined test speed and should try to maintain the assumed speed throughout the curve. The path of the car should be maintained as nearly as possible in the center of the inner-most lane (the lane closest to the inside edge of the curve) in the direction of travel. If there is more than one lane in the direction of travel, and these lanes have differing superelevation rates, drive in the lane with the lowest amount of superelevation. Subsequent trial runs are conducted at 5 mph speed increments.
- (10) On each test run, the driver should maintain the same speed throughout the length of the curve. Because it is often difficult to drive the exact radius of the curve and keep the vehicle at a constant speed (cruise-control helps to maintain a constant speed), the curve should be driven a number of times until at least two matching ball bank readings (i.e., number of degrees) are obtained for each direction of travel. Testing should be conducted separately for each direction of travel.
- (11) On each test run, the recorder must carefully observe the position of the ball throughout the length of the curve and record the deflection reading that occurs when the vehicle is as nearly as possible driving the exact radius of the curve.

- (12) If the reading on the ball-bank indicator for a test run does not exceed an acceptable level (as indicated by the recommended criteria in Table 11-1 then the speed of the vehicle is increased by 5 mph and the test is repeated. The vehicle speed is repeatedly increased in 5 mph increments until the ball-bank indicator reading exceeds an acceptable level. The curve advisory speed is set at the nearest 5 mph incremental speed that is closest to where the ball-bank indicator reading reaches the maximum acceptable level.

11.4 ESTABLISHING CURVE ADVISORY SPEEDS

- (1) Using either of the two methods noted above (design speed equation or ball-bank indicator) should result in the same advisory speed for a curve. The advisory speed for the curve should be set at the 5-mph increment nearest to this maximum comfortable speed. The advisory speed to be posted should not be arbitrarily reduced below the comfortable speed determined using these methods, because an unrealistically low advisory speed will lose credibility among drivers, and create inconsistencies that may lead drivers into traveling at too high a speed through other curves.
- (2) In some cases, there may be other factors that influence the selection of the advisory speed in addition to the comfortable operating speed on the curve. Available stopping sight distance through the curve and sight distance from intersections or driveways within the curve (see Chapter 6) or deceleration distance (on an exit ramp) may, in some cases, require an advisory speed somewhat lower than the comfortable operating speed for the curve.
- (3) Each direction should be checked independently and may be posted with different speeds.
- (4) Advisory speed plaques should be used in conjunction with curve and turn signs when the advisory speed is below the posted speed limit on the roadway. Advisory speed plaques are only used in conjunction with appropriate warning signs, and never alone. Turn, Curve, Reverse Turn, Reverse Curve, and Winding Road signs are used in locations where it is desirable to warn drivers of changes in the horizontal alignment of the roadway. The *MUTCD* indicates that the use of Turn or Reverse Turn signs should be limited to changes in alignment where the advisory speed is 30 mph or less. The Curve or Reverse Curve signs are intended for use where the advisory speed is greater than 30 mph.
- (5) Where a Reverse Curve warning sign or a Winding Road warning sign is used, the advisory speed should be based on the curve with the lowest comfortable operating speed. However, if one curve in the series has a dramatically lower comfortable speed, it would be desirable to place a separate warning sign with the appropriate advisory speed for that individual curve.
- (6) Since warning signs are primarily for the benefit of the driver who is unfamiliar with the road, it is very important that care be given to the placement of such signs. Warning signs should provide adequate time for the driver to perceive, identify, decide, and perform any necessary maneuver to safely negotiate the curve. The advance distance for the placement of warning signs is determined by the posted speed limit on the section of roadway being studied. Once the type of warning signs has been selected, the proper sign location can be determined. The advance warning sign placement shall be in accordance Table 2C-4 in the *MUTCD*.
- (7) Figure 11-4 is an example of a data collection form that can be used to record the results of curve advisory speed studies.
- (8) Additional information on sign placement and establishing curve advisory speeds is contained in the Traffic Control Devices Handbook, Chapter 4 – Regulatory and Warning Signs, Pages 107 - 110. This handbook is available through the Institute of Transportation Engineers, 1099 14th Street, NW, Suite 300 West, Washington, D.C. 20005-3438.

11.5 USE OF CURVE ADVISORY SPEED STUDY FORM

- (1) Enter the location so that the curve study location is thoroughly identified. The highway route number(s) and/or name, county, and maintenance section number should be included.
- (2) Enter the posted speed limit, pavement condition, date of study, vehicle make model and year, and the people performing the study (i.e., driver and recorder) in the appropriate spaces. Include any information that may need to be considered in addition to data being collected in the Remarks area.
- (3) Enter the travel direction of the study vehicle through the curve and the reference markers for the start and end of the curve.
- (4) Enter the run speeds in 5 mph increments. The first run should be made at a speed that is slightly lower than the anticipated maximum comfortable speed. For existing curves with posted advisory speeds, a good rule of thumb is to make the first run at a speed of 5 mph below the existing advisory speed.
- (5) Enter the degree of deflection shown on the ball-bank indicator as the vehicle passes through the curve at the initial run speed. If the reading on the first run is significantly less than the respective threshold reading in Table 11-1, only one run is necessary at that run speed and you can make the next run at the next higher speed. Once the readings are relatively close to the threshold values, drive the curve at each run speed up to three times, or until at least two matching ball bank readings are obtained for each direction of travel.
- (6) In the example in Figure 11-4, the first test run was made at 30 mph in the northbound direction, with a ball-bank indicator reading of 5°. This is well below the suggested criteria of 10° for a speed of 30 mph. Therefore, on the return pass in the southbound direction, the first run was made at 35 mph and resulted in a reading of 7°. This is still well below the threshold reading of 10° for speeds greater than 25 mph. Therefore the next run in the northbound direction was made at 40 mph and resulted in a reading of 9°, which is close to the threshold value. The return pass in the southbound direction was also made at 40 mph and gave a reading of 10°. Test runs at 40 mph were repeated in each direction until there were two readings of 10° in each direction. These are the highest readings attained without exceeding the suggested criteria of 10° for a speed greater than 25 mph as shown in Table 11-1. This study would result in an advisory speed of 40 mph for both directions of travel for this curve.
- (7) In the example, since one run in each direction at 40 mph resulted in a reading of 9°, an additional run in each direction was made at the next higher run speed of 45 mph to see what readings would be achieved if the advisory speed were 5 mph higher. Those runs were purely optional.

Figure 11-4 Example of Curve Advisory Speed Study Form

[illegible]

11.6 TRUCK ADVISORY SPEEDS

- (1) Large trucks, tank trailers and truck freight trailers have a higher center of gravity and are more susceptible to rollover crashes on a sharp curve. The loop ramps on freeway interchanges and direct freeway to freeway connections are sometimes subject to truck rollover problems. The potential for such crashes may increase because of the radius of horizontal curvature, inadequate deceleration length or deficient specific signing. The appropriate warning signs for truck rollover concerns require more than just determination of curve advisory speeds for passenger vehicles as previously discussed.
- (2) When a truck rollover problem exists, the use of truck rollover signing with a truck advisory speed should be considered. It is suggested that the engineering study for truck rollover warning signs address the following considerations:

 - (a) Speed data and advisory speed determinations.
 - (b) Traffic characteristics.
 - (c) Roadway geometrics.
 - (d) Recommended traffic control devices.
- (3) Truck rollover theoretically can occur when the lateral acceleration exceeds 0.30g, but no calculated lateral acceleration less than 0.35g has been determined in any truck rollover crashes. It is recommended that any posted advisory speed for the truck rollover signing should reflect a ball-bank reading of 10 degrees (side friction factor of 0.17g) for all advisory speeds in order to provide a reasonable factor of safety. The use of the 0.17g side friction value is about half the critical side friction factor and accommodates those occasions where the truck may exceed the posted truck advisory speed or the truck travels a curve radius that is less than the actual roadway curvature.
- (4) The *MUTCD* provides a number of other devices that can be used in conjunction with Horizontal Alignment signs and Truck Rollover signs to address truck rollover consideration such as:

 - (a) Chevron Alignment signs (W1-8)
 - (b) Combination Horizontal Alignment/Advisory Speed sign (W1-1a and W1-2a)
 - (c) One Direction Large Arrow sign (W1-6)
 - (d) Advisory Exit and/or Advisory Ramp Speed Signs
- (5) Additionally, the warning can be enhanced with enlarged signing, a TRUCK header panel, flashing beacons and changeable message signs.

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CHAPTER 12 – NO-PASSING ZONE STUDY

12.1 PURPOSE

- (1) The Department of Transportation is authorized by Wyoming Statute 31-5-207 to determine those portions of any highway under its jurisdiction where overtaking and passing or driving to the left of the roadway would be especially hazardous. Those portions of the highway shall be marked with no-passing zone markings.
- (2) The no-passing areas include vertical and horizontal curves, railroad grade crossings, narrow bridges, intersections, transitions to and from multi-lane sections of roadway, and other locations where passing must be prohibited because of inadequate sight distance or other special conditions.
- (3) The requirements and details for the marking of no passing zones are contained in Chapter III of the *WYDOT Pavement Marking Manual*, 2002. No-passing zones that are not governed by passing sight distance (e.g., railroad grade crossings, narrow bridges, intersections, or transitions to and from multi-lane sections) shall be established in accordance with that manual. All no-passing zones governed by passing sight distance (i.e., horizontal and vertical curves) shall be established in accordance with the guidelines provided in this chapter.
- (4) The purpose of a no-passing zone study is to establish locations where it is not safe to pass, and to mark those locations with no-passing zone markings. Locations that are not striped with no-passing zone markings are not necessarily locations where it is safe to pass, but rather where motorists may lawfully pass only if they can do so safely.

12.2 NO-PASSING ZONE CRITERIA

- (1) The criteria for checking and establishing no-passing zones in the State of Wyoming shall be the minimum passing sight distance (see Table 12-1). Minimum passing sight distance represents the minimum sight distance necessary at the critical position (passing and passed vehicle abreast) to permit a passing driver to perceive an opposing vehicle at a distance sufficient to allow safe completion of a passing maneuver.

Table 12-1 Minimum Passing Sight Distance

POSTED SPEED LIMIT (mph)	MINIMUM PASSING SIGHT DISTANCE (feet)
25	450
30	500
35	550
40	600
45	700
50	800
55	900
60	1000
65	1100
*70	*1200

Use for highways posted 65 mph

- (2) Passing sight distance on a vertical curve is the distance at which an object 3.5 feet above the pavement surface can just be seen from a point 3.5 feet above the pavement. Similarly, passing sight distance on a horizontal curve is the distance measured along the centerline between two points 3.5 feet above the pavement on a line tangent to the embankment or other obstruction that cuts off the view on the inside of the curve. Where centerlines are installed and a curve warrants a no-passing zone, it should be so marked where the sight distance is equal to or less than that listed in Table 12-1.
- (3) The beginning of a no-passing zone is the point at which the sight distance is less than specified in Table 12-1. The end of the zone is the point at which the sight distance again becomes greater than the minimum specified. In no case shall a no-passing zone marking be less than 500 feet in length. If the actual no-passing distance is less than 500 feet, the additional length of marking shall be added to the beginning of the zone.
- (4) Where the distance between successive no-passing zones is less than the minimum distance between no-passing zones as shown in Table 12-1, the appropriate no-passing marking (one direction or two directions) should connect the zones.

Table 12-2 Minimum Distance between No-passing Zones

POSTED SPEED LIMIT (mph)	DISTANCE (feet)
25	280
30	320
35	370
40	410
45	500
50	550
55	650
60	700
65	800
*70	*850

* Use for highways posted 65 mph

12.3 ESTABLISHING NO-PASSING ZONES

- (1) WYDOT policy for the establishment of no-passing zones on the State highway system is to use the minimum passing sight distance associated with the posted speed limit on the roadway being checked, except on highways that are posted at 65 mph, where the 70 mph sight distance criteria will be used.
- (2) All permanent no-passing zones on all highways under the jurisdiction of WYDOT shall be determined by the Department's Traffic Program using the Department's Novastar II Range Track Survey System.
- (3) No-passing zones on all paved highways under County jurisdiction that have been rebuilt using funds administered by WYDOT shall be determined by the Department's Traffic Program using the Department's range tracking system. The request for range tracking shall be in writing from the proper County authority.

- (4) Other paved county highways that have been reconstructed using other funding sources will be range tracked by the Department's Traffic Program using the Department's range tracking system only upon written request by the proper County authority, and after an Authority for Rendering Services (ARS) agreement has been established with proper charge numbers for billing the County for the range tracking crew's time, travel expenses and mileage.
- (5) The letter of request from the County to range track a county highway shall include the posted speed limit(s) that apply on the roadway being range tracked. That is the speed that will be used for the minimum passing sight distance in establishing the length of no-passing zones unless the letter specifies the County's desire to establish the no-passing barriers at a speed other than the posted speed limit.
- (6) The Department prefers that any no-passing zone be established using the range tracking system prior to any no-passing zone markings being applied. However, emergency situations can arise that require the installation of some form of reasonable no-passing zone markings before the roadway can be properly range tracked. The one-vehicle method may be used to establish the interim no-passing zone markings in those emergency situations.

12.4 RANGE TRACKING

- (1) Range tracking requires two vehicles equipped with drivers, two-way radios, and the Novastar II Range Track Survey System. The vehicles used shall be intermediate size. The lead vehicle is equipped with a calibrated DMI, telemetry modem to transmit its road track distance to the trailing vehicle, and a target for eye height. The trailing vehicle is equipped with a calibrated DMI, telemetry modem to receive the lead vehicle's road track distance, the range tracking computer, printer, and a pressurized paint canister with a spray nozzle and remote actuator.
- (2) The two vehicles are driven over the roadway in question at a pre-determined speed and spaced at the appropriate minimum passing sight distance apart. The driver of the lead vehicle maintains as steady of speed as possible so the driver of the trailing vehicle can maintain the proper separation distance. A complete no-passing zone study requires three passes along the roadway.
- (3) On the first pass, whenever the operator of the range tracking computer observes that the lead vehicle's target disappears, the beginning of a no-passing zone is documented on the range tracking computer. When the lead vehicle's target reappears, the end of the no-passing zone is documented on the range tracking computer. The process of documenting the beginning and end of each no-passing zone location on the range tracking computer is continued throughout the segment until the end the section of roadway being checked is reached. No marks are placed on the highway during this run.
- (4) After the first run, the operator of the range tracking computer uses the computer's printouts to check the beginning and ending of each no-passing zone. The distance between successive no-passing zones is checked and any locations where successive no-passing zones are separated by less than the minimum distance between no-passing zones as shown in Table 12-2 are noted. In those cases, the theoretical end of the first and beginning of the second no-passing zone will not be marked on the roadway, so the entire section between the closely spaced no-passing zones will be striped as a continuous no-passing zone.
- (5) The operator of the range tracking computer also checks the length of each no-passing zone documented in the first run using the computer's printouts. The length of each no-passing zone that is less than 500 feet long is checked against the maximum sight distance restriction to allow omission of no-passing zone shown in Table 12-3. If the no-passing zone length exceeds the maximum sight distance restriction listed in Table 12-3, the no-passing zone will be marked. No-passing zones installed under this condition are extended to a length of 500 feet, with the additional length added to the beginning of the no-passing zone. The DMI reading for the new

beginning point for the no-passing zone is marked on the printout so the pavement can be marked in advance of the actual point where the sight restriction begins.

- (6) If the length of no-passing zone is less than the distance shown in Table 12-3, then conditions in either direction beyond the sight restriction are evaluated to determine whether or not the area should be marked as a no-passing zone. If the situation causing the brief sight restriction doesn't warrant a no-passing zone, the section will not be marked as a no-passing zone. If the conditions do warrant a no-passing zone, its length will be increased to 500 feet as in the previous paragraph.

Table 12-3
Maximum Sight Distance Restriction to Allow Omission of No-passing Zone

POSTED SPEED LIMIT (mph)	MAXIMUM SIGHT DISTANCE RESTRICTION (feet)
25	75
30	90
35	105
40	120
45	135
50	150
55	165
60	180
65	195
70	210

- (7) The second pass is made with the vehicles traveling at the same pre-determined separation distance as the first run. During this run, the operator of the range tracking computer documents the beginning and end of each no-passing zone on the computer as well as on the pavement by painting a mark on the highway with a short burst of paint from the paint canister's nozzle using the remote actuator. The operator also keeps track of the DMI reading and marks the beginning of the short no-passing zones prior to the actual point where the sight restriction begins. The DMI reading is also monitored in the areas of closely spaced successive no-passing zones, so the operator does not mark the end of the first or the beginning of the second no-passing zone.
- (8) The third and final pass repeats the same process as the second pass, but in the opposite direction. At the completion of the third pass, the roadway is marked in each direction with a paint mark at the beginning and end of each no-passing zone in each lane.
- (9) The District striping crew then follows-up the range tracking crew by permanently marking the beginning and end of each no-passing zone with delineator posts, and the respective pavement markings are applied.

12.5 ONE VEHICLE METHOD

- (1) This method should only be used as a last resort for emergency situations where some type of reasonable no-passing zone markings must be established prior to the roadway being properly range tracked by the range tracking crew.

- (2) This method only requires one employee in a vehicle equipped with a DMI. To mark a curve or hill for passing sight distance, the driver moves slowly through it. When the driver reaches the point at which the vista opens up and the driver is sure there is a stretch of road ahead which is sufficient for safe passing, he or she stops the vehicle and places a paint mark on the right side of the roadway. Drivers usually sight down the ditch-line as an aid to finding this point when measuring curves for sight distance. This point is the end of the no-passing zone in the direction of travel. The point where the vista opens is usually much easier to locate accurately than the point where the sight distance decreases below the minimum while coming into a curve or hill.
- (3) The driver then resets the DMI to 0.00, travels the required passing sight distance, and stops to place a paint mark on the left side of the roadway. This marks the beginning of the no-passing zone in the opposite direction.
- (4) A trip through the site in the opposite direction, following the same procedure, completes the determination of the location of the no-passing zones for that site in both directions.
- (5) This one vehicle method essentially assumes a zero-height object as there is no practical way to adjust this object height. The method is therefore more likely to be conservative, especially on hills where 3.5 feet high objects could be seen some distance further than zero-height objects. This method can miss some short no-passing zones and may require a second pass in each direction to close any passing opportunities that are less than the minimum distance between no-passing zones shown in Table 12-2.

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CHAPTER 13 – SPEED STUDIES

13.1 PURPOSE

- (1) Title 31, Chapter 5 – Article 3 of the Wyoming Statutes establishes the speed regulations for all public roadways in Wyoming. Effective July 1, 2011 the statutory speed limits are:
 - (a) 20 mph in school zones
 - (b) 30 mph in urban districts, as defined by W.S. 31-5-102 (a) (lvii)
 - (c) 30 mph in any residence district, as defined by W.S. 31-5-102 (a) (xxxviii)
 - (d) 30 mph in any subdivision, pursuant to W.S. 18-5-304
 - (e) 75 mph on interstate highways
 - (f) 65 mph on all other paved roadways
 - (g) 55 mph on all other unpaved roadways
- (2) The statutes, under W.S. 31-5-302, authorize the director of the department of transportation to establish specific maximum speed limits on localized geographic areas of the state highway system based on engineering and traffic investigations. Such speed limits may be greater or less than the normal statutory speed limits for the roadways being considered.
- (3) The statutes also include a basic speed law [W.S. 31-5-301 (a)], prohibiting drivers from traveling at a speed greater than what is reasonable and prudent under the conditions and having regard to the actual and potential hazards that may exist, which recognizes that driving conditions and speeds may vary widely from time to time. No posted speed limit can adequately serve all driving conditions. Motorists must constantly adjust their driving behavior to fit the conditions they encounter.
- (4) Any speed limit, other than a statutory speed limit listed above, that is posted on the Wyoming state highway system must be based on an engineering study. That study must include an analysis of free-flow traffic speeds. A Spot Speed Study is used to measure the free-flowing traffic speed characteristics at a specified location under the traffic and environmental conditions prevailing at the time of the study. Spot speed data is also used in various other traffic engineering activities, such as determining traffic signal timings, establishing highway design elements, analyzing roadway capacity, and evaluating the effectiveness of improvements.
- (5) The purpose of this chapter is to establish the proper study procedures for completing the engineering and traffic investigation in accordance with the statutes, to provide guidance in setting appropriate speed limits based on the study data, and to establish the documentation and notification procedures when establishing new speed limits.

13.2 SPEED STUDY DATA COLLECTION

- (1) The basics of spot speed study data collection, such as site selection, sample size requirements and the selection of target vehicles are described in the ITE Manual of Transportation Engineering Studies. For most spot speed studies used by WYDOT, vehicle speeds should be measured using automated methods such as radar or laser speed detection. The individual vehicle selection method is the preferred method of obtaining free-flow speeds, with sample sizes of at least 50 and preferably 100 vehicles per direction being considered representative samples. The lower sample size can be used on lower volume (i.e., having two-way traffic volumes of less than 1,000 vehicles per day) roadways where the time to collect 100 samples per direction could be excessive.
- (2) An Excel spreadsheet has been developed to assist with the collection and analysis of spot speed study data. The spreadsheet includes a Speed Study Data Collection Sheet (Form TR-10), to be

printed out and used in the field for tabulating the speed samples by hand. It also contains a data input sheet where the raw data from the data collection sheet can be input into the spreadsheet for detailed analysis. Speed Study Worksheets (Form TR-11) that provide detailed speed statistics for each direction and the combination of both directions, as well as a “clean” computer printout of the data collection sheet are also included.

- (3) The worksheet was designed to where it can only process speed data having a maximum range of 40 mph between the highest recorded speed and the lowest recorded speed. This limitation was required to allow the data to properly display on the Display sheets. This 40 mph range is sufficient for almost all free-flow speed conditions. In the rare case where speeds spanning more than 40 mph may be recorded, the highest and lowest speeds can be disregarded without seriously affecting the speed study statistics. If that doesn’t reduce the speed range to 40 mph or less, then the speed statistics for that case will have to be calculated manually.

13.3 SPEED STUDY DATA COLLECTION SHEET

- (1) The Speed Study Data Collection Sheet (Form TR-10) has been developed in conjunction with the Speed Study Worksheet (Form TR-11) for the collection of speed data in the field. An example of a blank collection sheet is shown in Figure 13-1. In order to limit the range of speeds to what is allowed by the worksheet; the lowest anticipated free-flow speed at the study location must be entered in the red box. The remaining speed values are then automatically updated. To help determine what value to enter in the red box, Table 13-1 provides some guidance on what lowest anticipated free-flow speeds might apply based on the posted speed limit and whether the area of the study is in an urban area, urban/rural fringe or in a rural area.

Table 13-1 Lowest Anticipated Free-flow Speeds

Posted Speed (mph)	Extent of Roadside Development		
	Urban	Fringe Area	Rural
≤ 30	10	10	—
35 – 40	10	15	20
45 – 50	15	20	25
55 – 60	25	30	35
≥ 65	—	40	45

- (2) Prior to heading to the field to collect spot speed study data, it is recommended that several Speed Study Data Collection Sheets having varying lower limits be printed out for use by the data collection personnel.
- (3) When collecting speed study data, fill out the heading of the Speed Study Data Collection Sheet completely.
- (4) The observer enters a tally mark (\) in a data block under the appropriate direction for each observance of a speed. If more than 15 vehicles are observed at any particular speed in one direction, tally marks slanting in the opposite direction can be entered over the tally mark previously entered thus forming an “X”, which represents two vehicles observed at that speed. An example of a completed Speed Study Data Collection Sheet is shown in Figure 13-2.
- (5) If there is no interest in knowing the speed statistics for each direction, but only the combined directions, then all speed observations for both directions of travel can be entered in one column. This avoids having to add the number of tally marks from the two directions when entering the data into the Speed Study Worksheet.

Figure 13-1 Blank Speed Study Data Collection Sheet
SPEED STUDY DATA COLLECTION SHEET
 Wyoming Department of Transportation

CITY _____
 ROUTE _____
 POSTED SPEED _____

COUNTY _____
 LOCATION _____
 COMMENTS _____

NOTE: This sheet is not for computer data entry. Print out and use for field data collection.

DIRECTION OF TRAVEL _____
 OBSERVER _____
 DATE _____
 TIME _____ TO _____
 WEATHER _____

DIRECTION OF TRAVEL _____
 OBSERVER _____
 DATE _____
 TIME _____ TO _____
 WEATHER _____

Enter the lowest anticipated measured freeflow speed in the red square (Must be a multiple of 5 MPH).

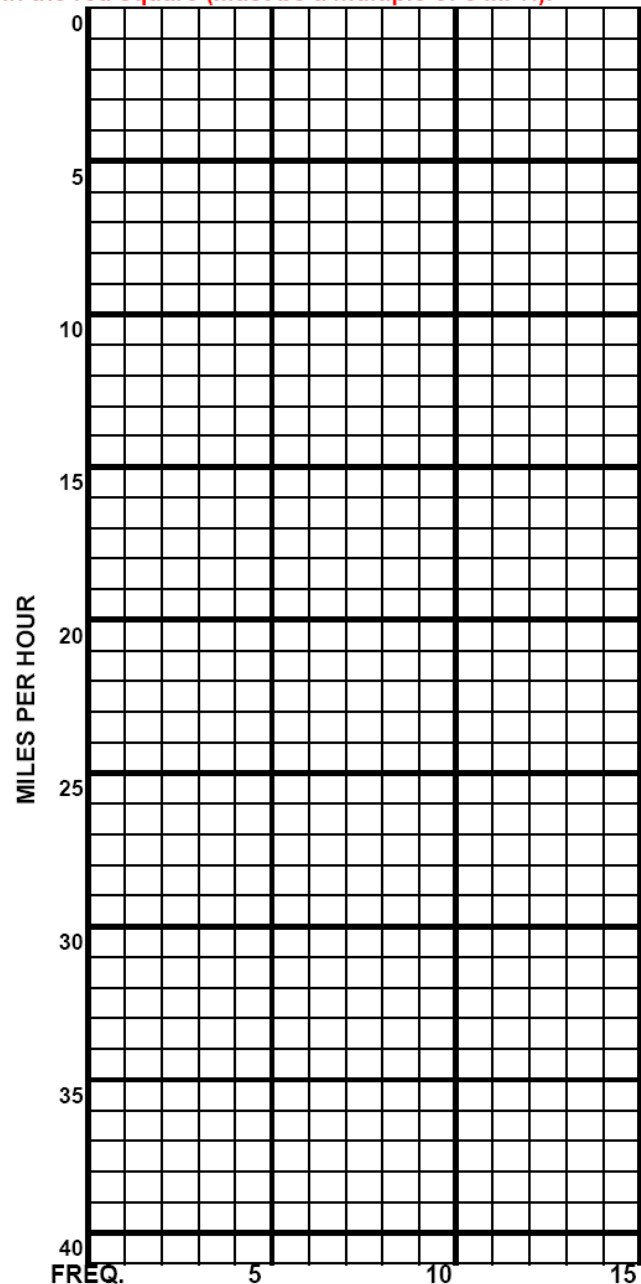
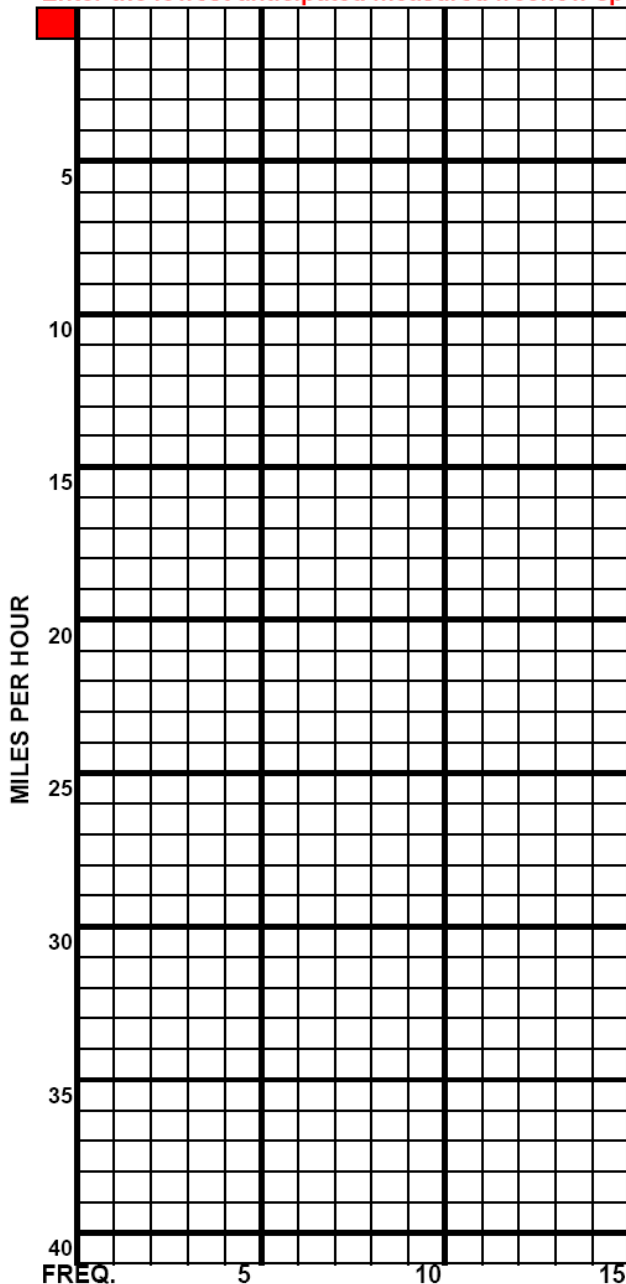


