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16. Abstract
This report describes a 15-month project conducted for the Texas Department of Transportation (TxDOT) to evaluate various considerations for inclusion into the traffic signal warranting procedure. Researchers conducted several research tasks including surveys of TxDOT, other state DOTs, and city engineers. Analyses were also conducted to investigate the feasibility of incorporating heavy vehicle factors into the warranting analysis procedure. Other considerations that were addressed include accident severity and exceptions to the warrants similar to the emergency-traffic signal. The project developed guidelines for conducting traffic signal warrant analyses. Adoption of the guidelines by the TxDOT will provide clarification of many interpretations that may be made of the language that makes up the warrants. Additionally, the guidelines will help improve the consistency with which the warrants are used.

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EVALUATION OF POTENTIAL TRAFFIC SIGNAL WARRANT CONSIDERATIONS

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The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of this project was H. Gene Hawkins, Jr., P.E. #61509.

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- Peter Eng, Director of Tyler Transportation Operations, Texas Department of Transportation
- Scott Wainwright, chair of the Signals Technical Committee, National Committee on Uniform Traffic Control Devices

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CHAPTER 1
INTRODUCTION

BACKGROUND

Traffic signals are a highly visible and important element of the roadway transportation network. Traffic signals are often seen by the public and elected officials as a cure-all for operational and safety problems at intersections. At other times, signals are viewed as a hindrance to movement, as exemplified by the commonly used name "stop lights." The reality is that the traffic signal represents one of the most restrictive forms of right-of-way control at an intersection. Traffic signals should not be installed unless the advantages to be gained from the signal will outweigh the disadvantages of the signal.

When the installation of a traffic signal is properly justified, and its design, operation, and maintenance are in accordance with current principles, the signal can have many positive benefits on the efficiency and safety of vehicular and pedestrian traffic at the intersection. The advantages to a properly justified and installed traffic signal may include one or more of the following:

- It can provide for the orderly movement of traffic.
- It can increase the traffic-handling capacity of the intersection if proper physical layouts and control measures are used.
- It can reduce the frequency of certain types of accidents, especially right-angle collisions.
- By coordinating the signal with adjacent signals, it can provide for continuous or nearly continuous movement of traffic at a definite speed along a given route under favorable conditions.
- It can be used to interrupt heavy traffic on the major street to permit vehicular and pedestrian traffic on the minor street to cross.

Even when properly justified and installed, a traffic signal can have a detrimental impact on certain aspects of traffic flow at an intersection. If a signal is properly justified and installed, however, the associated disadvantages are offset by the resulting advantages. The disadvantages that may be associated with a properly justified, designed, and installed traffic signal include:

- It can increase the delay experienced by the major traffic movements.
- It can increase the frequency of certain types of accidents (primarily rear-end accidents).
- It can reduce the freedom of road users to control their own progress.

However, additional disadvantages may result if a traffic signal is not properly justified or if the traffic signal is ill-designed, ineffectively placed, improperly operated, or poorly maintained. The disadvantages that may be associated with an improperly justified or installed traffic signal include:

- It can increase delay for all traffic movements.
- It can lead to an increase in traffic violations at the intersection.
- It can increase the frequency of traffic accidents at the intersection.

- It can cause road users to increase the use of alternative routes to avoid the signal. Often, these alternative routes travel through neighborhoods or other less adequate roads.

Traffic Signal Warrants

In order to ensure that the advantages outweigh the disadvantages, that there is sufficient justification for a traffic signal, and to provide some consistency in the application of traffic signals, a series of warrants has been developed to define the ***minimum*** conditions under which further consideration of a traffic signal is appropriate. Simply meeting the warranting criteria does not mean that a signal is justified at a given location. There are many factors that impact the effectiveness of a signal, and all should be evaluated before a decision to install a signal is made. However, failure to meet any of the warranting criteria indicates that a traffic signal should not be installed, as there should be a better way of addressing the problems or needs at that location. Furthermore, if an existing traffic signal no longer meets any of the warrants, the Texas MUTCD states that it should not continue to operate (1). Table 1 lists the traffic signal warrants currently contained in the Texas MUTCD.

Table 1. Texas MUTCD Traffic Signal Warrants

Number and Title		Basis
1	Minimum Vehicular Volume	8-hour vehicular volume
2	Interruption of Continuous Traffic	8-hour vehicular volume
3	Minimum Pedestrian Volume	4-hour pedestrian volumes and gaps
4	School Crossing	number of school children and gaps
5	Progressive Movement	signal progression
6	Accident Experience	accidents and warrant #1, #2, or #3 volumes
7	Systems Warrant	vehicular volume
8	Combination of Warrants	vehicular volumes and pedestrians
9	Four Hour Volume	4-hour vehicular volume
10	Peak Hour Delay	vehicular volume and delay on minor street
11	Peak Hour Volume	1-hour vehicular volume
12	Warrant Volumes for Traffic Actuated Signals	2- or 8-hour vehicular volume

The first eleven warrants listed in Table 1 are the same as those in the national MUTCD (2) published by the Federal Highway Administration (FHWA). The twelfth warrant was added to the Texas MUTCD but does not appear in the national MUTCD. The warrants contained in the national

and Texas MUTCDs have evolved over many years. For instance, Warrants 1 and 2, which are used to warrant the majority of traffic signals, have been in the Texas MUTCD since the first edition in 1954. As such, these warrants have withstood the test of time and have been found, on the basis of experience, to be appropriate guidelines for establishing minimum warranting criteria. Unfortunately, there is a significant lack of information in the literature that supports the basis for some of the warrants.

Accidents and Warrants

One of the warrants for which the value is often questioned is Warrant 6, the Accident Experience Warrant. The public believes that the occurrence of traffic accidents will disappear when a traffic signal is installed at an intersection. This belief was studied, and according to Box and Alroth (3), they could not produce a correlation between the safety impacts of traffic signals and accidents. However, other sources such as the Institute of Transportation Engineers (ITE) cite in their *Transportation and Traffic Engineering Handbook* that traffic signals can be expected to reduce the total occurrence of traffic accidents by 18 percent (4). This is not surprising because of the complexities involved in comparing different intersections' characteristics and their effect on traffic safety. Although the literature at this point in time may not be able to define the exact safety benefits associated with traffic signals, one thing has been proven—the severity of injuries that result from accidents at intersections typically decrease with the installation of traffic signals. Before an intersection is signalized, right-angle accidents are very common. After the signal installation, rear-end accidents tend to become the more common type of accident. Generally, rear-end accidents result in less severe injuries for two reasons: 1) the vehicles are traveling in the same direction, and 2) there is more distance between the driver and the point of impact and more material in the rear-end of the vehicle to absorb the energy of the crash.

The National Cooperative Highway Research Program (NCHRP), funded through the Transportation Research Board, has recognized the lack of basis for the accident warrant and has funded a research project to evaluate it. NCHRP Project 17-16, *Accident Warrant for Traffic Signals*, is a 25-month study that began in the spring of 1997. In addition to accident frequency, the project is to address accident severity and safety impacts of signal removal. The objectives of the project are to develop an improved accident warrant for traffic signals and to provide a model(s) to estimate the safety impacts of installing or removing traffic signals.

The research to be addressed in this TxDOT project has, as its origin, a fatal accident involving a school bus and another vehicle. As a result of this accident, an official has requested that TxDOT consider the inclusion of school buses and fatal accidents in the warranting process. At the present time, neither of these issues is directly addressed in the current warrants for signals. In fact, previous research has not concentrated on the consideration of school buses and/or heavy vehicles. However, accident severity has been researched, although not recently.

Project Goals

After a kick-off meeting between the Project Director, the Project Advisors, and the research team, several key decisions were made that modified the original direction of this project. It was decided that school bus issues should be expanded to include all heavy vehicles rather than

exclusively focusing on school buses. Furthermore, because of the similarity of the NCHRP project discussed above and its larger funding and longer time period allocations, the priority of the accident severity issue was lessened. However, an agreement was made that included coordination of efforts with the NCHRP research team and efforts included herein. Furthermore, because of the decreased effort dedicated to accident severity considerations, the research team has developed an additional document that is intended to provide for consistency in signal warranting activities throughout the state. The research team was also asked to determine the concerns of other signal warranting jurisdictions in regards to emergency signals. Specifically, the task involved identifying concerns about emergency signal installations at locations not clearly defined in the MUTCD.

RESEARCH OBJECTIVES

The research objectives for this project are:

1. To determine if, and possibly how, heavy vehicle considerations can be incorporated into existing traffic signal warrants or as part of a new warrant.
2. To coordinate research efforts with the NCHRP Project 17-16 research team with respect to accident severity issues, to provide an initial assessment of accident severity issues, and to provide an update to Project 17-16 at the termination of this project.
3. To identify concerns about emergency signal installations at locations not clearly defined in the MUTCD.
4. To develop an additional document that will be used by engineers throughout the Department to provide more consistency in the warranting analysis procedures.

ORGANIZATION OF REPORT

This report details the findings from the research conducted pertaining to the stated objectives. It is divided into the following eight chapters and 3 appendices:

- Chapter 1 contains background information on traffic signal warrants and defines the research objectives for this project.
- Chapter 2 provides an overview of the evolution of traffic signal warrants.
- Chapter 3 presents a review of literature pertaining to heavy vehicle and accident severity considerations in regard to inclusion into the warranting procedures.
- Chapter 4 summarizes the results of the surveys constructed as part of this research.
- Chapter 5 presents the analyses used to determine the feasibility of incorporating heavy vehicle considerations into the warranting procedures.
- Chapter 6 discusses the current status of NCHRP Project 17-16, *Accident Warrant for Traffic Signals*.
- Chapter 7 presents the conclusions and recommendations.

- Chapter 8 presents the implementable results of this research project.
- Appendix A contains the survey instrument used to acquire the national perspectives on heavy vehicle and accident severity considerations. It also summarizes the responses received.
- Appendix B contains a listing of the current warrants in the Texas MUTCD.
- Appendix C contains a listing of the proposed warrants for the next edition of the MUTCD.

WARRANT ANALYSIS GUIDELINES

Two products were produced from this project – a final report and a traffic signal warranting guideline (5). The guidelines were developed to assist transportation officials in conducting a signal warrant analysis. Specifically, this second document discusses the philosophy of the warranting methodology, the warrants themselves, official and unofficial interpretations of the language that make up the warrants, and provides examples of warranting procedures.

CHAPTER 2
TRAFFIC SIGNAL WARRANTS

EVOLUTION OF TRAFFIC SIGNAL WARRANTS

The evolution of traffic signal warrants parallels the evolution of the MUTCD. Each new edition of the MUTCD coincided with slight to moderate changes in the traffic signal warrants. Therefore, it is necessary to have a basic understanding of the various editions of the MUTCD and the related revisions to conduct research related to the traffic signal criteria. Table 2 identifies the editions of the national MUTCDs and the revisions of each edition. More detailed information about the evolution of the MUTCD can be found in other publications (6-8).

Table 2. Evolution of the National MUTCD

Year	Name	Month/Year Revised
1927	Manual and Specifications for the Manufacture, Display, and Erection of U.S. Standard Road Markers and Signs [1]	4/29, 12/31
1930	Manual on Street Traffic Signs, Signals, and Markings [2]	No revisions
1935	Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) [3]	2/39
1942	MUTCD - War Emergency Edition	No revisions
1948	MUTCD	9/54
1961	MUTCD	No revisions
1971	MUTCD	11/71, 4/72, 3/73, 10/73, 6/74, 6/75, 9/76, 12/77
1978	MUTCD	12/79, 12/83, 9/84, 3/86
1988	MUTCD	1/90, 3/92, 9/93

[1] Rural sign manual published by the American Association of State Highway Officials.
[2] Urban traffic control device manual published by the National Conference on Street and Highway Safety.
[3] First edition of the MUTCD.

The Texas MUTCD is based on the national MUTCD. The first Texas MUTCD was published in 1954 and was based on the 1948 national MUTCD. Subsequent editions were published in 1967, 1973, and 1980, and were based on the 1961, 1971, and 1978 MUTCD, respectively. Each edition of the Texas MUTCD has been revised multiple times. The revisions to the 1980 Texas MUTCD reflect the changes to the 1988 national MUTCD and its revisions.

The part of the Manual dealing with traffic signals has been included in every edition of the Manual. From the very first edition in 1935, traffic signal warrants have been included in the signals part. Table 3 summarizes when each of the twelve warrants in the current Texas MUTCD was added to the MUTCD.

One of the interesting aspects of the MUTCD signal warrants is that there were separate warrants for fixed time and actuated signals in the 1935, 1948, and 1961 editions of the national MUTCD. It was not until 1971 that the fixed and actuated warrants were permanently combined into a single set of warrants.

Table 3. Evolution of Texas MUTCD Traffic Signal Warrants

Number and Title		Basis	Year Added[1]	
			National	Texas
1	Minimum Vehicular Volume	8-hour volumes	1935	1954
2	Interruption of Continuous Traffic	8-hour volumes	1935	1954
3	Minimum Pedestrian Volume	4-hour pedestrian volumes and gaps	1935	1954
4	School Crossing	number of school children and gaps	1971	1967
5	Progressive Movement	signal progression	1935	1954
6	Accident Experience	accidents and warrant 1, 2, or 3 volumes	1935	1954
7	Systems Warrant	volumes	1971	1973
8	Combination of Warrants	volumes and pedestrians	1935	1954
9	Four Hour Volume	4-hour volume	1978	1973
10	Peak Hour Delay	volume and delay on minor street	1978	1980
11	Peak Hour Volume	1-hour volume	1978	1973
12	Warrant Volumes for Traffic Actuated Signals	2- or 8-hour volumes	n/a	1973

[1] Year added to the national or Texas MUTCDs. Warranting values may have changed since original introduction. Year indicates first edition warrant appeared.

The following paragraphs highlight the history of traffic signal warrants through the various editions of the MUTCD. These descriptions are intended only to provide a sense of how the current warrants have evolved. This information does not include all aspects of the warrant criteria in the seven editions of the national MUTCD.

Warrants in the 1935 National MUTCD

The 1935 MUTCD (9) contained the warrants and warranting conditions listed in Table 4. These warrants were specifically intended for fixed-time traffic signals. The sections that contained these provisions also provided additional guidance relative to the use of signals in the described situations. The Manual contained separate warrants for actuated traffic signals. These actuated warrants generally stated that "The [warrant criterion] is a sound general minimum for either fixed-time or traffic-actuated signalization. If a signal is installed for lesser volumes, traffic-actuated control should be used." Exceptions to this generalization were provided for the Progressive Movement Warrant and the Through Highway Warrant. The 1935 MUTCD was revised in 1939. This revision included minor changes to a few of the signal warrants (10).

One of the insightful statements in the combination warrant is, "These exceptional cases should be decided on the basis of thorough analysis of facts – never on the basis of petitions or complaints." The accident warrant contained another interesting aspect that is not part of the modern warrants. It listed the types of accidents that could be expected to be reduced by a signal and those that could not. This information is listed below.