Figure 13-2 Example of a Completed Speed Study Data Collection Sheet

SPEED STUDY DATA COLLECTION SHEET

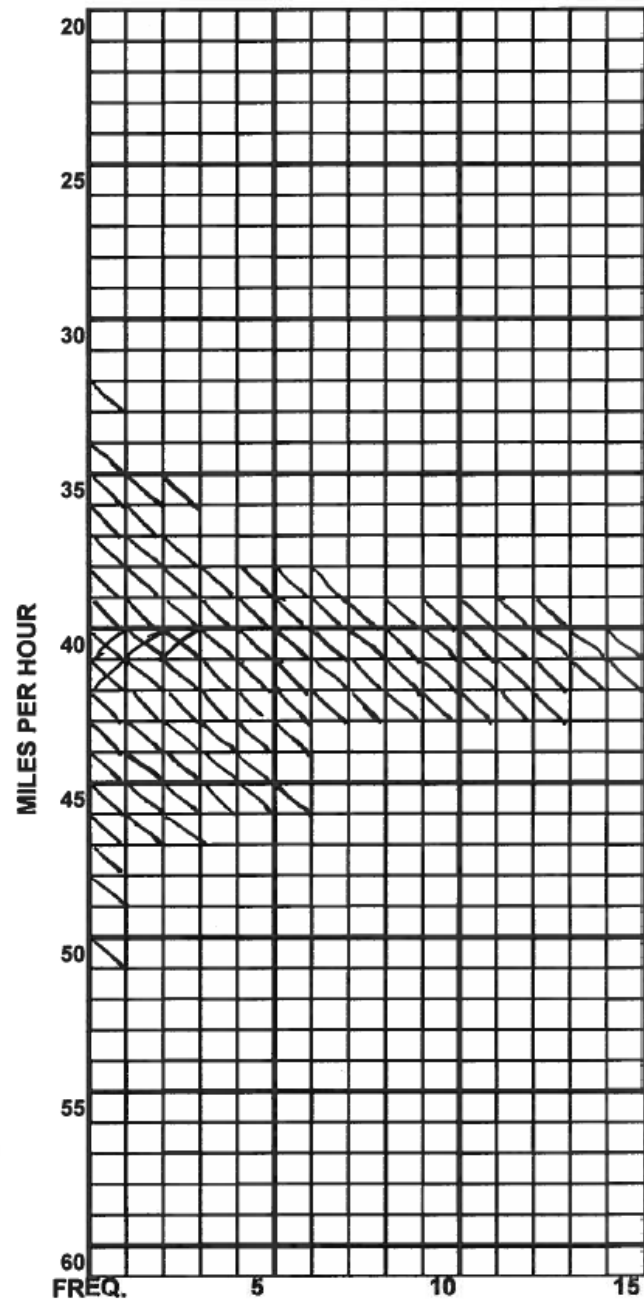
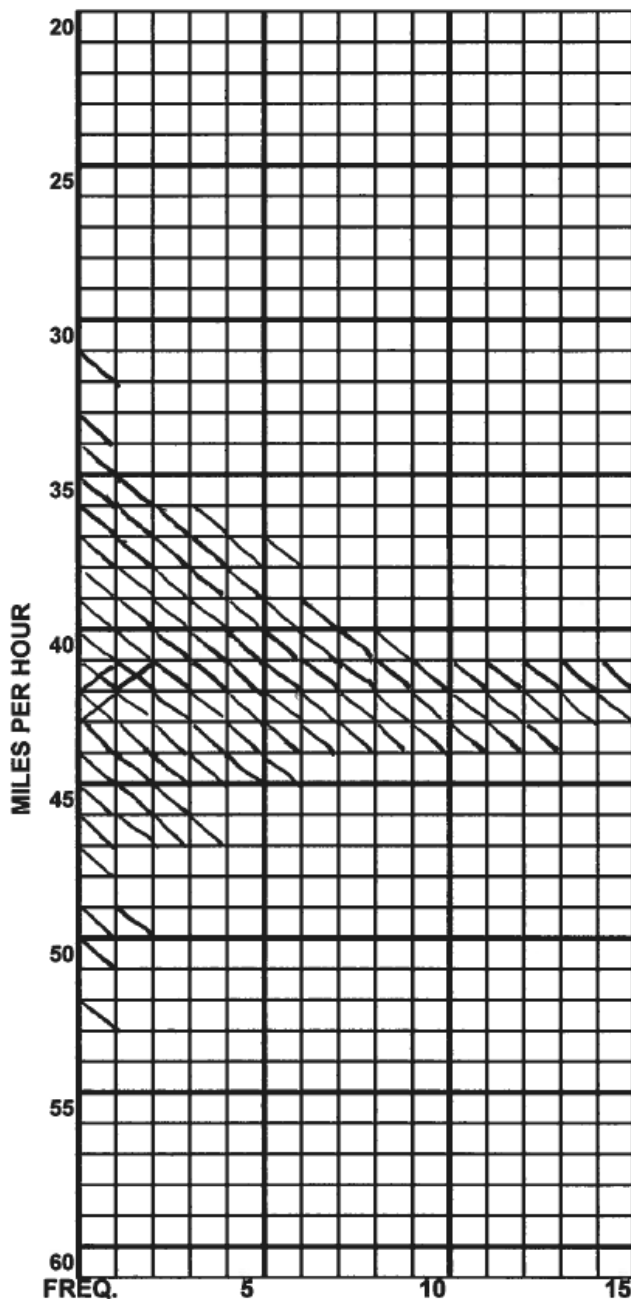
Wyoming Department of Transportation

CITY Ranchester
 ROUTE US 14 (Dayton St)
 POSTED SPEED 40

COUNTY Sheridan
 LOCATION At 4th Ave. W.
 COMMENTS Example Only

DIRECTION OF TRAVEL EB
 OBSERVER J.D.T.
 DATE 5/19/10
 TIME 8:40AM TO 9:50AM
 WEATHER Clear & warm

DIRECTION OF TRAVEL WB
 OBSERVER J.D.T.
 DATE 5/19/10
 TIME 9:55 TO 10:45AM
 WEATHER clear & warm



- (6) The Speed Study Data Collection Sheet can also be used to document speeds based on vehicle class, either by direction or for both directions. This is accomplished by utilizing one-letter classification codes rather than tally marks. Classification codes that may be used include the following:
- P = passenger vehicle (includes cars, pickups, vans and SUVs)
 - T = truck (includes single units with 6 or more tires, buses, RVs and pickups pulling trailers)
 - S = semi-truck (tractor-trailer combinations)
 - M = motorcycle

13.4 SPEED STUDY WORKSHEET

- (1) The Speed Study Worksheet has been developed to simplify and automate the processing of speed study field data. This helps reduce the chances of errors in the processing as well. The worksheet is an Excel spreadsheet with an input sheet and display sheets for each direction of travel as well as the combination of both directions analyzed. All data is entered on the input sheet, and the results are displayed on the display sheets for printing.
- (2) The location-related data is entered at the top of the Input sheet from the data on the Speed Study Data Collection Sheet. An example of the data input sheet for the previous field data collection sheet is shown in Figure 13-3.
- (3) Enter the lowest speed recorded and the highest speed recorded. This will help adjust the display of output data so that it is relatively centered in the display graph. If the difference between the highest and lowest recorded speeds exceeds 40 mph, an error message will display.
- (4) The number of observations at each respective speed is then entered under the appropriate direction column. If no vehicles were observed at a given speed, the respective line can be left blank or a zero (0) can be entered.
- (5) The Speed Study worksheet is designed to analyze speed statistics for each direction of travel as well as both directions at once.
- (6) If the speed study is checking speeds by vehicle classification, the Speed Study Worksheet can only process one vehicle class at a time. The class of vehicle being studied should be noted in the Comments space of the input sheet.
- (7) Once all of the necessary data is entered on the input sheet, the speed study statistics can be viewed by selecting one of the display sheets. Figure 13-4 gives an example of the Speed Study Worksheet output for one direction of travel.
- (8) For a neat computer-generated sheet that duplicates the hand-written data from the data collection sheet, the cleaned field data sheet uses the same data entered on the input sheet to provide a copy of the Speed Data Collection Sheet with the heading data and tally marks filled in to match the form completed by hand. Figure 13-5 gives an example of the cleaned field data collection sheet.

Figure 13-3 Example Speed Study Worksheet Data Input

CITY	Ranchester		
COUNTY	Sheridan		
ROUTE	US 14 (Dayton St.)		
LOCATION	At 4th Ave. W.		
POSTED SPEED LIMIT	40		
LOWEST SPEED RECORDED	30		
HIGHEST SPEED RECORDED	52		
COMMENTS	Example Only		
DIRECTION 1	Eastbound	DIRECTION 2	Westbound
OBSERVER	J.D.T.	OBSERVER	J.D.T.
DATE	5/19/10	DATE	5/19/10
START TIME	8:40 AM	START TIME	9:55 AM
END TIME	9:50 AM	END TIME	10:45 AM
WEATHER	Clear & Warm	WEATHER	Clear & Warm

SPEED	NUMBER OF OBSERVATIONS AT SPEED PER DIRECTION	
	Eastbound	Westbound
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31	1	
32		1
33	1	
34	1	1
35	2	3
36	4	2
37	6	3
38	5	7
39	7	13
40	9	18
41	17	16
42	16	13
43	13	6
44	6	5
45	3	6
46	4	3
47	1	1
48		1
49	2	
50	1	1
51		
52	1	
53		
54		
55		
56		
57		
58		
59		
60		

Figure 13-4 Example Speed Study Worksheet Output

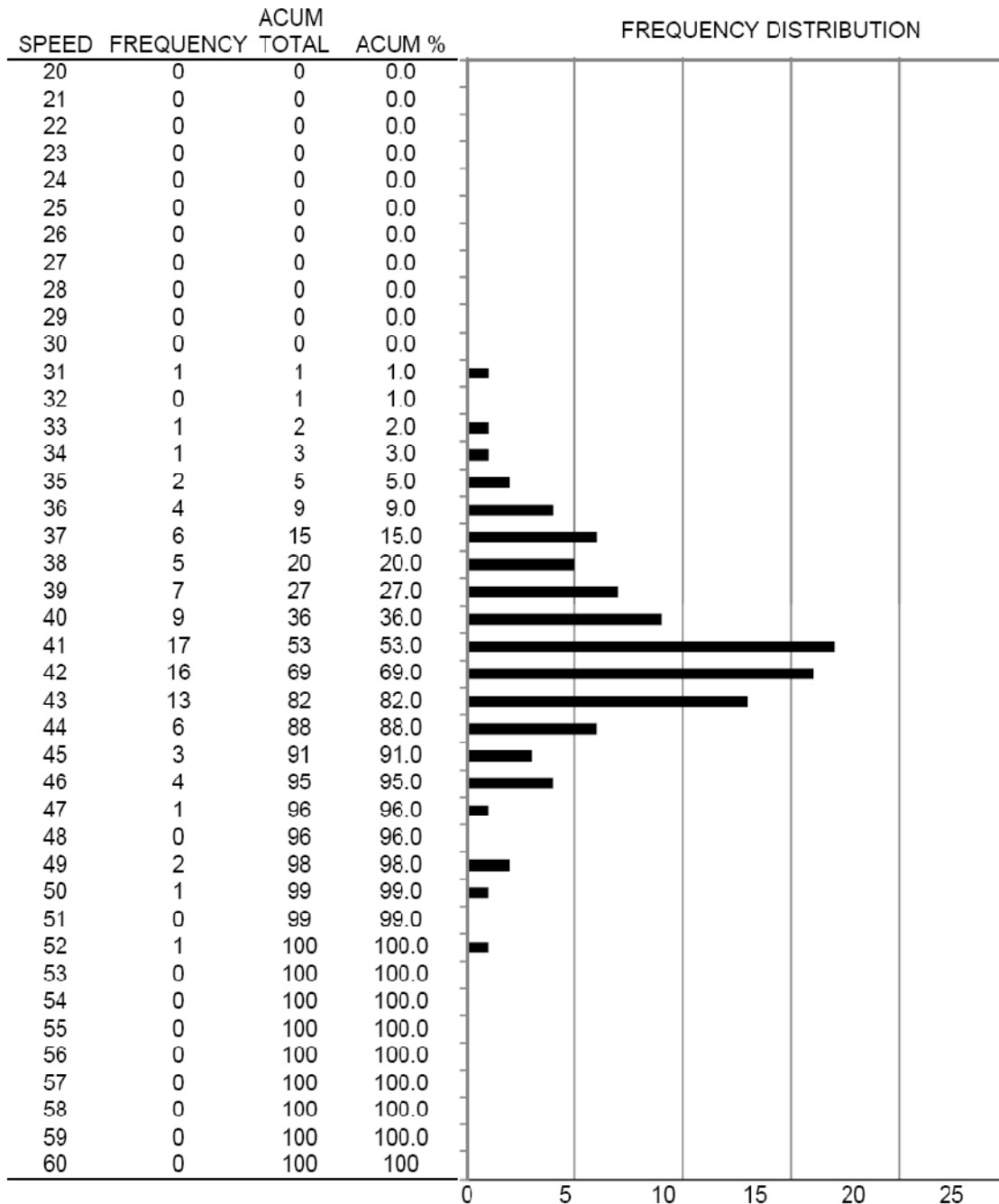
SPEED STUDY

Wyoming Department of Transportation

CITY: Ranchester
SPEED LIMIT: 40 MPH
OBSERVER: J.D.T.
DATE: 5/19/10

COUNTY: Sheridan
DIRECTION: Eastbound
START TIME: 8:40 AM
END TIME: 9:50 AM

ROUTE: US 14 (Dayton St.)
LOCATION: At 4th Ave. W.
WEATHER: Clear & Warm
COMMENTS: Example Only



AVERAGE SPEED = 41.2
50th PERCENTILE = 41
67th PERCENTILE = 42
85th PERCENTILE = 44
95th PERCENTILE = 46

TRAFFIC STUDIES MANUAL

PACE SPEED = 36 to 45
VEHICLES IN PACE = 86
% IN PACE = 86
% BELOW PACE = 5
% ABOVE PACE = 9

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STANDARD DEVIATION = 3.48
% EXCEEDING POSTED LIMIT = 64
RECOMMENDED SPEED LIMIT = 45

March 9, 2011

Figure 13-5 Example of Cleaned Speed Study Data Collection Sheet

SPEED STUDY DATA COLLECTION SHEET

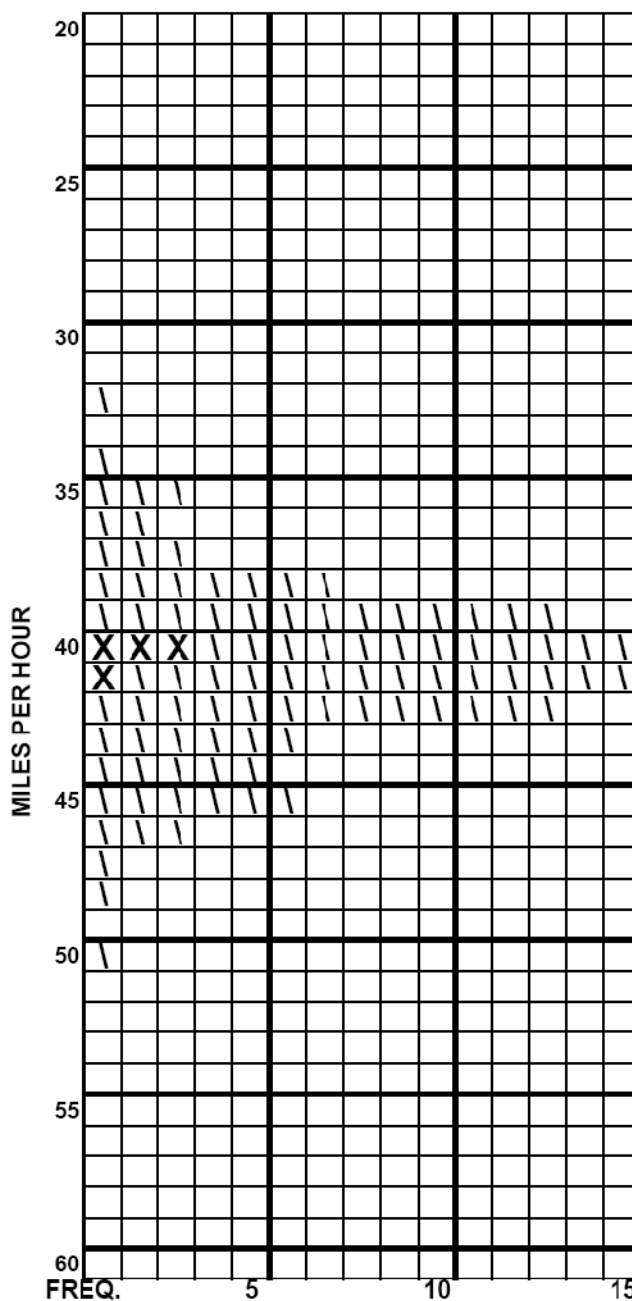
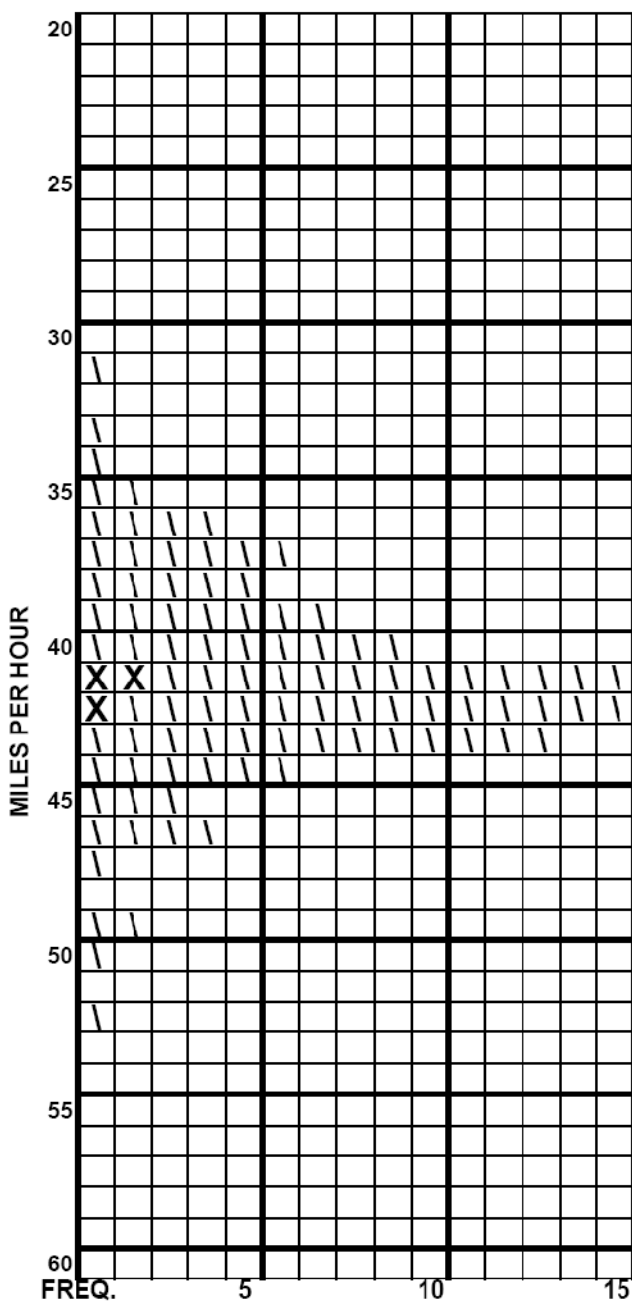
Wyoming Department of Transportation

CITY Ranchester
 ROUTE US 14 (Dayton St.)
 POSTED SPEED 40

COUNTY Sheridan
 LOCATION At 4th Ave. W.
 COMMENTS Example Only

DIRECTION OF TRAVEL Eastbound
 OBSERVER J.D.T.
 DATE 5/19/10
 TIME 8:40 AM TO 9:50 AM
 WEATHER Clear & Warm

DIRECTION OF TRAVEL Westbound
 OBSERVER J.D.T.
 DATE 5/19/10
 TIME 9:55 AM TO 10:45 AM
 WEATHER Clear & Warm



13.5 DETERMINATION OF APPROPRIATE SPEED LIMIT

- (1) Speed limits and speed zoning remain one of the more controversial tasks for the traffic engineering profession. Engineers, public safety officials, and others involved in setting and enforcing speed limits may disagree on the appropriate balance between safety and road-user convenience that should prevail on particular road segments, considering conditions of topography, weather, adjacent activities, and traffic. Motorists, other road users, and roadway neighbors have their own perspectives on this balance and may or may not abide by the professionals' judgments.
- (2) Wyoming speed laws define speed limits as absolute speed limits; traveling at a speed above the absolute limit is by definition illegal and presumably imprudent and unreasonable. WYDOT is empowered to lower or raise speed limits on a particular state highway segment if these altered limits are judged to be reasonable and safe under conditions found to exist at that location. Engineering and traffic studies typically provide the basis for making such speed-zone judgments. These studies generally consider such factors as the physical features of the roadway, crash experience, traffic characteristics and control (for example, signals and other control devices), and the length of the roadway segment under consideration (speed-limit changes should not be too frequent or applied to very short road segments).
- (3) If the regulation of speed is to be effective, the posted limit must be generally consistent with speeds that drivers feel are safe and proper. Enforcement is widely recognized to be crucial to the success of speed limits as a means for making roads safer. If law enforcement officers and the courts are confident that speed limits have been developed on a reasonable basis, their enforcement of the limits will be more effective. Generally, speed limits should be set at levels that are self-enforcing so that law enforcement officials can concentrate their efforts on the worst offenders.
- (4) One of the factors considered very important for setting a speed limit is the prevailing vehicle speed. The *MUTCD* is quite explicit, stating that "when a speed limit within a speed zone is posted, it should be within 5 mph of the 85th-percentile speed of free-flowing traffic." The Speed Study output sheets show the recommended speed limit based on this criterion.
- (5) The *MUTCD* indicates other factors may also influence the appropriate speed limit, including roadway characteristics such as shoulder condition, grade, alignment, and sight distance; the pace; roadside development and environment; parking practices and pedestrian activity; and reported crash experience for at least a 12-month period.
- (6) These other factors may be used to justify a speed limit somewhat lower than the 85th-percentile speed, but in no circumstance should the speed limit be posted below the 50th-percentile speed or lower limit of the 10-mph pace. The Speed Study output sheet compares the posted speed limit to these two factors and raises a red flag whenever the posted speed limit is posted too low.

RECOMMENDED SPEED LIMIT = 45

POSTED SPEED IS TOO LOW

- (7) In cases where the speed limit is posted below the 85th-percentile speed based on the other factors, the speed limit sign serves to remind motorists that conditions in the area are such that the speed reduction is reasonable. Proper use of speed limit signs would instill confidence in the minds of drivers that the information on the speed limit sign is accurate and not simply a desire on the part of a policy maker to reduce speed arbitrarily for emotional or political reasons.
- (8) For additional guidance on determining appropriate speed limits, a web-based expert system was developed by the FHWA as part of NCHRP Project 3-67 to help determine the most appropriate speed limit for a given route. This system can be found at: <http://www2.uslimits.org/index.cfm>. This site requires users to establish a user name and password to access the system.

13.6 DECLARATION OF SPEED LIMIT

Posted speed limits (other than statutory speed limits) on the state highway system that have been established by engineering and traffic investigation shall be documented by a Declaration of Speed Limit (Form M-10). An example of a completed M-10 form is shown in Figure 13-6.

When declaring a speed limit, the M-10 form shall be signed by the District Engineer and forwarded to the State Traffic Engineer, along with the supporting documentation, for concurrence. If the State Traffic Engineer concurs, the form is then signed and forwarded to the Director for formal declaration of the speed limit. After the form is signed by the Director or his designee, the form is returned to the district so the appropriate signing changes can be made. Enforcement of the new speed limit cannot occur until the appropriate signs giving notice thereof have been erected.

Once the signing changes have been made, the installation date shall be noted on the form and copies of the completed form shall be distributed to the District Engineer, District Traffic Engineer, State Traffic Engineer, and Traffic Studies Engineer. It is also recommended that copies be sent to the local Highway Patrol division captain, and local law enforcement agency(ies) for help with enforcement.

13.7 MINIMUM SPEED LIMITS

WYDOT does not post minimum speed limits.

Figure 13-6 Example of Completed Declaration of Speed Limit Form

Form M-10
Rev. 10-00

WYOMING DEPARTMENT OF TRANSPORTATION

DECLARATION OF SPEED LIMIT

LOCATION: Wyo 212, Four Mile Road, LA08A, MP 13.11 - MP 13.57
Results of Engineering and Traffic Investigation

Method Used:

Visual inspection and engineering judgement.
Free flow spot speeds to determine 85th percentile speed and pace.

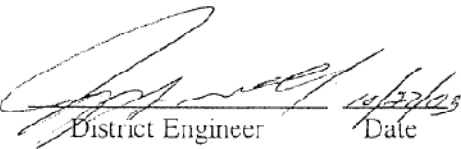
Summary of Results:


The existing speed limit is 40 mph. The 85th percentile speeds are 51 mph eastbound and 52 mph westbound with a ten mile per hour pace of 39 mph to 48 mph in both directions.

Recommendations:

Post a 50 mph speed limit by replacing the existing 40 mph speed limit sign westbound at MP 13.11 with a 50 mph sign. Replace the existing eastbound 40 mph sign at MP 13.43 with a 50 mph speed limit sign.

Approved:


District Engineer Date

 11-13-03
State Traffic Engineer Date

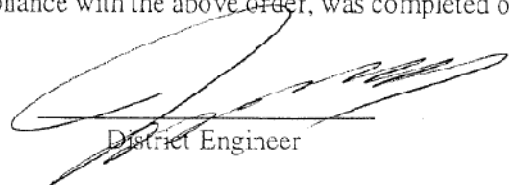
ORDER TO ESTABLISH RESTRICTED SPEED ZONE

It is determined and declared that fifty (50) miles per hour is a safe and reasonable speed limit of the location designated and the District Engineer at said location is hereby directed to cause appropriate signs to be erected, with the concurrence of the State Traffic Engineer, thereat giving notice of said speed limits.

Dated this 17th day of NOVEMBER, 2003


FOR Director

ERECTION OF SIGNS: The erection of appropriate signs, in compliance with the above order, was completed on 1-15, 2004.


District Engineer

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CHAPTER 14 – TRAVEL TIME AND DELAY STUDY

14.1 PURPOSE

- (1) The purpose of a travel time and delay study is to evaluate the quality of traffic movement along a route and determine the locations, types, and extent of traffic delays by using a moving test vehicle.
- (2) This type of study can be used to compare operational conditions before and after roadway or intersection improvements have been made or signal coordination has been implemented or modified. It can also be used as a tool to assist in prioritizing projects by comparing the magnitude of the operational deficiencies (such as delays and stops) for each project under consideration.
- (3) The travel time and delay study can also be used for the following purposes:
 - (a) By planners to monitor level of service for local government comprehensive plans.
 - (b) Determination of route operational efficiency or delay.
 - (c) Identification of congested locations such as driveways, entrances, etc., where a significant number of turning movements occur.
 - (d) Evaluation of the effectiveness of traffic engineering improvements using before and after studies on projects such as signal retiming or the addition of turn lanes.
 - (e) Determination of level of service from average travel speed data.
- (4) The methodology presented herein provides the engineer with quantitative information with which he can develop recommendations for improvements such as traffic signal retiming, safety improvements, turn lane additions, and channelization enhancements.

14.2 DEFINITIONS

- Average Speed** *The total distance covered divided by the elapsed time.* The average speed for each section (node to node distance) and a total average speed for the entire route are calculated separately.
- Before and After** *A way to categorize a group of runs so that two different groups of runs can be compared.* The terms Before and After mean only that the data is summarized into two separate groups so the statistics of each group can be compared. If all of one set of runs are made under the same conditions, they may all be defined as before runs. Later, identical runs made under different conditions (after an arterial has been re-timed, for example) may be defined as after runs. The analysis can then compare statistics for the before runs as a group, the after runs as a group, and changes in the various statistics from before to after.
- Fixed-Route** *Data collection along a pre-determined route.* When doing fixed-route studies, run data is collected along the same route several times. One run is rarely sufficient to find the travel time characteristics of a route. The operator may never hit a red light during a run, or may hit several. If several runs are collected, the averages of the individual run data will be a better representation of the true traffic characteristics of the route. Fixed-route studies usually have segments defined at the time the runs are made. The route is divided into geographic segments, using easily determined landmarks to separate the segments. For arterials, the segment boundaries will typically be signalized intersections, but the segments may be defined any way you want.

Node	<i>The boundary between two segments of a run.</i> Every run has a starting node, which is where you start collecting data on a fixed-route study, an ending node, which is where you stop collecting data, and several segment nodes in between. If intersections are used to define the nodes, the landmark used to define the node should be at a point exiting the intersection (a good rule-of-thumb is the far right traffic signal pole). This will ensure that any delay associated with stops at the intersection will be reported in the correct section.
Normal Speed	<i>Ideal speed at which the traffic should travel on an arterial.</i> The Normal Speed is used to find Total Delay statistics for runs and studies (see Total Delay, below) and is plotted on the Time/Space Diagrams to show perfect progression. This is set at the beginning of the study and is usually the posted speed limit on the corridor.
Number of Stops	<i>A stop is defined as a one-second interval where the speed is less than X mph for one second when the speed was greater than X mph in the previous second.</i> X is normally 5 mph but can be set to any speed you want. This speed is called the Stop Speed and is set at the beginning of the study. Each time the vehicle slows down and crosses the Stop Speed boundary, a stop is counted. The vehicle must speed up faster than the threshold before another stop can be counted.
Primary Run	<i>A run where the user collected segment node data.</i> Most users, when doing a run, will collect segment node data by noting their location as they pass by the pre-determined nodes in the route. The distances measured for a single run are not very accurate, so collecting segment node data on multiple runs and averaging the node distances from each of the primary runs in a study will result in more accurate distances between nodes.
Run	<i>A single collection of travel time data.</i> For example, when data is collected along an arterial, the user drives to the beginning of the arterial under study, starts data collection, proceeds along the arterial to the end of the study area, and then stops data collection. He has just completed one run. If he turns around and collects data in the other direction, it is another run. All runs are stored as separate entities.
Secondary Run	<i>A run where the user did not collect segment node data.</i> <i>or</i> <i>A primary run in which the user decides not to use the segment node data to find the node distances for the study.</i> You do not have to collect segment node data while doing a run. You may have done several runs in that direction and know you have sufficient data to find accurate node distances, or you may have made several mistakes marking the node on a particular run, or you simply don't need node by node statistics for this route. You can define a run as Secondary and any node distance data in the run will be ignored in the analysis.
Study	<i>A collection of runs.</i> When the user collects data, he is making data runs, and when he gets back to the office, he collects those runs into studies. The difference is important because runs can be collected into different studies. For example, a user may make a number of runs at an arterial during one or two days. Back in the office he may create a study with just the morning runs. He may also create a study with all of the runs, which of course use some of the morning runs. There is one critical rule for studies: All of the runs in a study must start at the same place, end at the same place, and follow the same route. Only runs in the same direction can be part of the same study. Since you usually collect runs in two directions (up and back), you will typically create at least two studies for each data collection session.

Study Group	<i>A folder where related runs and studies are stored.</i> Since studies must be created from runs that start in the same place, end in the same place, and go in the same direction, it makes sense to store all runs that fit those criteria in one place on the computer, along with any studies that are created from those runs. Since at least two sets of runs are usually collected, one in one direction and another in the opposite direction, two Study Groups will usually be created when the data is read from the traffic data collector.
Time \leq X mph	<i>Total time the vehicle spent at or below the given speed.</i> There are three speed categories, which you can set for different purposes. You can measure stopped delay (time vehicle is stopped) by setting Category 1 to 0 mph. You can measure queue delay by setting Category 2 to 7 mph. The third category might be set to 30 mph to show how much time vehicles spent in car following mode rather than free flow (assuming free flow speed is 40 or 45 mph). Many other uses for these three categories are possible, limited only by your imagination.
Total Delay	<i>Difference between actual travel time and ideal travel time.</i> Actual travel time is calculated from the data. The ideal travel time is based on the Normal Speed set at the beginning of the study.
Travel Time	<i>The elapsed time to travel between two points, in seconds.</i> This is probably the most fundamental of the reported statistics. It is measured directly in the field.

14.3 STUDY PROCEDURES

- (1) To conduct a travel time and delay study, one must first define the study area by selecting all control points before beginning the study. The time periods recommended for studies are A.M. and P.M. peak hours as well as off peak hours in the direction of heaviest traffic movements (other times may be requested by the District Traffic Engineer).
- (2) These studies should be made during reasonably good weather so that unusual conditions do not influence the study. Also, since crashes or other unusual delays will produce erroneous results, any runs made during such an occurrence should be terminated and another run conducted. These studies should be conducted during average or typical weekday traffic conditions.
- (3) When conducting a travel time and delay study, the floating car technique should be used. In using the floating car technique, the driver floats with traffic by passing as many vehicles as pass the test car. The idea is to emulate an average driver for each section of roadway.
- (4) In order to determine the number of runs required for statistical significance, the engineer/analyst should use the following method:
 - (a) Estimate the number of runs required by using Table 14-1.
 - (b) Conduct the runs.
 - (c) Calculate the average range in running speed (R) using the equation below.
 - (d) Using the average range in running speed as calculated, again use Table 14-1 to determine the number of runs required.
 - (e) Make additional runs if required.
 - (f) Engineering judgment should also be used in applying this procedure to fit the purpose of the study.
- (5) To elaborate on (4)(c), after the first group of running speeds has been computed, the absolute differences between the first and second values, the second and third values, etc., are obtained. These differences are summed and the total is divided by the number of differences (N-1) to provide the average range in running speed for the initial data.

- (6) This procedure is represented by the following equation:

$$R = \frac{S}{N - 1}$$

Example:

Run #	RS	Absolute Difference
1	38	0
2	35	3
3	32	3
4	33	1
5	36	3
		10 (Total = S)

$$R = S/(N - 1) = 10/(5 - 1) = 2.5$$

Where:

RS	=	Average running speed in mph
R	=	Average range in running speed in mph
S	=	Sum of absolute differences
N	=	Number of completed test runs

- (7) The approximate minimum sample size is selected from Table 14-1 for the calculated average range in running speed and the desired permitted error. If the required sample size is greater than the number of runs made, then additional runs must be performed under similar traffic and environmental conditions to reach the minimum sample size.
- (8) The specified permitted error for traffic operations studies involving efficiency (i.e., timing studies) should be ± 3.0 mph.
- (9) The permitted error for before and after studies should be ± 3.0 mph for studies predominately involving efficiency, and ± 2.0 mph for studies predominately concerned with safety.
- (10) Table 14-1 also includes ranges for specified permitted errors of ± 4.0 mph, and ± 5.0 mph. These data are provided as background information for the traffic engineer. There may be special projects where the traffic engineer would deem it appropriate to use one of these other specified permitted errors. Any exceptions to the previously noted standards should be approved by the State Traffic Engineer on a project by project basis.

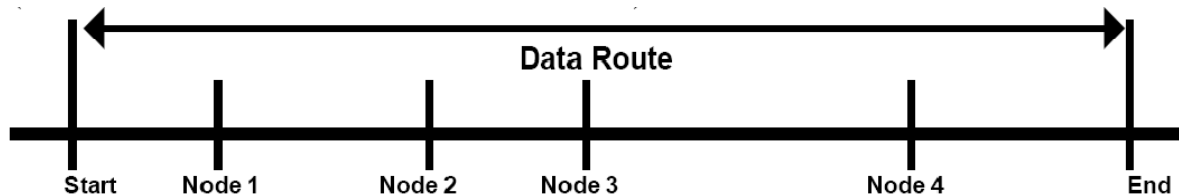
Table 14-1

APPROXIMATE MINIMUM SAMPLE SIZE REQUIREMENTS FOR TRAVEL TIME AND DELAY STUDIES WITH 95 PERCENT CONFIDENCE LEVEL					
Average Range in Running Speed (mph) * R	Minimum Number of Runs for Specified Permitted Error				
	+/- 1.0 mph	+/- 2.0 mph	+/- 3.0 mph	+/- 4.0 mph	+/- 5.0 mph
2.5	4	2	2	2	2
5.0	8	4	3	2	2
10.0	21	8	5	4	3
15.0	38	14	8	6	5
20.0	59	21	12	8	6
*Interpolation should be used when R is other than the numbers shown in column 1.					

14.4 COLLECTING THE DATA

WYDOT uses PC-Travel for Windows Travel Time and Delay Analysis Software to conduct travel time and delay studies. This study method requires a test vehicle with a transmission sensor installed, JAMAR TDC-8 traffic data collector, New Link pushbutton switch connected to the TDC-8, TDC-8 Sensor Interface Cable, and PC-Travel Field Worksheet (see Figure 14-1).

- (1) Define the starting point, ending point and the intermediate nodes. Normally the starting, ending, and intermediate nodes are intersections, but they can be other landmarks such as bridge abutments, mile post markers, or other fixed landmarks. Pick points that can be easily identified now and when future after runs may be collected. The drawing below shows a simplified diagram of a typical study route. There is a starting node, which could be an intersection, four nodes, which could be signalized intersections, and an ending node. Make a rough sketch of the route, clearly showing the starting and ending points and list the intermediate nodes you want to use (see step 4). You don't have to make every intersection a node. It is important to understand the type of information you want the data to give you before you define the route and nodes. Don't use more nodes than you really need; it just needlessly complicates the analysis.



- (2) You should always keep field notes when you do travel time studies. The field notes help you keep track of the runs when you get back to the office. The PC-Travel Field Worksheet will help you store all of the information about the runs you make. Figure 14-1 is an example of a worksheet that has been filled out to give you an idea of how the form is used. Before you start the data collection, fill in the general information about the session at the top of the sheet. List the starting point, ending point, and any intermediate nodes.
- (3) Connect the TDC-8 to the vehicle's transmission sensor using the Sensor Interface Cable and Plug the pushbutton switch into the jack labeled Bank 1 on the side of the TDC-8. This is actually connected to the Bank 2 switch in the counter. The labels for the two jacks are reversed on the side of the TDC-8.
- (4) Calibrate the TDC-8 according to the procedure described in the *PC-Travel for Windows Reference Manual*. The calibration constant should be recorded on the PC-Travel Field Worksheet.
- (5) Prepare the TDC-8 for a travel time (TT) study following the procedure described in the *TDC-8 User's Manual*.
- (6) Start a run by driving to the starting point so that when you pass the starting point you are traveling at the proper speed with the rest of the traffic. Press the DO button on the TDC-8 as accurately as you can as you pass the starting point; this begins data collection. The display shows the run number, link number (how many times you have pressed the New Link button this run), time, distance traveled so far this run, speed, as well as the last delay button pushed (the L Key = value). As you proceed along the route, press the New Link button as you pass each new section.

Note: Check the speed reading on the TDC-8 and make sure it is close to the speed on the speedometer. If they are not reasonably close (within a few miles per hour) it may indicate a problem with the sensor or an incorrect Calibration Constant. Don't collect data if the speed isn't right; the data almost certainly won't be correct.

Note: If you have chosen intersections as your nodes, wait until you exit the intersection to press the New Link button. This will ensure that any delay associated with stops at the intersection will be reported in the correct section.

More information about collecting travel time and delay study data is contained in the *PC-Travel for Windows Reference Manual*.

- (7) Stop the run by pressing the DO button on the TDC-8 when you have reached the end of the route. If the end is the last intersection, remember to press the button as you depart the intersection. This ends the run and the TDC-8 stops collecting data until you press the DO button again, signifying the start of a new run.
- (8) Turn around and collect data in the other direction using the same nodes for both directions. In this case you press the DO key when you go by the first intersection (the END node of the previous run), press the New Link button as you go through each of the nodes, and press the DO button to end the run when you get to the last node (the START node of the previous run).
Note: Remember that you press the DO button to start and stop a run. You press the New Link button for nodes in between.
- (9) Repeat steps 6 & 7 until you have completed the recommended number of runs, then just turn off the TDC-8.
- (10) The TDC-8 is then downloaded to a computer and the data processed following the procedures outlined in the *PC-Travel for Windows Reference Manual*.

14.5 ANALYSIS

- (1) From the data collected, the analysis program determines the time spent stopped and the speed at any time or distance. The program is thus able to calculate average speed, running speed, amount of delay, number of stops, distance and time between traffic signals, fuel consumption, and miles per gallon. The data can also be used to produce a speed plot and/or a time space trajectory plot.
- (2) These outputs must then be analyzed, and engineering judgment should be applied to the numbers and graphs to determine if problem areas exist. If they do, then the appropriate corrective action must be determined. Engineering judgment should be applied in order to analyze the results and to determine any actions that can be taken to reduce delay and improve operational efficiency.
- (3) Things to look for include:
 - (a) More than one stop between intersections. This may indicate interference with the traffic flow from sources other than traffic signals, possibly caused by traffic generators.
 - (b) Travel speed (average speed) significantly less than running speed. This could be caused by delay at the traffic signals or accesses.
 - (c) Delay significantly higher during peak versus off-peak periods. This could be caused by heavy cross street traffic during a peak volume at an intersection exceeding or close to capacity, lack of left-turn lane storage capacity, etc.
- (4) Typical solutions for delays would include turn lanes, traffic signal retiming, and restriction of certain movements responsible for delay. The engineer must determine the best solution for each particular situation.

Figure 14-1 Example PC-Travel Field Worksheet

Form TR-22

Revised 11/17/08

PC- TRAVEL FIELD WORKSHEET

Location: _____ Date: _____

Operator: _____ Cal Constant: _____

Nodes:

Start/End

<u>1</u>	<u>16</u>
<u>2</u>	<u>17</u>
<u>3</u>	<u>18</u>
<u>4</u>	<u>19</u>
<u>5</u>	<u>20</u>
<u>6</u>	<u>21</u>
<u>7</u>	<u>22</u>
<u>8</u>	<u>23</u>
<u>9</u>	<u>24</u>
<u>10</u>	<u>25</u>
<u>11</u>	<u>26</u>
<u>12</u>	<u>27</u>
<u>13</u>	<u>28</u>
<u>14</u>	<u>29</u>
<u>15</u>	<u>30</u>

Runs:

#___ Dir___ Time___ Comments

#___ Dir___ Time___ Comments

<u>1</u>	<u>2</u>
<u>3</u>	<u>4</u>
<u>5</u>	<u>6</u>
<u>7</u>	<u>8</u>
<u>9</u>	<u>10</u>
<u>11</u>	<u>12</u>
<u>13</u>	<u>14</u>
<u>15</u>	<u>16</u>
<u>17</u>	<u>18</u>
<u>19</u>	<u>20</u>

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CHAPTER 15 – HIGHWAY LIGHTING STUDIES

15.1 PURPOSE

- (1) The investment of public funds in roadway lighting returns benefits to the public in several ways. Lighting benefits motorists by improving their ability to see roadway geometry and other vehicles at extended distances ahead. This results in greater driver confidence and improved safety, particularly in inclement weather. Lighting may also improve roadway capacity. Other benefits include improved pedestrian safety, improved public safety and security, convenience, and civic pride and recognition.
- (2) WYDOT Operating Policy 25-1, Traffic Control and Roadway Lighting Devices, establishes much of the criteria by which lighting will be installed at many intersections on the state highway system. It lists rural and urban interstate highways including interchanges, ramp termini, and crossroads within the interstate right-of-way meeting the interchange lighting criteria of the traffic program. It also lists rural locations on other state highway intersections meeting the intersection lighting criteria of the Traffic Program. This chapter includes a summary of the Traffic Program's interchange and intersection lighting criteria.

15.2 LIGHTING WARRANTS

- (1) The primary purpose of warrants is to assist administrators and designers in evaluating locations for lighting needs and selecting locations for installing lighting. Warrants give conditions that should be satisfied to justify the installation of lighting. Meeting these warrants does not obligate the state or other agencies to provide lighting or participate in its cost. Conversely, local information in addition to that reflected by the warrants, such as roadway geometry, ambient lighting, sight distance, signing, crash rates, or frequent occurrences of fog, ice, or snow, may influence the decision to install lighting.
- (2) Per WYDOT Operating Policy 25-1, WYDOT is responsible for the design, installation and maintenance for roadway lighting systems on the state highway system as follows:
- (3) The traffic program has adopted the warrants for freeway lighting that have been established by the American Association of State Highway and Transportation Officials (AASHTO) in the *Roadway Lighting Design Guide, 2005*. The warrants for freeway lighting contained in the AASHTO Guide are indicated below:
 - (a) On existing traffic signal poles when the lighting system is upgraded to WYDOT standards;
 - (b) On traffic signal poles at new or reconstructed traffic signal installations;
 - (c) Rural intersections of US-numbered routes with other US-numbered routes;
 - (d) Rural intersections with raised channelization.

15.2.1 CONTINUOUS FREEWAY LIGHTING

Case CFL-1 - Continuous freeway lighting is considered to be warranted on those sections in and near cities where the current ADT (both directions) is 30,000 or more.

Case CFL-2 - Continuous freeway lighting is considered to be warranted on those sections where three or more successive interchanges are located with an average spacing of 1½ miles or less, and adjacent areas outside the right-of-way are substantially urban in character.

Case CFL-3 - Continuous freeway lighting is considered to be warranted where for a length of 2 miles or more, the freeway passes through a substantially developed suburban or urban area in which one or more of the following conditions exist:

- (a) Local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway;
- (b) The freeway passes through a series of developments such as residential, commercial, industrial and civic areas, colleges, parks, terminals, etc., which includes roads, streets and parking areas, yards, etc., that are lighted;
- (c) Separate cross streets, both with and without connecting ramps, occur with an average spacing of ½ mile or less, some of which are lighted as part of the local street system;
- (d) The freeway cross section elements, such as median and borders, are substantially reduced in width below desirable sections used in relatively open country.

Case CFL-4 - Continuous freeway lighting is considered to be warranted on those sections where the ratio of night to day crash rate is at least 2.0 or higher than the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate.

Continuous freeway lighting should be considered for all roadway facilities in urban areas that have median barriers. In rural areas each location must be individually evaluated as to its need for illumination.

15.2.2 COMPLETE INTERCHANGE LIGHTING

Case CIL-1 - Complete interchange lighting may be warranted where the total current ADT ramp traffic entering and leaving the freeway within the interchange exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

Case CIL-2 - Complete interchange lighting may be warranted where the current ADT on the crossroad exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

Case CIL-3 - Complete interchange lighting may be warranted where existing substantial commercial or industrial development that is lighted during hours of darkness is located in the immediate vicinity of the interchange, or where the crossroad approach legs are lighted for 0.5 miles or more on each side of the interchange.

Case CIL-4 - Complete interchange lighting may be warranted where the ratio of night to day crash rate within the interchange area is at least 1.5 times the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate.

15.2.3 PARTIAL INTERCHANGE LIGHTING

Case PIL-1 - Partial interchange lighting is considered to be warranted where the total current ADT ramp traffic entering and leaving the freeway within the interchange areas exceeds 5,000 for urban conditions, 3,000 for suburban conditions, or 1,000 for rural conditions.

Case PIL-2 - Partial interchange lighting is considered to be warranted where the current ADT on the freeway through traffic lanes exceeds 25,000 for urban conditions, 20,000 for suburban conditions, or 10,000 for rural conditions.

Case PIL-3 - Partial interchange lighting is considered to be warranted where the ratio of night to day crash rate within the interchange area is at least 1.25 or higher than the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate.

15.2.4 NON-FREEWAY LIGHTING

The AASHTO Guide also contains guidelines on special considerations for roadway lighting. The AASHTO Guide gives no specific warrants for continuous lighting of roadways other than freeways (roads with fully controlled access, no at-grade intersections), but does suggest some general criteria that may apply when considering the installation of lighting.

Lighting of rural at-grade intersections is warranted if the geometric conditions mentioned in the AASHTO Guide exist or if the intersection scores a total of 50 or more points on the Intersection Lighting Criteria form (see Figure 15-1).

Figure 15-1 Example Intersection Lighting Criteria

Form TR-17	WYOMING DEPARTMENT OF TRANSPORTATION		Revised 10/29/2010
RURAL INTERSECTION LIGHTING CRITERIA			
Major Roadway: <u> US 30 </u>		Minor Roadway: <u> Whitney Rd. </u>	
CRITERIA 1 - ROADWAY SYSTEM DESIGNATION			POINTS
Primary:	10 points	Major: <u> Primary </u>	<u> 10 </u>
Secondary:	5 points		
County:	2 points	Minor: <u> County </u>	<u> 2 </u>
Local or driveway:	0 points		
CRITERIA 2 - GEOMETRIC CONDITIONS			
Intersection Type		Type: <u> Four-leg </u>	<u> 5 </u>
Four-leg:	5 points		
Three-leg:	2 points		
Roadside Development		Quadrants: <u> Two or More </u>	<u> 5 </u>
Two or more quadrants:	5 points		
One quadrant:	2 points		
No development:	0 points		
Major Roadway Turn Lanes		Turn Lanes: <u> Yes </u>	<u> 0 </u>
No:	5 points		
Yes:	0 points		
Major Roadway Posted Speed		Speed: <u> 55 </u>	<u> 5 </u>
Over 45 mph:	5 points		
45 mph or less:	0 points		
Major Roadway Stopping Sight Distance		Adequate: <u> Yes </u>	<u> 0 </u>
Inadequate for operating speed:	5 points		
Adequate for operating speed:	0 points		
CRITERIA 3 - TRAFFIC VOLUME			
Major Road Daily Volume (Highest two-way volume)		Major: <u> 8,080 </u>	<u> 10 </u>
5,000 vpd or more:	10 points		
1,000 vpd or more:	5 points		
Less than 1,000 vpd:	0 points		
Minor Road Daily Volume (Highest two-way volume)		Minor: <u> 1,600 </u>	<u> 10 </u>
1,000 vpd or more:	10 points		
500 vpd or more:	5 points		
Less than 500 vpd:	0 points		
Night Minor Road Hourly Volume (5:00 pm to 6:00 am)		Minor: <u> 240 </u>	<u> 0 </u>
250 vph or more:	10 points		
Less than 250 vph:	0 points		
CRITERIA 4 - CRASH EXPERIENCE			
Number of night crashes in past five years.		Number: <u> 3 </u> X 5	<u> 15 </u>
Ratio of night to day crashes.		Ratio: <u> 0.25 </u>	<u> 0 </u>
2.0 or more:	10 points		
1.0 or more:	5 points		
Less than 1.0:	0 points		
TOTAL POINTS			<u> 62 </u>
Minimum of 50 points required for consideration of intersection lighting.			

CHAPTER 16 – TRAFFIC SIGNAL REMOVAL STUDY

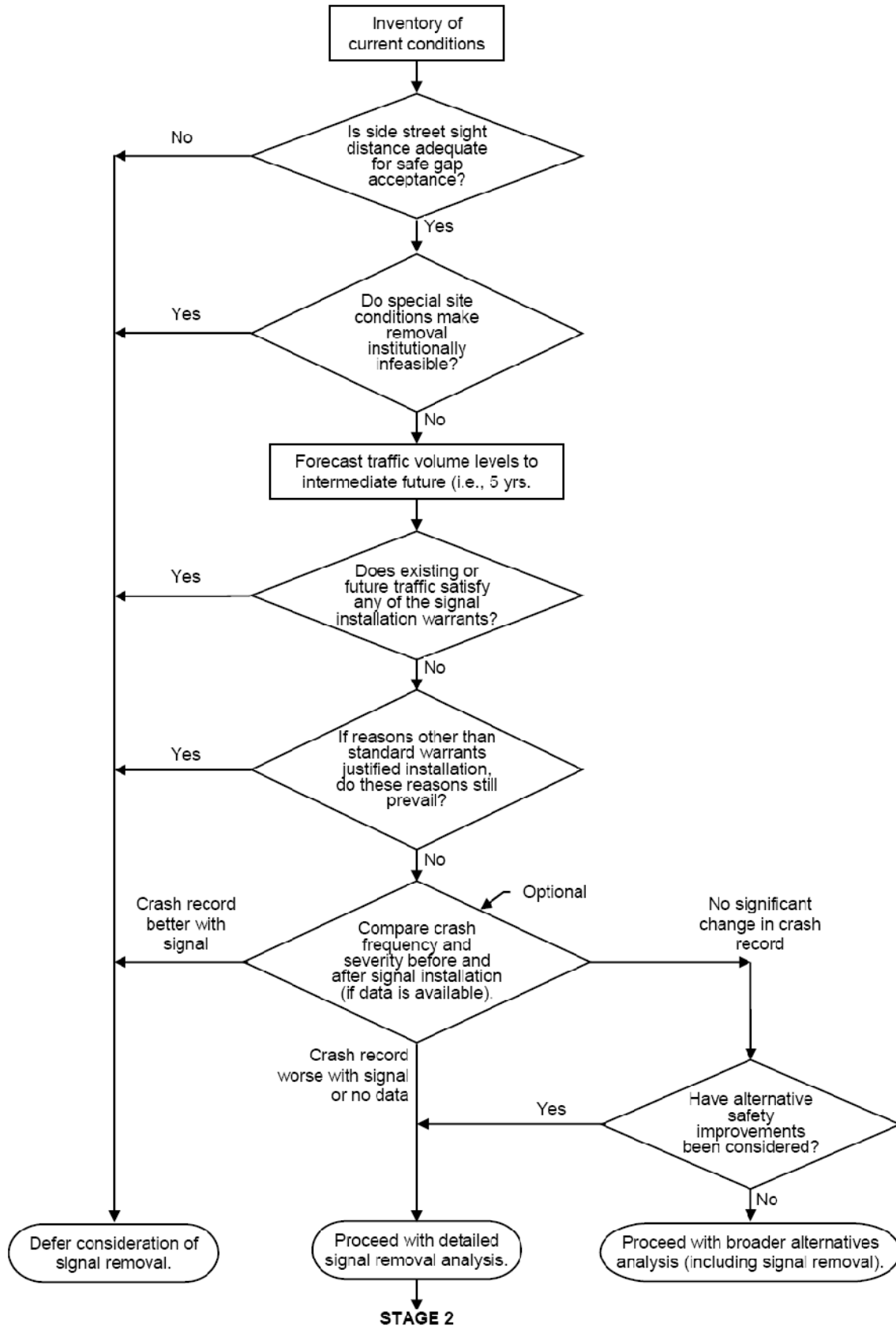
16.1 PURPOSE

- (1) No matter what reason was used to justify a traffic signal installation, changes over time may reduce the need for, and effectiveness of, the traffic signal. When this occurs, problems created by unwarranted signals, such as excessive delay, increased rerouting of traffic to less-appropriate roads and intersections, higher crash rates, and disobedience of the traffic signal can often be addressed by removing the signal if doing so would not create worse problems.
- (2) The *MUTCD* contains no specific warrants for the removal of traffic signals. The only guidance relative to signal removal is a statement in Section 4B.02 that states, “*If changes in traffic patterns eliminate the need for a traffic control signal, consideration should be given to removing it and replacing it with appropriate alternative traffic control devices, if any are needed.*” The first indication that a traffic signal may no longer be justified is if the traffic volumes at the intersection do not meet any of the *MUTCD* warrants for signal installation. However, it is possible that a signalized intersection that does not meet any of the warrants will meet at least one warrant after the signal is removed (due to increases in crashes, delay, or traffic patterns). Therefore, the removal of a traffic signal requires thorough engineering study.
- (3) The decision to remove an existing signal can be a difficult one. There is a public perception that traffic signals are a panacea for all traffic problems at an intersection, and therefore signals enjoy a high status among many segments of the public, elected officials, and public administrators. If the removal of an existing traffic signal is to be successful, this perception by the general public is the greatest hurdle to overcome. Given this popular bias, the practical reality is that signals are considerably harder to remove than to install. While this can be a very high hurdle, it is possible to clear if the proper engineering considerations are made and supported.
- (4) This chapter sets forth the procedure required to justify the removal of an existing traffic control signal. The discussion and analysis process is adapted from the Federal Highway Administration (FHWA) publication prepared by JHK & Associates and Wagner-McGee Associates entitled *User Guide for Removal of Not Needed Traffic Signals*, Implementation package FHWA-IP-80-12, November 1980. The procedure is intended to provide documented support for the decision to remove an unwarranted signal, to determine the appropriate alternative traffic control, and to make the transition from signalized to unsignalized control as safe and efficient as possible. The process consists of a series of criteria, all of which must be satisfied, and the various impacts predicted before signal removal is recommended.
- (5) The decision process has been built into a series of forms and nomographs to aid the traffic engineer in making the decision to remove or retain an existing. Signal. The use of these forms and nomographs is explained in detail at the end of this chapter (see Page 121).

16.2 STAGE 1 – PRELIMINARY SCREENING

- (1) The first step in the removal process is to indentify whether or not the intersection is a legitimate candidate for possible signal removal. There are five areas that need to be considered before seriously pursuing the removal of an existing signal: sight distance, special site considerations, warrants, crash experience, and special justifications. The decision to pursue the removal should only be made after these areas have been thoroughly evaluated.
- (2) This part of the process can be completed fairly quickly based on existing intersection data. The purpose of this quick screening is to determine if additional analysis of the intersection is justified. Figure 16-1 gives an example of the preliminary (Stage 1) signal removal decision process in the form of a flowchart.

Figure 16-1
Signal Removal Decision Process Stage 1 – Preliminary Screening



- (3) The intersection data required to perform the signal removal analysis are basic – specifically:
 - (a) Side street sight distance
 - (b) The traffic volumes entering the intersection in each hour during a representative day
 - (c) The crash history at the intersection for at least three, and preferably five or more preceding years.
- (4) Depending on site-specific conditions, additional data, such as major street speeds, heavy turning movements, pedestrian counts, etc. may also be necessary.
- (5) After the intersection data is obtained a series of criteria are considered, each of which must be satisfied in order for the intersection to survive the screening.

16.2.1 SIGHT DISTANCE

- (1) The sight distance available to the side street, particularly if two-way stop control is proposed, is very important to the removal decision. If the sight distance available for the side street is less than the stopping sight distance for the mainline approach speed, signal removal should not be further considered unless the sight restriction can be reasonably mitigated. Removing a traffic signal at an intersection without adequate sight distance will more than likely double the number of expected right-angle crashes when compared to intersections with adequate sight distance.
- (2) The sight distance should be measured in each direction from each minor street approach in accordance with Chapter 6. The line of sight should be from the driver's eye position where traffic would normally be expected to stop and look for gaps in approaching traffic if the intersection were stop-controlled.
- (3) If limited sight distance is caused by an easily removed obstruction (e.g., overgrown foliage), or all-way stop control or a roundabout is planned after signal removal, consider this criterion satisfied and proceed to the next step in the screening process.

16.2.2 SPECIAL SITE CONSIDERATIONS

- (1) The intersection should be reviewed to determine if any special site conditions exist that would make signal removal institutionally infeasible. Two major types of recurring conditions are of special concern:
 - (a) Signals located at major traffic generators (especially employment sites) where sharp peaks occur during commuting periods and problems in crossing or entering the main road are perceived for these short periods.
 - (b) Signals located near special generators which generate either substantial or special categories of pedestrian traffic (as perceived by those opposing removal). Examples would include schools, libraries, homes for the elderly, hospitals, etc.
- (2) At these locations it may be best to first discuss the proposed removal with representatives of the affected employment site, school or neighborhood association prior to making an in-depth study.
- (3) While the special pedestrian situations are the most common type generating intense, emotional opposition, it is very possible that the safety of the general pedestrian traffic may also be an issue that is brought up by signal removal opponents. Regardless of the number of pedestrians that actually cross the major street, signal removal opponents will often argue that pedestrian safety is compromised with the removal of a signal. However, this belief has not been substantiated at previous signal removal locations. Locations having relatively few (typically 15 or less) pedestrians crossing the major street during the peak hour have shown no increases in pedestrian crashes after signal removal. While this information may be useful, discussions with signal removal opponents on the subject of pedestrian safety will still require a very careful and tactful approach.

16.2.3 WARRANTS

- (1) The *MUTCD* contains no specific warrants for the removal of traffic signals. The primary indicator that a traffic signal may no longer be needed is the intersection's failure to satisfy any of the *MUTCD* signal installation warrants. However, it is possible that a signalized intersection that does not meet any of the warrants will meet at least one warrant after the signal is removed (due to increases in crashes, delay, or traffic patterns). Therefore, the removal of a traffic signal requires additional engineering analysis.
- (2) If current or expected future traffic volumes meet any of the *MUTCD* warrants, then signal removal should be deferred.
- (3) Sometimes traffic signals are installed at new intersections or at existing intersections based on projected volumes based on new development or construction in the area. Unless the engineering study used the satisfaction of Warrant 8 to justify the signal, a traffic control signal installed under projected conditions should have an engineering study done within 1 year of putting the signal into stop-and-go operation to determine if the signal is justified. If not justified, the signal should be taken out of stop-and-go operation or removed.
- (4) There may be special situations where an existing signal meets one or more of the *MUTCD* warrants, but its location (spacing from adjacent signals) is detrimental to the smooth progressive flow of traffic on the major street, and the reason for considering its removal is to facilitate a new or relocated traffic signal at a location that provides more acceptable signal spacing. In such a situation, emphasis should be given to providing traffic that would normally use the existing signal convenient access to the new or relocated signal via nearby parallel streets or construction of new street connections. This can dispel most of the concern associated with the side street traffic needing a traffic signal to gain safe and convenient access to the major street.

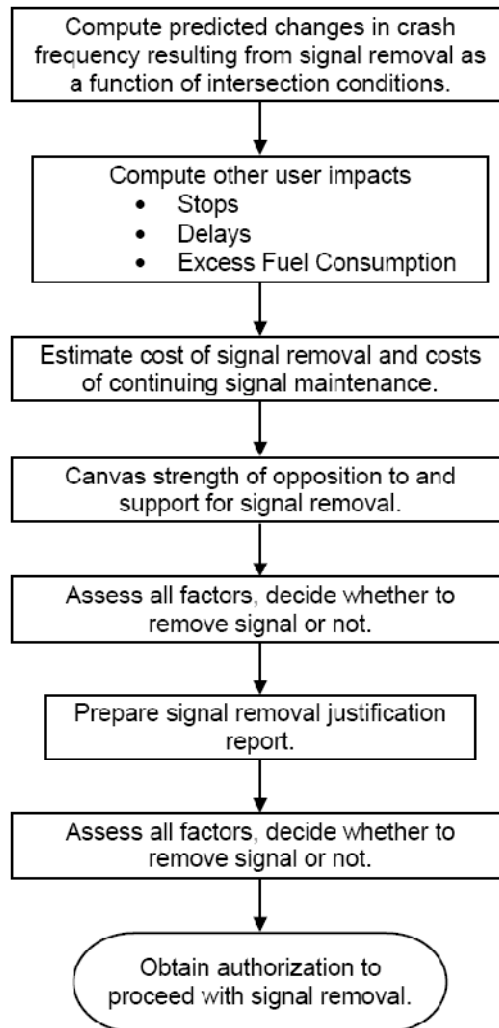
16.2.4 SPECIAL JUSTIFICATIONS

- (1) There have been reasons other than the standard warrants that have been used to justify traffic signal installations. There are undoubtedly cases where unwarranted signals have been installed as a result of pressure from a small special interest group based on reasons which either are no longer perceived as problems or can be shown to be invalid. The review should determine if such a special justification was used and whether or not it is still valid. If still valid, signal removal will be very difficult unless the special interest group is included in the decision-making process and they buy into the signal removal concept.
- (2) A review of the original reasons for installing the signal should be done. If all of the original needs are no longer present, then consideration may continue. A review of the political implications should also be done to determine if the climate is favorable to proceed.