- A signal, when obeyed, can be expected to eliminate or reduce materially the number and seriousness of the following types of accidents:
  - Those involving collisions between vehicles on intersecting streets which will move on separate GO intervals.
  - Those involving pedestrians and vehicles which will move during different GO intervals – PROVIDED PEDESTRIANS OBEY THE SIGNALS.
  - Those between straight-moving and left-turning vehicles where these are to move on separate GO intervals.
  - Those involving excessive speed in cases where coordination restricts speed to a reasonable rate.
- On the other hand, signals cannot be expected to reduce the following types of accidents:
  - Rear-end collisions, which often increase after signalization.
  - Collisions between vehicles proceeding in the same or opposite directions, one of which makes a turn across the path of the other.
  - Accidents involving pedestrians and turning vehicles, both moving on the same GO interval.
  - Other types of pedestrian accidents, IF PEDESTRIANS DO NOT OBEY THE SIGNALS.

Table 4. Fixed-Time Traffic Signal Warrants from the 1935 National MUTCD

Warrant	Warranting Conditions
Minimum Vehicular Volume	The minimum vehicular volume ... is as follows for the usual intersection: 1. Total vehicular volume entering the intersection from all directions must average at least 1,000 vph for 8 hours, and 2. Total vehicular volume entering the intersection from the minor street must average at least 250 vph for 8 hours and must be a sufficient percentage of the total from all directions to require the GO indication for at least 25 percent of the time.
Heavy Left Turn	The minimum left turning volume and volumes of other traffic ... are as follows: 1. Total vehicular volume entering the intersection from all directions must average at least 1,000 vph for 8 hours, and 2. Vehicular volume making a left turn from one or more directions during a GO interval must involve at least an average of 5 vehicles per minute for the heaviest traffic hour and cross through an opposing stream of at least equal volume.
Minimum Pedestrian Volume	The minimum pedestrian and vehicular volumes ... are as follows: 1. Pedestrian volume crossing the major street must average at least 300 persons per hour for at least 6 hours per day. 2. Vehicular traffic entering the intersection from the major street must average at least 750 vph for the same 6 hours, and 3. Vehicular speeds during the 6 hours must frequently exceed 15 mph.
Coordinated Movement	A fixed-time traffic control signal which would not be justified under any of the preceding warrants may be warranted as part of a coordinated signal system if a majority of the signalized intersections composing the system comply with one or more of them, and if the proposed signal installation is necessary to maintain compact group movement or desired group speed.
Through Highway	A fixed-time traffic control signal which would not be justified under the preceding warrants may be warranted: 1. At an intersection on a through highway where the vehicular volume is so nearly continuous that pedestrians and vehicles on the cross street frequently cannot find safe and convenient opportunities to enter or cross the through highway after reasonable waiting periods; or 2. As part of a speed controlling, coordinated signal system along a through highway on which speeds are so high that pedestrians and vehicles at cross streets have the same difficulty.
Accident Hazard	A fixed-time traffic control signal which would not be justified under any of the preceding warrants may be justified where: 1. Five or more reported accidents of types susceptible to correction by a traffic control signal have occurred within a 12-month period, each accident involving personal injury or property damage to an apparent extent of $50 or more; and 2. Adequate trial of less restrictive remedies with satisfactory observerance and enforcement has failed to reduce the accident toll.
Combination of Warrants	Signals may occasionally be justified where no one warrant is satisfied but two or more are nearly satisfied, particularly if there are present other factors, such as: 1. A sudden change from rural conditions, where relatively high speeds are safe, to those of an urban business district; 2. Extreme width of roadway which pedestrians must cross; 3. Predominance of especially handicapped pedestrians, such as small children, blind, aged, or crippled adults, who need to cross the roadway; 4. Points where large numbers of pedestrians must cross a fast-moving stream of vehicles; or 5. An intersection on or at the bottom of a long or steep grade.

Warrants in the 1942 National MUTCD

A new edition of the MUTCD was issued at the beginning of World War II to address special wartime traffic control situations (11). There were a few minor changes to the signal warrants in the 1942 edition. All of the warrants eliminated reference to fixed-time signals. The most significant of these changes include:

- **Heavy Left Turn Warrant** - The average number of vehicles was changed from 5/minute to 300/hour.
- **Minimum Pedestrian Volume Warrant** - The speed criteria (3) was eliminated.
- **Through Highway Warrant** - The title was changed to "Interruption of Through Highway Traffic Warrant." The speed provisions of the second criteria (2) were incorporated into the first criteria (1).
- **Accident Hazard Warrant** - The criteria for adequate trial of less restrictive measures was eliminated.
- **Combination of Warrants** - Military vehicles were added to the list of criteria.

Warrants in the 1948 National MUTCD

The 1948 MUTCD was significantly different from its predecessor (12). The content in this edition was reorganized, and much of it was rewritten. This applied to the warrant material as well. The 1948 MUTCD contains six warrants. These warrants are described in Tables 5 and 6.

Table 5. Fixed-Time Warrants from the 1948 MUTCD

Warrant	Criteria
Minimum Vehicular Volume	In urban areas: 1. Total vehicular volume entering the intersection from all approaches must average at least 750 vph for any 8 hours of an average day, and 2. Total vehicular volume entering the intersection from the minor street or streets must average at least 175 vph for the same 8 hours. In rural areas: 1. Total vehicular volume entering the intersection from all approaches must average at least 500 vph for any 8 hours of an average day, and 2. Total vehicular volume entering the intersection from the minor street or streets must average at least 125 vph for the same 8 hours.
Interruption of Continuous Traffic	In urban areas: 1. At an intersection on an important street, the vehicle volume along that principal street must average at least 750 vph for any 8 hours of an average day; 2. The combined vehicle and pedestrian volume from the side street or streets must average at least 75 units per hour for the same 8 hours; and 3. The average vehicle speed must exceed 20 mph on the principal street approaches to the intersection. In rural areas: 1. At an intersection on an important street, the vehicle volume along that principal street must average at least 500 vph for any 8 hours of an average day; 2. The combined vehicle and pedestrian volume from the side street or streets must average at least 50 units per hour for the same 8 hours; and 3. The average vehicle speed must exceed 35 mph on the principal street approaches to the intersection. In addition to the above-described conditions, there are similar instances where traffic signals can provide a genuine service over a somewhat shorter period of time. For this special purpose, there are presented below a series of additional warrants, any one of which may justify signal installation: In urban areas: 1. Vehicular volume on the major thoroughfare past an establishment of the type mentioned above exceeds 800 cars per hour at the approximate time of the major movement of traffic to and from the establishment, and traffic to or from the establishment roadway during the same period of time meets one of the following warrants: (a) A minimum of 300 cars per hour, or (b) A minimum of 200 pedestrians crossing per hour, or (c) A minimum of 200 cars and 100 pedestrians crossing per hour. 2. Left turns into or from the establishment roadway exceed 30 percent of the 800 cars per hour past the establishment. 3. Four lanes of traffic moving past the establishment exceed an average speed of 40 mph during major movement of traffic. 4. A sharp vertical or horizontal curve or view obstruction exists near the entrance or exit of the establishment, one or a combination of which creates a serious accident hazard. In rural areas: Warrants for establishments located in rural areas are 50 percent of the foregoing traffic volumes for major thoroughfare and establishment entrance or exit.
Warrants continued in Table 6.	

Table 6. Fixed-Time and Actuated Warrants from the 1948 MUTCD

Warrants	Criteria
Minimum Pedestrian Volume	In urban areas: 1. Pedestrian volume crossing the major street must average at least 250 persons per hour for any 8 hours of an average day; and 2. Vehicular traffic entering from the major street must average at least 600 vph for the same 8 hours; and 3. The average vehicle speed must exceed 15 mph on the approaches to the intersection. In rural areas: 1. Pedestrian volume crossing the major street must average at least 125 persons per hour for any 8 hours of an average day; and 2. Vehicular traffic entering from the major street must average at least 300 vph for the same 8 hours; and 3. The average vehicle speed must exceed 30 mph on the approaches to the intersection.
Coordinated Movement	A fixed-time signal may be warranted as part of a coordinated signal system if a majority of the signalized intersections composing the system comply with one or more of the established warrants and if the proposed signal installation is necessary to maintain compact group movement or desired group speed. In general, additional signals for coordinated movement are not warranted if the distance between signalized intersections is already less than 1,200 feet.
Accident Hazard	If none of the warrants except the accident-hazard warrant is fulfilled, the initial presumption should be against signalization. In general, however, a fixed-time signal may be considered warranted only where: 1. Adequate trial of less restrictive remedies with satisfactory observance and enforcement has failed to reduce the accident frequency; and 2. Five or more reported accidents of types susceptible of correction by a traffic control signal have occurred within a 12-month period, each accident involving personal injury or property damage to an apparent extent of $25 or more; and 3. There exists a volume of vehicular and pedestrian traffic not less than 50 percent of the requirements specified in the minimum vehicular volume warrant, the interruption of continuous traffic warrant, or the minimum pedestrian warrant.
Combination of Warrants	Fixed-time signals may occasionally be justified where no one warrant is satisfied but two or more are satisfied to the extent of 80 percent or more of the stated values, particularly if there are present other important factors, such as: 1. A sudden change from rural conditions, where relatively high speeds are safe, to those of an urban business district; 2. Extreme width of roadway which pedestrians must cross; 3. Predominance of especially handicapped pedestrians, such as small children, blind, aged, or crippled adults, who need to cross the roadway; or 4. An intersection on or at the bottom of a long or steep grade.
Traffic Actuated Intersection Signal Control	Because traffic-actuated signals at intersections do not normally delay traffic except when it needs to be delayed to avoid conflict with traffic on cross streets, it is not advisable to set values of minimum traffic volumes or other fixed warrants for their installation.

Warrants in the 1961 National MUTCD

The 1961 national MUTCD is the first MUTCD of the modern era (13). Much of the language contained in the 1961 MUTCD is the same as in the current MUTCD. This applies to many of the warrants as well. The 1961 MUTCD contained the same general warrant categories contained in the 1948 MUTCD, although some of the titles and the warrants themselves were changed. These six warrants are described below.

- **Minimum Vehicular Volume** - This warrant is the same as in the 1988 MUTCD, including the provision to reduce volumes to 70 percent for isolated intersections or high speeds.
- **Interruption of Continuous Traffic** - This warrant is the same as in the 1988 MUTCD, including the provision to reduce volumes to 70 percent for isolated intersections or high speeds.
- **Minimum Pedestrian Volume** - See Table 7 for this warrant.
- **Progressive Movement** - See Table 7 for this warrant.
- **Accident Experience** - The accident experience warrant is the same as that in the 1948 MUTCD, with three changes:
  - The minimum damage amount was increased from $25 to $100,
  - The percentage of other warrant criteria was increased from 50 to 80 percent, and
  - A fourth criterion was added. This criterion stated, "The signal installation will not seriously disrupt progressive traffic flow."
- **Combination of Warrants** - See Table 7 for this warrant.

As with previous editions, the 1961 national MUTCD treated warrants for traffic-actuated signals separately from the warrants for fixed-time signals. The actuated warrant is also included in Table 7.

Table 7. Selected Signals Warrants from the 1961 MUTCD

Warrants	Criteria
Minimum Pedestrian Volume	This warrant is satisfied when for each of any 8 hours of an average day, the following volumes exist: 1. On the major street, 600 or more vph enter the intersection (total of both approaches); or 1,000 or more vph (total of both approaches) enter the intersection on the major street where there is a raised median island 4 feet or more in width; and 2. During the same 8 hours as in paragraph 1, there are 150 or more pedestrians per hour on the highest volume crosswalk crossing the major street. When the 85th percentile of major street traffic exceeds 40 mph, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the minimum pedestrian volume warrant is 70 percent of the requirements above, in recognition of the differences in the nature and operational characteristics of traffic in urban and rural environments and smaller municipalities.
Progressive Movement	The progressive movement warrant is satisfied when: 1. On an isolated one-way street or on a street which preponderantly has unidirectional traffic significance, adjacent signals are so far apart that the desired degree of platooning and speed control of vehicles would otherwise be lost. 2. On a two-way street, adjacent signals do not provide the desired degree of platooning and speed control; and the proposed and adjacent signals can constitute a progressive signal system.
Combination of Warrants	Signals may occasionally be justified where no one warrant is satisfied, but two or more are satisfied to the extent of 80 percent or more of the stated values. These exceptional cases should be decided on the basis of a thorough analysis of facts. Adequate trial of other remedial measures which cause less delay and inconvenience to traffic should precede installation of signals under this warrant.
Warrants for Actuated Intersection Control	Because traffic-actuated signals at intersections are responsive to rapid fluctuations in traffic conditions and do not normally delay traffic unnecessarily, it is not advisable to set values of minimum traffic volumes or other fixed warrants for their installation.

Warrants in the 1971 National MUTCD

There have not been any major rewrites of the MUTCD since the 1971 edition of the MUTCD was introduced (14). Therefore, the 1971 MUTCD can be considered as an early version of the 1988 MUTCD. The 1971 MUTCD contained eight signal warrants and eliminated the distinction between warrants for fixed-time and actuated signals. Two new warrants were added, the School Crossing Warrant and the Systems Warrant. Table 8 summarizes the warrants from the 1971 MUTCD that are essentially the same as the 1961 MUTCD. Table 9 summarizes the criteria for the two new warrants.

Table 8. Warrants in the 1971 MUTCD that are the Same as in the 1961 MUTCD

Warrant	Criteria
Minimum Vehicular Volume	Same as the 1961 MUTCD (also same as current warrant).
Interruption of Continuous Traffic	Same as the 1961 MUTCD (also same as current warrant).
Minimum Pedestrian Volume	Same as the 1961 MUTCD.
Progressive	Essentially the same as the 1961 MUTCD, with the following additions: The installation of a signal according to this warrant should be based on the 85th percentile speed unless an engineering study indicates that another speed is more desirable. The installation of a signal according to this warrant should not be considered where the resultant signal spacing would be less than 1,000 feet.
Accident Experience	Same as the 1961 MUTCD (also same as current warrant).
Combination of Warrants	Same as the 1961 MUTCD (also same as current warrant).

Table 9. New Warrants in the 1971 MUTCD

Warrant	Criteria
School Crossing	A traffic signal may be warranted at an established school crossing when a traffic engineering study of the frequency and adequacy of gaps in the vehicular traffic stream as related to the number and size of groups of school children at the school crossing shows that the number of adequate gaps in the traffic stream during the period when the children are using the crossing is less than the number of minutes in the same period.
Systems	The systems warrant is applicable when the common intersection of two or more major routes has a total existing, or immediately projected, entering volume of at least 800 vehicles during the peak hour of a typical weekday, or each of any five hours of a Saturday and/or Sunday.

Warrants in the National 1978 MUTCD and Subsequent Revisions

At the time of publication, the warrants in the 1978 MUTCD were the same as those in the 1971 MUTCD. However, between 1979 and 1986, there were four revisions of the 1978 MUTCD (15). In the fourth revision (issued in March 1986), three new warrants were added. These warrants are described below.

- **Four Hour Volume Warrant** - This warrant is the same as that found in the 1988 MUTCD. It consists of a series of curves. Volumes for the major and minor approaches are plotted on the curve. If there are at least 4 hours where the points representing volumes are above the applicable curve, then this warrant is satisfied.

- **Peak Hour Delay Warrant** - This warrant is the same as that found in the 1988 MUTCD. It states that the warrant is satisfied when:
  - The total delay experiences by the traffic on one minor street approach (one direction only) controlled by a Stop sign equals or exceeds four vehicle-hours for a one lane approach and five vehicle hours for a two lane approach, and
  - The volume on the same minor street approach (one direction only) equals or exceeds 100 vph for one moving lane of traffic or 150 vph for two moving lanes, and
  - The total entering volume serviced during the hour equals or exceeds 800 vph for intersections with four (or more) approaches or 650 vph for intersections with three approaches.
- **Peak Hour Volume Warrant** - This warrant is similar to the Four Hour Volume warrant. A separate set of curves is provided. Only one hour of major and minor street volumes needs to be located above the applicable curve.

Warrants in the National 1988 MUTCD

The 1988 MUTCD was developed based on the four 1978 revisions and one new revision. No new warrants were added, but several warrants were revised. The warrant revisions are described below.

- **Pedestrian Warrant** - The new revised language is shown in Table 10.
- **Accident Experience Warrant** - The monetary threshold for a qualifying accident was changed from $100 to "exceeding the applicable requirements for a reportable accident."
- **Systems Warrant** - This warrant was revised, and the new language is shown in Table 10.
- **Combination of Warrants** - The minimum pedestrian volume warrant was eliminated from the list of warrants that can be used in combination.

Table 10. Revised Warrants in the 1988 MUTCD

Warrant	Criteria
Minimum Pedestrian Volume	A traffic signal may be warranted where the pedestrian volume crossing the major street at an intersection or mid-block location during an average day is: (a) 100 or more for each of any four hours, or (b) 190 or more during any one hour. In addition to the volumes stated above, there shall be less than 60 gaps per hour in the traffic stream of adequate length for pedestrians to cross during the same period when the pedestrian volume criterion is satisfied.
Systems	The systems warrant is applicable when the common intersection of two or more major routes (1) has a total existing, or immediately projected, entering volume of at least 1,000 vehicles during the peak hour of a typical weekday and has five year projected traffic volumes, based on an engineering study, which meet one or more of Warrants 1, 2, 8, and 11 during an average weekday, or (2) has a total existing, or immediately projected, entering volume of at least 1,000 for each of any five hours of a Saturday and/or Sunday.

CHAPTER 3
STATE-OF-THE-ART

The basic philosophy of intersection control is that the least restrictive form should be used while maintaining some acceptable degree of efficiency and safety. The primary concerns of this project, heavy vehicles and accident severity, deal directly with both of these fundamental criteria. Therefore, a thorough understanding of related work is essential to expand the knowledge of these issues. This chapter documents the findings from previous research regarding heavy vehicles and their consideration into the warranting analysis along with their operational effect on unsignalized intersections. Also included in this chapter are findings from previous work related the Accident Experience Warrant and safety impacts of signals at intersections.

HEAVY VEHICLES

Little research has been conducted in terms of considering heavy vehicle factors into the warranting procedures. However, considerable work has been completed that focuses on heavy vehicle impacts at signalized intersections. This section reviews the literature available on heavy vehicle considerations into the warranting procedure and heavy vehicle impacts on unsignalized intersection operations.

Heavy Vehicle Considerations Pertaining to the Warranting Analysis

In 1967, perhaps the most comprehensive review of traffic signals warrants and related factors was published (16). In this work, Box et al. critically reviewed 264 published and unpublished reports and data sources in order to prepare and suggest factors and considerations that should be included in the warranting procedures. The findings resulted in the suggestion of several warrants – one for existing intersections based primarily on delay, another for intersections not completely constructed, and a third based on pedestrian needs. Findings pertaining to the accident warrant were inconclusive, and little justification was found concerning the retention of the Progressive Systems Warrant or the Combination Warrant.

One of this research's major findings related to additional factors and considerations for warranting procedures is the following – when considering only vehicular needs, the primary warrant for existing conditions should include a central measure of these needs. The simple use of volumes, even with consideration of available lanes, is at best a gross approximation. If we attempt refinements such as a classification of turns and measurement of turning conflicts caused by pedestrians, by deficient corner radii, substandard lanes, and traffic composition, we introduce unwieldily complications. Worse yet, we lack the research data to allow full adjustment of these factors.

In 1976, NCHRP Project 3-20, *Traffic Signal Warrants*, was published (17). The objective of this research was to evaluate the adequacy of the traffic signal warrants at that time and to determine the need for revised or additional warrants. A total of ten warrants were recommended – three were replaced, three were revised, two were retained, and two more were developed with respect to the warrants contained in the 1971 national MUTCD.

One of the suggested revised warrants was the volume warrant. In an attempt to account for delay on the minor approach, the researchers adopted a value of 25 seconds per minor street vehicle which was meant to represent "tolerable" delay. Using this definition, along with other factors, the researchers developed minimum vehicular volume thresholds that had to be met to warrant a signal. One of the additional factors that was incorporated into this study was "truck vehicles." The procedure to account for a truck vehicle on a minor approach was given by the following relationship:

$$Q_{SS} = SSV + Q_T$$

where: Q_{SS} = Equivalent side street volume
SSV = Measured side street volume
Q_T = Truck and bus volume, where one truck/bus is equivalent to two passenger cars

No further explanation of a "truck vehicle" was provided. This same equivalency factor was also recommended for the proposed peak-hour warrant developed as part of this research.

Upon further investigation of this equivalency factor, the researchers of NCHRP 3-20 did not conduct field studies of their own. Rather, in an attempt to assess the performance of trucks discharging from approaches controlled by a Stop sign, they relied on work completed by Yurysta (18).

However, Yurysta's work was aimed at determining an equivalency factor of passenger cars to commercial vehicles at *signalized intersections*, with respect to the type of commercial vehicle and the type of intersection approach. He studied twenty intersection approaches and determined equivalency factors for single unit trucks, combination trucks, and commercial vehicles. All vehicle types were further categorized by approach. Approaches studied included three-lane approach, two-lane approach, through and left-turn lane, through lane, and through and right-turn lane.

In this study, a commercial vehicle was defined as any vehicle with at least six tires and two or more axles. Equivalency factors were determined based on a displacement factor. The displacement factor was the difference between the number of vehicles traveling through a saturated approach during green when no commercial vehicles were present and the number of vehicles traveling through a saturated approach during green when commercial vehicles were present over the number of average commercial vehicles traveling through a saturated approach during green. To obtain an equivalency factor, one was added to the displacement factor. Table 11 summarizes the results of these calculations.

Table 11. Truck Equivalency Factors at Signalized Intersections

Approach Type	Truck Type		
	Commercial Vehicle	**Single Unit or Bus**	**Truck Combination**
3-Lane Approach: Exclusive Left Exclusive Through Shared Through and Right	1.85	1.71	2.37
2-Lane Approach: Shared Left and Through Shared Through and Right	1.86	1.74	2.38
1-Lane Approach: Shared Left and Through	2.22	2.30	2.29
1-Lane Approach: Through Only	1.92	1.61	2.24
1-Lane Approach: Shared Through and Right	1.74	1.57	2.31

Yurysta concludes that, in a capacity sense, one commercial vehicle is equivalent to 1.85 passenger cars at a *signalized intersection*. Also, one single unit truck is equivalent to 1.72 passenger cars, and one truck combination is equivalent to 2.37 passenger cars at a *signalized intersection*. Additional emphasis is placed on the words "signalized intersection" since this was the focus of Yurysta's work. Although no attempt was made to determine an equivalency factor of a heavy vehicle from a Stop controlled approach, further analysis of the suggested volume and peak-hour warrants produced by NCHRP 3-20 continued – even with the assumed relationship that one heavy vehicle at a Stop controlled approach is equivalent to two passenger cars.

This continued work appears in NCHRP 249, *Peak-Hour Traffic Signal Warrants* (19). The objectives of this research were twofold. First, the researchers were to evaluate and verify the peak-hour warrant suggested by the Signals Subcommittee of the National Advisory Committee on Uniform Traffic Control Devices and the peak-hour warrant developed as part of NCHRP Project 3-20. Secondly, they were to recommend, with supporting documentation and justification, a peak-hour warrant, including modifications to the above warrants that may result from this research, or consideration of an alternative warrant.

In analyzing the two different peak-hour warrants, many differences were noted that made it difficult to compare the warrants directly. One of these differences was that the NCHRP warrant applied a truck and right-turn factor to adjust the side street demand volumes. During the analyses of the peak-hour warrants, the truck factor was investigated further. As described in NCHRP 3-20, one truck is considered as operationally equivalent to two passenger cars.

It was found that the impact of the percentage of trucks on the outcome was small, particularly considering the range of typical truck percentages. For each one percent of trucks in the traffic stream, the side street volume threshold to satisfy the peak-hour warrant was reduced by one percent. Thus, an approach with ten percent trucks would require ten percent less volume on the side street to satisfy the warrant than with no trucks.

The analysis yielded the conclusion that there is little need to include the percentage of trucks in the process for determining when the peak-hour warrant is satisfied. However, the authors did recognize the fact that there may be rare situations where trucks need to be considered; sound engineering judgement is implicitly implied as the means to do so.

In light of the recommendation not to include some form of an equivalency factor for heavy vehicles in the warranting procedure, a notable caveat is that this specific investigation focused on peak-hour warrants where many of the additional vehicles are likely driven by commuters. Furthermore, these commuters are typically driving passenger vehicles and not heavy vehicles. Also worth considering is the fact that of the 241 intersections studied (a total of 817 25-minute sampling periods), nearly 90 percent had truck percentages less than 3.4 percent, and only 2.4 percent of the sampling periods had truck percentages of ten or more. Therefore, the intersections selected for study in this project were not specifically focused on intersections that may have heavy vehicle-related problems. Consequently, the effect of heavy vehicles on the warranting process has yet to be completely resolved.

In another traffic signal warrant study, Lee et al. (20) focused on, among other items, the development of a methodology for evaluating traffic control installations. In particular, they emphasized the establishment of suitable warrants for selecting the proper equipment at individual intersections. The project resulted in a set of minimum volume warrants for the installation of a four-way Stop control and the validation of a proposed set of traffic volume warrants for the installation of traffic actuated warrants.

Again, the authors make reference to the many variables worthy of consideration when studying intersection characteristics. Factors named include directional volumes, turning movements, approach speeds, width and number of lanes, truck and pedestrian traffic, intersection geometry, and distance to adjacent intersections. However, like the previous studies reviewed, truck traffic was not a primary concern when choosing intersections to study and therefore, during the analysis procedures, variables to account for the number or percent of trucks were deemed nonsignificant. Consequently, the findings from this research did not recommend the inclusion of heavy vehicles in the warranting procedure.

Operational Effect of Heavy Vehicles at Unsignalized Intersections

Besides the work that has been focused on developing criteria for heavy vehicles into the warranting analysis procedures, other related work exists. Perhaps one of the most useful is the operational work that has been completed in regard to unsignalized intersection operation, in particular, the Unsignalized Intersection chapter of the Transportation Research Board's Special Report 209 (*Highway Capacity Manual* or HCM) (Chapter 10) (21).

The most recent edition of the HCM was published in 1985. In 1994, an update to the 1985 HCM was released. Most recently, a 1997 update to the HCM has been released. The next edition of the HCM is scheduled to be released in the year 2000. This edition is expected to be significantly different from the 1985 edition which has not changed significantly even with the two updates.

The most recent update (i.e., the 1997 update), includes improved analytical procedures for the following types of facilities:

- Basic freeway segments,
- Weaving areas,
- Signalized intersections,
- Unsignalized intersections, and
- Arterials.

Of interest herein are the changes to the Unsignalized Intersection chapter. This chapter deals with analysis procedures for two-way stop controlled (TWSC) intersections, all-way stop controlled (AWSC) intersections, and roundabouts (introduced as a new analysis in the 1997 update). The1997 update is primarily based on the results of the recently completed NCHRP Project 3-46, *Capacity and Level of Service at Unsignalized Intersections* (22).

In this recent effort to develop new capacity and level of service analysis procedures for unsignalized intersections, Kyte et al. studied the effect of vehicle type on critical gap and follow-up time. To complete this analysis, gap events related to heavy vehicles were extracted from the collected data and then aggregated based on intersection geometry and movement type. Table 12 lists the results. As indicated, critical gaps for heavy vehicles are significantly higher than for passenger cars.

Table 12. Critical Gap for Heavy Vehicles at Unsignalized Intersections

Geometry Type	Movement	Critical Gap	
		Heavy Vehicle	Passenger Car
3-leg Single	LT RT	7.2 6.0	6.0 5.2
4-leg Single	LT TH RT	7.6 6.3 6.7	7.1 6.4 5.9
3-leg Multi-lane	LT TR	9.0 9.4	7.2 6.9
4-leg Multi-lane	LT TH RT	9.0 9.5 8.2	7.4 7.6 6.8
Multi-lane	LT TH RT	9.0 9.5 8.8	7.3 7.6 6.8
Single-lane	LT TH RT	7.4 6.3 6.4	6.4 6.4 5.5
Any	MajLT	5.5	4.1

Kyte et al. also studied follow-up time for heavy vehicles. They classified a heavy vehicle related follow-up time has an event that included one of three possible scenarios:

1. The first vehicle in the follow-up event was a heavy vehicle;
2. The second vehicle in the follow-up event was a heavy vehicle; or
3. Both vehicles in the follow-up event were heavy vehicles.

Although not many observations were recorded in which one of the three previously explained events occurred, the researchers concluded that follow-up times for heavy vehicles are about one second higher than those for passenger cars.

The main objective of NCHRP 3-46 was to develop enhanced procedures to estimate capacity and level of service at unsignalized intersections. Consequently, as part of the project findings, a new chapter for the *Highway Capacity Manual* (Chapter 10, Unsignalized Intersection) is offered. Among many recommended changes, one is the removal of passenger car equivalency factors (Table 10-1 in the 1994 update of the 1984 HCM) from the capacity and level of service procedures. This table, reproduced as Table 13 for this report, incorporates many vehicle types, including heavy vehicles as well as grade impacts.

Table 13. Passenger Car Equivalents

Type of Vehicle	Grade (%)				
	- 4	- 2	0	2	4
Motorcycles	0.3	0.4	0.5	0.6	0.7
Passenger Cars	0.8	0.9	1.0	1.2	1.4
SU/RVs [a]	1.0	1.2	1.5	2.0	3.0
Combination Vehicles [b]	1.2	1.5	2.0	3.0	6.0
All Vehicles [c]	0.9	1.0	1.1	1.4	1.7

Notes: a Single-unit trucks and recreational vehicles
b Includes tractor-trailer combinations and buses
c If vehicle composition is unknown, these values may used as an approximation

The values in the previous table are used to convert the "vehicles per hour" to "passenger cars per hour." When vehicle classification data is not available, the HCM recommends using a factor of 1.1 for no grade to reflect "normal" traffic composition, which consists of five percent combination vehicles and nominal numbers of other vehicle types (other than passenger cars). Through and right-turning volumes on the major street are not converted to passenger cars per hour because the major street right-turn and through volumes are used only in the computation of conflicting traffic volume, which is done in terms of vehicles per hour.

The 1994 HCM also recommends critical gap and follow-up time values for two-way Stop controlled (TWSC) intersections. The values are reported to apply to most typical intersections; however, if more appropriate values are known, then it is suggested that these values be used. Table 14 shows the values recommended in the HCM.