16.3 STAGE 2 – DETAILED REMOVAL ANALYSIS

- (1) This is a more time consuming analysis process which is pursued only if the candidate intersection survives the preliminary screening process.
- (2) At this time a preliminary decision should be made concerning the type of intersection control that will be installed after the signal is removed – namely, two-way stop control, all-way stop control, or a roundabout. The possible intersection control alternatives are discussed later on in this chapter (see Section 16.4).
- (3) Figure 16-2 gives an example of the decision process for Stage 2 of the signal removal study procedure in flowchart form.

Figure 16-2
Signal Removal Decision Process Stage 2 – Detailed Analysis



- (4) The steps contained in the detailed analysis are designed to allow the traffic engineer to estimate the expected impacts that will result from the removal of the traffic signal at a particular intersection. Knowledge of these expected impacts forms the technical basis for the final decision to remove or not remove the signal.

16.3.1 EXPECTED INFLUENCE ON CRASHES

- (1) Crash experience, both historical and expected, can be a very tough issue when considering a signal for removal. A thorough review of the crash history should be done to determine what has been occurring at the intersection. Historically, the removal of unwarranted signals and conversion to two-way stop control will cause a reduction in rear-end type collisions, but an increase in right angle crashes might be expected.
- (2) The nature of the crashes that could be expected after the removal of the signal is influenced by the type of control that will replace the signal. If an all-way stop is to be used then, in general, a decrease in crashes could be expected. If, however, two-way stop control is planned then the changes described above can be expected. If a multilane roundabout is to be used, the frequency of crashes could be expected to decrease slightly, but the severity of crashes would be expected to be significantly reduced. If a single lane roundabout is to be used, a significant decrease in both frequency and severity of crashes would be expected.

- (3) If the signal installation is relatively recent (i.e., five to ten years old), and adequate crash data is available, and where traffic volumes have not changed substantially during the life of the signal, the crash records prior to the signal installation should be compared to those after the signal was installed.
- (a) If the crash frequency or severity improved significantly after signalization, removal should not be further considered.
 - (b) If the crash frequency or severity increased significantly after the signal installation, the signal removal process should continue to the next stage.
 - (c) If crash patterns were unchanged or changed only slightly after signal installation, alternative safety improvements may be considered in lieu of signal removal. These alternative improvements include:
 - signal display upgrades
 - increased signal clearance intervals if right angle crash frequency is high
 - signal offset improvements (if possible) to achieve smoother flow and reduce stops
 - semi-actuation or full-actuation (if pretimed)
 - shortening of average side street green intervals through pedestrian actuation
 - installation of advance warning devices
 - improved pavement friction
 - turn prohibitions
 - parking prohibitions
 - improved geometric design features
 - (d) If such alternatives have not been considered, then their potential and relative costs should be investigated as possible alternatives to signal removal, as minor and relatively inexpensive improvements to the signal might improve the safety performance of the intersection to where removal of the signal may become infeasible.
 - (e) If the alternative safety improvements have been considered and they would not be expected to improve the safety performance of the intersection, then the signal removal process should proceed to the next stage.
- (4) Regardless of the traffic control that is planned after the signal is removed a detailed before/after review of crashes must be done after the signals are removed and needs to be well documented. This is because fear of an increase in crashes will be one of the most significant points of opposition to the proposal.
- (5) If the signal is to be replaced with two-way stop control, the following equation can be used to predict the change in the annual crash frequency resulting from signal removal:

Equation 16-1

$$Y = 1.01 + 0.139X_1 - 0.605X_2$$

Where:

- Y = Estimate of change in average annual crash frequency resulting from the removal of a signal and installation of two-way stop control
- X_1 = Volume magnitude as measured by the number of hours per day when the traffic volumes satisfy at least 60% of the signal installation volume warrant – MUTCD Warrant 1, Condition A (see Table 16-1)
- X_2 = Average annual crash frequency at the intersection under signal control

Table 16-1 Volume Magnitude

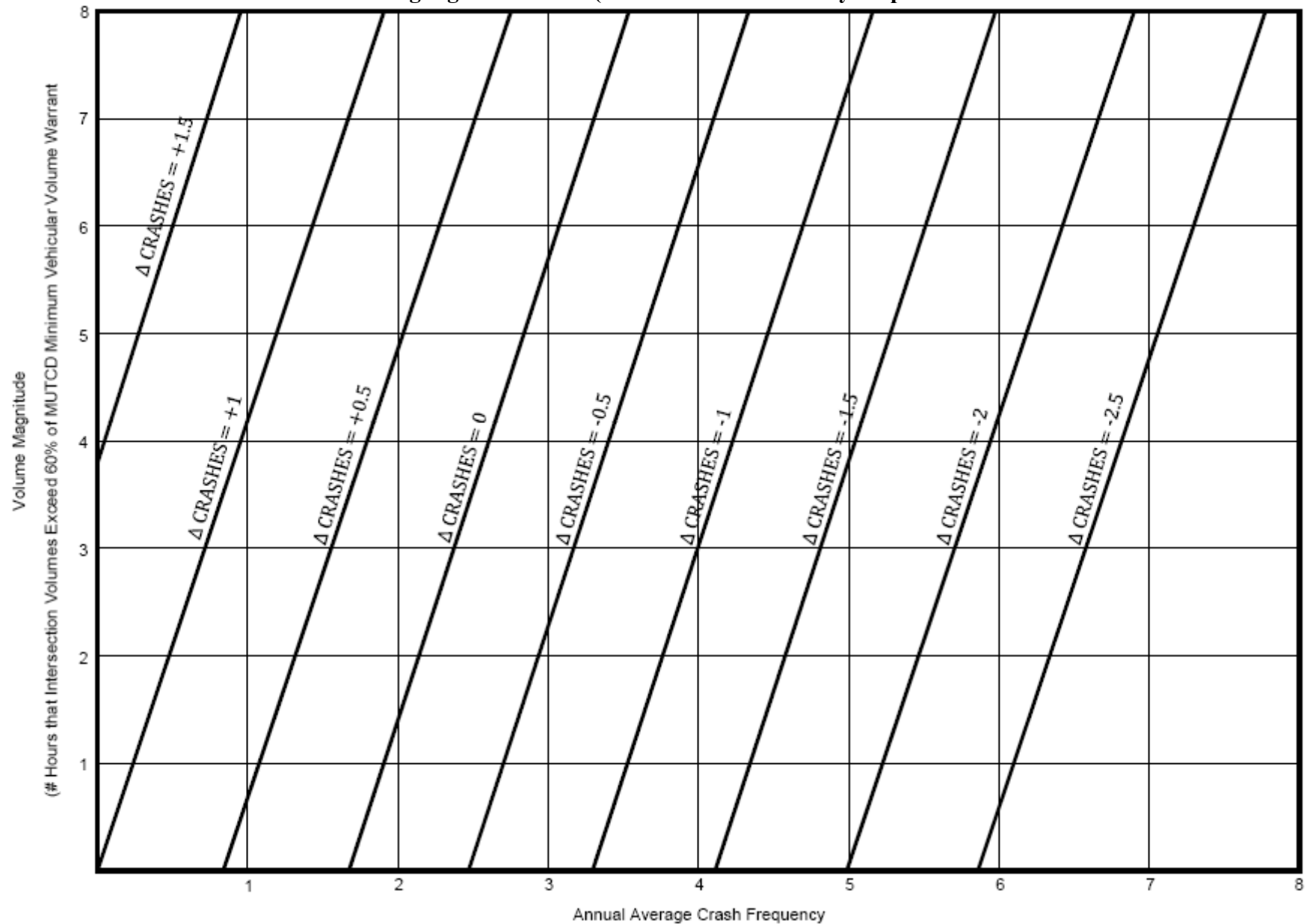
NUMBER OF HOURS/DAY THAT INTERSECTION VOLUMES EXCEED THE FOLLOWING VOLUME LEVELS			
LANES/APPROACH		MAJOR STREET BOTH APPROACHES (vph)	MINOR STREET HIGHER VOLUME APPROACH ONLY (vph)
MAJOR	MINOR		
1	1	300	90
2+	1	360	90
2+	2+	360	120
1	2+	300	120

- (6) A nomograph of predicted changes in annual crash frequency for various combinations of X_1 and X_2 was developed using Equation 16-1. It is shown in Figure 16-3 and may be used for estimating the expected changes in crash frequency resulting from signal removal.
- (7) If all-way stop control is planned after removal of the signal, a decrease in crashes of approximately 60 percent can generally be expected, provided the intersection has the following characteristics:
 - (a) Low volumes (less than 800 entering vehicles during the peak hour)
 - (b) Relatively balanced flows (ratio of major street volumes / minor street volumes < 3:1)
- (8) If a roundabout is planned after removal of the signal, a reduction in overall crash frequency of approximately 35 percent, and an approximately 75 percent reduction in injury and fatality crashes can be expected.

16.3.2 EXPECTED TRAFFIC FLOW RELATED IMPACTS

- (1) Traffic signal removal results in substantial impacts on intersection delays, stops, and the resulting excess fuel consumption.
- (2) Replacing an unjustified signal with two-way stop control at a four-legged intersection has the following estimated effects:
 - (a) Total delay is reduced by about 10 seconds per vehicle.
 - (b) Idling delay is reduced by about 5 to 6 seconds per vehicle.
 - (c) Stops are reduced from about 50 percent of the total to about 20 to 25 percent or even less if side road volumes are low in relation to total intersection volume.
 - (d) Excess fuel consumption due to intersection stops and delays is reduced by about 0.002 gallons per vehicle.
- (3) In the case of similar volumes at a T-intersection, the reductions in delays, stops, and fuel consumption would be slightly greater.
- (4) Replacing an unjustified signal with all-way stop control at four-legged intersections has the following estimated effects:
 - (a) Total delay per vehicle does not change by much.
 - (b) Idling delay is reduced by about 5 seconds per vehicle.
 - (c) Stops always equal 100 percent of total traffic, approximately double that experienced under signal control.
 - (d) Excess fuel consumption is increased by about 0.0015 gallons per vehicle.

**Figure 16-3 Predicted Changes in Average Annual Crash Frequency
Following Signal Removal (Conversion to Two-Way Stop Control)**



- (5) Replacing an unjustified signal with a roundabout at four-legged intersections has the following estimated effects:
- (a) Total delay is reduced by approximately 62 to 74 percent.
 - (b) Idling delay is reduced by approximately 25 percent.
 - (c) Stops are reduced by approximately 25 percent.
 - (d) Fuel consumption is reduced by approximately 16 percent.

16.3.3 JURISDICTION-RELATED COSTS

- (1) Traffic signal removal is one of those rare activities that actually saves money for the traffic engineering agency.
- (2) The costs of continued signal operation include the annual costs of maintenance, electricity, and other operational costs such as signal timing. Additionally, the annualized cost of upgrading the signal display may also be included if it is below design standards.
- (3) The cost of signal removal includes the one-time costs of removing the signal hardware and installing STOP signs, and the annual cost of maintaining the signs.
- (4) These costs vary widely between individual intersections and between jurisdictions. When these various costs are properly accounted for and adequate records are kept, the jurisdiction should use their own cost data to calculate the cost savings of signal removal. If local “actual” costs are not available, Tables 16-2 and 16-3 provide ranges of these costs which can be used to estimate the cost impacts.

Table 16-2 Annual Cost per intersection of continued signal operation

Cost Component	Type of Signal Control		
	Pretimed	Semi-Actuated	Fully Actuated
Electrical	\$180 - \$550	\$180 - \$550	\$180 - \$550
Maintenance	\$600 - \$1600	\$750 - \$3000	\$750 - \$3500
Signal Timing	\$80 - \$125	\$80 - \$125	\$80 - \$125
Annual Total Cost	\$860 - \$2275	\$1010 - \$3675	\$1010 - \$4175

Table 16-3 Cost Impacts of signal removal

Item	Implementation Cost	Equivalent Uniform Annual Cost *
Remove Signal Hardware	\$3,000 - \$10,000	\$447 - \$1490
Install Stop Signs	\$120 - \$500	\$18 - \$75
Sign Maintenance	-	\$16 - \$30

*Note – Analysis period is 15 years and an interest rate of 12%, capital recovery factor = 0.149

16.3.4 CANVAS PUBLIC OPPOSITION

Assess the relative strength of opposition to, or support for, the proposed signal removal. This is a consideration that begins here and continues even after the decision to remove a signal has been made. Initially, at this stage of the decision process, the local governing agency representatives, neighborhood and business leaders, and police can be contacted for their opinions. This initial canvassing provides a general idea of the opposition or support that may be expected during the interim control period and/or at council meetings. This item is pursued further during the public notification process which is discussed in Section 16.5.1.

16.3.5 SIGNAL REMOVAL DECISION

- (1) All of the above findings are then weighed by the traffic engineer and the decision is made whether or not to recommend removal of the traffic signal. It is neither possible nor desirable to avoid a significant amount of professional judgment in this final decision. In most cases, a number of institutional constraints must also be considered. However, the technical findings from the detailed analysis should provide a strong factual basis for reaching, supporting, and defending the final decision or recommendation.
- (2) All of the findings of the decision process should be summarized by the traffic engineer in a signal removal justification report for use in gaining necessary authorization to proceed.

16.4 INTERSECTION CONTROL ALTERNATIVES

There are three alternatives to signalized intersection control: two-way stop control, all-way stop control, or roundabout control. Each has its own operational strengths and limitations in comparison with traffic signal control, and the appropriate alternative control is dependent on the conditions present at the intersection. Each alternative will be discussed separately.

16.4.1 TWO-WAY STOP CONTROL (TWSC)

- (1) TWSC can accommodate low traffic volumes with much less delay than traffic signals, but this type of control favors the major street (unstopped) movements at the expense of the minor street (stopped) movements. When the major street traffic volumes are heavy there can be little or no opportunity for cross street access. This places a definite limit on the application of TWSC. Even when TWSC capacity is not exceeded, there is often strong public pressure to keep the signals rather than convert to TWSC at the intersection. Unless there is an interconnected street network that will allow traffic on the minor street reasonable access to another signalized access to the major street, that public pressure can be almost impossible to overcome.
- (2) If the signal being removed is located between existing coordinated signals, TWSC is the only acceptable form of alternative traffic control. If the spacing to adjacent signalized intersections is favorable, the time/space and time/flow diagrams associated with each of the time-of-day traffic signal coordination plans should be carefully analyzed to determine if the adjacent signals will provide sufficient gaps in major street traffic to permit minor street traffic to enter without unacceptable delays.

16.4.2 ALL-WAY STOP CONTROL (AWSC)

- (1) AWSC should only be considered if the intersection meets the minimum volume criteria associated with the multiway stop criteria contained in Section 2B.07 of the *MUTCD*.
- (2) AWSC treats the cross street movements more favorably, without the wasted time associated with traffic signals. However, the rate at which vehicles may enter an intersection (i.e., headway) under all-way stop control is limited.

16.4.3 ROUNDABOUT CONTROL

- (1) The installation of roundabouts in lieu of stop control or even traffic signals has consistently shown a substantial improvement in intersection safety and efficiency.
- (2) Roundabouts are well suited to more isolated intersections, but can also be effective when used in a corridor setting, provided they are not used between coordinated signalized intersections.
- (3) One impediment to the construction of roundabouts involves the logistical challenges associated with converting existing intersections. Temporary traffic control measures, which can be expensive, must be implemented during the construction process to maintain orderly and safe traffic flow. However, this problem can be minimized or avoided by constructing roundabouts when new intersections are first built and when major modifications are proposed for existing intersections.

16.5 REMOVAL PROCEDURE

After all of the above areas have been thoroughly considered and if the decision is made to proceed with the removal, the following steps need to be taken:

16.5.1 PUBLIC NOTIFICATION

- (1) The Traffic Program, District Office, Resident Engineer, and local governing agency should be advised of the decision and provided with documentation of the above noted areas to support the decision.
- (2) The public should be given notice of the intention to remove the traffic control signal. Set a firm date for the turn-off of the signals to occur and notify the public. This can consist of news releases, public hearings and/or presentations at city council meetings. This is a very important step and the District must be prepared to fully answer any questions that may arise. How this phase is handled is critical since incomplete or insincere answers to those opposed to the signal removal could cause the whole process to fail.
- (3) Distribution of a news release to local newspapers, radio and television stations can potentially provide the widest coverage when notifying the public of the proposed removal. When city council approval is required for signal removal, press coverage of the council meeting will often have the same value as a news release. However, a news release prior to the council meeting is more likely to present the matter in a positive light, whereas news coverage of the matter in city council may give more emphasis to any controversy or colorful statements of the opposition. The major drawback to the release is that there is no guarantee that those residents, commercial establishments and drivers most affected by the signal removal will receive the information.
- (4) The release should include information such as the intersection location, the date and time that the signal is to go into the interim control mode, what the new control will be, general reasons that the signal is being removed (e.g., change in traffic flow patterns, closing of nearby generator) and a description of the benefits that will be derived by its removal (reduction in delay, fuel consumption and crashes).
- (5) To ensure that the citizens in the immediate vicinity will be notified of the proposed signal removal, a letter containing the same information as the press release can be sent directly to the residents and commercial establishments within the immediate vicinity of the candidate intersection.

16.5.2 INSTALL INTERIM CONTROL

If the intersection will be stop controlled once the traffic signal is removed, in order to transition the public to the removal of the traffic signals the following steps should be followed prior to the removal of the signal:

- (1) The traffic signal should be placed in flashing operation reflecting two-way (yellow/red) or all-way (all-red) stop control, as appropriate, and temporary STOP signs installed on the respective approaches. This operation should be maintained for a day or two (typically no more than one week) to make sure the intersection will not fail under the proposed stop control.
- (2) If, after the initial flashing operation, the operation and safety is acceptable, the signal should be turned off and permanent (post mounted) STOP signs should be installed on the appropriate approaches. The signal heads should be covered or turned away from traffic. Signal related signing should be removed from the intersection. The signal poles, mast arms, controller cabinet and all wiring should be left in place at this time.
- (3) If, after approximately 3 months of STOP sign control, intersection operation and safety is acceptable, the signal heads and mast arms can be removed.

- (4) After an extended (typically 12 months) period of acceptable sign control operation, the remaining signal components should be removed. A comprehensive removal should be completed with all signal poles, controller cabinet and wiring removed and all concrete foundations and bases removed to at least flush (preferably at least 8 inches below grade in turf areas) with the ground. All pull boxes should either be removed or filled to prevent them from collapsing in the future.
- (5) If the intersection will be converted to a roundabout, the intersection modifications will require a significant construction project to modify the approaches and install the appropriate center island and splitter islands. This work will more than likely encroach on the existing signal hardware installations. Therefore the removal of the traffic signal should be coordinated with and occur during the construction project.

16.5.3 MONITOR CRASHES

- (1) Since crashes at individual intersections cannot be predicted with complete accuracy, it is vital to closely monitor crashes throughout the interim control period. This may require the development of a close liaison between the traffic engineer and the local police department's crash records division in order to obtain copies of the crash reports shortly after any crashes might occur.
- (2) An increase in crashes (particularly if they are right angle or involve injuries) during the first critical month is not a sufficient reason to abandon the plans for removing the signal. Although, if an increase does occur, the signal should remain in the transition control mode for a few more months. If the crash rate is still higher after a few months, an in-depth crash analysis should be performed and retention of the signal should be seriously considered.
- (3) Accurate crash records should be kept on the intersections in the jurisdiction where the signal has been removed for several years following the signal removal. Assuming that there will be a decrease in crashes at most of these intersections, this kind of "positive" information which is based on intersections within the jurisdiction itself not only lends credibility to the local signal removal, but also sets the valuable precedent for additional signal removals.



INSTRUCTIONS
for the
Wyoming Department of Transportation
SIGNAL REMOVAL ANALYSIS WORKSHEETS

USING THESE INSTRUCTIONS

The purpose of these instructions is to assist WYDOT personnel in completing the Signal Removal Analysis Worksheet and the Worksheet for Estimating Daily Impacts of Signal Removal and Replacement by Two-Way Stops. The main purpose of the worksheets is to determine if the removal of an existing unwarranted traffic signal can be accomplished without an increase in crashes and with improvements to intersection operations.

This process is only valid for intersections that are being converted from signalized control to two-way stop control.

The Signal Removal Analysis Worksheet has been developed into a two-page .PDF form. The first page covers the intersection inventory and preliminary screening, and the second page covers the detailed analysis. The detailed analysis also requires the completion of the Signal Removal Impacts worksheet which is also covered in these instructions.

STAGE 1 – INTERSECTION INVENTORY

Fill out the appropriate information as required:

- (1) Identify the intersection and city.
- (2) Indicate which street is the major street and which one is the minor street.
- (3) Indicate the number of lanes per approach for each street.
- (4) The ADT required is the two-way average daily traffic volume.
- (5) Note the posted speed limit on the major street.
- (6) Note the side-street sight distance for all side-street approaches.

STAGE 2 – PRELIMINARY SCREENING

This is a quick screening to determine if additional analysis of the intersection is justified. It is made up of the following four separate criteria, each involving a go/no-go decision concerning signal removal.

- (1) **Minimum required sight distance.** Compare the measured sight distance (see Chapter 6) in each direction from each minor street approach to the suggested departure sight distance at intersections as shown in Table 16-4. If the measured sight distance is less than those shown in the table, check YES next to line 1 and defer signal removal unless the sight obstructions can be easily remedied.

Table 16-4 Suggested Departure Sight Distance at Intersections

Design Speed	-	mph	20	30	40	50
Minimum Departure Sight Distance	-	ft	225	335	445	555

Source: AASHTO, *A Policy on Geometric Design of Streets and Highways*, 2004, Exhibit 9-55

- (2) **Special site conditions.** Note whether or not any special site conditions exist (per Section 16.2.2). If no special conditions exist, check NO, otherwise check YES and note in the comments field what those conditions are. If you check YES, initiate communication with representatives

from the affected facilities to assess the possible strength of opposition to or support for the possible signal removal before proceeding any further with the signal removal process.

- (3) **Existing signal warrants met.** This can be estimated by comparing the actual ADT's with the approximate ADT volumes above which *MUTCD* signal warrants are likely to be met (see Table 3-2 on Page 15). If current or projected traffic volumes do not meet *MUTCD* signal warrants, check NO. If *MUTCD* signal warrants are met or projected to be met in the near future check YES and defer signal removal.
- (4) **Special justifications.** Note whether or not the signal was installed based on any special justifications that are still valid. If the signal was installed based on special justification (per Section 16.2.4) that is still valid, note what the justification is in the comments field and check the YES box. If the installation was based on a special justification that is no longer valid, note what the justification was and briefly explain why it is no longer valid in the comments field, then check the NO box. If there was no special justification, simply check the NO box.
- (5) If you checked YES for any of the above criteria, consider deferring the signal removal unless there is strong local support for the signal's removal. Otherwise, proceed with the detailed analysis. An example of Signal Removal Analysis worksheet is shown in Figure 16-4.

STAGE 3 – DETAILED ANALYSIS, TWO-WAY STOP CONTROL

This analysis is pursued only if the intersection survives the preliminary screening process. It involves predicting the impacts from signal removal and installation of two-way stop control.

STAGE 3.1 – EXPECTED INFLUENCE ON CRASHES

- (1) From Table 16-1 list the minimum required volume for determining the Volume Magnitude. The minimum required volume is dependent on the number of lanes per approach. See Section 3.4 about how to determine the number of lanes to use when turn lanes are present.
- (2) List the major street volume (two-way) and higher side-street volume (one approach only) for the eight peak hours. The major street and side street volumes are listed for the same hour. However, during the eight hours, the higher volume on the side street may be one approach during some hours and on the opposite approach during the other hours.
- (3) If both the major street and minor street volumes exceed the minimum values, put a check in the box to the right. The number of boxes checked is the Volume Magnitude.
- (4) The average annual crash frequency is calculated as follows:

Equation 16-2

$$CF = \frac{N}{t} \times 12$$

Where:

CF	=	average annual crash frequency
t	=	number of months in the period covered
N	=	number of intersection crashes during the period

- (5) The predicted change in annual crash frequency is then calculated using Equation 16-1 on page 114. A positive number indicates an expected increase in crashes and a negative number indicates and expected reduction in crashes.

STAGE 3.2 – EXPECTED TRAFFIC FLOW-RELATED IMPACTS

This step requires the completion of the Signal Removal Impacts worksheet (Form TR-04) using the appropriate nomographs as described below. The following instructions explain how to use the nomographs and worksheet for predicting the estimated daily impacts of signal removal and replacement by two-way stop control. The worksheet is a .PDF form that automatically calculates many of the fields

once the volumes and four impact variables are input from the respective nomographs. An example worksheet for a 4-way intersection, 4-lane major and 2-lane minor street is presented in Figure 16-5.

- (1) Enter the intersection type (4-way or T) and the number of lanes (2 or 4) on the major road and minor road by clicking on the respective check boxes. The number of lanes is defined as the total number of through lanes in both directions on a given road (e.g., 4 lane means two through lanes in each direction).
- (2) Enter the traffic volumes for the average of the 2 peak hours of the day. The following volumes were used for the example in Figure 16-5,:

- (a) For the major road, enter the total volume for the 2 approaches averaged for the 2 peak hours. For example:

Main Road (Spruce Street Example)			
	Eastbound Appr.	Westbound Appr.	Total
Highest Hour	354	356	710
2 nd Highest Hour	342	347	689
		Divide by 2	1399
Total main road volume per hour = 700 vph			

- (b) For the side road, enter the average volume per approach for the 2 side road approaches averaged for the same 2 peak hours as above. For example:

Side Road (7th Street Example)			
	Northbound Appr.	Southbound Appr.	Average
Highest Hour	27	70	49
2 nd Highest Hour	18	90	54
		Divide by 2	103
Total side road volume per hour per approach = 52 vph			

(For a T-intersection, simply average the volumes for the 2 peak hours on the only side road approach.)

- (c) The total intersection approach volume averaged for the two peak hours is then calculated automatically. For a 4-way intersection, the sum of the total main road volume (entry 2a) and 2 times the side road volume per approach (2 times entry 2b) is entered. For example:

Total main road volume per hour =	700 vph
2 x Average side road volume per approach =	2 x 52 vph
Total =	804 vph

(For a T-intersection, the total main road volume plus the only side road approach volume is used. The form automatically adjusts the total intersection approach volume calculation for a T-intersection if the T-Intersection box is checked.)

- (3) For the average of the 2 peak hours, read from the nomographs the per hour estimates of the four impact variables: idling delay, total delay, total stops and excess fuel consumption. Figure 16-8 is a list of nomographs by intersection type to guide you in the selection of the correct nomographs).
 - (a) Estimate the four impact variables for signal control. On each nomograph:
 - Enter the side road volume per approach (from Step 2b, use 52 for the example) on the bottom horizontal axis.
 - Draw a vertical line and locate on it the point equal to the total main road volume (from Step 2a, use 700 for the example) on the family of lines representing signal control (the dashed lines). You will need to interpolate between the lines in order to find the point.

- From this point, draw a horizontal line to the left vertical axis and read the estimated value of the impact variable (for the example, the results are 1.4, 3.1, 390 and 2.6). Enter these values in their respective columns on the worksheet on line 3a.
- (b) Estimate the four impact variables for two-way stop control. Use the same nomographs in the same manner as Step 3a, but for total main road volume use the family of lines representing two-way stop control (the dotted lines). Enter the estimates on the worksheet on line 3b (for the example, the results are 0.2, 0.7, 110 and 0.6) Nomographs for the example worksheet are shown in Figures 16-6 and 16-7.

Note: The user should not attempt to estimate values from the nomographs to any closer precision than 2 significant digits. Graphical interpolation can be no more precise.

- (c) For each of the four impact variables, the difference between the signal control and two-way stop control estimates is calculated (i.e., the 3b entries are subtracted from the 3a entries).
- (4) The impacts for the total of the 2 peak hours are then calculated.
- (a) The total intersection approach volume for the total of the 2 peak hours is calculated (i.e., the entry on line 2c is multiplied by 2).
- (b) The signal removal impacts for the total of the 2 peak hours is calculated (i.e., each of the four impact variables entered on line 3c are multiplied by 2).
- (5) Enter the traffic volumes for the average of the 22 remaining hours of the day.
- (a) For the main road, calculate the average total main road volume for the remaining 22 hours using the following method:
- Subtract the total of the 2 peak hours of the main road volumes from the major street ADT (from Form TR-03).
 - Divide by 22 to get the average for the remaining 22 hours.
 - For the example, use $(9350 - 2 \times 700)/22$ to get an average of 361 vehicles per hour for the total main road volume for the remaining 22 hours.
- (b) For the side road, the same basic process used for line 5a is used, except with the following modifications:
- Multiply the side road volume per approach by 2 to get the total average side road volume for the peak 2 hours.
 - Multiply that by 2 again to get the total peak 2 hour side road volume.
 - Subtract that total from the side street ADT (from Form TR-03) and then divide by 22 to get the average total side road volume for the remaining 22 hours.
 - Divide that by 2 to get the average side road volume per approach for each of the remaining 22 hours.
 - For the example, use $(1220 - 52 \times 2 \times 2)/22/2$ to get 23 as the average volume per approach for each of the remaining 22 hours.
 - In some instances, the minor street ADT may not be known. A reasonable estimate of the side road ADT can be determined by determining what proportion of the major street ADT is included in the turning movement count used for the analysis, and then assuming the minor street volume constitutes the same proportion of the minor street ADT. Using the turning movement count volumes, the following equation can be used to estimate the minor street ADT to be used in the previous steps:
- $$ADT_{\text{Minor Street}} = \frac{\sum(\text{Minor Street Volumes})}{[\sum(\text{Major Street Volumes})]/ADT_{\text{Major Street}}}$$
- (c) The total intersection approach volume, averaged for the 22 remaining hours, is then calculated automatically by the form.