Table 14. HCM's Critical Gap and Follow-Up Values

Maneuver	Critical Gap (sec)		Follow-Up Time (sec)
	Two-Lane Major	Four-Lane Major	
Left turn from major	5.0	5.5	2.1
Right turn from minor	5.5	5.5	2.6
Through traffic from minor	6.0	6.5	3.3
Left turn from minor	6.5	7.0	3.4

It should be noted that the values in the previous table reflect data obtained on roadways where the average speed of the major street through vehicles approximated 30 mph. Where approach speeds differ from 30 mph or when more reliable data is available, then it is suggested that the table values should be replaced. Furthermore, the values shown in Table 14 were derived from international studies of passenger cars. Although U.S. conditions may result in similar values for passenger cars, heavy vehicles which have very different operating characteristics are not included in the analysis.

The newly recommended procedure in the 1997 HCM replaces the passenger car equivalency factors with critical gap and follow-up time adjustments for heavy vehicles. Other types of vehicles are not considered. The recommended critical gap and follow-up values are shown in Table 15. For critical gaps on single-lane approaches, an adjustment factor of one second is made for heavy vehicles, and for multi-lane approaches, a two second adjust is recommended. Follow-up times that include heavy vehicles are adjusted 0.9 seconds for single-lane sites and one second for multi-lane sites. Combined values of critical gap and follow-up time are composites based on the proportions of passenger cars and heavy vehicles.

Table 15. Recommended Heavy Vehicle Adjustment Factors

Geometry		**Single-Lane**				**Multi-Lane**			
Movement		Maj LT	Min RT	Min Thru	Min LT	Maj LT	Min RT	Min Thru	Min LT
Critical Gap (sec)		4.1	6.2	6.5	7.1	4.1	6.9	6.5	7.5
Follow-Up (sec)		2.2	3.3	4.0	3.5	2.2	3.3	4.0	3.5
Heavy Vehicle Adjustment Factors	Critical Gap (sec)	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0
	Follow-Up (sec)	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0

Summary

The amount of previous research that considers the inclusion of heavy vehicle factors in the warranting analysis procedures is limited. All but one set of findings indicate that heavy vehicles do not significantly impact intersection safety or operations at the volume levels contained within the warranting procedures. However, the studies did not specifically focus on heavy vehicle considerations. Rather, heavy vehicles were considered more as an after-thought and therefore, were deemed insignificant. However, recommended HCM unsignalized procedures include provisions for heavy vehicles in terms of adjusted critical gap and follow-up times. This, therefore, indicates that heavy vehicles do have an impact on unsignalized intersection operations. Consequently, additional work is needed to quantify the feasibility of heavy vehicle considerations in the warranting analysis procedures.

ACCIDENT SEVERITY

Two primary concerns initiated this project. The first, heavy vehicle considerations, was discussed above. The second, accident severity considerations, is discussed below. Currently, the only analysis of accidents in terms of determining needs for signalization is in Warrant 6 - Accidents Experience. The current status of this warrant is discussed below. Drawbacks of this warrant primarily include the vague language used to define minimum criteria for signalization. To consider modifications to the existing warrant, safety impacts of intersection improvements and accident experience must be quantified or assessed. These issues are discussed below as well as other factors that may justify consideration.

Warrant 6 – Accident Warrant

Many individuals perceive traffic signals as the solution to all traffic problems within a municipality and thus expect traffic signals to be used as a remedy for each particular traffic problem. The public also believes that the occurrence of traffic accidents will disappear when a traffic signal is installed at an intersection. This belief was studied, and according to Box and Alroth (3), no correlation between the safety impacts of traffic signals and accidents could be produced. However, other sources, such as the Institute of Transportation Engineers (ITE), cite in their *Traffic Engineering Handbook* that traffic signals can be expected to reduce the total occurrence of traffic accidents by 18 percent (4). The existence of this conflict of opinion is not surprising because of the complexities that are involved in comparing different intersections' characteristics and their effect on traffic safety. Although the literature at this point in time may not be able to define the exact safety benefits associated with traffic signals, one thing has been proven – the severity of injuries that result from accidents at intersections decrease with the installation of traffic signals. Before an intersection is signalized, right-angle accidents are very common. After the signal installation, rear-end accidents tend to become the more common type of accident. Generally, rear-end accidents result in less severe injuries for two reasons: (1) the vehicles are traveling in the same direction, and (2) there is more distance between the driver and the point of impact and more material in the rear-end of the vehicle to absorb the energy of the crash.

Since traffic signals may cause some types of accidents to increase at an intersection, other methods of controlling traffic should be considered prior to installing a traffic signal. At some unsignalized intersections, certain movements may experience a large amount of delay and causing drivers to become impatient and accept gaps in the traffic stream that are too small. In some cases, the addition of a right-turn lane could improve the flow of traffic and reduce the delay that, in turn, causes the driver to become impatient. In other cases, roadway geometrics may be a contributing factor to the accidents. A few of these roadway geometric deficiencies are: absence of a left-turn lane, inadequate intersection sight distance, poor intersection alignment on the cross street, and exiting grades on the roadway. Traffic stream characteristics often contribute to an intersection's accident history. High speed facilities and heavy truck traffic ingressing or egressing to/from the cross street can contribute to other motorists being required to make an unexpected maneuver.

The requirements and description of the Accident Experience Warrant for traffic signals MUTCD are more vaguely described than other warrants. For this reason, engineers frequently have to use their own judgement to define criteria as to when to use different types of treatments and as

to how to evaluate the treatments' effectiveness. This engineering judgement is very dependent upon the engineer's previous experience and knowledge of the particular issues associated with the subject intersection. Since this warrant is so vague in defining a "preventable" accident, it is difficult to evaluate the safety benefits associated with installing a traffic signal.

Parts of the Accident Warrant

There are four primary items in the Accident Experience Warrant which must be met in order to justify a traffic signal installation based on accident history. The first item is the trial of less restrictive "remedies" that have been satisfactorily observed and enforced and which have failed to decrease the accident frequency at the intersection. Although the intent of this part of the warrant is correct in that other devices or treatments should be implemented, the lack of scientific recommendations or requirements can cause an inappropriate device to be used. Furthermore, this part does not describe what types of accidents should be evaluated when determining the treatment's effectiveness.

Part 2 of the warrant is the need to have five reported accidents, within a 12 month period, that are correctable with the installation of a traffic signal. This part of the warrant is an attempt to provide guidance to the engineer as to where signals should be installed to prevent or correct accidents-prone intersections. As discussed earlier, research has not been able to fully identify the safety benefits or fully define what types of accidents (other than right-angle) that can be prevented from installing a traffic signal. Also, not all right-angle accidents are prevented by the installation of a traffic signal, especially those on high-speed facilities that have a medium or high truck volume. It has been the experience of the researchers that this part of the warrant is most applicable to determining when a protected left-turn phase should be added to prevent or reduce accidents.

Part 3 of the Accident Warrant has a tie to volume requirements in that it must meet a minimum of 80 percent of the Minimum Vehicular Volume, or the Interruption of Continuous Traffic, or Minimum Pedestrian Volume Warrant. This portion of the warrant is beneficial to the engineer because of its quantitative requirements for having a minimum amount of traffic that is being exposed at the accident location. This portion of the warrant implies that the accidents are related to the existing traffic volumes and not just a geometric feature of the intersection. This allows the engineer with a tool to analyze the need for a traffic signal relative to other potential signal locations and intersections that are already signalized.

Part 4 of the warrant requires that the installation will not seriously interrupt progressive traffic flow. Again, the vague nature of the warrant is presented with the term "seriously." For an engineer to evaluate progressive flow of the roadway and how seriously it will be affected by the installation, some parameters should be established. These parameters would provide the engineer with a gauge to better define what effect should be considered serious. The spirit of this part of the warrant is to prevent other accidents and/or increased delay due to the new signal installation. This associated disruption could be carried on to a higher level of analysis to estimate the delay costs associated with the installation. The warrant does go on to elaborate on the types of actuation that should be used with the signal when based on accident history.

The Accident Experience Warrant is currently under review through an NCHRP project (23) evaluating the current status of the warrant. The objective of the project is to develop an improved Accident Experience Warrant based on a better understanding of the safety impacts of signalization. This project was initiated in the spring of 1997 and is estimated to be completed in the summer of 1999. TTI has coordinated selected activities with the NCHRP research team. These efforts and the current status of this project are discussed in subsequent sections of this report.

Issues and Challenges in Assessing Safety Impacts

There are two potential confounding factors that can obscure conclusions in assessing safety impacts in before/after studies using vehicle accidents as the measure of effectiveness. The first factor involves changes that might have occurred in the after period which affect accidents but are unrelated to the treatment being assessed. Examples of such factors are construction, roadway geometric changes, weather, traffic flow, or driver/vehicle composition changes from the before to after period.

The second potential confounding factor is a phenomenon known as regression to the mean. This is the situation where, because the sites selected were experiencing a high accident rate before the implementation of the traffic signal, there is a good chance that the following year there would be a decrease in accidents without signal installation simply because the site's accident rate was "regressing" or returning to the site's true mean rate.

Another issue to consider in accident analyses is exposure - i.e., the potential for an accident to occur. For intersections, this frequently means some measure of traffic volume and congestion. The issue of what is the best measure of exposure for intersection safety studies has recently been investigated (24). When exposure measures are not available, there are statistical methods and experimental designs to attempt to control for exposure changes, but these require large sample sizes to be able to detect modest safety improvement. A manual of such methods has recently been developed for the FHWA (25).

Another factor that can affect safety analyses is how (and if) accidents are reported. For example, on July 1, 1995, the state of Texas ceased reporting PDO (property damage only) accidents unless one or more vehicles involved in the accident was towed from the scene. The impact of this change in reporting threshold in Texas has been to greatly reduce the number of accidents recorded in the state database, including accidents at intersections.

Accident Experience at Signalized Intersections

The current Accident Warrant refers to an "accident problem" and suggests that this is indicated by a certain "number of reported accidents of a type susceptible to correction" that occur in a 12-month period. However, there are no generally accepted tools to help the traffic practitioner determine the likely impact of safety from installing a traffic signal. One attempt in developing a model to estimate the safety of signalized intersections found that given the traffic flow for a signalized intersection, one can predict how many and what kinds of accidents should be expected to occur (26). One can also show the probability density function of the estimate. Knowledge of this allows the determination of what an unusually high number of accidents would be for such an

intersection. If the traffic flow of the intersection changes from year to year, one can estimate the changes in safety that would be attributed to such changes. Most importantly, one can estimate safety when both flows and accident history are given, and, on this basis, judge whether an intersection is unusually hazardous.

The study resulted in 15 models used to estimate the safety based on accident patterns by vehicle streams. The more common categorization of initial impact type (such as sideswipe, rear-end, angle, etc.) was avoided due to its ambiguity which rests in the fact that the cause-and-effect relationship with traffic flow is weakened when more classical categorization techniques are used.

The advantages of using 15 patterns to describe accidents is the precision one can achieve and the more distinct categorization methods that better relate the cause-and-effect to the traffic flow. The total observed counts, the predicted counts, and the predicted variability of accidents are shown in Table 16. The data are based on a three year period. The estimated mean and variance for total number of accidents is shown in the last row.

Table 16. Correspondence Between Observed and Estimated Number of Accidents

Pattern	Observed Accident Count (1982-1984)	Predicted Accident Count	Variability
1	4	4.837	1.295
2	2	1.886	0.457
3	0	0.119	0.004
4	1	2.38	0.257
5	0	0.318	0.013
6	6	6.565	5.245
7	0	0.327	0.139
8	1	0.22	0.006
9	0	0.137	0.003
10	0	0.011	0
11	0	0.034	0
12	1	0.141	0.003
13	1	0.601	0.051
14	0	0.772	0.088
15	0	0.116	0.002
TOTAL	16	18.464	7.563

A Florida Department of Transportation report provided accident reduction factors for use in calculating benefit/cost ratios (27). Those values for signalized intersections are shown in Table 17. In addition, several other documents contain information on accident rates and accident prediction models for signalized intersections. These are discussed below.

Table 17. Estimated Accident Reduction Factors for Intersection Improvements (27)

Signalization	Accident Reduction (Percent)			
	All	Fatal	Injury	PDO
New Signal at Channelized Intersection	42	- - -	42	43
New Signal at Non-Channelized Intersection	20	- - -	21	24
Add Signal and Channelization	25	- - -	30	22
Modify Both Signal and Channelization	52	- - -	71	43
Modify Signal and Add Channelization	28	- - -	- - -	34
Interconnect Traffic Signals	10	30	29	- - -

Radwan and Wing (28) in 1987 reported on a state-of-the-art project that produced a comprehensive review of signal installations and their impacts on accident patterns, and accident frequency and severity. The report contains information on accident statistics by type and severity, accident rates for stop controlled and signalized intersections, accident patterns on arterials, and accident statistics for different signal types. A report (29) on the Highway Safety Information System (HSIS) discussed applying the Empirical Bayes Estimation of Safety and Transportation methodology to actual data from the HSIS. The installation of traffic signal controls at previously unsignalized intersections was selected as the treatment to be evaluated.

A Nebraska project conducted by Bonneson and McCoy (30) focused on the development of accident prediction models applicable to intersections and interchanges on rural expressways. Their examination of the expected accident frequency for each junction type indicated that a two-way stop controlled intersection is likely to have more accidents per year than a signalized intersection under the same traffic demand conditions. Another research project sponsored by the Nebraska Department of Roads (31) made an attempt to show a relationship between the approach volume and the frequency and rates of accidents at signalized intersections. Accident prediction equations were developed for four accident types (rear end, left-turn leaving, left-turn entering, and cross traffic) and for two severities (property damage only and personal injury). The study developed a number of equations that can be used to predict accident frequencies and rates at signalized intersections. An Iowa study (32) developed models which estimate approach accident rates at high speed signalized intersections. The objective of the research was to quantify the relationship between traffic and intersection characteristics, and accident potential for different left-turn treatments.

Datta et al.(33) investigated 102 intersections in Michigan in the late 1980s where traffic signals were installed to determine the change in accident characteristics and severity after the installations.

The common criteria among the sites chosen was that they met the warrants set out in the *Manual on Uniform Traffic Control Devices* for installation of traffic signals. The before and after study yielded the results shown in the Table 18.

Table 18. Change in Accident Rates by Type (33)

Accident Type	Before (acc/mv)	After (acc/mv)	Percent Change (+) Increase or (-) Decrease
Total	1.82	1.47	-19.2
Injury	0.58	0.48	-17.24
Rear-End	0.32	0.49	+53.0
Right-Angle	0.56	0.24	-57.1
Head-on, Left-Turn	0.14	0.21	+50.0
Other	0.8	0.53	-33.8

All of the differences in mean accident rates were found to be significantly different. It was noted that some of the accident rate changes could have been influenced by geometric changes in the intersection. A similar statistical comparison was made for only the sites with no changes in geometry, and similar results were obtained. The study found that the installation of a traffic signal tends to create a reduction in the total injuries at the intersection, with right-angle collisions and personal injury accidents showing a decrease. However, signal installations may also have a tendency to cause an increase in rear-end and head-on collisions.

Another study, overlapping with the same study conducted by Datta et al. (34) but with more focus on the evaluation of the effect of traffic signal installation at intersections with no geometric changes, resulted in (34):

- The total accident rate was reduced by 15.1 percent (statistically significant).
- The right angle accident rate was reduced by 52.5 percent (statistically significant).
- The injury accident rate was reduced by 7.0 percent (not statistically significant).
- The head-on, left-turn accident rate increased 75.0 percent (statistically significant).
- The rear-end accident rate increased by 64.5 percent (statistically significant).
- Other accident rates decreased by 31.8 percent (statistically significant).

Accident Experience at Unsignalized Intersections

Lovell et al. (35) studied the safety effect of converting intersection traffic control to all-way stop control. Before this study was conducted, several studies were published showing impressive accident reductions when intersections were converted to all-way stop controlled. However, as Lovell explains, it is difficult to know how much of the reduction was real and how much was an artifact of regression-to-the-mean. Therefore, Lovell et al. reanalyzed and unbiased three previous

studies regarding the safety effects of converting intersections to all-way stop controlled. Analyses revealed that, although somewhat inflated, the reductions reported in the earlier studies were quite real and were confirmed by the new data. From the analyses of the unbiased data, Lovell showed total accident reductions ranging from 37 to 62 percent (see Table 19).

Table 19. Most Likely Percent Accident Reductions (35)

Accident Type	San Francisco	Philadelphia	Michigan	Toronto	Combined
Right-angle	84	78	64	48	72
Rear-end	-305	20	19	22	13
Left-turn	33	--	-7	25	20
Pedestrian	66	40	--	42	39
Fixed object	--	-30	--	--	--
Injury	74	74	62	63	71
Total	62	47	59	37	47

Persuad (36) studied the effective management of safety when converting a one-street-stopped intersection to an all-way controlled intersection. The issues involved include:

1. Is it better to treat sites with many accidents?
2. Does safety migrate?
3. Do traffic volumes play a role?
4. Does an "acquaintance" period help? and,
5. Does effectiveness decline as more sites are treated?

On the first issue, the results support a long-held belief that the more accidents a site is expected to have, the more effective a safety measure is likely to be. Persuad also found that safety migration may indeed exist (i.e., improved safety at one location leads to degradation of safety elsewhere). Accordingly, safety benefits at one site should be weighed against safety degradation elsewhere. The study found, contrary to common belief, that there is no evidence that the conversion of intersections to multi-way stop control is effective only for certain ranges of total entering volumes. The effectiveness does not necessarily depend on how the volume is split among the approaches. Also, it was determined that a learning period after conversion does not appear to be detrimental to safety. Finally, effectiveness does not appear to decline as the use of the measure becomes widespread.

FHWA initiated a national study with the following two objectives: (1) to develop and test procedures to convert multi-way stop-sign-controlled intersections to two-way stop-sign-controlled intersections, and (2) to document the safety effects of converting multi-way stop controls to two-way controls (37). The analysis contained 172 intersections under 33 jurisdictions in 12 states. Results are given in the Table 20.

Table 20. Accident Summary Statistics of Conversion from Multi-Way Stop to Two-Way Stop Control (37)

Condition	Total	Supplementary Sign	
		Yes	No
No. of accidents before	88	77	11
No. of accidents after	144	101	43
Total (all intersections)	232	178	54
No. of intersections with increased accidents	28	13	15
No. of intersections with decreased accidents	16	12	4
No. of intersections with no change	128	32	96
Total	172	57	115

Important findings from this analysis include the following:

- The significant increase in accidents resulted from an increase at only 16 percent of the 172 sites, with only 9 percent experiencing a decrease. This finding indicates that there is probably a geometric or operating characteristic that determines the increase or decrease.
- The percentage increase in accidents was significantly higher where no supplementary signs were used.
- Seventy-four percent of the 172 sites experienced no change in the number of accidents.

A recommended procedure for removal of multi-way stop signs was proposed with preconversion, conversion, and postconversion phases.

A study examining 222 intersections in Philadelphia, Pennsylvania, where two-way stop control was converted to all-way stop control during the years of 1970 to 1973, was conducted to relate the effectiveness of the conversion to the expected number of accidents (38). Persaud pointed out that many studies involving the evaluation of safety improvements do not consider the expected number of accidents during the after period (statistically referred to as the regression-to-the-mean) that would occur had the treatment not been effective. The main finding from this study was that conversion to all-way stop control can be more effective at intersections expected to have many accidents than at locations with relatively low accident rates. This finding suggests:

- More investment can be justified for treating the locations with higher accident rates,
- The effectiveness of safety treatments should be expressed in terms of the relationship to the expected number of accidents as opposed to the usual single accident reduction factor.

In regard to marginally warranted intersections, Williams et al. (39) conducted field and simulation studies to determine conditions under which installation of a signal at a marginally warranted intersection was recommended. The results showed beyond a doubt that signalizing a marginally warranted intersection, whether in an urban or rural area, will not improve intersection operation. In terms of safety at marginally warranted intersections, it was found that signalization would significantly reduce right-angle accident frequency only under low-speed rural conditions. No other situation was found where signalization would increase safety as measured through expected accidents.

In their concluding remarks, Williams et al. note that when signalization is only marginally warranted at an intersection, the public's perception that delay and number of stops can be reduced through signalization is generally false. Furthermore, safety enhancements through signalization may only be achieved under very few circumstances.

Summary

It is clear that a significant amount of work has been completed with the focus of quantifying safety impacts of signalization. What remains unclear are the findings from these efforts. Most recently, NCHRP Project 17-16 has been started in order to identify a clearer relationship in terms of safety at intersections and the effect of installing and removing traffic signals. The findings from this effort are expected to be used to develop a revised Accident Warrant for the MUTCD.

CHAPTER 4
SURVEY OF TRAFFIC SIGNAL WARRANTING PROCEDURES

To address the concerns, difficulties, and issues regarding traffic signal warranting procedures, researchers surveyed TxDOT, state, and city traffic engineers through the use of a mail-out survey and an electronically-based survey available through the world wide web (WWW). A survey was mailed out to all 25 jurisdictional TxDOT districts within Texas. A total of 19 districts responded.

Researchers mailed a second survey (similar to the first but designed and based on the national Manual rather than the Texas MUTCD) to the state traffic engineers in all remaining 49 states. A total of 27 states returned completed surveys. From one state, six surveys were received – one from each district office. This brought the total number of completed surveys to 32.

The second survey was also sent to various cities around the U.S. To select the cities, a list of all cities with an estimated 1994 population greater than 100,000 was obtained through the Populations Distribution and Populations Estimates Branches of the U.S. Bureau of the Census. Researchers identified a total of 209 cities, but because of difficulties in obtaining addresses to all cities, only 152 city surveys were mailed. Of these, 50 completed surveys were returned.

Both mailings included the survey on paper but also included a flyer indicating the availability of the survey through the WWW. This alternative means of soliciting information served three purposes:

1. To provide the recipients a variety of means to respond to the survey (in hopes of increasing the response rate);
2. To reach jurisdictions that were not mailed the survey; and
3. To determine the future feasibility of conducting such information-gathering tasks exclusively through the WWW.

This chapter summarizes the pertinent results from the combination of these surveys. The final section of the chapter addresses the survey available through the WWW. A more detailed description of the survey instruments and survey data are provided in Appendix A. Return rates and survey respondents by agency type are shown below in Table 21.

Table 21. Survey Return Rates

Agency Type	Number of Surveys Mailed	Number of Surveys Returned	Percent of Surveys Returned
TxDOT	25	19	76.0
State	49	32	65.3
City/County	152	50	32.9
Total	226	101	44.7

Table 22. Survey Response Distribution

Agency Type	Number of Respondents	Percent of Total Respondents
TxDOT	19	18.8
State	32	31.7
City/County	49	48.5
Total	101	100.0

WARRANT USAGE

One of the interesting results to come from the survey was the breakdown of warrants used to justify signal installation or upgrade. Agencies were asked to indicate which warrant they primarily used to warrant installation or upgrade within the time period defined from January 1, 1995, to December 31, 1997. The results are summarized in Table 23.

Table 23. Percentage of Primary Warrant Used for Signalization

Agency	Warrant Number												
	1	2	3	4	5	6	7	8	9	10	11	12	Other
TxDOT	28	16	0	2	3	7	4	4	3	2	12	19	0
States	44	27	0	2	0	6	1	5	4	2	7	0	1
Cities	36	21	2	2	2	11	1	5	9	1	11	0	4

It is evident from Table 23 that the Minimum Vehicular Volume Warrant is the most commonly used warrant to justify signalization. Considering just TxDOT operations, the Minimum Vehicular Volume, the Traffic Actuated, the Interruption of Continuous Traffic, and the Peak Hour Volume Warrants (numbers 1, 12, 2, and 11, respectively) combined were used to warrant about 75 percent of intersections signalized within the state from 1995 to 1997. However, these four warrants only make up 33 percent of the available warrants for signalization. Other jurisdictions rely even more heavily on the Minimum Vehicular Volume and the Interruption of Continuous Traffic Warrants.

CURRENT VOLUME CLASSIFICATION PRACTICES

The current Texas MUTCD and the National MUTCD preface the traffic signal warrants with the following statement, "A comprehensive investigation of traffic conditions and physical characteristics of the location is required to determine the necessity for a signal installation and to furnish necessary data for the proper design and operation of a signal that is found to be warranted." An enumerated list of *desired* data follows this statement. The second itemized suggestion in this list is, "Vehicular volumes for each traffic movement from each approach, classified by vehicle type

(heavy trucks, passenger cars and light trucks, public-transit vehicles, and in some locations, bicycles), during each 15-minute period of the two hours in the morning and the of two hours in the afternoon during which total traffic entering the intersection is greatest."

Keeping the above in mind, both sets of warrant criteria (i.e., in the Texas MUTCD and the national MUTCD) refer to volume as *vehicles* or *vehicles per hour* and do not distinguish between vehicle classifications. For example, Warrants 1 and 2 are typically thought of as the "volume warrants." This name is justifiable; both warrants deal directly with volume counts. However, neither of these warrants describe or indicate that vehicle classification should be considered when determining the number of vehicles. They simply refer to *vehicles per hour* on the major and minor approach.

Warrants 9, 11, and 12 also include volume as a main factor in determining signal justification. Likewise, these warrants, as well as all other warrants mentioning volume as a criteria for determining signal justification, use *vehicles per hour* or *any four consecutive 15-minute periods* to describe the conditions pertaining to volume.

Therefore, according to the quoted MUTCD phrase found in the beginning of this section, the suggestion to classify vehicles during traffic counts must be meant to, "...furnish necessary data for the proper design and operation of a signal that is found to be warranted." Therefore, the signal warranting procedure does not currently appear to include the consideration of vehicle classification in the warranting procedure.

To assess the current practice within TxDOT as well as around the country, the following question was asked of each jurisdiction surveyed. The results are summarized below.

Does your agency classify these volume data as part of the warrant analysis process?

☐ *Yes* ☐ *No* *If yes, indicate the classifications used:*

☐ *Heavy trucks* ☐ *Light trucks* ☐ *Passenger cars*
☐ *Buses* ☐ *Motorcycles* ☐ *Bicycles*

How do you use these data? _____

_____

_____

TxDOT

Most of the districts responding indicated that they did not classify vehicles during their vehicular counts associated with traffic signal warrant analyses (74 percent). However, of those districts indicating that vehicle classification was included in the counts, two specifically mentioned that the data are used for signal timing and phasing purposes. It should be noted that one district appears to classify vehicles when marginally warranted conditions exist. Of those districts classifying vehicles, heavy vehicle and passenger car are the only two classifications used. Moreover, some districts mentioned that they "count" *vehicles* by obtaining axle counts (with temporarily installed tape switches). Using this raw count, the number of *vehicles* is calculated by

dividing by two. This procedure assumes all are passenger cars. However, it also weighs vehicles with more than two axles proportionately, based on the total number of axles. Therefore, a typical tractor-trailer combination accounts for 2.5 *vehicles* while a passenger car towing a two-axle trailer accounts for two *vehicles*. A disadvantage of this method is that it is crude and may not represent the operational aspects of the intersection caused by vehicles with more than two axles. However, the advantages include its simplicity as well as cost savings. In other words, equipment used to make simple counts costs less than equipment used to classify vehicles. Furthermore, from additional contacts with several districts, it appears that simple counting equipment is what most districts currently have available for use.

States

Through the mail-out surveys, each state was asked if they classified vehicles as part of the warrant analysis. Only nine states indicated that they do classify vehicles during the warrant analysis procedures. The majority of these only separate heavy vehicles (typically composed of heavy trucks and buses) from passenger cars; however, at least one state indicated that they classify light trucks, buses, motorcycles, and bicycles as well.

The anecdotal information obtained through the survey comments offers additional clues as to how vehicle classification is used. Most of the states classifying vehicles use the data for purposes of capacity estimates and signal phasing and timing procedures. Buses and heavy trucks are usually classified together as a heavy vehicle, and the remaining type of vehicles all fall under a more ubiquitous passenger car category. Finally, many states indicated that they make classification counts based on a perceived impression of safety or efficiency problems associated with unusually high heavy vehicle volumes.

Cities

The cities responding to this question typically do not classify vehicles when conducting a warrant analysis. Of the 18 percent that said they did, heavy trucks and passenger cars are the two most frequently used categories. The primary reason reported for the use of vehicle classification was for signal timing plans that may be needed if signalization is justified.

CURRENT TURNING MOVEMENT COUNT PRACTICES

The MUTCD suggests collecting turning movement counts as part of the analysis that goes into determining the need for signalization at an intersection. However, the warrants do not include guidelines as to how to use this data. Furthermore, the national MUTCD has incorporated interpretations of turning movements that are not included in the Texas MUTCD (see Appendix B for a list of interpretations pertaining to signal warranting analysis that have been ruled upon by FHWA and are included in the national MUTCD). Because of the limited guidelines provided by the MUTCD as to how to use the turning movement counts, the following question was asked to determine how often turning movements are counted and how the results are used.

Are turning movements collected as part of the warrant analysis process?

☐ *Yes* ☐ *No*

How do you use these data? _____

_____

_____

TxDOT

Only 40 percent of the districts collect turning movement counts as part of the warrant analysis. The data is reported as being used to reduce the overall number of vehicles based on right-turn movements where signals are marginally warranted and to determine signal timing and phasing, and intersection geometrics.

States

Almost all of the states make turning movement counts when conducting a signal warrant analysis. In fact, only one state indicated that they did not collect turning movement information. Of the states that did, the uses of the data varied considerably but was focused on possible reductions in overall volume counts based on right turning vehicles, capacity analysis, delay estimated, geometrics, marginally warranted intersections, signal timing and phasing, and adjustments for left-turning vehicles.

Cities

Almost three-quarters of the cities that responded include turning movement counts in their warranting procedures. By far, most cities indicate that they use these not for determining signal warranting needs, but for signal phasing and timing calculations if the intersection warrants a signal. However, four cities indicated that they use turning movement counts to reduce the total volume by the number of right-turning vehicles. Two cities use the turning movement counts to conduct intersection capacity analysis, and one city indicated that they use turning movement counts to assess geometric improvements that would relieve the "need" for signalization.

CURRENT ACCIDENT DATA INCORPORATION

Possibly the most controversial warrant contained within the MUTCD is the Accident Experience Warrant. It as been called a "catch-all" warrant, indicating that when an intersection fails to meet any of the other warrants then, only after a certain number of accidents occur, can the intersection be deemed worthy of a signal. The following question was posed to obtain an understanding of how the various jurisdictions currently use and interpret this warrant.

Does your agency consider accident data when conducting a warrant analysis?