- (6) For the average of the 22 remaining hours, and using the same nomographs as in Step 3, read from the nomographs the per hour estimates of the four impact variables: idling delay, total delay, total stops and excess fuel consumption (Follow the same procedures as Steps 3 a and b, except use the volume data for the 22 remaining hours instead of the 2 peak hours.).
 - (a) Estimate the four impact variables for signal control (using the same procedure as Step 3a). For the example, use the side road volume of 23 and the main road volume of 361.
 - (b) Estimate the four impact variables for two-way stop control using the same procedure as Step 3b and the same volumes as the previous step (For the example, use a side road volume of 23 and main road volume of 361).
 - (c) For each of the four impact variables, the difference between signal control and two-way stop control is calculated (i.e., the 6b entries are subtracted from the 6a entries).
- (7) Impacts for the total of the 22 remaining hours are calculated.
 - (a) The total intersection approach volume for the total of the 22 hours is calculate (i.e., the entry on line 5c is multiplied by 22).
 - (b) The signal removal impacts for the total of the 22 hours are calculated (i.e., each of the entries on line 6c are multiplied by 22).
- (8) The 24 hour total impacts are calculated.
 - (a) The 24 hour total intersection approach volume is calculated (i.e., line 4a and line 7a are added together).
 - (b) The signal removal impacts for the total of 24 hours are calculated (i.e., the 4b entries and the 7b entries are summed for each of the four impact variables).
- (9) The per vehicle impacts are calculated by dividing the 24 hour total impacts on line 8b by the 24 hour total volume on line 8a. In the case of idling delays, per vehicle delays are converted from hours to seconds by multiplying by 3600.
- (10) Enter the estimated per vehicle and daily changes in idling delay, total delay, total stops, and excess fuel consumption (line 8b entries on the impacts worksheet (see Page 129) into the respective traffic flow-related impacts fields on Form TR-03. Multiplying the daily values by 320 will provide the estimated expected annual change.

STAGE 3.3 – JURISDICTION-RELATED COSTS

- (1) Enter the annual electrical, maintenance and timing costs associated with continued signal operation. If available, these costs should be the actual costs for the intersection in question. If the specific costs are not readily available, reasonable estimates should be made using the ranges of costs contained in Table 16-2. These costs are then totaled automatically by the form.
- (2) Estimate the one-time costs of signal removal and STOP sign installation and enter these costs into their respective fields (i.e., “Remove Hardware” and “Install Stop Signs” on Form TR-03. If the specific costs are not readily available, reasonable estimates should be made using the ranges of costs contained in Table 16-3. These costs are then converted to equivalent annual costs by multiplying them by 0.149 (the capital recovery factor assuming 15 years at 12% interest).
- (3) Enter the estimated annual sign maintenance costs. The total annualized cost of signal removal is then computed by the form by adding this and the previous costs.
- (4) The difference between the annual costs of operation and the annual removal costs is the annual cost savings from signal removal. (Note: If the result for the annual cost savings from signal removal is negative, that implies that the removal of the signal could actually cost more than its continued operation. Although possible, that is a very rare occurrence and the estimated costs of both continued operation and removal should be rechecked to verify that the continued operation costs are not underestimated and/or the removal costs are not overestimated).

STAGE 3.4 – ANTICIPATED STRENGTH OF OPPOSITION/SUPPORT FOR SIGNAL REMOVAL

By this time, the traffic engineer should have been in contact with the local governmental agency representatives, local police department, affected business leaders and neighborhood associations to obtain their opinions and possible opposition or support for the signal removal concept. A brief summary of that opposition or support should be entered in the comments field.

STAGE 3.5 – FINAL DECISION

After thoroughly analyzing the results of the Signal Removal Analysis worksheet and the Signal Removal Impacts worksheet, decide whether to retain or recommend removal of the signal and place a checkmark in the respective field. A brief summary explaining the decision can be entered in the comments field.

Figure 16-4 Example Signal Removal Analysis Worksheet (Page 1 of 2)
SIGNAL REMOVAL ANALYSIS WORKSHEET

Stage 1 – Intersection Inventory

Intersection: _____ City: Rawlins

Major St. Spruce Street Lanes/Approach 2 ADT: 9,350

Minor St. 7th Street Lanes/Approach 1 ADT: 1,220

Major Street Speed: 30 (mph)

Side-Street Sight Distance: 350' east and 350' west from north leg

400' east and 400' west from south leg

Stage 2 – Preliminary Screening

		NO	YES
1.	Minimum Required Sight Distance (from Table 16-4) <u>335'</u>		
	Is Intersection Sight Distance Less Than Minimum?	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2.	Do Special Site Conditions Make Signal Removal Institutionally Infeasible?	<input checked="" type="checkbox"/>	<input type="checkbox"/>
	Comments: <u>None that are known</u>		

3.	Does Existing (or future) Traffic Satisfy Signal Installation Warrants?	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4.	Did Any Special Reasons Justify Signal Installation?		
	Are These Reasons Still Valid?	<input checked="" type="checkbox"/>	<input type="checkbox"/>
	Comments: <u>Unknown. Signal will need to be upgraded if left in place.</u>		

IF ANY OF THE ABOVE QUESTIONS ARE ANSWERED "YES" – DEFER SIGNAL REMOVAL.
 OTHERWISE, PROCEED WITH DETAILED ANALYSIS

Figure 16-4 Example Signal Removal Analysis Worksheet (Page 2 of 2)

SIGNAL REMOVAL ANALYSIS WORKSHEET

Stage 3 – Detailed Analysis: Two-Way Stop Control

3.1 Estimated Impacts on Crashes

Total Major Street Volume		Higher Volume Side Street Approach		Check if Minimum Satisfied	Crash Experience	
Minimum Required (Table 10-1)	360	90				
Nth Highest Hour - Volume	1st	710	70	<input type="checkbox"/>	Total Crashes	14
	2nd	689	90	<input checked="" type="checkbox"/>	Period Covered: From	01 - 1997 To 12 - 2001
	3rd	695	67	<input type="checkbox"/>		MM-YYYY MM-YYYY
	4th	674	73	<input type="checkbox"/>	Length of Time Period	5.00 years
	5th	652	63	<input type="checkbox"/>	Average Annual Crash Frequency (X ₂)	2.8
	6th	578	80	<input type="checkbox"/>		
	7th	518	44	<input type="checkbox"/>		
	8th	439	57	<input type="checkbox"/>		
Volume Magnitude (No. of Hours Meeting Requirement) X ₁ =				1	From Equation 16-1 $Y = 1.01 + 0.139X_1 - 0.605X_2$ Predicted Change in Annual Crash Frequency (Y) = -0.5	

3.2 Traffic Flow Related Impacts

Change Per Vehicle (From Impacts Worksheet)	Daily Change (From Impacts Worksheet)	x 320	=	Annual Change
5.3	15.6	Idling Delay	→	4,992
12.1	35.6	Total Delay	→	11,392
0.39	4,080	Total Stops	→	1,305,600
0.0025	26	Excess Fuel	→	8,320

3.3 Junction – Related Cost Impacts

Annual Signal Operation Costs		Costs Of Signal Removal x CRF* = Annual Costs			
Electrical	\$250.00	Remove Hardware	\$5,000.00	x 0.142	\$710.00
Maintenance	\$1,700.00	Install Stop Signs	\$150.00	x 0.142	\$21.30
Timing	\$50.00	Annual Stop Sign Maintenance			\$20.00
Total	\$2,000.00			Total	\$751.30

* (CRF – Capital Recovery Factor For 15 Years At 12% Interest)

Annual Operation Costs – Annual Removal Costs = Annual Cost Savings From Signal Removal:

\$1,248.70

3.4 Anticipated Strength of Opposition/Support For Signal Removal

Comments: The general consensus seems to be that this signal is causing more problems that it is helping. Objections to its removal should be minimal.

3.5 Final Decision:

Retain Signal ☐

Recommend Removal ☒

Comments: Signal removal should reduce crashes and significantly improve efficiency. The cost to reconstruct Spruce Street will be reduced by not having to upgrade this signal.

Figure 16-5 Example of Worksheet for Estimating Daily Impacts of Signal Removal and Replacement by Two-way Stops

INTERSECTION TYPE			IDLING DELAY (VEH. HRS.)	TOTAL DELAY (VEH. HRS.)	TOTAL STOPS (VEH. STOPS)	EXCESS FUEL CON- SUMP- TION (GAL.)	
(1) Main Road	<input checked="" type="checkbox"/> 4-Way	<input type="checkbox"/> T-Intersection					
Side Road	<input type="checkbox"/> 2 Lane	<input checked="" type="checkbox"/> 4 Lane					
	<input checked="" type="checkbox"/> 2 Lane	<input type="checkbox"/> 4 Lane					
AVERAGE OF THE 2 PEAK HOURS			(3) a. Signal Control	1.4	3.1	390	2.6
			b. 2 Way Stop Control	0.2	0.7	110	0.6
a. Total Main Road Vol. = 700			From Nomographs				
(2) b. Side Road Vol./Approach = 52							
c. Total Intersection Vol. = 804							
c. DIFFERENCE			1.2	2.4	280	2	
(4) TOTAL OF THE TWO PEAK HOURS	a. $\frac{x 2}{1,608}$	b. $\frac{x 2}{= \text{DIFFERENCE}}$	$\frac{x 2}{2.4}$	$\frac{x 2}{4.8}$	$\frac{x 2}{560}$	$\frac{x 2}{4}$	
AVERAGE OF THE REMAINING 22 HOURS			(6) a. Signal Control	0.7	1.7	200	1.2
			b. 2 Way Stop Control	0.1	0.3	40	0.2
a. Total Main Road Vol. = 361			From Nomographs				
(5) b. Side Road Vol./Approach = 23							
c. Total Intersection Vol. = 407							
c. DIFFERENCE			0.6	1.4	160	1	
(7) TOTAL OF THE RE- MAINING 22 HOURS	a. $\frac{x 22}{8,954}$	b. $\frac{x 22}{= \text{DIFFERENCE}}$	$\frac{x 22}{13.2}$	$\frac{x 22}{30.8}$	$\frac{x 22}{3,520}$	$\frac{x 22}{22}$	
(8) 24 HOUR TOTAL	2 Hrs. + 22 Hrs. a. 10,562	b. 2 Hrs. + 22 Hrs. = DIFFERENCE	$\frac{2 + 22}{15.6}$	$\frac{2 + 22}{35.6}$	$\frac{2 + 22}{4,080}$	$\frac{2 + 22}{26}$	
(9) PER VEHICLE IMPACTS (Delay in Sec./Veh.) (Divide 24 Hour Differences by 24 Hour Volume)			5.3	12.1	0.39	0.0025	

**Figure 16-6 Example Idling and Total Delay Estimates
(Four-Way Intersection, Four-Lane Major, Two-Lane Minor)**

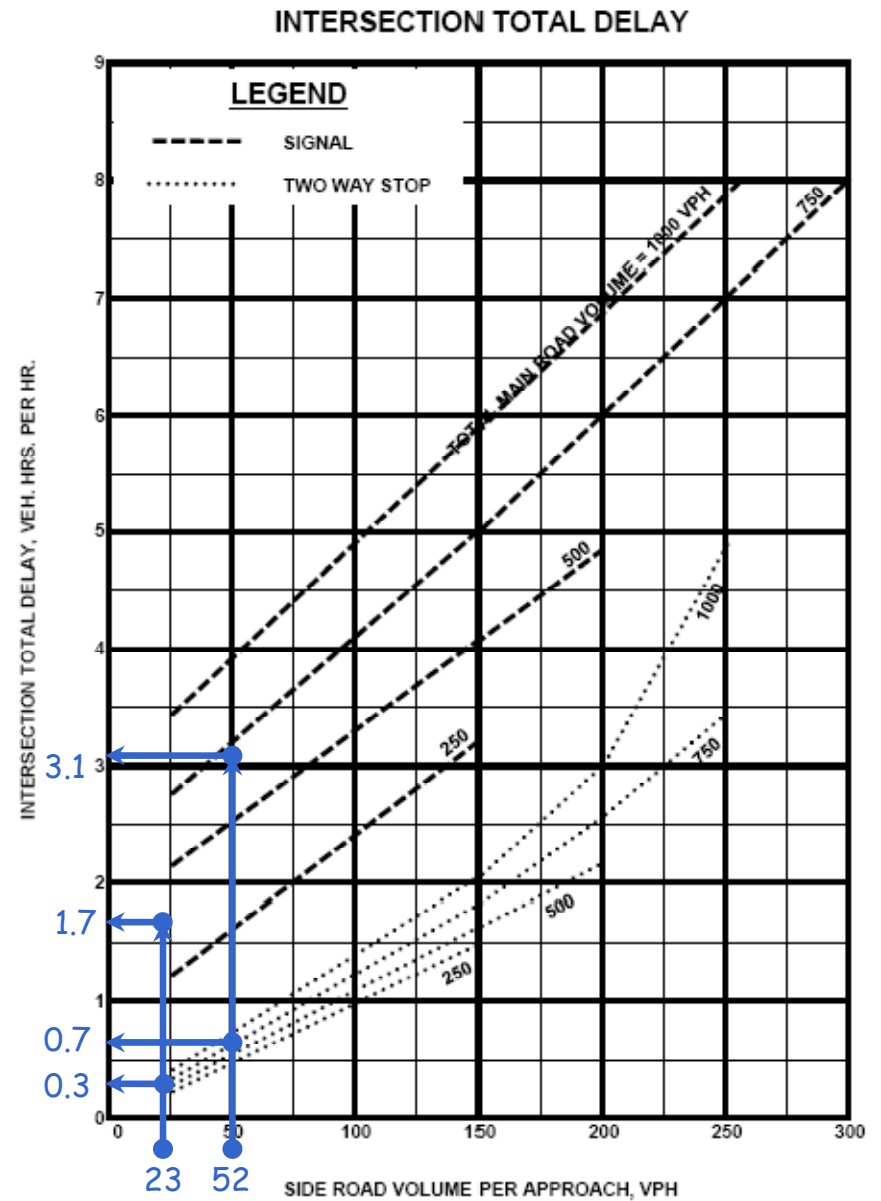
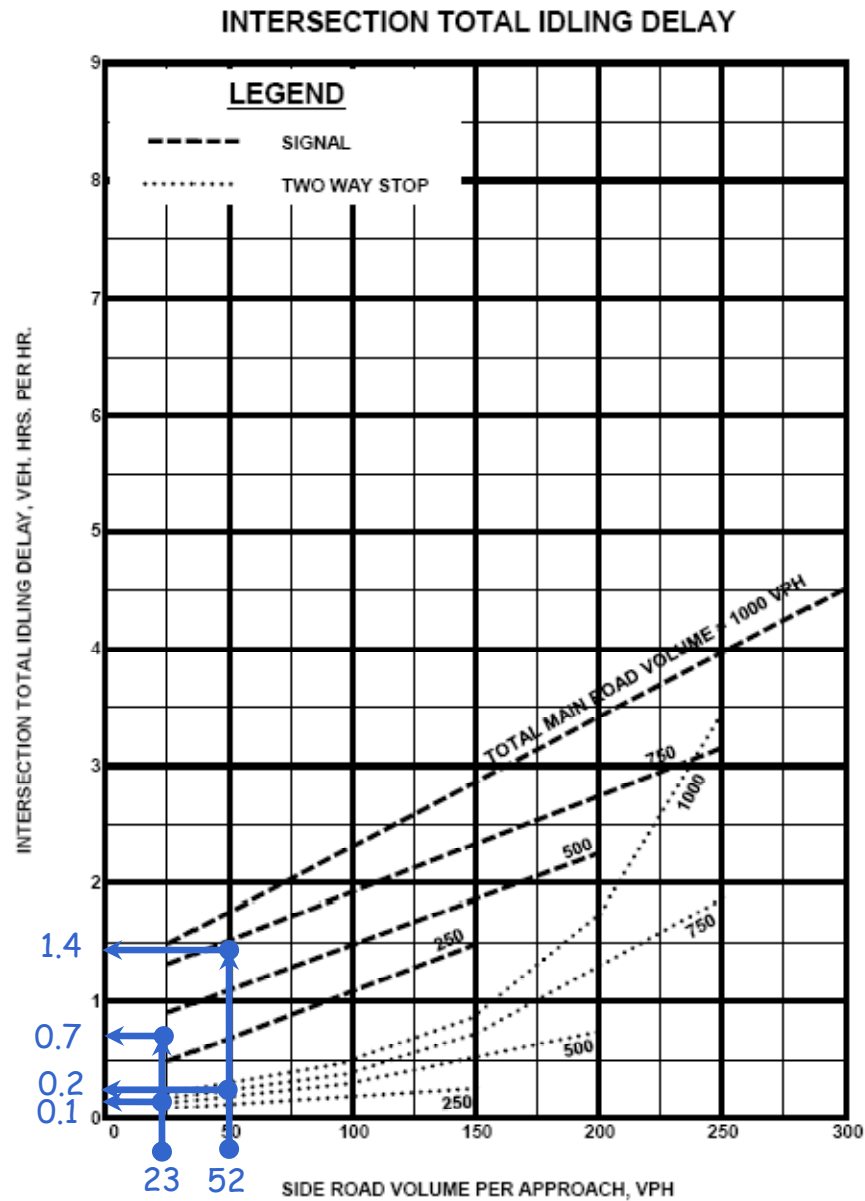


Figure 16-7 Example Stops and Excess Fuel Consumption Estimates
(Four-Way Intersection, Four-Lane Major, Two-Lane Minor)

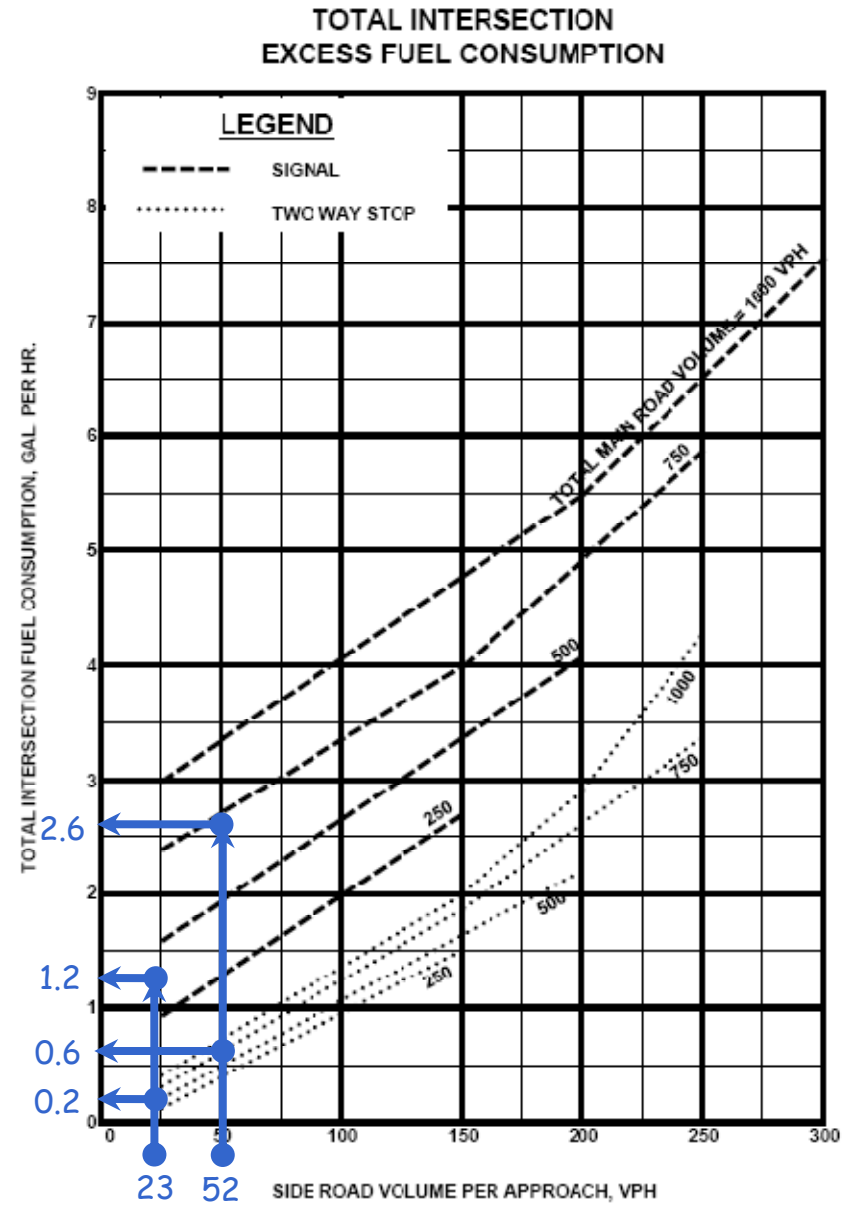
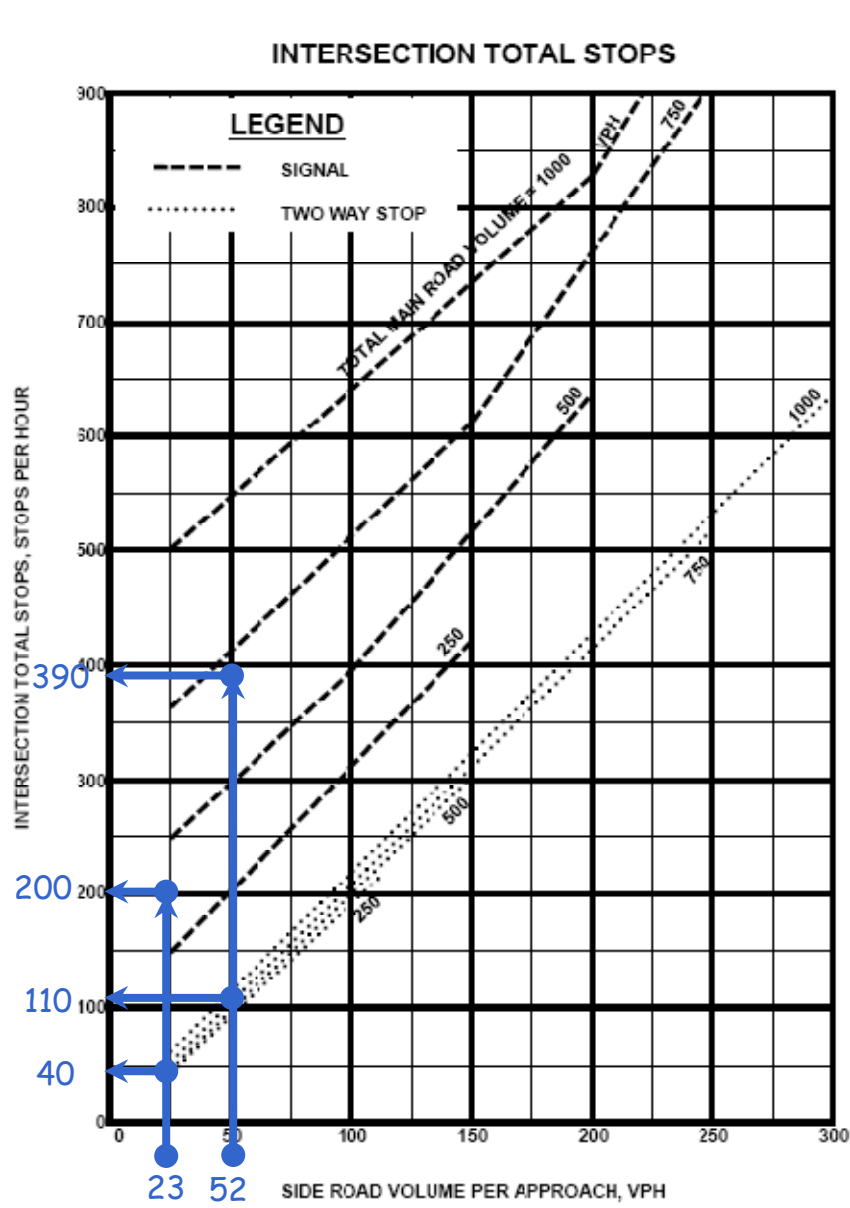
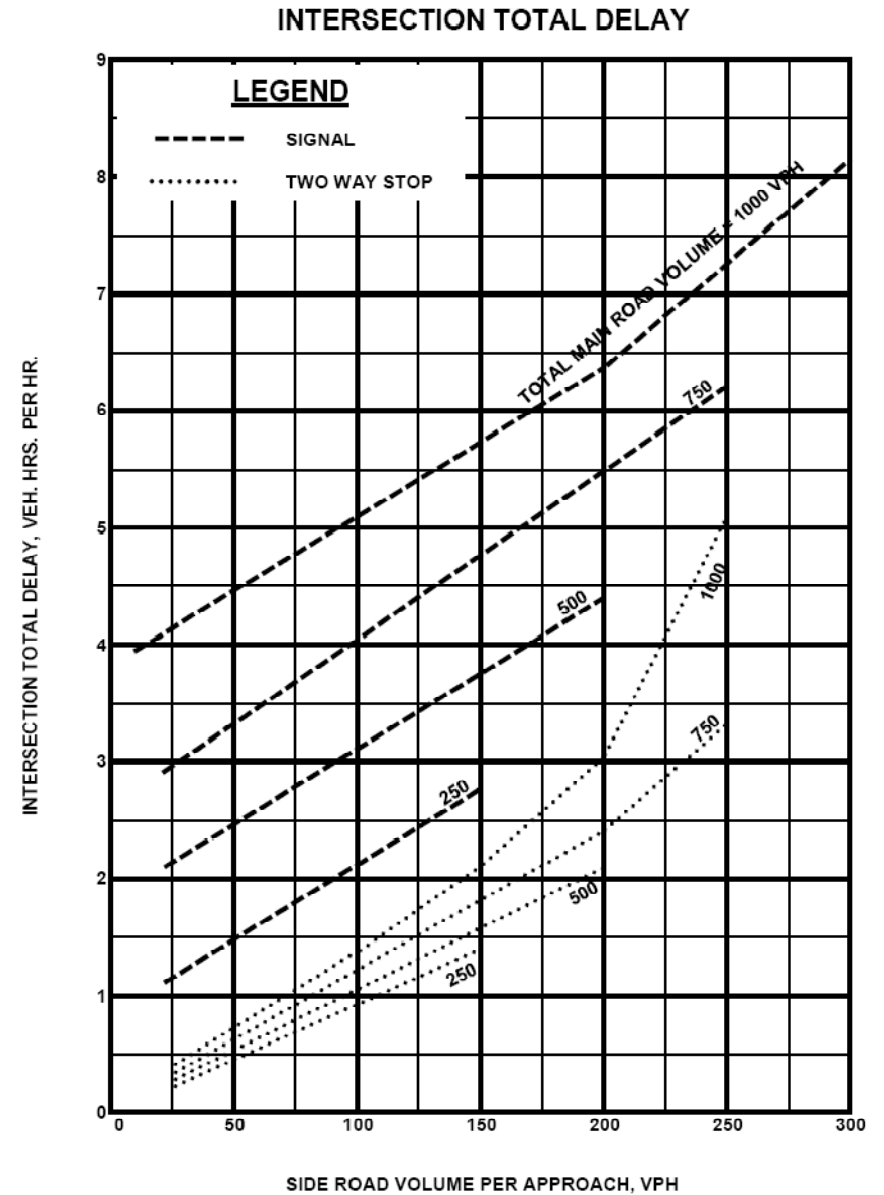
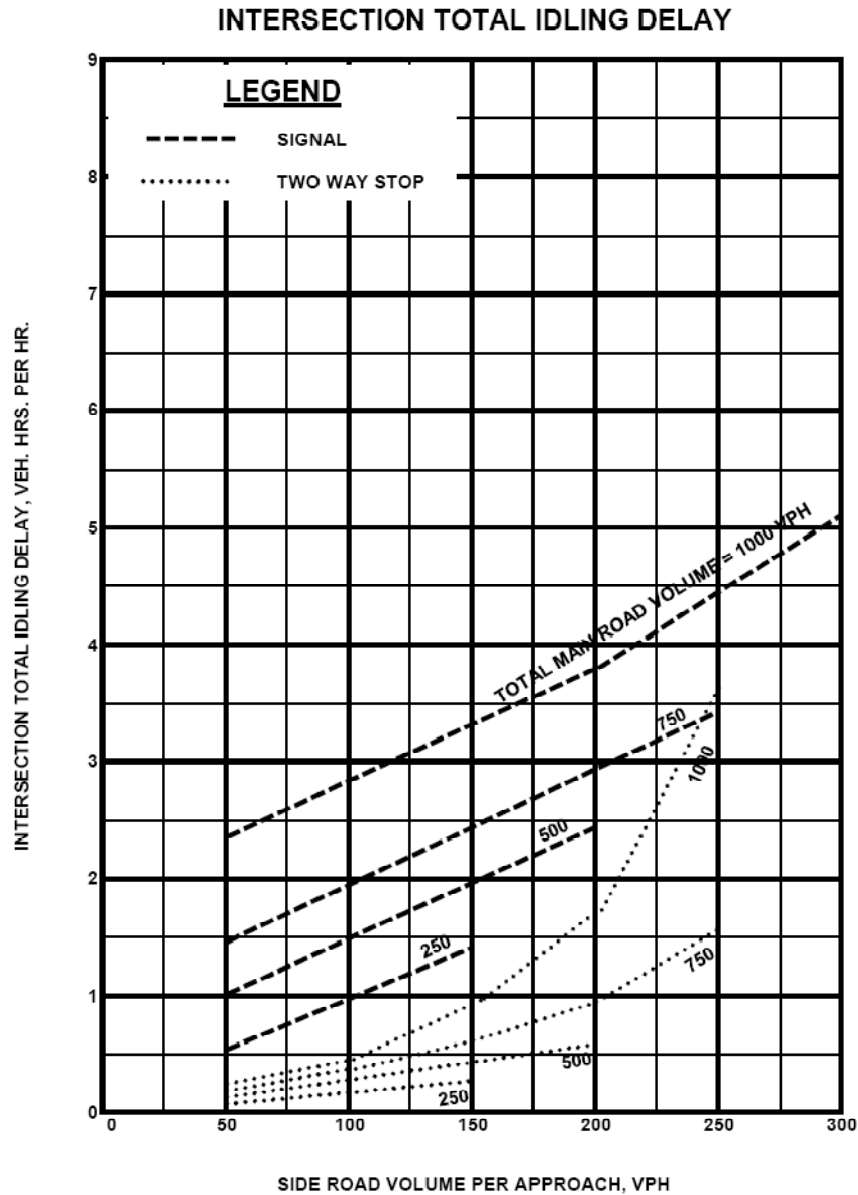