☐Yes ☐No If yes: ☐by frequency (e.g., number per time period)
☐by type (e.g., side-swipe, rear-end, etc)
☐by severity (e.g., fatal, injury, or PDO)

How do you define "accidents susceptible to correction by traffic signal control?" _____

If severity is considered, how? _____

TxDOT

All of the districts currently use accidents data when conducting a signal warrant analysis. A breakdown of uses by accident frequency, type, and severity shows that most districts use accidents frequency (84 percent), and most use accident type (68 percent), but fewer use accident severity (26 percent).

Part of the controversy surrounding this warrant has been the vague phrase, "accidents susceptible to correction by traffic control." TxDOT districts were asked what their interpretation of this phrase was. Table 24 is meant to summarize the results.

Table 24. TxDOT's Interpretation of Accidents Susceptible to Correction by Traffic Signal Control

Accident Type	Number of Responses
Right Angle	11
Angle	3
Left Turn	3
Opposite Direction	3
Turning Maneuver	2
Same Direction	1
Side Swipe	1
Time of Day and Speed	1

Finally, when asked about severity, few respondents replied. Fatalities were a major concern, as indicated by being included in four of the five comments. One district looks at severity when the intersection is marginally warranted, while another uses severity to determine possible geometric improvements.

States

All but one state indicated that accident data are used when determining the needs for signalization. The survey which contained the response indicating accident data were not used carefully studied. After a review of the entire survey, including the comments, it was obvious that the wrong response was marked. A decision was then made that changed the response to a yes (i.e., accident data are used when determining the needs for signalization).

The breakdown of the use of accident data is similar to TxDOT's responses. Accident data by frequency is used by 76 percent of the responding states; accident data by type is used by 83 percent of the states, and accident data by severity is used by 28 percent of the states. The breakdown of the states' interpretation of the phrase, "accidents susceptible to correction by a traffic signal control" is shown in Table 25.

Table 25. States' Interpretation of Accidents Susceptible to Correction by Traffic Signal Control

Accident Type	Number of Responses
Angle	12
Left Turn	11
Right Angle	10
Rear End	1
All Reportable Accidents	1

When asked how severity was used, most states indicated that if it was used, it was not a stand-alone criteria but an aid to help determine other factors such as benefit-cost calculations, geometric improvements, and a possible indicator of other problems. Some states indicated that a fatal accident may push a nearly warranted intersection over the threshold, and engineering judgement may be used to deem the intersection as warranting an signal.

Cities

All of the cities responding to the survey indicated that they use accident data in the warranting analysis. The breakdown of how the data is used is similar to TxDOT and the other states. For instance, 80 percent use accident frequency, 82 percent use accident type, and 31 percent use accident severity.

The breakdown of the states' interpretation of the phrase, "accidents susceptible to correction by a traffic signal control" is shown in Table 26.

Table 26. Cities' Interpretation of Accidents Susceptible to Correction by Traffic Signal Control

Accident Type	Number of Responses
Right Angle	10
Left Turn	7
Angle	1
Turning Maneuver	1

When asked how severity is used, several good comments were received. For instance, several cities use accident severity in a ranking formula to determine if the intersection warrants a signal and then to develop a priority list of intersections needing signalization. Other cities only use fatal and injury accidents in the warranting analysis, while others use all reportable accidents. One city uses warranting criteria that requires six or more fatal accidents within the previous two years.

PERSPECTIVE ON CURRENT WARRANT ADEQUACY

As indicated by the wide array of research studies discussed and referenced in the literature review section of this report, there is no mistaking that the current signal warranting process has been under scrutiny by traffic engineers for years. The current warrants have been composed by group consensus developed in order to achieve consistency in determining signalization needs. In order to determine how engineers today feel about the adequacy of the current warrants and to elicit comments pertaining to needs for new warrants, the following two questions were proposed. The results of these questions are summarized below by jurisdiction.

Should the existing warrants in the national MUTCD be modified? ☐ *Yes* ☐ *No*

If yes, please specify your recommendations for such modifications: _____

_____

_____

Is there a need for a new warrant(s)? ☐ *Yes* ☐ *No*

If yes, please describe: _____

_____

_____

TxDOT

Nearly 75 percent of the respondents who replied suggested that the existing warrants contained in the Texas MUTCD should not be modified. Those who believed that modifications to the existing warrants are needed expanded their views by providing an array of comments. Most of these comments suggested more stringent warranting criteria. However, a comment of particular interest to this research suggested that intersections near schools or on school bus routes may need special consideration. Further elaboration was not provided.

Similarly, when asked about new warrants, almost all respondents (82 percent) indicated that none are needed. However, two of the three comments were directed towards the inclusion of fatal accidents into the warranting procedure. Accident severity happened to be a focus of the survey, and therefore, more detailed discussion of this topic can be found in the subsequent section.

States

Almost half (43 percent) of the states responding indicated that they believe the existing warrants in the national MUTCD should be modified. However, when asked if new warrants are needed, over 80 percent indicated that there was no need for new warrant(s). The responses to these two questions varied greatly. Table 27 was developed to summarize the comments.

Table 27. States' Views on Current Warrant Adequacy

Warrant/Consideration	Add	Remove	Modify
Peak-Hour Warrants	- -	4	3
Interruption Warrant	- -	1	4
Accident Warrant	- -	- -	3
Delay Consideration	3	- -	- -
High Speed Consideration	- -	- -	3
Left-Turn Consideration	3	- -	- -
Four-Hour Volume Warrant	- -	2	- -
Minimum Volume Warrant	- -	- -	2
Combination Warrant	- -	1	- -

The categorization of the comments is, of course, subject to opinion; however, the results provide a useful tool for establishing a concensus from a wide distribution of comments. The number in each cell of Table 27 refers to the number of comments addressing that particular issue. Some comments addressed multiple issues, and therefore, the total number of remarks, as indicated by the cell totals, are higher than the actual number of responses received.

Overall, the comments generally indicated that the current warrants are too easily satisfied. No comments were received that suggested lowering the thresholds or making warrant criteria more easily attainable. Clearer definitions and more focused guidelines were the basis for some comments, but by and large, the majority of the responses were directed to higher minimum thresholds and more precise estimates of delay and left-turn considerations.

More specifically, results indicate that the conditions established by the Peak Hour Warrants for signalization are too easily met, and therefore, states would like to see more stringent criteria or the removal of these warrants. Other comments pertaining to the volume-based warrants were that the minor street volume conditions were generally set too low, and delay estimates should be obtained before deciding whether these type of warrants are satisfied. Also, the Accident Experience Warrant was a popular topic for remarks. Most often, severity seems to be the main concern. This topic is addressed in greater detail in subsequent sections.

Cities

About 40 percent of the cities responding indicated that they believe the existing warrants in the national MUTCD should be modified. However, when asked if new warrants are needed, only about 30 percent indicated a need. Like the state survey, the responses to these two questions varied greatly. Table 28 was developed to summarize the comments that appeared most often.

Table 28. Cities' Views on Current Warrant Adequacy

Warrant/Consideration	Add	Remove	Modify
Accident Warrant	- -	- -	4
Minimum Volume Warrant	- -	- -	3
Interruption Warrant	- -	- -	3
Speed Consideration	1	- -	2
Turning Movement Considerations	2	- -	1
Delay Consideration	2	- -	- -
Emergency Signal Consideration	2	- -	- -
Four-Hour Volume Warrant	- -	2	- -
PCEs	2	- -	- -
Peak-Hour Warrants	- -	2	- -

The number in each cell of Table 28 refers to the number of comments addressing that particular issue. Some comments addressed multiple issues, and therefore, the total number of remarks, as indicated by the cell totals, are higher than the actual number of responses received.

The cities appear to have the same general feeling about the current warrant adequacy as the states. In other words, most of the comments involved language that is directed toward more stringent criteria to make justification for signalization less likely. The cities' major concern was with the Accident Warrant in that severity or an accident rate (rather than a frequency based) modification may provide more consistent results when compared to engineering judgement.

Like the states, the cities feel that the minor street volume criteria for the volume-based warrants are set too low, and the reduction to 70 percent of the volume under certain situations provides criteria that allow too many intersection to be warranted. Speed, delay, turning movements, and passenger car equivalents were some other considerations the cities noted. Unlike the other jurisdictions surveyed, the cities are concerned about emergency signal criteria. They would like to see clearer guidelines for the justification of emergency signals.

PERSPECTIVE ON THE INCLUSION OF ACCIDENT SEVERITY

As indicated by the completion of recent related research and the ongoing NCHRP Project 17-16, *Accident Warrant for Traffic Signal*, accidents are currently a hot topic with regard to the warranting procedure. The following two questions were designed to elicit comments pertaining to possible methods for including accident severity in the warranting analysis.

Should accident severity be incorporated into the accident warrant?

☐ *Yes* ☐ *No* ☐ *Uncertain*

Comment: _____

_____

_____

If the accident warrant is modified to include accident severity, how should it be done?

☐ *Weighted based on severity of accidents (i.e., fatal, injury, and PDO)*
☐ *Other:* _____

_____

_____

If weighted, indicate the weights you would recommend.

_____ *Fatal accidents*
_____ *Injury accident*
_____ *Property Damage Only accidents (mark an ✗ if these are not to be included)*

Comment: _____

_____

_____

TxDOT

When asked if accident severity should be included in the warrants, 32 percent of the TxDOT respondents replied yes; 68 percent replied no, and 22 percent were uncertain. Comments included a suggestion for possible guidelines for the inclusion of accident severity, but the decision should be ultimately based on engineering judgement. Another suggestion was an exclusion of all alcohol-involved accidents from the warrant analysis.

Only 59 percent of the total TxDOT respondents answered the second question dealing with accident severity. Of these, 63 percent thought that severity should be weighted based on fatal, injury, and PDO. The standardized proportions recommended were 0.56 - fatal, 0.41 injury, and 0.27 PDO. The other 32 percent recommended some other type of method to include severity in the warranting analysis. Of these, two recommended the exclusion of PDO accidents from the warranting analysis. Other comments included suggestions for a combination of accidents and minimum volume criteria. This appears to be based from a high-speed rural intersection where some accidents occur, but, in the engineer's opinion, a traffic signal would obviously not be warranted under operationally-based warrants.

States

When the states were asked to comment on whether they thought accident severity should be incorporated into the warrants, only 7 percent said yes; 65 percent replied no, and 28 percent were uncertain. Comments included such thoughts as accident severity being so highly correlated with high speeds that no inclusion of severity should be included, rather, speed limits should be given further justification. Other comments included worries about all the various factors that are associated with accidents, and if guidelines were set as to how many of a certain type of accidents warrant signals, then the engineering judgement factor that is so crucial in makimg sound engineering decisions would be reduced. Other thoughts included the belief that the difference between a fatal and injury accident is so slight and depends on so many factors, that a guideline could not fully take all factors into account.

When asked if accident severity should be weighted, 58 percent marked yes. The standardized proportions are 0.43 for fatal accidents, 0.33 for injury accidents, and 0.30 for PDO accidents. Seventy-six percent said something other than weighted based on fatal, injury, and PDO. Comments included developing a statewide average for given types of intersections and comparing the study intersection rates to the appropriate statewide average. Another comment suggested using a weighted system based on severity potential of accident type potentially correctable by a traffic signal.

Cities

Twenty-two percent of the cities responded that they think accident severity should be incorporated into the warranting procedure. However, 47 percent did not agree, and 31 percent remained uncertain. The cities expressed the same concerns as did TxDOT districts and other state DOTs. For example, the cities were concerned about how all the factors might be incorporated. One respondent noted that a difference between an injury accident and a fatal accident might be the size

of the vehicle, or whether the occupants were wearing seatbelts. These types of uncontrollable factors should not go overlooked and are currently considered when sound engineering judgement is used. Another comment to note is that, in an indirect way, severity is considered since most PDO accidents are not reported and, therefore, not accounted for when a warrant analysis is conducted.

When asked if accident severity should be weighted based on fatal, injury, and PDO accidents, 56 percent indicated approval while 12 percent marked other and replied with a various array of comments. Examples of comments received include elimination of accidents involving PDO accidents under a certain predetermined amount and the correlation of severity to high speed versus low speed facilities.

Of those indicating approval of the weighting system, standardized scores showed the following results: 0.54 for fatal accidents, 0.30 for injury accidents, and 0.17 for PDO accidents. Comments about the weighting factors were similar to before. For instance, a common concern was that the cities did not want severity, and especially a fatal accident, to result in signalization regardless of other factors. In summary, sound engineering judgement appears to be the method recommended by most cities to account for severity when analyzing accidents data for purposes of signalization needs.

PERSPECTIVE ON THE INCLUSION OF VEHICLE CLASSIFICATION

To obtain an understanding and initial feedback of the inclusion of vehicle classification into the warranting procedure, the survey included the following two questions. The responses are categorized by jurisdiction and follow.

Should vehicle type (i.e., passenger car, heavy truck, bus, etc.) be considered in the warrants?

☐ *Yes* ☐ *No* ☐ *Uncertain*

Comment: _____

_____

_____

If the MUTCD warrants are modified to include vehicle type, how should it be done?

☐ *Equivalency factors*
☐ *Minimum number of heavy vehicles/buses to meet the reduced volume criteria in existing warrants*
☐ *Other:* _____

_____

_____

Comment: _____

_____

_____

TxDOT

Results of the first vehicle classification question asking if vehicle classification should be considered were mixed. While most respondents were uncertain (44 percent), the smallest proportion (19 percent) believed that vehicle consideration should be included in the warranting procedure. The comments were directed towards possible ways to include vehicle classification, and philosophical questions and concerns as to why one should include vehicle classification.

There are basically two ways to incorporate vehicle classification into the warranting procedure. The first is equivalency factors similar to what the HCM uses for capacity analysis. The other is a minimum threshold of certain vehicle types that would be required to meet the reduced volume criteria in the existing warrants. When provided the situation in which the MUTCD were to include vehicle classification into the warranting procedure, 42 percent of the respondents chose equivalency factors, and 28 percent chose the minimum number of certain vehicle types (likely heavy vehicles) to meet the reduced volume criteria in the existing warrants. The remainder of the respondents were uncertain.

States

As with the TxDOT survey, the response to the first vehicle classification question was mixed (approximately one-third believe that vehicle consideration should be considered while one-third do not, and the remaining third are undecided).

The anecdotal data received in the form of comments suggests that the primary concern for the inclusion of vehicle classification into the warranting procedure may be the associated delay of high percentages of larger-than-passenger-car vehicles at an intersection and the required larger gaps that these vehicles need. The use of passenger car equivalents was mentioned twice as a potential method for vehicle classification consideration.

Only 62 percent of the respondents answered the second question pertaining to vehicle classification into the warranting procedure (i.e., if incorporated, how should it be accomplished?). Equivalency factors were the primary method recommended making up 61 percent of the responses to this question. Approximately 22 percent thought that using a minimum threshold of certain vehicle types to reduce the volume criteria in the existing warrants would be a viable option. Finally, the remaining 16 percent had other ideas. One unique idea was to use a vehicle occupancy factor rather than a vehicle characteristic factor which is theoretically based on the degraded operational performance of heavier vehicles compared to passenger cars.

Cities

The cities, like TxDOT and the states, were asked two questions which were designed to elicit comments regarding the consideration of including vehicle classification into the warranting procedure. The first questions asked if vehicle classification should be considered. As before, the results were mixed. Here, the cities indicated a larger proportion of NO responses than TxDOT or the states indicated (44 percent versus 37 and 33 percent, respectively). Of those cities indicating that vehicle classification should be considered, reasons and issues raised were accident rates and

severity levels of larger vehicles compared to passenger cars, school buses, passenger car equivalents, and larger vehicle operational characteristics compared to passenger cars.