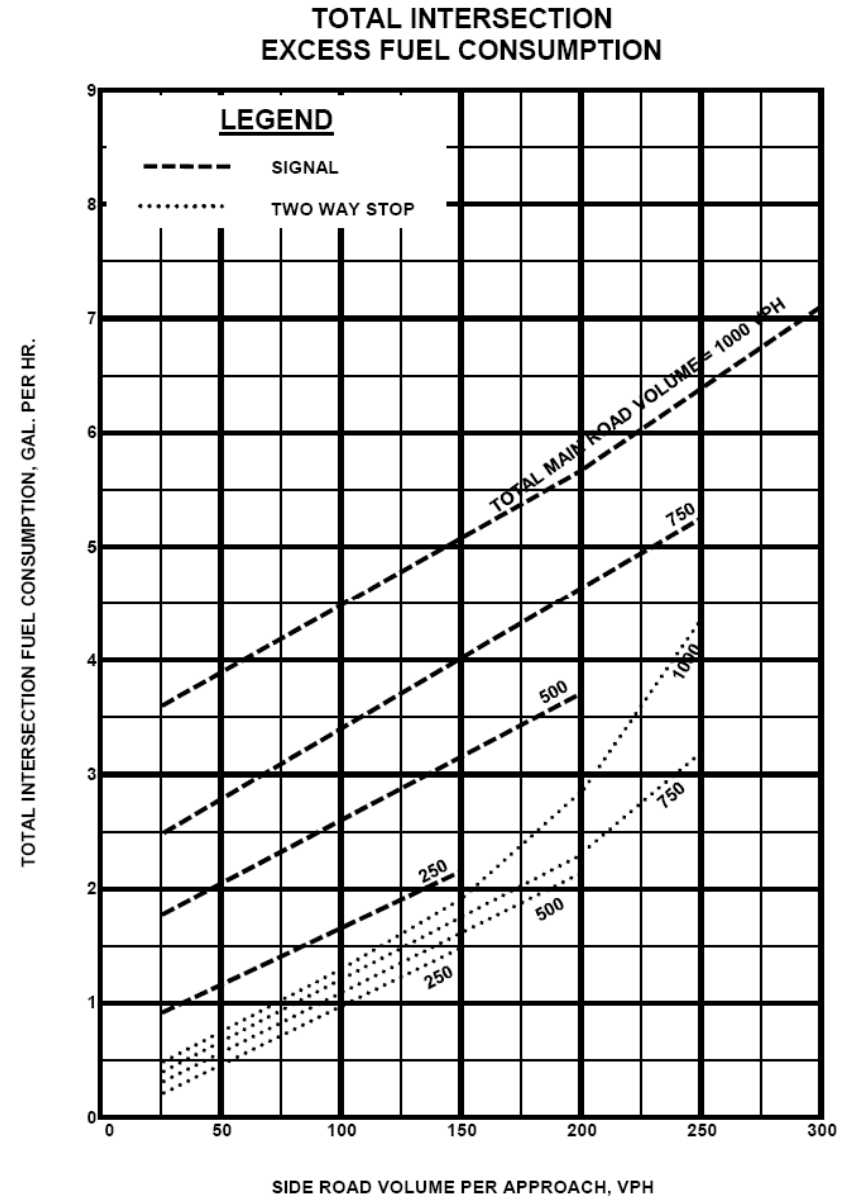
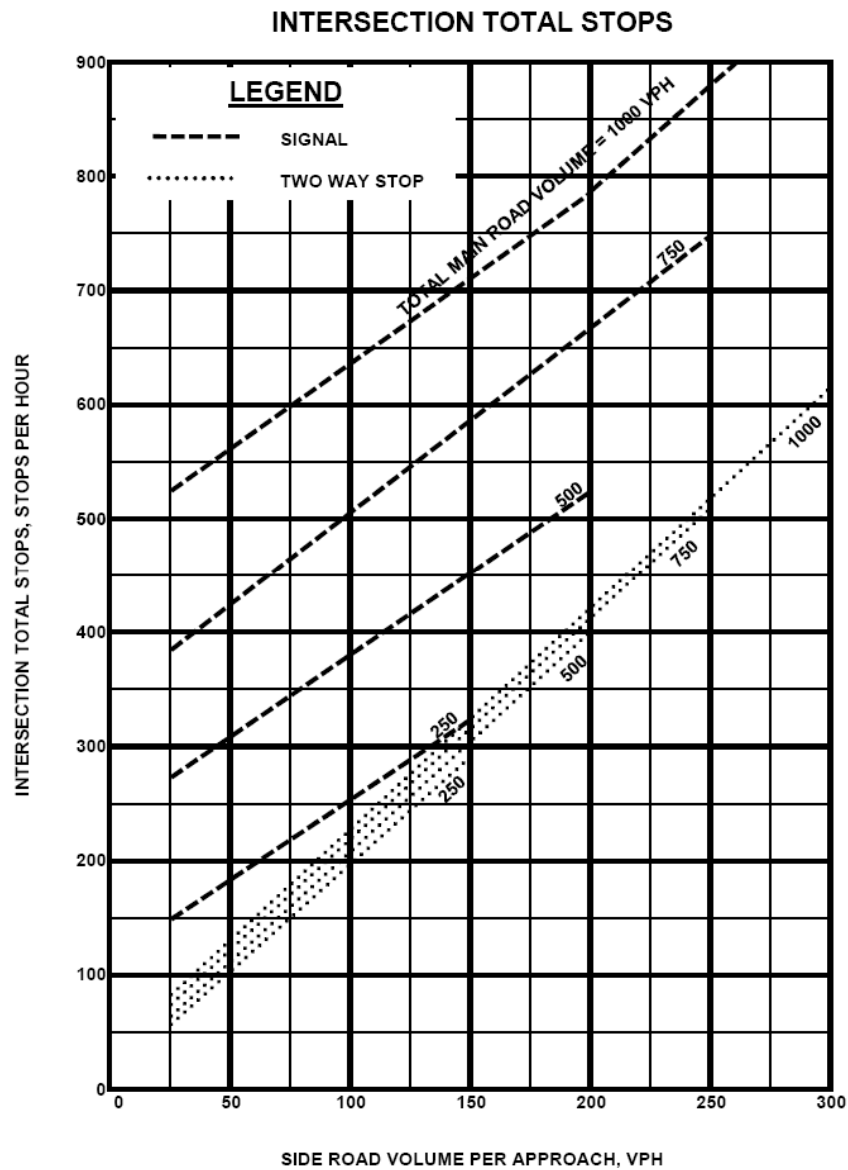
Figure 16-8 List of Nomographs by Intersection Type

INTERSECTION TYPE	ILLUSTRATION	NOMOGRAPH FIGURE NUMBERS	
		IDLING & TOTAL DELAY	STOPS & FUEL
4-WAY INTERSECTION, 2-LANE MAJOR ROAD, 2-LANE MINOR ROAD.		16-9	16-10
T-INTERSECTION, 2-LANE MAJOR ROAD, 2-LANE MINOR ROAD.		16-11	16-12
4-WAY INTERSECTION, 4-LANE MAJOR ROAD, 2-LANE MINOR ROAD.		16-13	16-14
T-INTERSECTION, 4-LANE MAJOR ROAD, 2-LANE MINOR ROAD.		16-15	16-16
4-WAY INTERSECTION, 4-LANE MAJOR ROAD, 4-LANE MINOR ROAD.		16-17	16-18
T-INTERSECTION, 4-LANE MAJOR ROAD, 4-LANE MINOR ROAD.		16-19	16-20

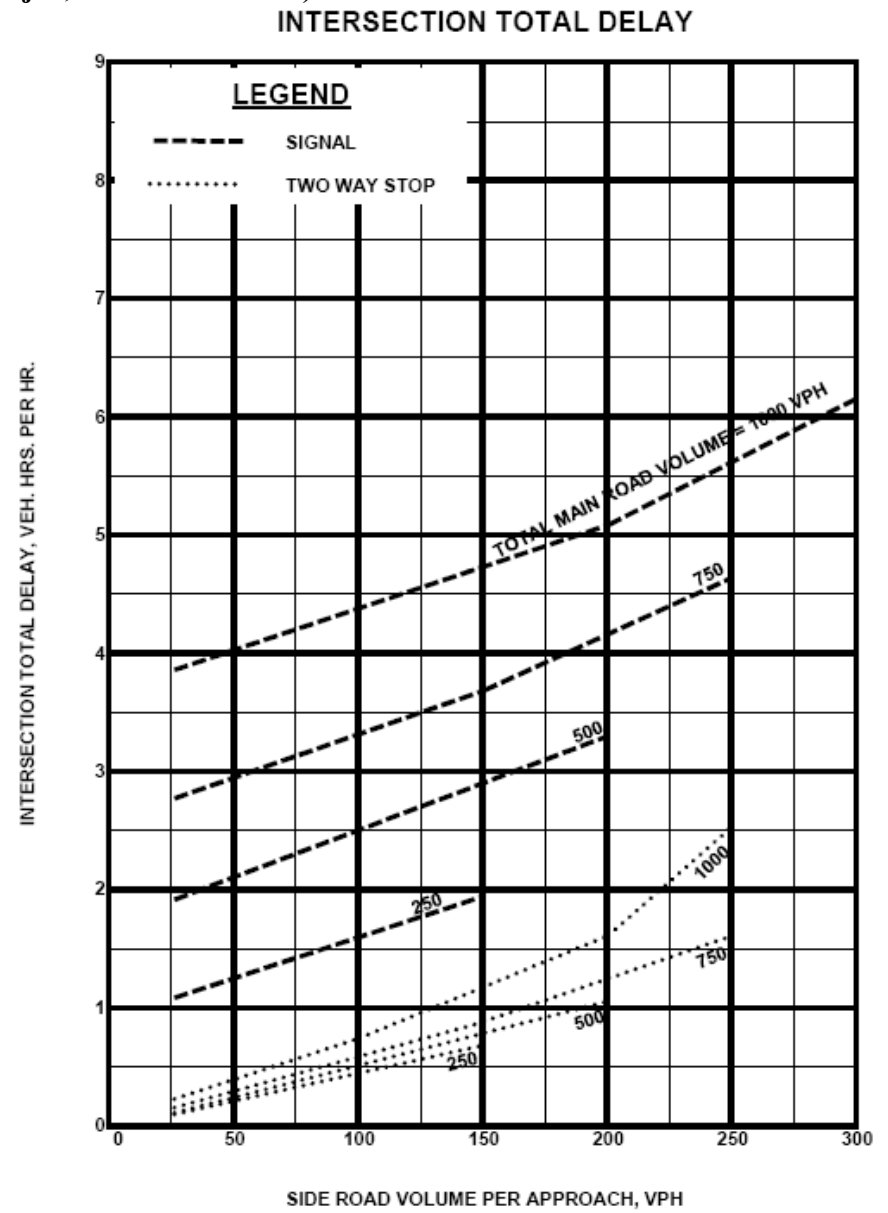
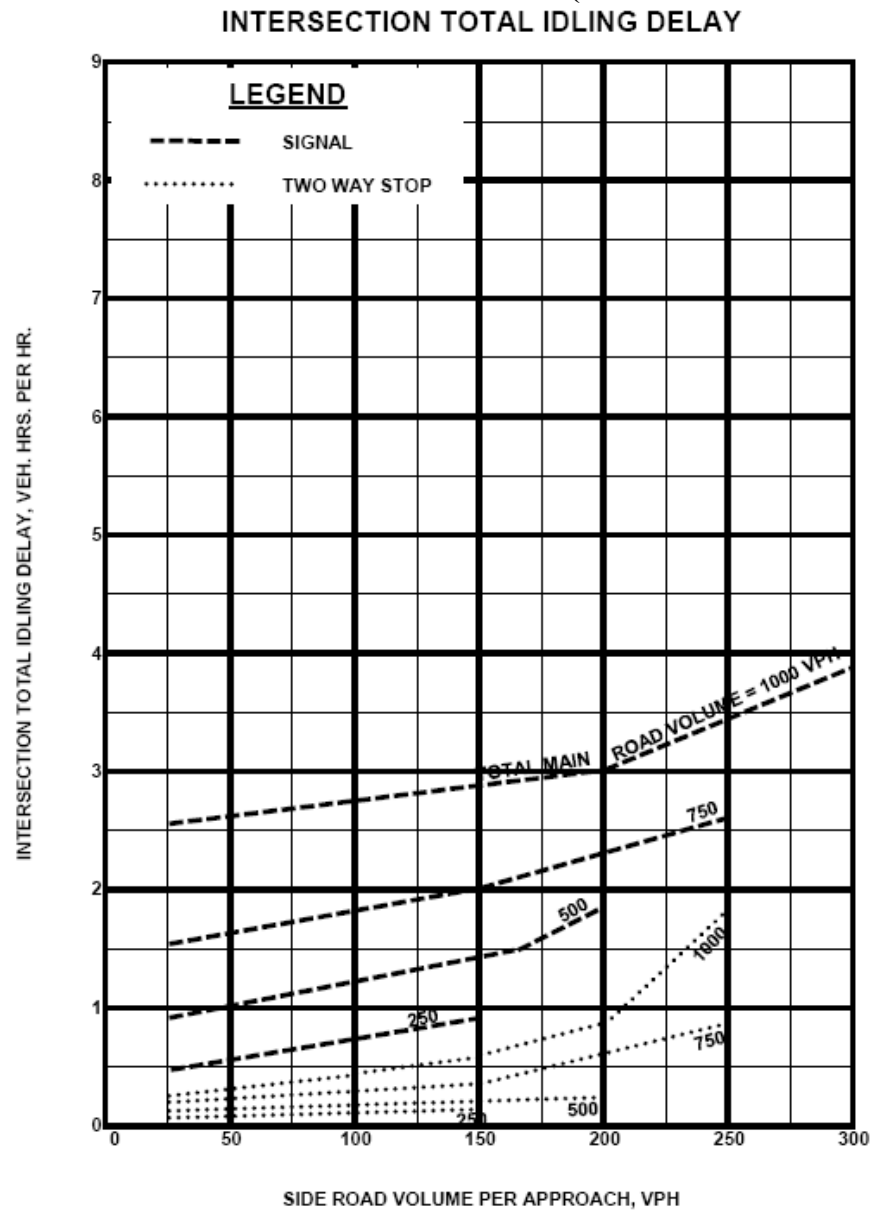
**Figure 16-9 Idling and Total Delay
(Four-way Intersection: Two-lane Major, Two-lane Minor)**



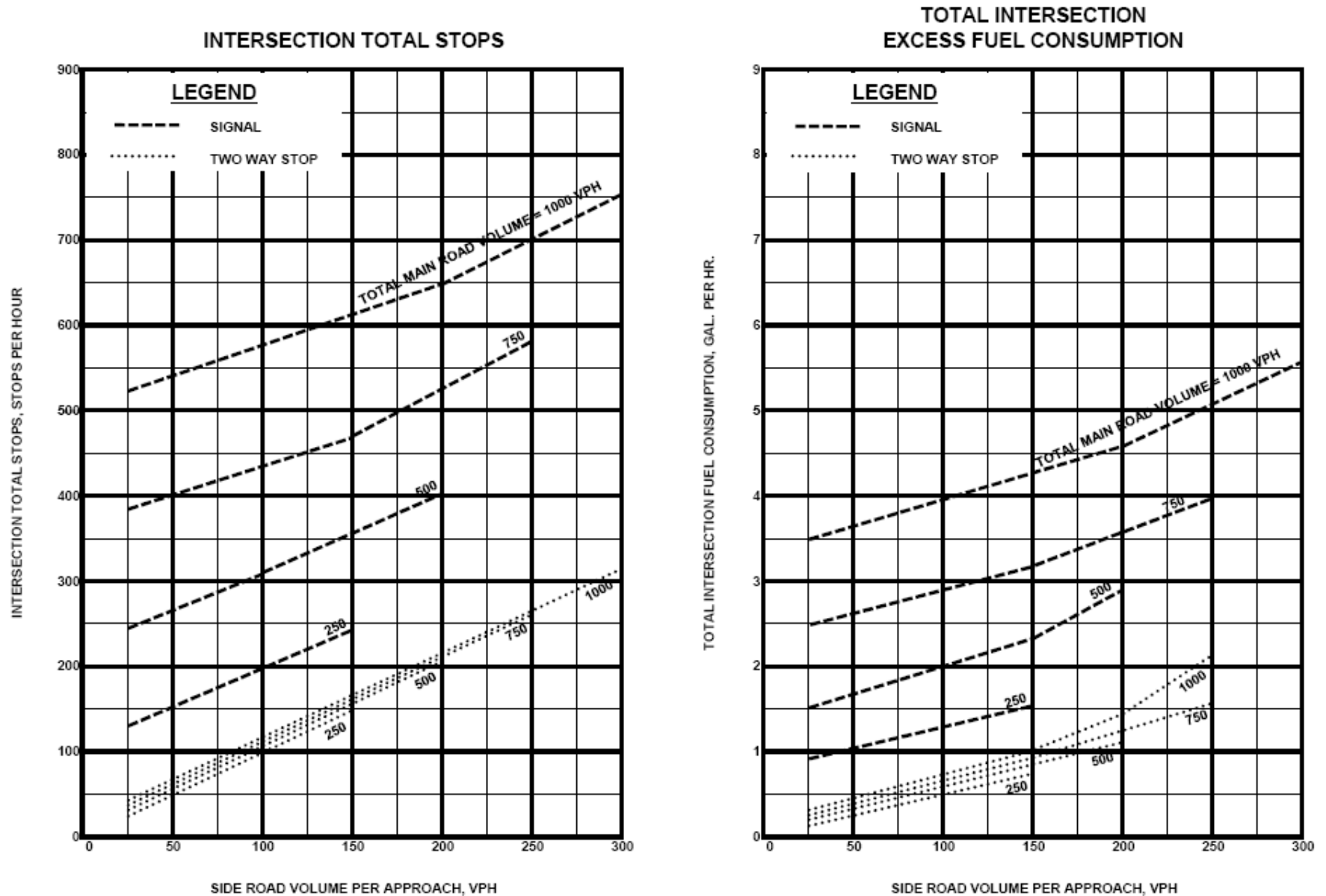
**Figure 16-10 Stops and Excess Fuel Consumption
(Four-way Intersection: Two-lane Major, Two-lane Minor)**



**Figure 16-11 Idling and Total Delay
(T-Intersection: Two-lane Major, Two-lane Minor)**



**Figure 16-12 Stops and Excess Fuel Consumption
(T-Intersection: Two-lane Major, Two-lane Minor)**



**Figure 16-13 Idling and Total Delay
(Four-way Intersection: Four-lane Major, Two-lane Minor)**

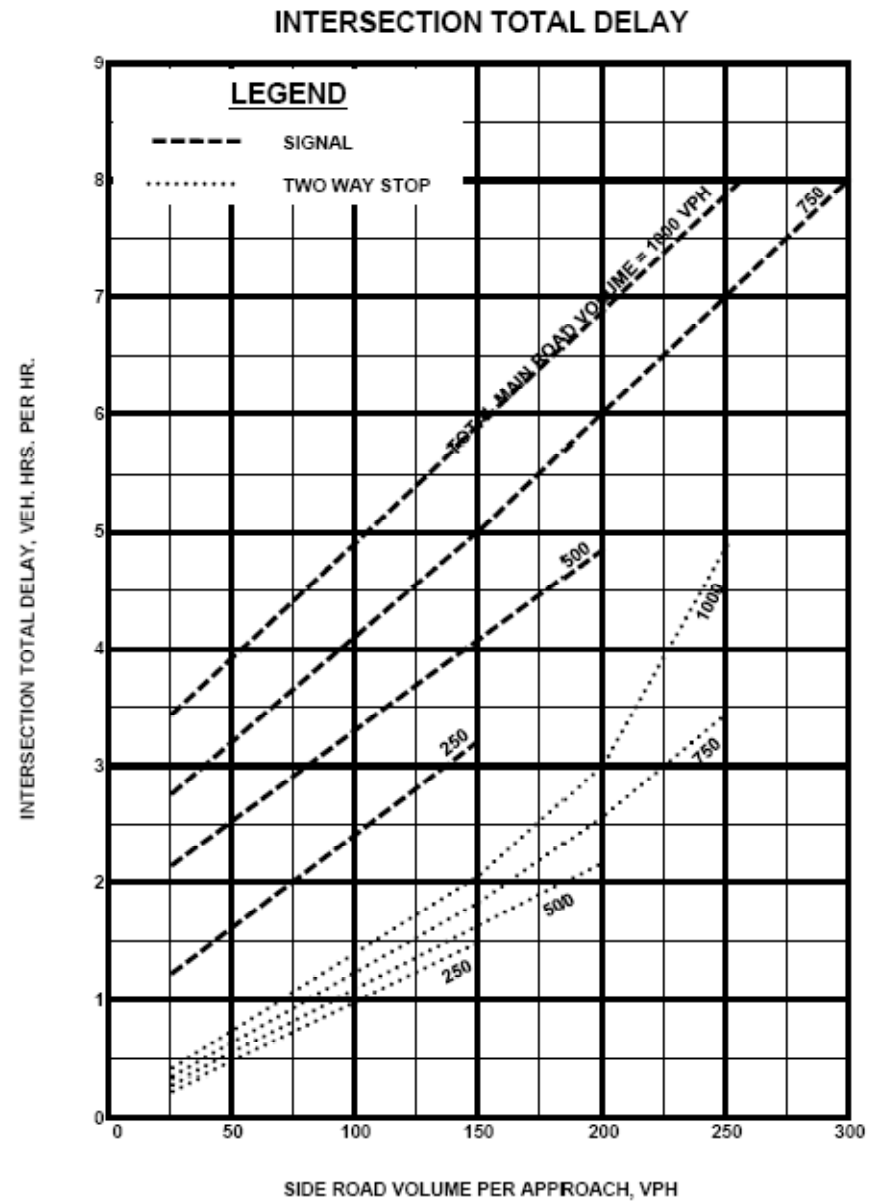
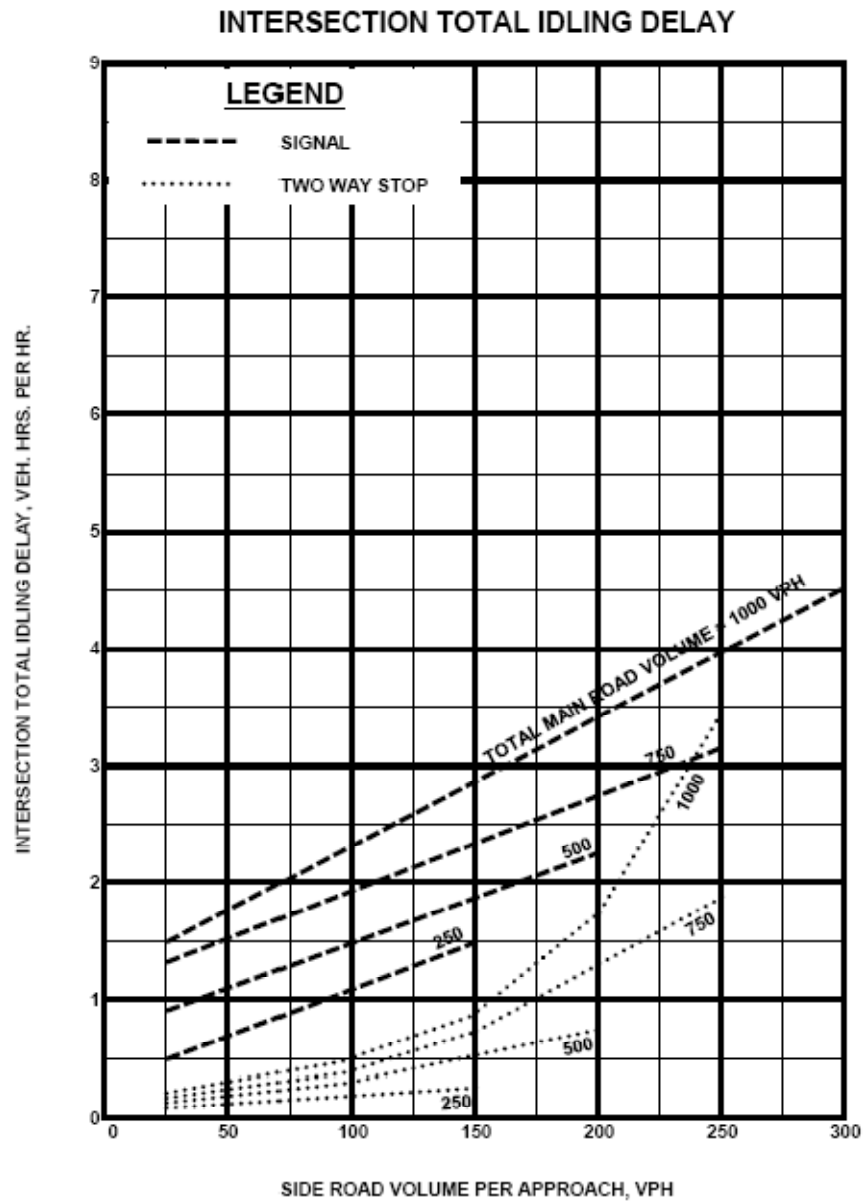
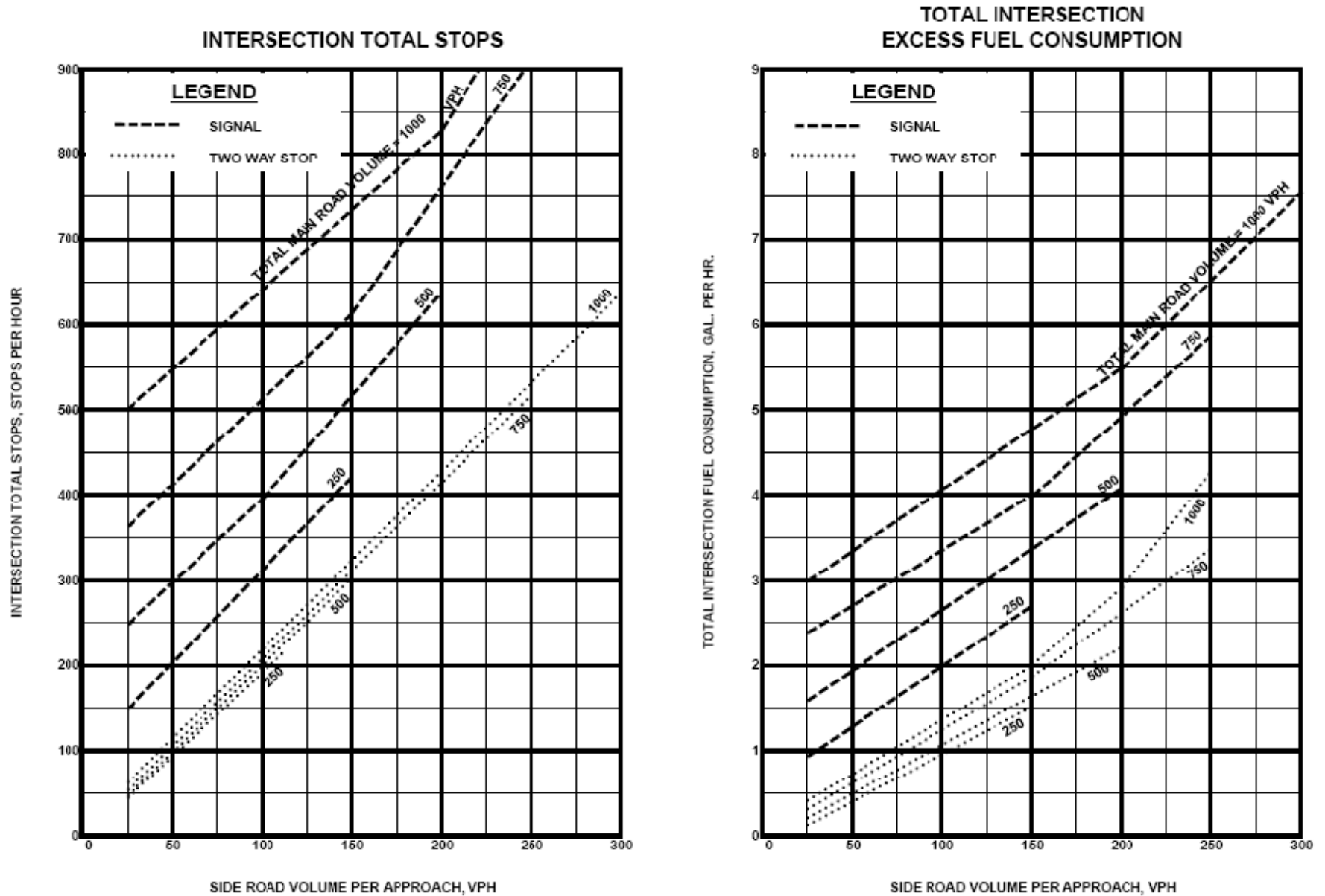


Figure 16-14 Stops and Excess Fuel Consumption
(Four-way Intersection: Four-lane Major, Two-lane Minor)