Eighty-five percent of the cities answered the second question dealing with methods to incorporate vehicle types. Over half suggested passenger car equivalency factors, while approximately 30 percent recommended using a minimum number of heavy vehicles and/or buses to meet the reduced volume criteria in existing warrants. The remaining proportion (approximately 12 percent) provided various comments. One city has used bus occupancy numbers to convert bus volumes to passenger car equivalency rates.

PERSPECTIVE ON THE INCLUSION OF EMERGENCY SIGNAL LOCATIONS

To address the concerns about emergency signals at locations not clearly defined in the MUTCD, this next question was posed to the district, state, and city engineers to determine if other jurisdictions had the same concerns, and if so, what has been done about them.

The MUTCD contains provisions for the installation of emergency traffic signals (section 4E-18) at locations that do not meet the standard warranting procedure. Similar reservations have been proposed within the scope of this project and are listed below. Indicate the situations in which you feel reservations from the standard signal warranting procedures may be granted.

- ☐ *Hazardous chemical plants adjacent to major roadways using fleets of heavy vehicles for transportation*
- ☐ *Industrial parks entrances with high peak traffic intersecting major roadways*
- ☐ *Military bases intersecting major roadways that frequently transport unknown but potentially hazardous cargo*
- ☐ *Other:* _____
- ☐ *No other exception should be provided*

Comment: _____

_____

_____

TxDOT

Just over half (58 percent) of the TxDOT respondents indicated that no other exceptions should be provided. However, the three options listed in the question, hazardous chemical plants, industrial parks, and military bases were selected by district respondents five, four, and five times, respectively.

Only two comments were provided. One reinforced the majority of the respondents' beliefs that additional provisions for emergency signals should not be provided. The other included concerns of motorists failing to stop at emergency signals because of the signal's almost always green or flashing yellow indication.

States

Forty percent of the states indicated that no other exceptions should be provided for the installation of emergency signals. The rest were split evenly between hazardous chemical plants, industrial parks, and military bases.

The states' comments were along the same lines as the TxDOT comments, with additional suggestions and concerns. A proposed suggestion for dealing with the three situations described in the original question is manual control of the intersection through flagging operations. A concern that was repeatedly noted in the comments was that situations like the ones described here are best dealt with by use of sound engineering judgement.

Cities

The cities were more receptive in terms of allowing for additional provisions to the emergency signal conditions. Only 35 percent felt that no other exceptions should be provided, and the split among the original three conditions was about equal. Other conditions where cities thought provisions should be given consideration include: entrances and exits to exclusive bus transit stations, fire stations and possibly hospitals, and adjacent to schools.

Considerably more comments were received from the cities for this question than others, possibly indicating that issues associated with emergency signals are more prevalent at local levels of government. Nonetheless, cities commented that many requests are made for signals, and with the generalities contained within the existing warrants, it can be difficult to provide justification that the requestor can understand and accept. Another comment received frequently was that emergency signals are for emergency vehicles. These vehicles benefit from a signal by reduced travel time. The original three conditions mentioned in the survey do not require the need for reduced travel time. They may, however, necessitate the need based on safety concerns. Finally, like TxDOT and the states, the cities commented frequently that "other" provisions for emergency signals should be left to sound engineering judgement.

ASSESSMENT OF SURVEY AVAILABLE THROUGH WWW

An electronic version of the survey that was sent to the states and cities was made available through the world wide web (WWW). The introduction page that was available on the WWW is shown in Figure 1. Since the conversion of the Word Perfect file to html required a nominal amount of time to accomplish, this task was chosen in order to accomplish three goals:

4. To provide the recipients a variety of means to respond to the survey (in hopes of increasing the response rate);
5. To reach jurisdictions that were not mailed the survey; and
6. To determine the future feasibility of conducting such information-gathering tasks exclusively through the WWW.

Design

The web page was designed in two stages. The page was an introduction to the project that explained what it was that the survey was to accomplish and who could be contacted if the user had further questions or comments. This page was linked to a second page that contained the survey. When the user accessed this page, they saw the survey. Each question looked practically the same as if it were on paper. In fact, one respondent printed out the WWW version and submitted his answers on it. The differences were slight. Comment boxes were provided instead of comment lines. Where multiple choices could be made, the default was set at no choices. Where choices were mutually exclusive, the use was not permitted have a multiple answer. After the user completed the survey, they entered it by clicking on a submit button located at the bottom of the survey page. Before the survey was accepted, several checks were automatically run to make sure that some predefined fields had been entered. These fields included name, phone number, jurisdiction, and other similar introductory information. If the user had not completed at least these parts of the survey, they were notified that they had missing information and the survey was entered into the database. They were returned to their partially completed survey in order to rectify the situation. Once all the predefined information was correctly entered, the survey was submitted.

The surveys, as well as the html code that was used to create the introduction and survey page, were located on a server within TTI. Once a survey was submitted, it was saved to this server in ASCII code. A program was developed that concatenated the results into one ASCII file that could easily be incorporated into the manually generated database from the mail-out surveys that were returned.

TTI/TxDOT Research Study on Traffic Signal Warrants

Thanks for visiting the signal warrant survey homepage. The survey has been converted electronically, and we look forward to receiving your response. A brief summary of the project is provided herein with a link to the survey at the bottom of the page. Thanks for your cooperation.

Background

A fatal accident in the Houston area involving a school bus prompted citizen demand for a traffic signal. TxDOT conducted two separate warrant analyses, both of which indicated that the intersection does not meet any traffic signal warrants. However, special features of the intersection indicate that a signal might be appropriate. These features include: high volume of heavy vehicles and especially school buses, close proximity to a high school, the major entrance to a subdivision, and high speeds on the major road.

Recognizing that there may be factors that support the installation of a traffic signal even though warrants are not met, TxDOT funded a research study to look at factors that should be incorporated into the warranting process. Two specific issues that were identified in the problem statement are school buses (and heavy vehicles) and fatal accidents. The research study is a one-year effort, with a budget of $80,000. The project started in April 1997.

Research Activities

The initial research activities have led researchers to the conclusion that the research should focus on the impact of vehicle types, specifically heavy vehicles, on the warranting process. This vehicle classification could include motorcycles, passenger cars, single-unit trucks/recreational vehicles, tractor-trailer combinations, and buses, including school buses. The expansion of the research from just school buses to include other vehicles types was prompted by the fact that Texas has a large number of plants producing hazardous chemicals. These plants are supported by fleets of heavy vehicles carrying volatile cargos, which create the need for extra safety measures. The research will focus on developing a means of incorporating vehicle classification into the warranting process. This could be done by developing a procedure/interpretation of an existing warrant(s), revising an existing warrant(s), or developing a new warrant(s).

The fatal accident issues will also be investigated but to a lesser extent. NCHRP recently began a study focusing on the development of an improved accident warrant. The NCHRP study will address many of the accident-related issues that TxDOT is concerned about. Therefore, the need to address fatal accidents as part of the TxDOT study has been reduced. TTI is coordinating research activities with the NCHRP study contractor, Bellomo-McGee, Inc. For more information about this NCHRP project, contact Michael Obermeyer at (703) 917-0710 or BMIVA1@AOL.COM.

Your Assistance

TTI is presenting this information to solicit comments and suggestions on the warrant issues being studied. If you have comments or suggestions, please contact Paul Carlson using the email address below. We are also asking that you take a few minutes to complete the signal warrant survey. This survey has been sent to the 25 TxDOT districts, all state transportation agencies, and cities with populations greater than 100,000.

Contacts	TTI Researchers	TxDOT Project Director
	Paul Carlson and Gene Hawkins	Dan Maupin
	(409) 845-6004	

Submission of survey results

You may return the survey results by mailing them to Paul Carlson or by using this web page. Please click on this link to fill in and submit the survey results.

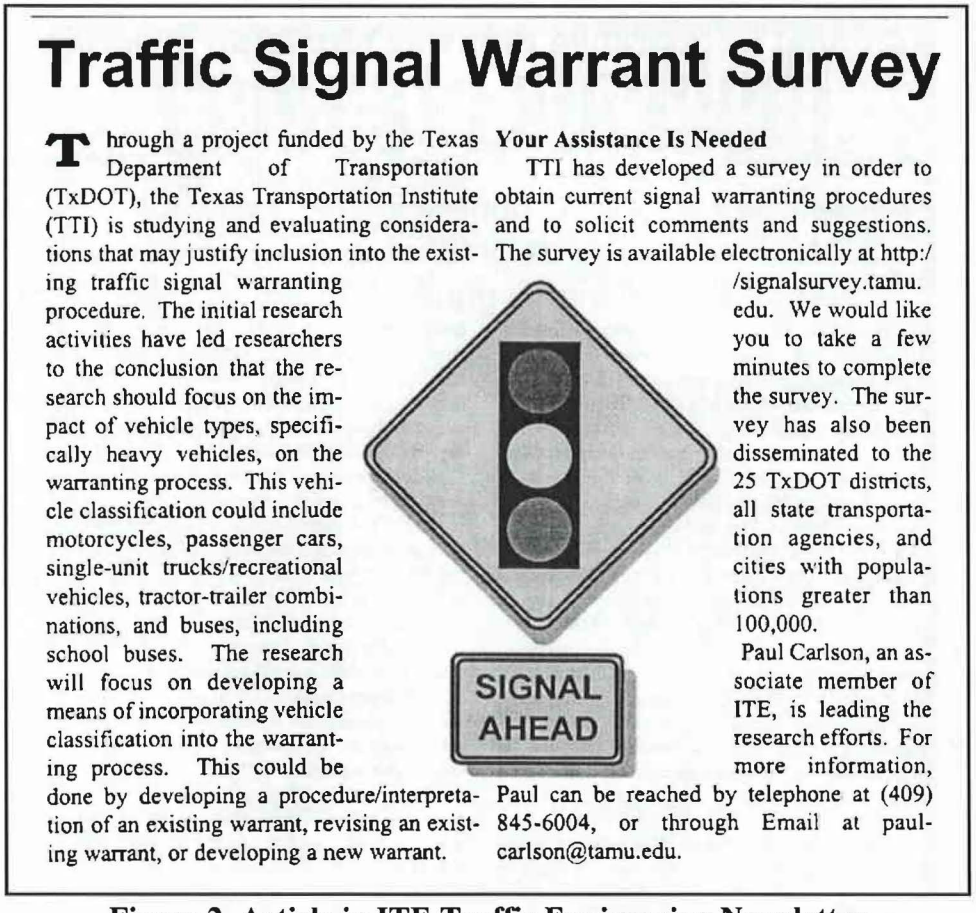
This page has been visited 4 times since 4 August, 1997.
Total number of survey submitted:
Last update: 9 September, 1997, 14:30 CDT

Figure 1. Internet Introduction

Awareness

Because awareness was not a main goal of the project, limited resources were devoted to making the traffic engineering profession aware of the survey's existence on the WWW. However, the following tasks were performed to inform the profession of the survey's availability.

1. A flyer was inserted into the mail-out surveys notifying the recipient of the survey's existence on the WWW.
2. The ITE Traffic Engineering Council publishes a quarterly newsletter to all its members. The 1997 Summer/Fall (Volume 3, Issue 3) issue of this newsletter contained the insert shown in Figure 2.
3. The ITE home page which contains a section entitled, "What's New" contained a brief introduction to the survey and a link to the survey WWW page.
4. Using the ITE Traffic Engineering list-serv (a list-serv is an internet feature that allows thousands of discussion groups, via e-mail, to place themselves on electronic mailing lists. These mailing lists are maintained by software. The software automatically distributes an e-mail message from one member of a list to all other members on that list. Thousands of lists in the form of digests, electronic journals, discussion groups, and the like are available), an announcement of the research, its goals, and the survey web page was made.



Traffic Signal Warrant Survey

Through a project funded by the Texas Department of Transportation (TxDOT), the Texas Transportation Institute (TTI) is studying and evaluating considerations that may justify inclusion into the existing traffic signal warranting procedure. The initial research activities have led researchers to the conclusion that the research should focus on the impact of vehicle types, specifically heavy vehicles, on the warranting process. This vehicle classification could include motorcycles, passenger cars, single-unit trucks/recreational vehicles, tractor-trailer combinations, and buses, including school buses. The research will focus on developing a means of incorporating vehicle classification into the warranting process. This could be done by developing a procedure/interpretation of an existing warrant, revising an existing warrant, or developing a new warrant.

Your Assistance Is Needed

TTI has developed a survey in order to obtain current signal warranting procedures and to solicit comments and suggestions. The survey is available electronically at http://signalsurvey.tamu.edu. We would like you to take a few minutes to complete the survey. The survey has also been disseminated to the 25 TxDOT districts, all state transportation agencies, and cities with populations greater than 100,000.

Paul Carlson, an associate member of ITE, is leading the research efforts. For more information, Paul can be reached by telephone at (409) 845-6004, or through Email at paul-carlson@tamu.edu.

Figure 2. Article in ITE Traffic Engineering Newsletter

Results

The introduction page included two counters – one which recorded the number of times the page had been visited and the other recorded how many surveys were submitted (see Figure 1). Tables 29 and 30 summarize the results of this effort.

Table 29. WWW Survey Usage

Number of visits	85
Number of partially completed surveys	11
Number of fully completed and usable surveys	8

Table 30. WWW Survey Respondents' Jurisdictional Origin

TxDOT	1
State	3
City	4

One of the goals of this task was to provide the recipients an alternative means to completing the survey. Five of the eight respondents can be classified into this category. Another goal was to reach jurisdictions not mailed a survey. This happened twice as two cities who were not mailed a survey completed the WWW survey. One city was located in Canada and the other was in California. The last goal of this task was to measure the feasibility of conducting "paperless" surveys through the internet and email. The results indicate that the technology is available to accomplish this; however, other issues remain unanswered. For instance, does the user prefer a hard copy version of the survey or would a letter informing the user of the survey on the WWW be sufficient? Which method would lead to a better response rate? Do the all the agencies have internet and email capabilities? Answers to these questions remain, but overall, it appears that it is too early to make the step to a paperless survey. Currently, to be as comprehensive as possible, the survey should be disseminated through traditional means and if so desired, then electronically-based surveys may be used to supplement the more traditional means.

CHAPTER 5
DETERMINATION OF HEAVY VEHICLE NEEDS

The review of the literature and the outcome of the survey result in mixed findings. While several warrants have been proposed that include considerations for heavy vehicles, none have been formally adopted by FHWA or TxDOT for inclusion in either respective MUTCD. Furthermore, from the supplemental warrants provided by other agencies (as requested in the survey), it appears that no formal consideration of heavy vehicles is used in the warranting analyses.

However, a significant amount of research has been conducted pertaining to operational effects of heavy vehicles at intersections, albeit the majority of this research has been related to operational effects at signalized intersections. Nonetheless, it is apparent that heavy vehicles do influence the overall intersection operations and hence, the consideration of heavy vehicles into the warranting process may, intuitively at least, justify further investigation.