**Figure 16-15 Idling and Total Delay
(T-Intersection: Four-lane Major, Two-lane Minor)**

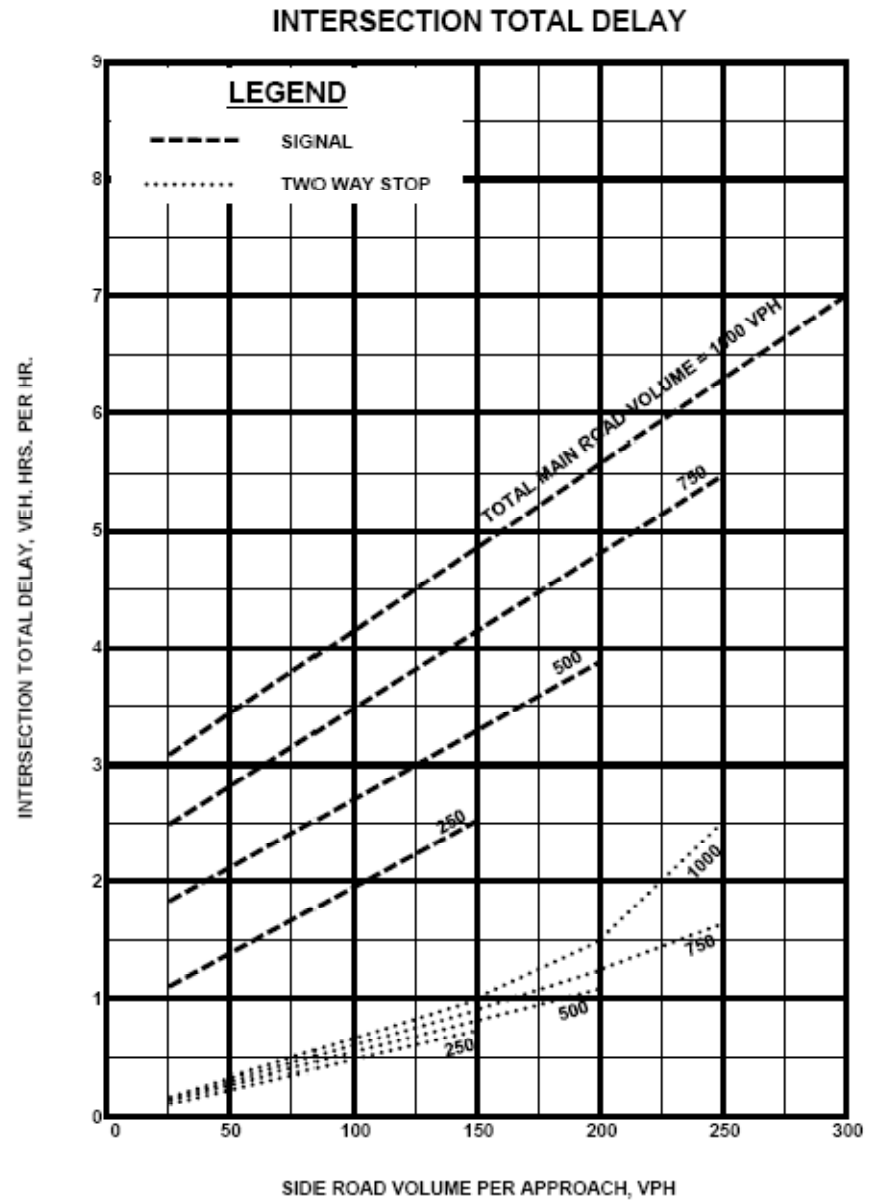
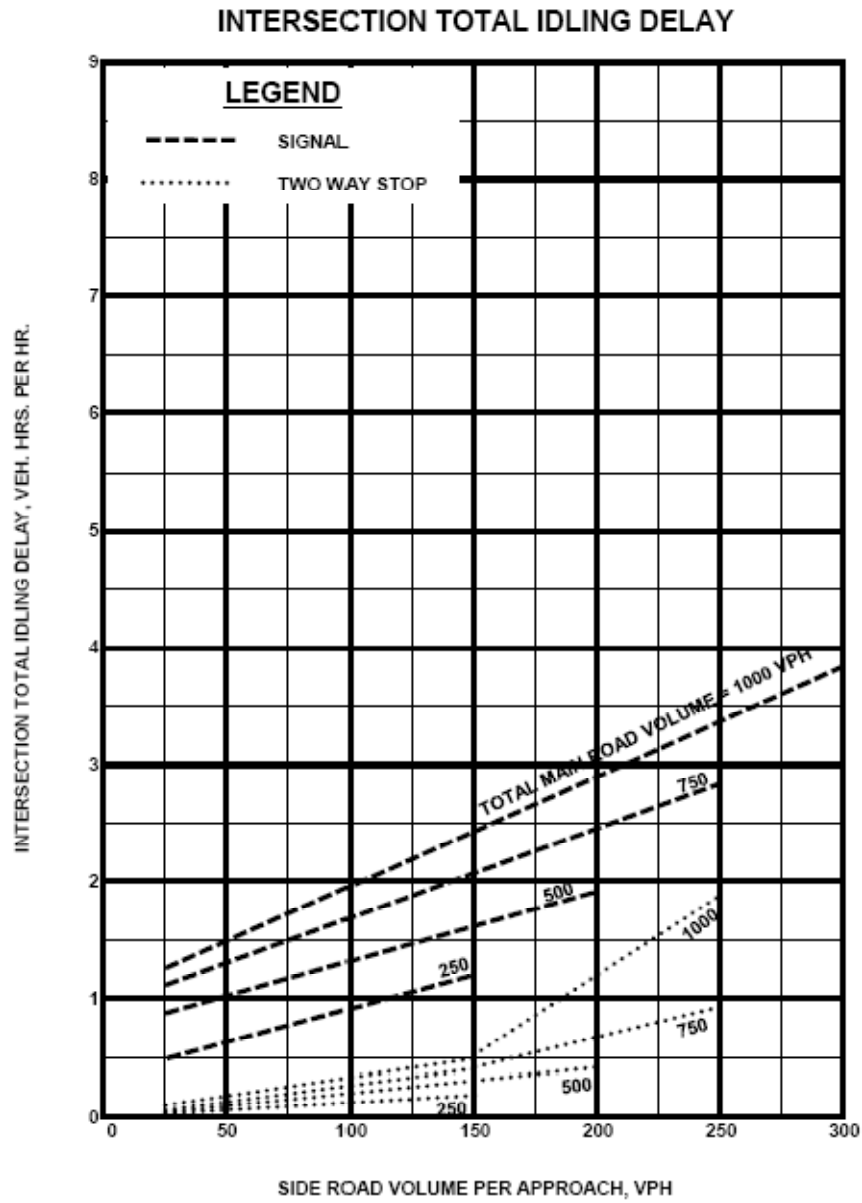
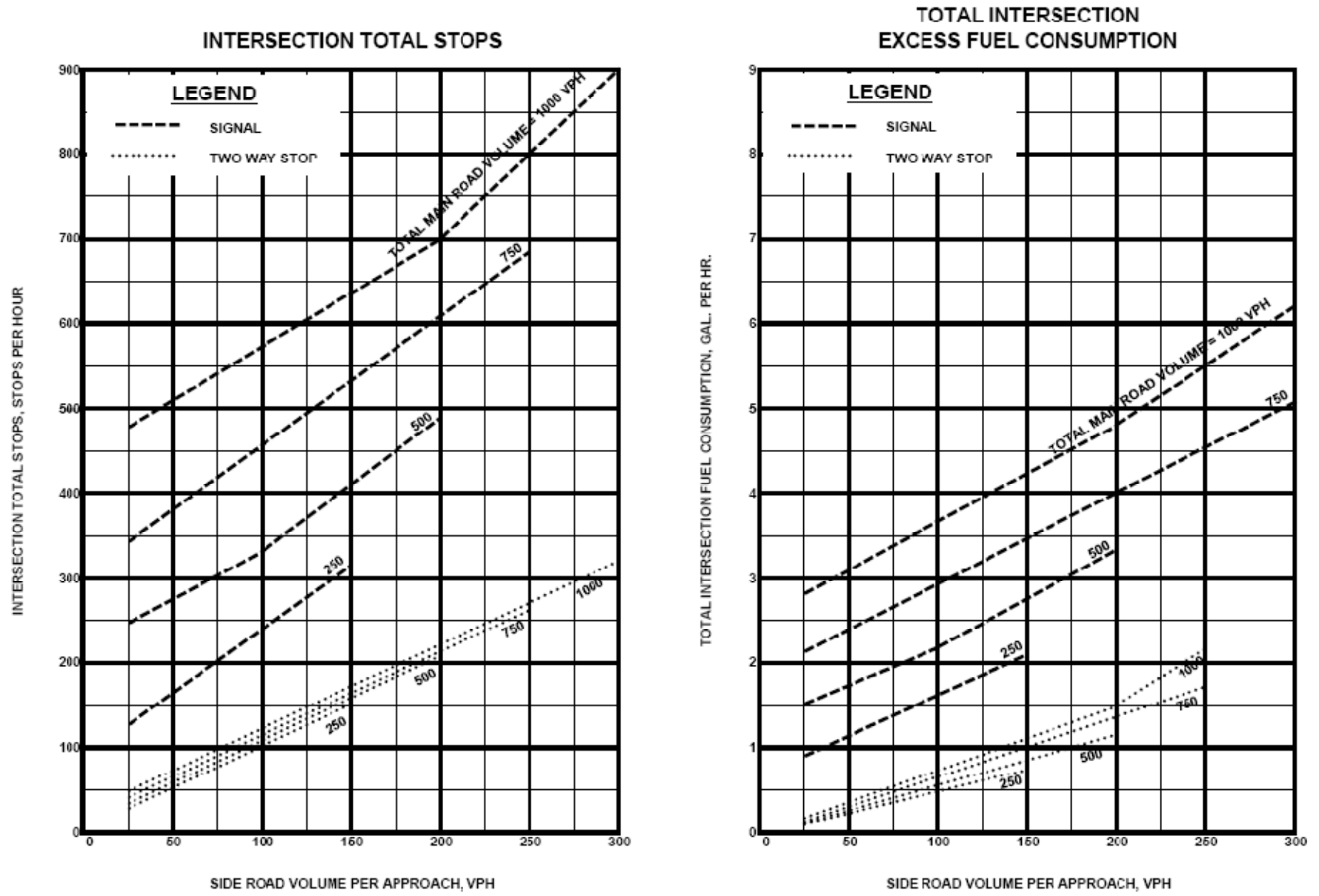
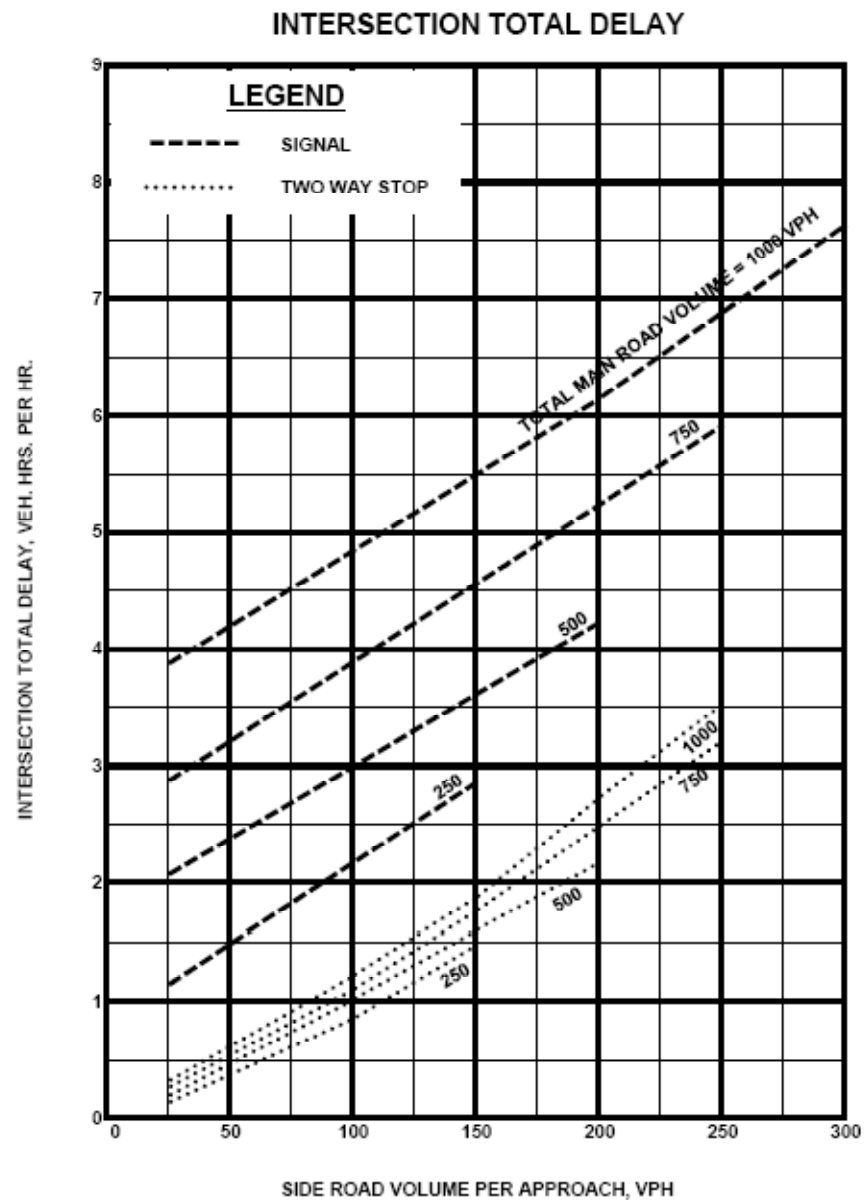
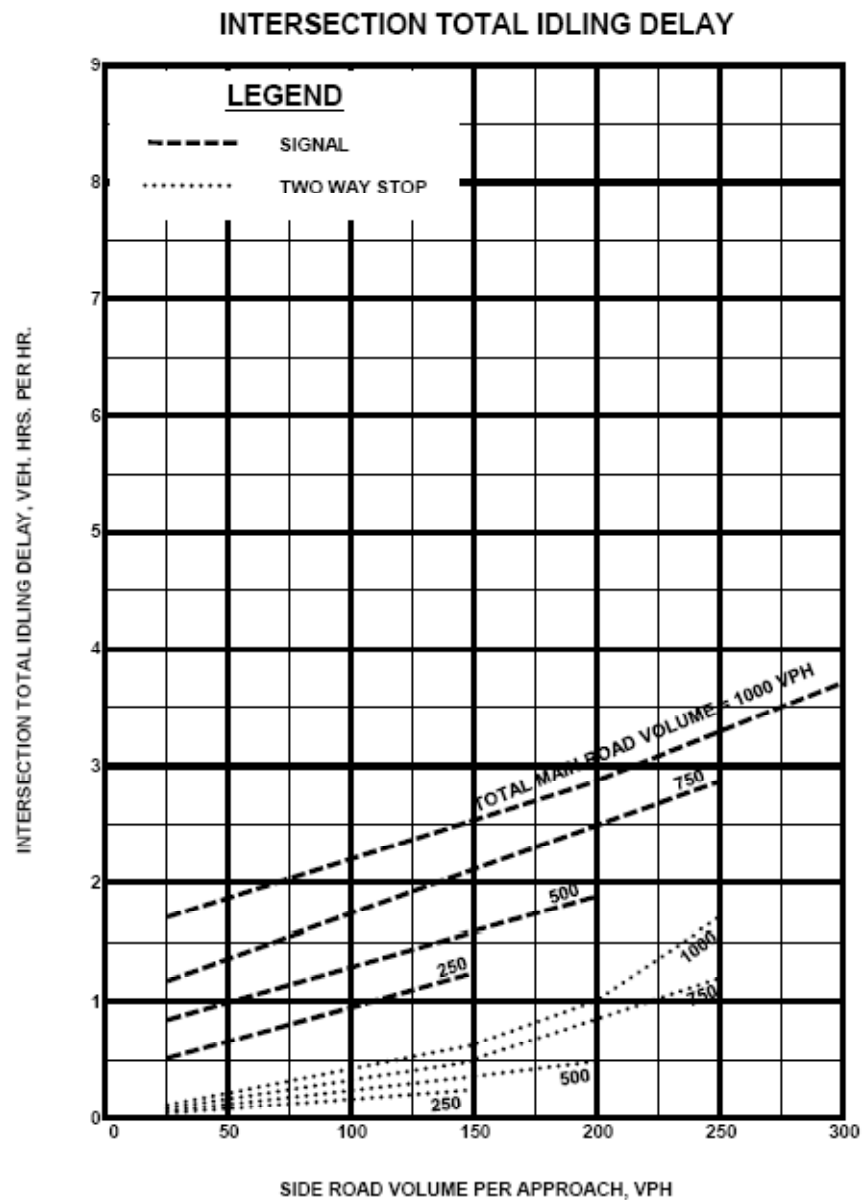


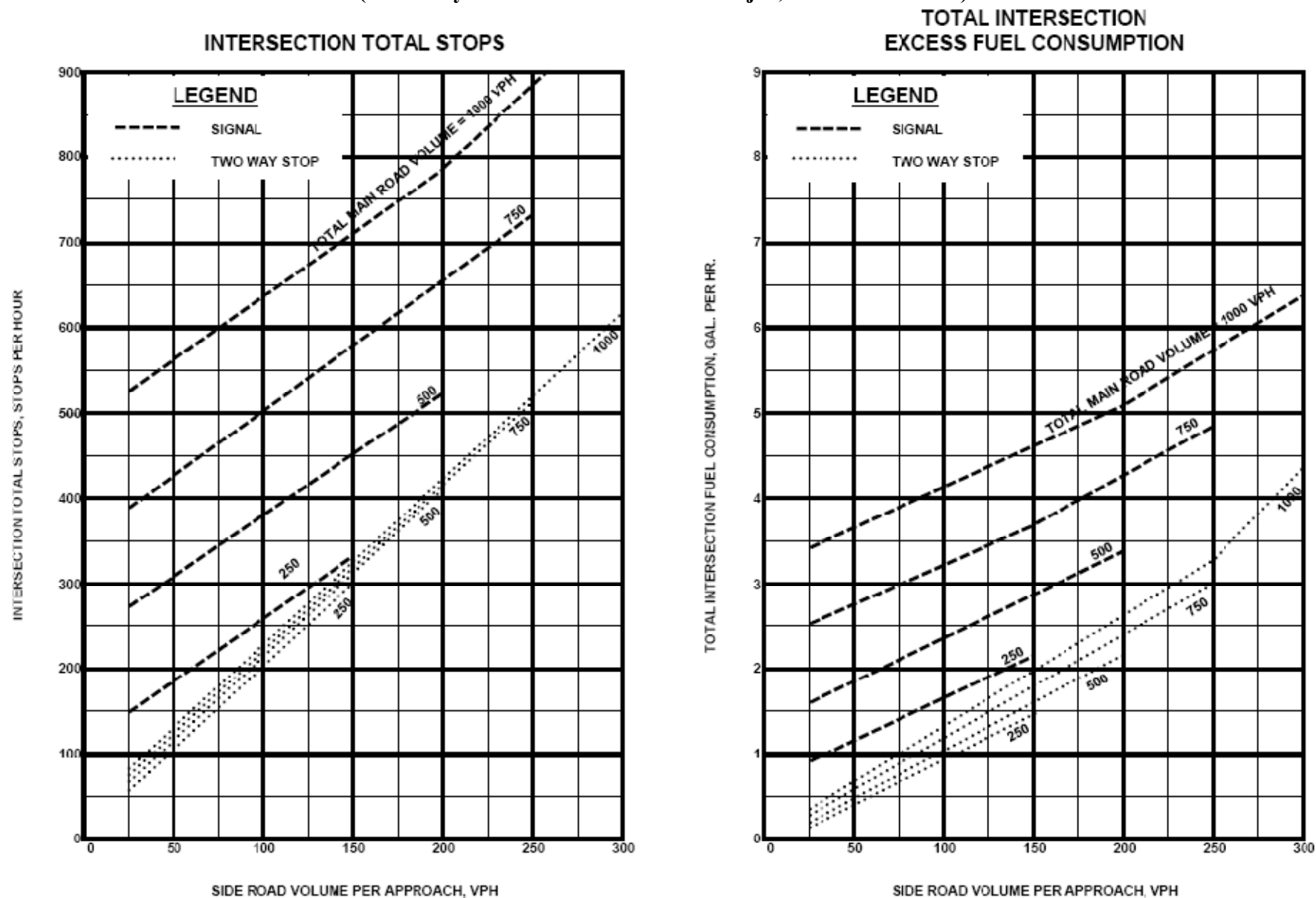
Figure 16-16 Stops and Excess Fuel Consumption
(T- Intersection: Four-lane Major, Two-lane Minor)



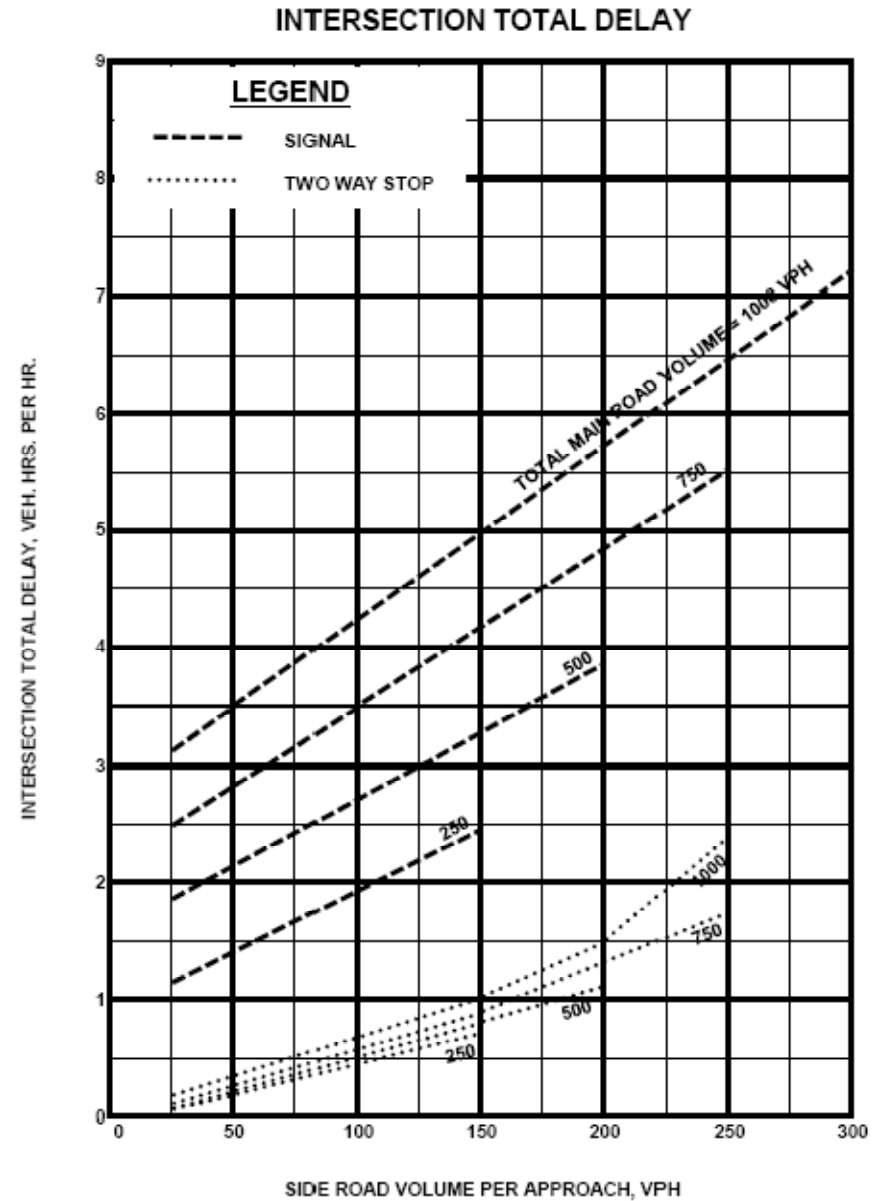
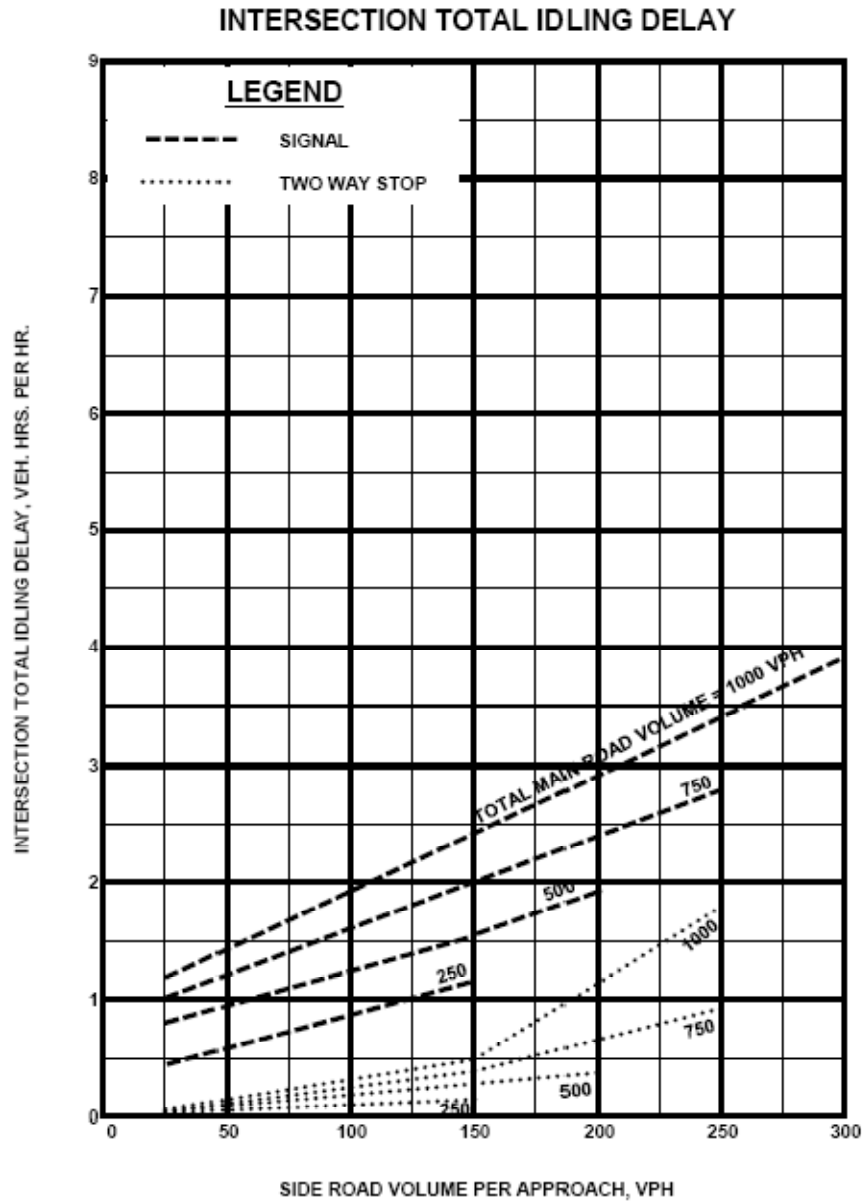
**Figure 16-17 Idling and Total Delay
(Four-way Intersection: Four-lane Major, Four-lane Minor)**



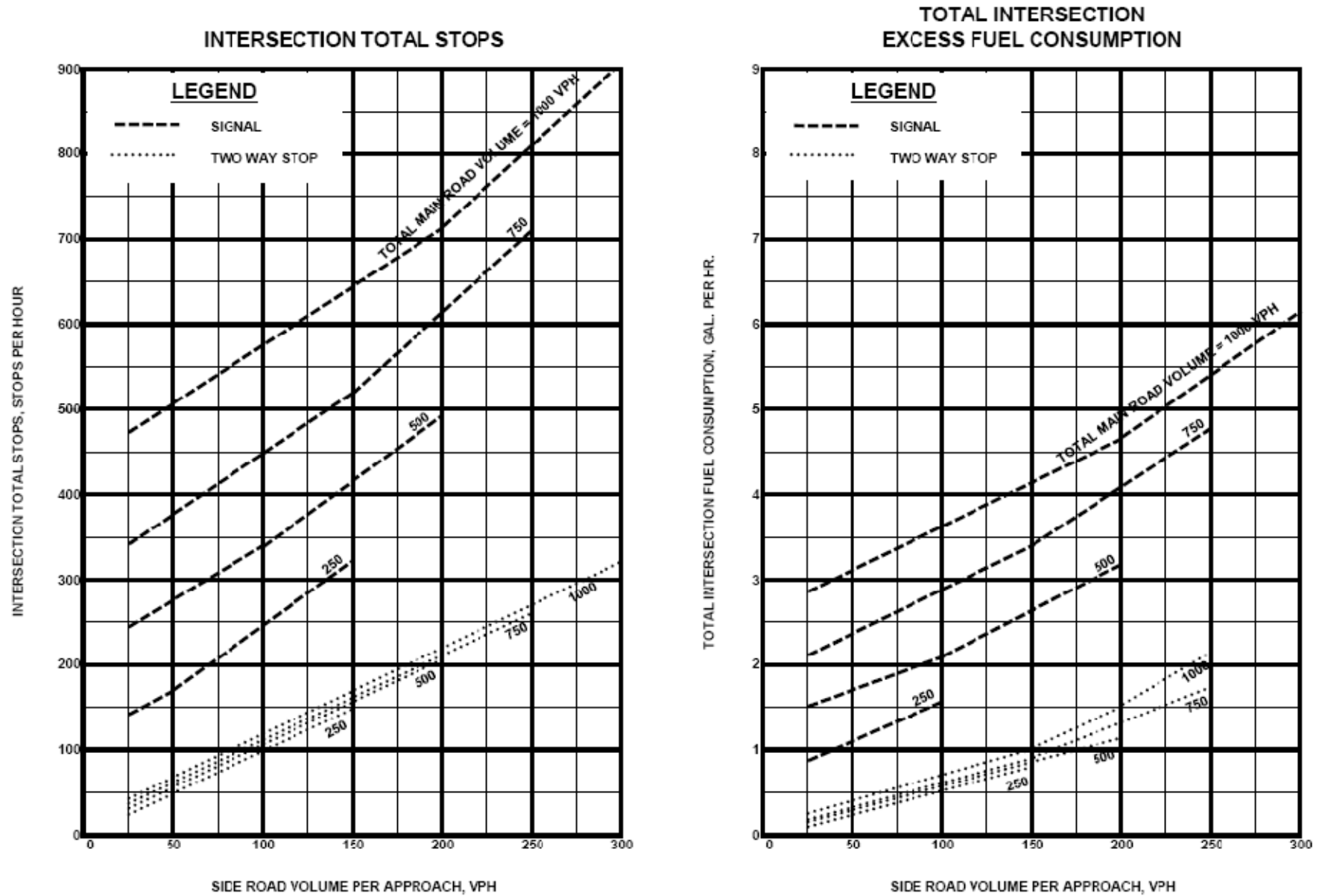
**Figure 16-18 Stops and Excess Fuel Consumption
(Four-way Intersection: Four-lane Major, Four-lane Minor)**



**Figure 16-19 Idling and Total Delay
(T-Intersection: Four-lane Major, Four-lane Minor)**



**Figure 16-20 Stops and Excess Fuel Consumption
(T- Intersection: Four-lane Major, Four-lane Minor)**



CHAPTER 17 – PREEMPTION

This chapter is under development

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CHAPTER 18

AUXILIARY LANE AND TRAFFIC IMPACT STUDIES

18.1 PURPOSE

- (1) In addition to the spacing of accesses, the number of traffic lanes at intersections and accesses and the configuration of those lanes for use by left, through and right-turning traffic play a vital role in the overall safety and operation of the transportation system. Dedicated left and right-turn lanes are helpful in promoting safety and improved traffic flow in situations where traffic volumes and speeds are relatively high and conflicts are likely to develop between through and turning traffic at public road intersections and driveways. On rural two-lane highways, the addition of truck climbing lanes and/or passing lanes can enhance the safety and efficiency of the highway by increasing opportunities to pass slower moving traffic.
- (2) The AASHTO *Green Book* contains most of the criteria necessary to justify and design auxiliary lanes. This chapter establishes WYDOT's warranting criteria for the construction of the various auxiliary lanes. A section is also included in this chapter to assist with the review of Traffic Impact Studies submitted in accordance with the WYDOT Access Manual.

18.2 AUXILIARY LEFT-TURN LANES

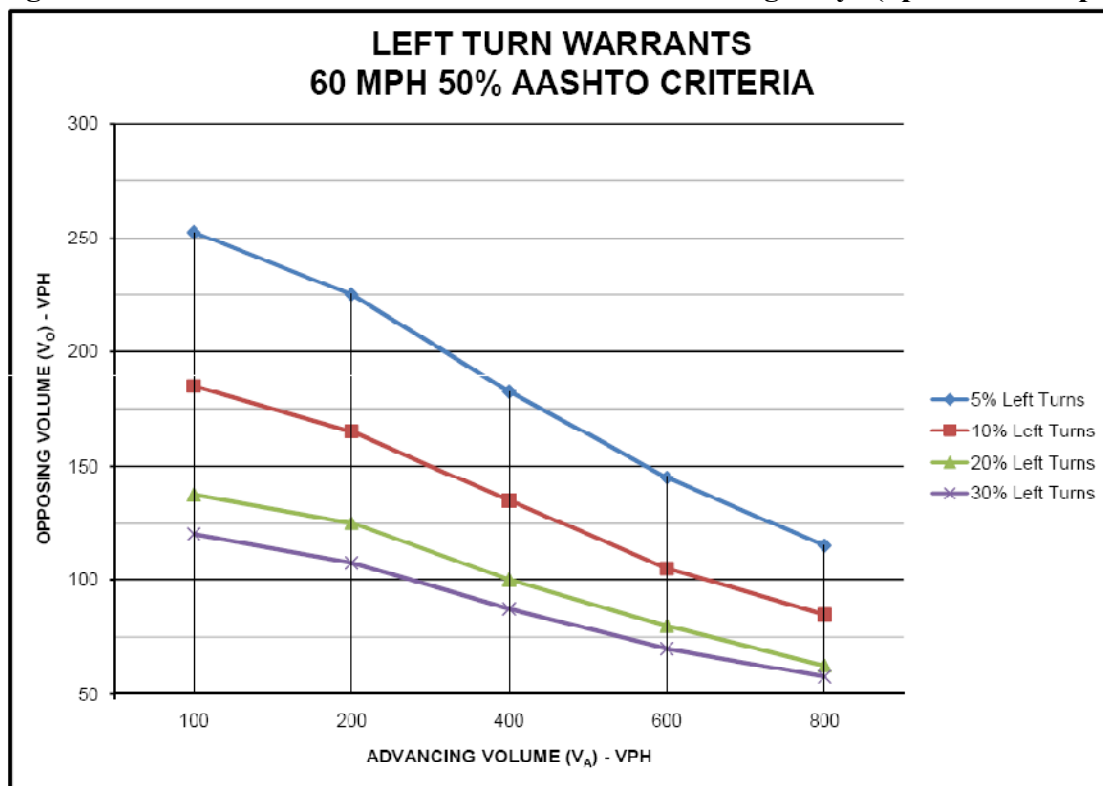
- (1) Left-turn lanes, installed in the center of the roadway, are intended to remove left-turning vehicles from the through traffic flow. This reduces the frequency of rear-end collisions at locations where there is significant left-turn ingress activity, such as major driveways and public road intersections. The use and design of auxiliary left-turn lanes should be based on a traffic study. In general, auxiliary left-turn lanes must be long enough to accommodate a safe deceleration distance and provide adequate storage for an expected peak hour turning traffic queue.
- (2) The following data are required to determine if an auxiliary left-turn lane is warranted:
 - (a) Opposing Volume (vph) - V_O - The opposing volume includes only the right-turn and through movements in the opposite direction of the left-turning vehicle.
 - (b) Advancing Volume (vph) - V_A - The advancing volume includes the right-turn, left-turn and through movements in the same direction as the left-turning vehicle.
 - (c) Operating Speed (mph) - The anticipated posted speed limit.
 - (d) Percentage of left turns in V_A .

18.2.1 RURAL GUIDELINES

- (1) WYDOT uses 50% of AASHTO's advancing volume criteria for left-turn lane warrants on rural two-lane highways. These criteria are dependent on the volumes of traffic entering the intersection during the peak hour and the approach speed on the approach opposing the left-turn movement, and are shown in Figure 18-1. To use the figure, peak hour traffic counts including directional splits, will be required (see Chapter 4). In addition, the ITE *Trip Generation Manual* may be used as an estimate for peak hour traffic counts when new or modified development is involved. The Planning Program can provide necessary growth rates for design year analysis.
- (2) The appropriate trend line is identified on the basis of the percentage of left turns in the advancing volume, rounded up to the nearest percentage trend line. If the advancing and opposing volume combination intersects above or to the right of this trend line, a left-turn lane can be considered appropriate. Since the construction of auxiliary left-turn lanes requires pavement marking that effectively eliminate passing opportunities for a substantial distance, constructing auxiliary left-turn lanes for volumes that do not meet the 50% AASHTO criteria should be avoided unless a crash problem has been identified at that location.

- (3) Left-turn lanes are typically not needed for left-turn volumes of less than 10 vph. However, criteria other than volume, such as crash experience, may be used to justify a left-turn lane.

Figure 18-1 Guide for Left-Turn Lanes on Two-Lane Highways (Speeds ≥ 60 mph)



18.2.2 URBAN AND FRINGE AREA GUIDELINES

- (1) In urban and rural/urban fringe areas, using the 50% AASHTO left-turn lane criteria for lower speed two-lane highways can be used to justify the construction of left-turn lanes. These criteria are shown in Figures 18-2 and 18-3. The appropriate figure to use is based on the posted speed limit on the highway at the study location. The appropriate trend line is identified on the basis of the percentage of left turns in the advancing volume, rounded up to the nearest percentage trend line. If the advancing and opposing volume combination intersects above or to the right of this trend line, a left-turn lane can be considered appropriate.
- (2) Other factors to consider when determining the need for left-turn lanes in urban and fringe areas include:
 - (a) Traffic volumes below the respective trend line on the appropriate left-turn lane guidelines figure can be used to justify a left-turn lane if the opposing through volume is very high, if the presence of left-turning vehicles would not be expected, or if a crash problem associated with left-turning traffic exists.
 - (b) Left-turn lanes should be considered for all approaches to signalized intersections that have 10 or more left turns per hour.
- (3) Left-turn lanes should be considered on the minor leg approaches to signalized intersections in order to minimize delays to the higher volume major street traffic.

Figure 18-2 Guide for Left-Turn Lanes on Two-Lane Highways (Speeds of 45 – 55 mph)

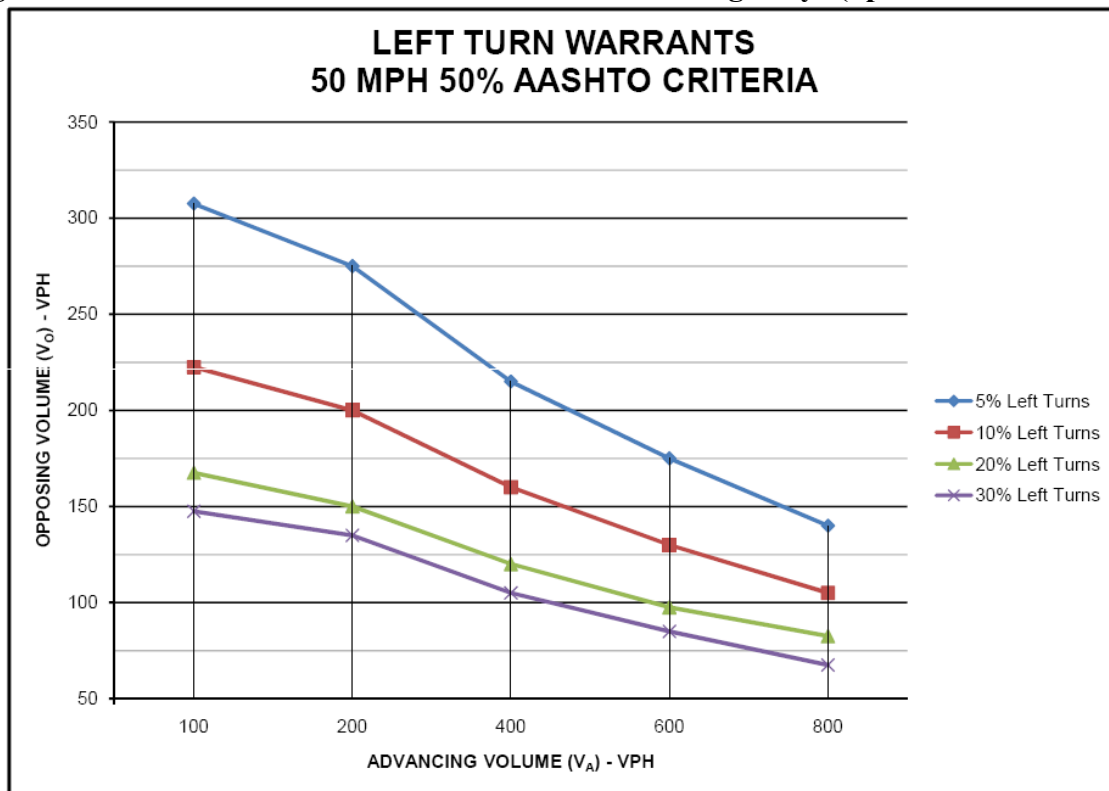
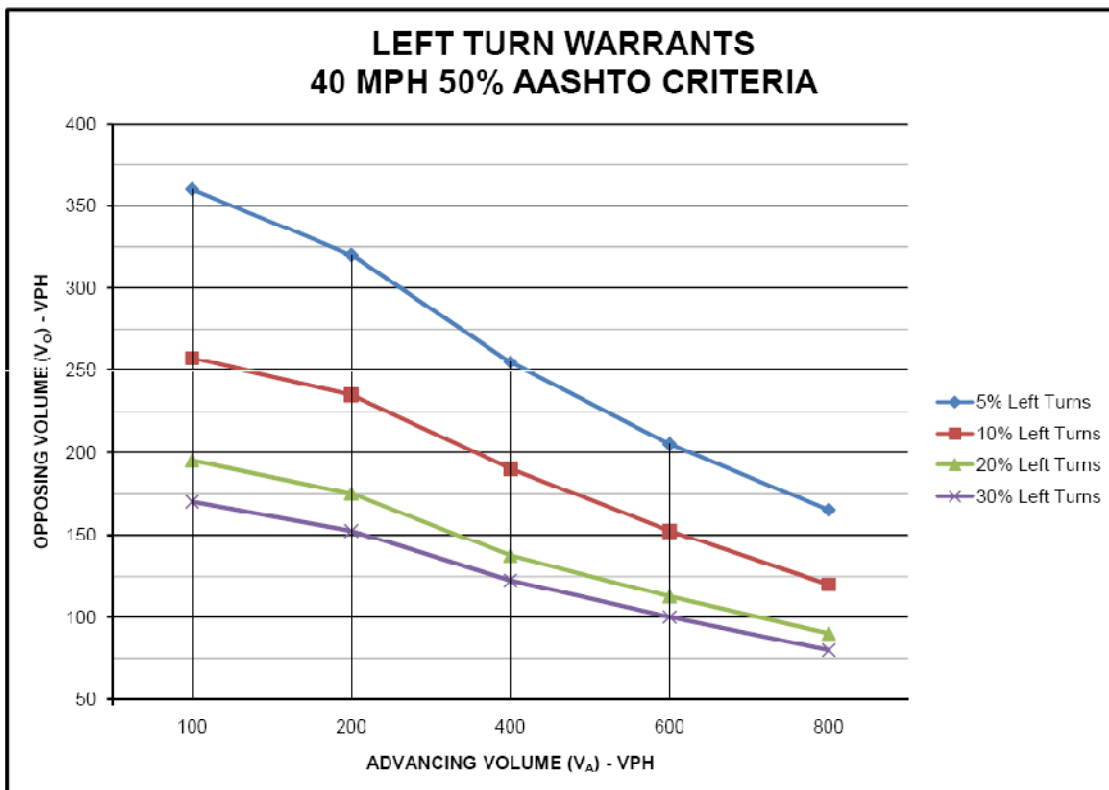


Figure 18-3 Guide for Left-Turn Lanes on Two-Lane Highways (Speeds ≤ 40 mph)



18.3 AUXILIARY RIGHT-TURN LANES

- (1) The use of and design of dedicated right-turn lanes should also be based on a traffic study. In general, dedicated right-turn lanes should be provided in both rural and urban areas on two-lane routes as shown in Figure 18-4. Figure 18-5 should be used to determine right-turn lane warrants on four-lane routes. To use the figures, peak hour traffic counts including directional splits, will be required (see Chapter 4). In addition, the *ITE Trip Generation Manual* may be used as an estimate for peak hour traffic counts when new or modified development is involved. The Planning Program can provide necessary growth rates for design year analyses.
- (2) The following data are required to determine if an auxiliary right-turn lane is warranted:
 - (a) Advancing Volume (vph) - The advancing volume includes the right-turn, left-turn and through movements in the same direction as the right-turning vehicle.
 - (b) Right Turning Volume (vph) - The right-turning volume is the number of advancing vehicles turning right.
 - (c) Operating Speed (mph) - The anticipated posted speed limit.
- (3) If the combination of major road approach volume and right-turn volume intersects above or to the right of the speed trend line corresponding to the major road operating speed, then a right-turn lane can be considered appropriate.

Figure 18-4 Right Turn Lane Guidelines for Two-Lane Highways

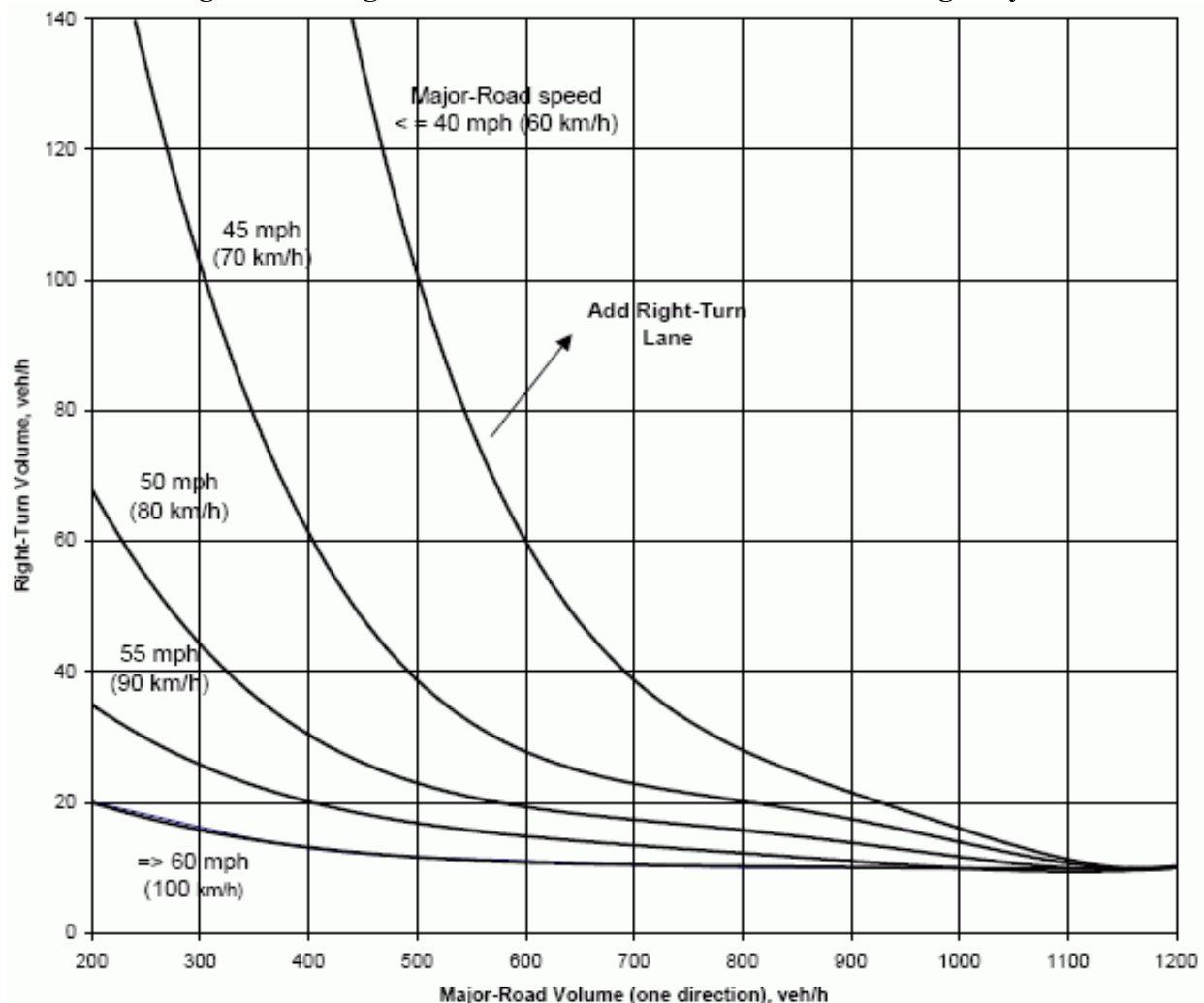
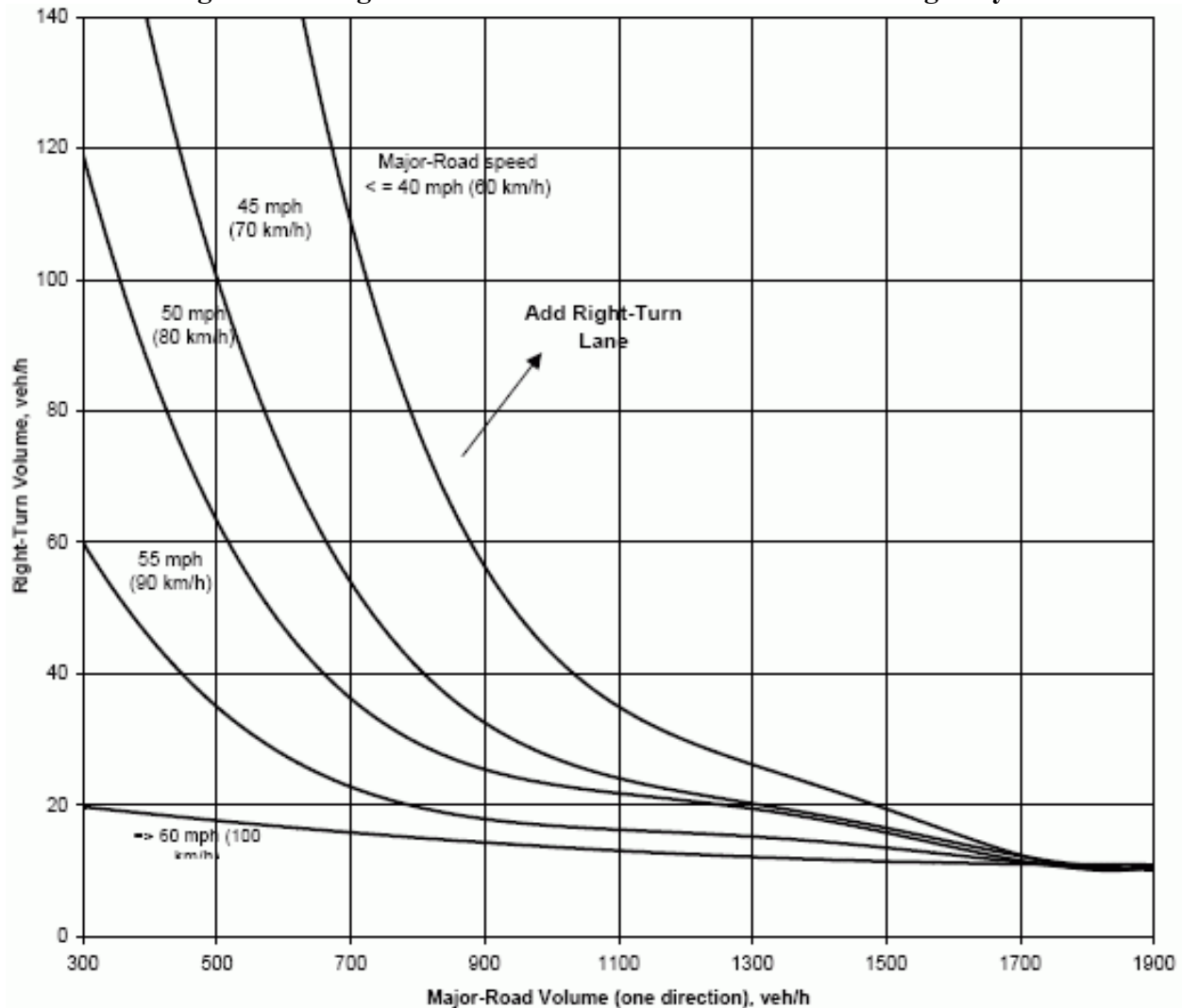


Figure 18-5 Right Turn Lane Guidelines for Four-Lane Highways



Note: A right-turn lane is typically not warranted for right-turn volumes of less than 10 vph. However, criteria other than volume, such as crash experience, may be used to justify a right-turn lane.

- (4) Dedicated right-turn lanes should also be strongly considered in situations where:
- (a) Poor internal site design and circulation leads to backups onto the mainline. Auto-oriented businesses with short drive-through lanes or poorly designed parking lots would be prime examples of this situation.
 - (b) The peak hour turning traffic activity is unusually high (e.g., greater than 10 percent of the daily total).
 - (c) Operating speeds on the mainline route are high (greater than 60 miles per hour) and drivers would generally not expect right turns.
 - (d) The driveway or minor public road intersection is difficult for drivers to see.
 - (e) The driveway entrance is gated or otherwise must be entered very slowly.
 - (f) Right-turning traffic consists of an unusually high number of trailers or other large vehicles.

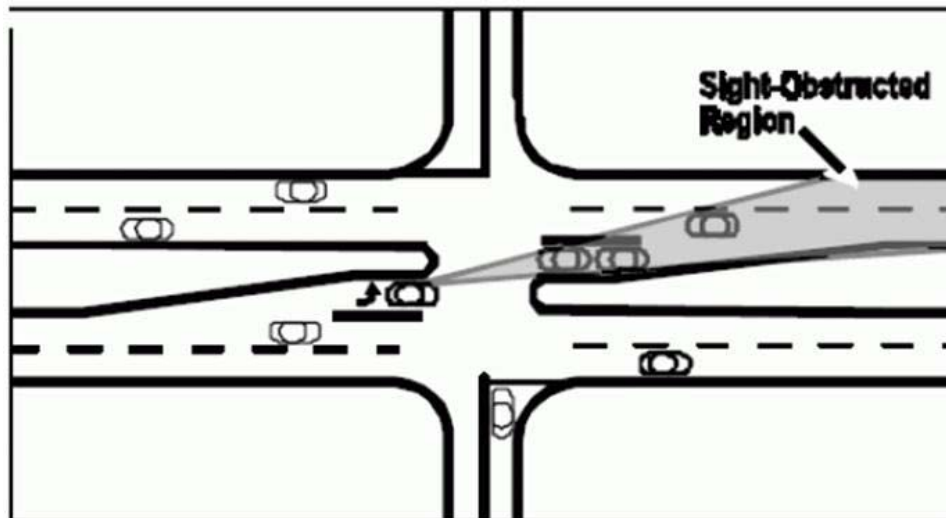
- (g) A parallel railroad track is sufficiently close to the intersection to cause right-turning traffic to queue back onto the through lane(s) of the highway when trains are using the crossing.
- (h) The intersection or driveway angle is highly skewed, requiring a turn of more than 110 degrees.
- (i) Rear end collision experience is unusually high at the location.

18.4 OFFSET RIGHT- AND LEFT-TURN LANES

Vehicles in the right-turn lane can tend to obstruct the vision of drivers waiting at the stop bar of the minor roadway. One way to reduce the obstruction of the minor roadway drivers' view is to offset the right-hand turning bay to the right. Offsetting right-turn lanes to the right gives drivers on the minor approach (at the stop bar) an unobstructed view of oncoming through traffic in the near lanes, which allows for more effective use of gaps. Similarly, vehicles in the opposing left-turn lane can block the views of left-turning vehicles from the opposite direction, as shown in Figure 18-6. Offsetting left-turn lanes to the left as far as practical improves the visibility of opposing traffic. Examples of positively offset left-turn lanes are shown in Figure 18-7. By improving the visibility of opposing traffic, drivers can more effectively use available gaps.

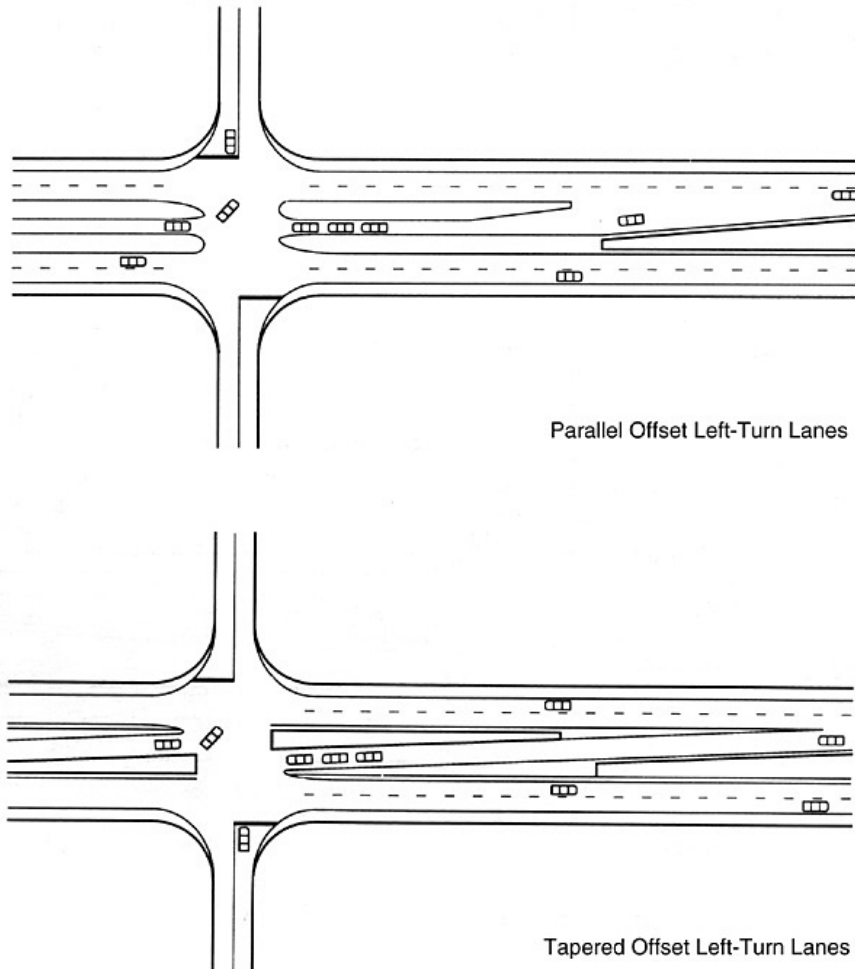
Consideration should be given to offset right- and left-turn lanes in locations with higher mainline operating speeds, large percentage of turning trucks, unique sight distance issues or crash experience where investigation of crash diagrams indicates that a safety benefit may be obtained from an offset turn lane. When implementing offset auxiliary turn lanes, make sure the horizontal geometry of the roadway does not negate the line-of-sight improvement.

Figure 18-6 Example of Negative Offset Left-Turn Lane Sight Obstruction



(Source: Missouri DOT)

Figure 18-7 Examples of Positively Offset Left-Turn Lanes



(Source: AASHTO, 2004)

18.5 AUXILIARY TRUCK CLIMBING LANES

The need for auxiliary truck climbing lanes is typically determined by the Geometrics Engineer in accordance with the AASHTO *Green Book*.

18.6 AUXILIARY PASSING LANES

Auxiliary passing lanes can be used to increase passing opportunities on two-lane highways. Passing lanes are typically applied to a corridor in a systematic approach to provide a passing opportunity at roughly five-minute intervals. The passing lane system can consist of alternating or offset three-lane sections, four- or five-lane sections, or a combination of the various sections, depending on the various features on the corridor.

The addition of auxiliary passing lanes is typically considered whenever traffic volumes exceed 4,000 vehicles per day. Auxiliary passing lanes can also be beneficial on somewhat lower-volume highways where there are very high peak travel periods or high volumes of tourist traffic during the peak tourism months.

The decision as to when and where to place auxiliary passing lanes is based on the engineering judgment of the Geometrics Engineer and/or Studies Engineer with appropriate input from the District personnel and other programs as needed.

18.7 AUXILIARY RIGHT-TURN ACCELERATION LANES

Auxiliary right-turn acceleration lanes allow entering vehicles (those that have turned right from a driveway or minor public road onto the major route) to accelerate before entering the through-traffic flow. Acceleration lanes should be provided where free-flow right-turn lanes are provided from the minor street onto the major street. Acceleration lanes may also be appropriate where crash experience indicates a problem with right-turning, entering vehicles. The right-turn acceleration lane should be sufficiently long to allow safe and efficient merge maneuvers. The design length, tapers and other features of right-turn acceleration lanes shall be determined by the Geometrics Engineer.

18.8 REVIEW OF TRAFFIC IMPACT STUDY REPORTS

The *WYDOT Access Manual* 2005 covers the rules and regulations and policy for accesses to Wyoming State highways. Chapter V of that manual discusses the basic requirements of a Traffic Impact Study (TIS) and when WYDOT requires the completion of a TIS. A Traffic Impact Study Review Checklist has been developed to assist with the review process. Figure 18-8 gives an example of the review checklist.

Figure 18-8 Example Traffic Impact Study Review Checklist

Traffic Impact Study Review Checklist

Town: _____ Reviewed By: _____ Date: _____

Proposed Development: _____

Report Developed By: _____

	OK	NO	COMMENTS
Report contains clear description of proposed project	_____	_____	_____
Identifies project sponsor and contact person	_____	_____	_____
Performed and stamped by WY registered P.E.	_____	_____	_____
Site Plan clearly labeled, showing site location and surrounding streets	_____	_____	_____
Shows all current and proposed streets and accesses	_____	_____	_____
Shows distance between streets/accesses	_____	_____	_____
Includes internal circulation network and any construction phasing	_____	_____	_____
Identifies any changes in adjacent land uses	_____	_____	_____
Includes a water drainage plan	_____	_____	_____
Proposed accesses meet Access Manual minimum spacing	_____	_____	_____
Existing Traffic: ADTs on all affected routes	_____	_____	_____
Design hourly volumes on all routes/intersections	_____	_____	_____
At least 4 peak hrs turning movements at all existing intersections	_____	_____	_____
Existing traffic control, including signal phasing and coordination	_____	_____	_____
Includes traffic generated by previously approved developments	_____	_____	_____
Existing LOS and delay analysis at affected locations is reasonable	_____	_____	_____
Site generated traffic: Projected volumes at full build-out	_____	_____	_____
If phased construction, includes volumes for each phase	_____	_____	_____
Includes an analysis of build-out year and years to build-out	_____	_____	_____
Volumes are per latest ITE Trip Generation	_____	_____	_____
Cites page number, graph, and/or formula from ITE Trip Generation	_____	_____	_____
Generated site traffic distribution is reasonable	_____	_____	_____
Entering and exiting directional splits are reasonable	_____	_____	_____
Includes 95th percentile queue lengths at all internal conflict points	_____	_____	_____
Internal circulation does not cause problems for mainline traffic	_____	_____	_____
Projected future traffic volumes (non-site generated) are reasonable	_____	_____	_____
LOS and delay analysis at affected locations is reasonable	_____	_____	_____
Includes 95th percentile queues at affected intersections	_____	_____	_____
Projected plus site generated traffic volumes are correct	_____	_____	_____
LOS and delay analysis at affected locations is reasonable	_____	_____	_____
Includes 95th percentile queues at affected intersections	_____	_____	_____
Mitigation Measures: Clearly identifies needed improvements	_____	_____	_____
Includes comparison of impacts with and without project	_____	_____	_____
Identifies mitigation costs, responsibilities and timeline	_____	_____	_____
Appendices include traffic data collected, worksheets and methodologies	_____	_____	_____

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