Before additional research is directed toward including heavy vehicles in the warranting process, perhaps the most critical initial step is to analyze the nature of heavy vehicle operations at intersections. For instance, prior to conducting field studies to determine particular values of heavy vehicles that may be appropriate for determining some form of criteria in the warranting analysis, the nature of heavy vehicles and how they influence operations at intersections could render studies irrelevant. An appreciation of the relative influence of heavy vehicles on intersection operations may help to determine if further studies are justified that focus on the determination of heavy vehicle criteria for inclusion into the warrants.

To evaluate this hypothesis, the impact of heavy vehicles on intersection operation was evaluated using intersection delay as the measure of effectiveness. Analyses were conducted under a variety of assumptions and goals. The proposed 1997 HCM unsignalized intersection analysis procedures (22) were used to determine intersection delay. It is expected that these proposed procedures will replace the current unsignalized intersection analysis procedures (contained in the 1994 update to the 1985 HCM) when a new update of the HCM is released (estimated release data is late summer, 1998). The analyses consist of a brief description of the assumptions followed by a sensitivity analysis of the pertinent warrants. The sensitivity analyses yield a value known as the elasticity. Elasticity is a concept used in economics to relate one parameter to another. In economic theory, elasticity is the sloe of the demand-price curve at a given time point. Elasticity is a measure of the change in demand for a unit change in price. The economic elasticity is weighted by the equilibrium point on the demand-price curve. In essence, the elasticity is a measure of the sensitivity of the demand curve to price. In the application of this study, the sensitivity of the HCM unsignalized intersection procedures are measured with respect to the heavy vehicle influence. These sensitivities are weighted by the mean. As both sensitivities measure the change in one variable with respect to a second independent variable, the term elasticity is adopted and used throughout this report as a single measure of a relationship's sensitivity.

The elasticity values computed in the sensitivity analyses for this report are expressed in terms of the ratio of the change in intersection delay over the range of interest to the mean intersection

delay divided by the ratio of change in the selected parameter over the range of interest to the mean of that parameter.

INTRODUCTION

The warrants that may be influenced by the inclusion of considerations for heavy vehicles are the volume and delay based warrants. These warrants include:

- Warrant 1 - Minimum Vehicular Volume
- Warrant 2 - Interruption of Continuous Traffic
- Warrant 8 - Combination of Warrants
- Warrant 9 - Four Hour Volume
- Warrant 10 - Peak Hour Delay
- Warrant 11 - Peak Hour Volume
- Warrant 12 - Traffic Actuated Signals

These warrants have been established to address various issues associated with signalization. They were also introduced into the Manual at various times and, thus, were developed during different times when signal control operations ranged from mostly pretimed to mostly actuated. Therefore, the conditions for which the warrants were developed vary greatly. For instance, warrants 1 - 3, 5 - 6, and 8 were developed for pretimed signal operation. They originated in the 1920s and 1930s (based on the consensus of traffic engineers) and have not changed significantly. Although warrants for actuated signals were also developed at this time, they were later dropped from the warranting procedures. As technology evolved and was applied to signalized intersection operations, it became apparent that changes were needed. This evolving technology allowed signal timings to be vehicle actuated with more flexibility and greater efficiency. During the same time, traffic engineers identified a need for warrants based on variable volumes. This became apparent when intersections were not formally warranted based on the discrete volume combinations in warrants 1, 2, or 8, but because of a significantly higher minor approach volume, perhaps nearing the major volume, signalization was clearly needed. Because of these issues, new warrants were needed that accounted for the increased flexibility with actuated signal operations and incorporated variable volume thresholds. Consequently, on January 1, 1985, warrants 9, 10, and 11 became effective (at least for the national Manual). These warrants are based on variable combinations of volumes and are also meant to account for the flexibility of actuated signal control.

This discussion provides a basis for classifying the warrants into categories for evaluation purposes. Warrants 1, 2, and 8 are discrete volume based warrants, and as such, should be classified separately from the remainder of the warrants under consideration. They could be analyzed as aggregated into this category; however, because of their significant use, they will be evaluated individually.

Warrants 9 through 12 are considerably different from warrants 1 through 8 in the purposes they serve, the conditions under which they were developed, and their defining criteria. These warrants, therefore, may justify a separate category for analysis. However, because the Peak Hour Delay Warrant (warrant 10) includes discrete criteria and is based on delay rather than variable volume, it will be classified separately from the remainder of the warrants.

This leads to five categories that will be analyzed in terms of heavy vehicle considerations. These categories include:

- Discrete Volume Based (Warrant 1 - Minimum Vehicular Volume)
- Discrete Volume Based (Warrant 2 - Interruption of Continuous Traffic)
- Combination of Discrete Volume Based (Warrant 8 - Combination of Warrants)
- Delay (Warrant 10 - Peak Hour Delay)
- Variable Volume Based Warrants (Warrant 9, 11, and 12 - Four Hour Volume, Peak Hour Volume, and Traffic Actuated Signals)

In order to maintain consistency between the analyses, one intersection configuration was evaluated. The intersection configuration was selected to represent the most common type of intersection that may require a warranting analysis. Descriptions of the study intersection configuration as well as assumptions made concerning the analyses are listed below:

- Intersection geometry consisted of one through lane on the major approaches supplemented with a left-turn bay on each major approach. The minor approaches consisted of one-lane approaches. Figure 11 illustrates the intersection geometry.
- In an earlier but related study (39), Williams et al. found that two-way stop controlled intersections at marginally warranted intersections always operated with less intersection delay than four-way stop controlled intersections. Therefore, four-way stop controlled intersections were not considered within these analyses. All calculations are based on two-way stop controlled intersections.
- The volume distributions and turning movement distributions were based on intersection data collected at a total of 68 sites. The data were collected for and used on another research study (22). Figure 3 shows the movement assignments at the intersection under study, and Table 31 summarizes the assumed volume and turning movement distributions.
- Calculations of capacity and delay were based on the recommended models and procedures developed as part of NCHRP 3-46. Harders basic capacity model including impedance and the 1994 HCM delay equation were used. The capacity model is based on gap acceptance theory. The delay equation is included in the 1994 HCM and is also recommended for the next edition of the HCM. It is based on random flows which coincide with the volume thresholds for traffic signal warrants. These models and their respective parameters are described below.
- Critical gaps and follow-up times were all based on the general recommendations of the NCHRP 3-46 report. The values used are shown in Table 32.

$$c_{p,x} = V_{c,i} \frac{e^{-\frac{\left(\sum_y V_{c,y}\right) t_c}{3600}}}{1 - e^{-\frac{\left(\sum_y V_{c,y}\right) t_f}{3600}}}$$

$$D = \frac{3600}{c_{p,x}} + 900T\left[\frac{V_x}{c_{p,x}} - 1 + \sqrt{\left(\frac{V_x}{c_{p,x}} - 1\right)^2 + \frac{\left(\frac{3600}{c_{p,x}}\right)\left(\frac{V_x}{c_{p,x}}\right)}{450T}}\right]$$

where:

$c_{p,x}$	=	potential capacity of minor movement x, (vph)
$V_{c,y}$	=	volume of traffic in conflicting stream y, (vph)
t_c	=	critical gap, (sec)
t_f	=	follow-up time, (sec)
D	=	average total delay (sec/veh)
T	=	analysis time period, (hours)
V_x	=	volume for movement x, (vph)

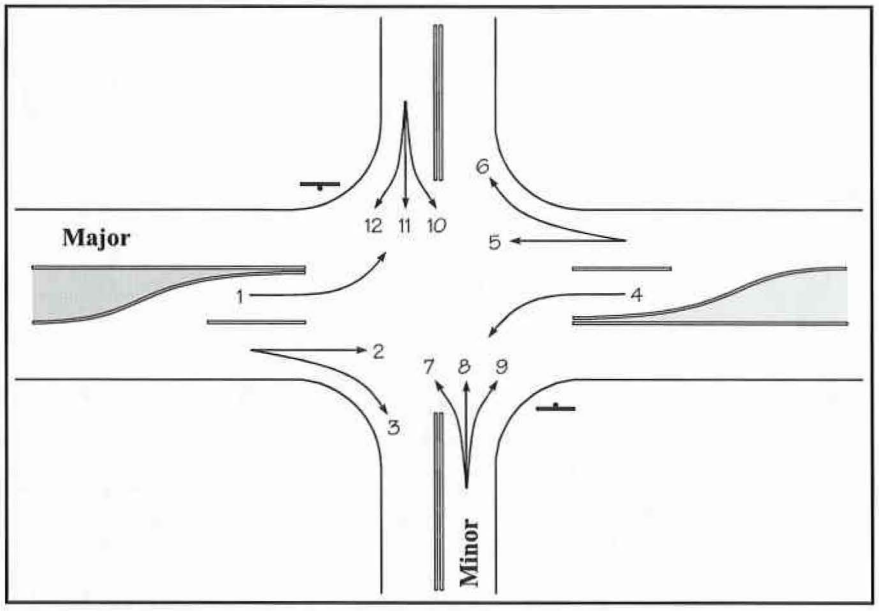


Figure 3. Intersection Movement Assignments

Table 31. Volume and Turning Movement Distributions

Volume	Approach Split (%)	Movement Split (%)	Movement
Total Major Volume	50	10	1
		75	2
		15	3
	50	15	4
		70	5
		15	6
Total Minor Volume	70	20	7
		40	8
		40	9
	30	25	10
		50	11
		25	12

Table 32. Critical Gap and Follow-Up Times for TWSC Intersections

Vehicle Maneuver	Critical Gap, t_c (sec)		Follow-Up Time, t_f (sec)
	2-Lane Major Road	4-Lane Major Road	
Left Turn Major	4.1	4.1	2.2
Right-Turn Minor	6.2	6.9	3.3
Through-Traffic Minor	6.5	6.5	4.0
Left-Turn Minor	7.1	7.5	3.5

Using the capacity and delay models presented above, it is apparent that the effect of vehicle composition is accounted for by critical gap and critical follow-up times. Therefore, to determine the effect of heavy vehicles on intersection operations, critical gap and follow-up times must be based on the traffic composition. Consequently, critical gap and follow-up times are needed for each vehicle type for each movement at an intersection. Several research studies have investigated all vehicle-movement combinations while other studies have focused on one or two possible combinations of all the possible vehicle-movement combinations. The results of these studies do

not provide consistent recommendations concerning discrete values of each vehicle type for each movement; however, they are in agreement that heavy vehicles require longer critical gaps and follow-up times. Perhaps the most comprehensive analysis of heavy vehicle critical gap and follow-up times was conducted as part of NCHRP 3-46. Although the work conducted as part of this research was not particularly focused on the determination of heavy vehicle critical gap and follow-up time values, it did manage to obtain a substantial number of heavy vehicle movements through the study intersections. The results of this work, in terms of critical gap and follow-up time adjustments for heavy vehicles and other factors, are the following:

$$t_{c,adj} = t_{c,base} + t_{c,HV} \times P_{HV} + t_{c,g} \times g - t_{c,T} - f_{3,LT}$$

$$t_{f,adj} = t_{f,base} + t_{f,HV} \times P_{HV}$$

where:

$t_{c,adj}$ = adjusted critical gap for movement x
$t_{c,base}$ = base critical gap for movement x from Table 32
$t_{c,HV}$ = adjustment factor for heavy vehicles: 1.0 for two-lane major streets and 2.0 for four-lane major streets
P_{HV} = proportion of heavy vehicles for movement x
$t_{c,g}$ = adjustment factor for grade: 0.1 for movements 9 and 12 and 0.2 for movements 7, 8, 10, and 11
g = percent grade divided by 100
$t_{c,T}$ = adjustment factor for each part of a two-stage gap acceptance process: -1.0 for first stage or second stage
$f_{3,LT}$ = -0.7 for minor street left-turn movement at three leg intersection; 0.0 otherwise
$t_{f,adj}$ = adjusted follow-up time for movement x
$t_{f,base}$ = base follow up time for movement x from Table 32
$t_{f,HV}$ = adjustment factor for heavy vehicles; 0.9 for two-lane major streets, and 1.0 for four-lane major streets

Using the critical gap and follow-up time relationships with the capacity and delay models, the effect of heavy vehicles at unsignalized intersections operating at volume levels similar to the thresholds found in the warrants can be analyzed. Therefore, the impact of various levels of heavy vehicles on intersection operations can be determined in order to assess the need to quantify traffic signal warrant thresholds for these types of vehicles.

To accomplish this, sensitivity analyses were performed on the recommended practice for two-way stop controlled intersections. As discussed previously, the measure of effectiveness used in all analyses was total intersection delay. Using the estimated total intersection delay values, elasticity values were calculated. The elasticity values are the ratio of the change in the total intersection delay over the range of interest to the mean total intersection delay divided by the ratio of the selected parameter over the range of interest to the mean of that parameter. Figure 4 illustrates an example of the elasticity value (E_d) calculated for a major street volume of 1,000 vehicles per hour and minor

street volume of 200 vehicles per hour (these volumes correspond to the threshold volume requirements for signalization according to the Peak Hour Volume Warrant curve associated with the stated assumptions), with a range of heavy vehicle percentages beginning at 0 percent and continuing to 20 percent.

MUTCD Peak Hour Volume Warrant Threshold for Signalization		Total Intersection Delay (sec/veh)		Elasticity, E_d
Major (vpd)	**Minor (vpd)**	**No HVs**	**20% HVs**	
1000	200	4.06	4.60	0.062

$$E_d = \frac{\frac{4.0636 - 4.5975}{\frac{4.0636 + 4.5975}{2}}}{\frac{20 - 0}{\frac{20 + 0}{2}}} = \frac{\frac{4.0636 - 4.5975}{\frac{4.0636 + 4.5975}{2}}}{\frac{20 - 0}{20 + 0}} = 0.062$$

Figure 4. Sample Calculation

The results of the sample computation shown in Figure 4 indicate that total intersection delay will change by 0.062 percent for each 1.00 percent heavy vehicle volume over the range of interest for heavy vehicle volume. It should be noted that in this analysis, when heavy vehicle volume is increased or is being interpreted as being increased by a certain percentage, the increase is assumed constant for both the major and minor street approaches. In other words, it is not sensitive to increases in minor or major volumes, exclusive of the other. Since the relationship between various parameters and intersection delay is not linear, the sensitivity of intersection delay to the parameter is not constant over the range of interest. However, the elasticity value is an accepted practice that represents the sensitivity with a discrete number. A positive value for E_d indicates that intersection delay increases with increasing values of the parameter of interest. A negative value of E_d indicates that intersection delay decreases with increasing values of the parameter.

SENSITIVITY ANALYSIS

Using a spreadsheet, sensitivity analyses were performed using the capacity and delay models introduced above. The goal was to determine the effect of heavy vehicles at two-way stop controlled intersections operating at volume levels similar to the thresholds found in the five volume-based warrants listed above. A multivariate sensitivity analysis approach was used where the measures of effectiveness were average total intersection delay and the maximum average minor approach delay. Using this technique, the major and minor volumes were varied by increments of 25 vph and stepped through ranges of 500 to 1,800 vph and 100 to 600 vph, respectively. For each volume combination, heavy vehicle percentage was also varied (by ten percent increments from zero to twenty percent). The results were 53 major street volumes × 21 minor street volumes × 3 heavy

vehicle percentages = 3,339 estimates of total intersection delay and 3,339 estimates of highest minor approach delay.

Using this technique, elasticity values were determined for the entire range of volume combinations. The results were tabulated and then plotted. Figure 5 shows a summary plot of the elasticity values calculated using total intersection delay as the measure of effectiveness.

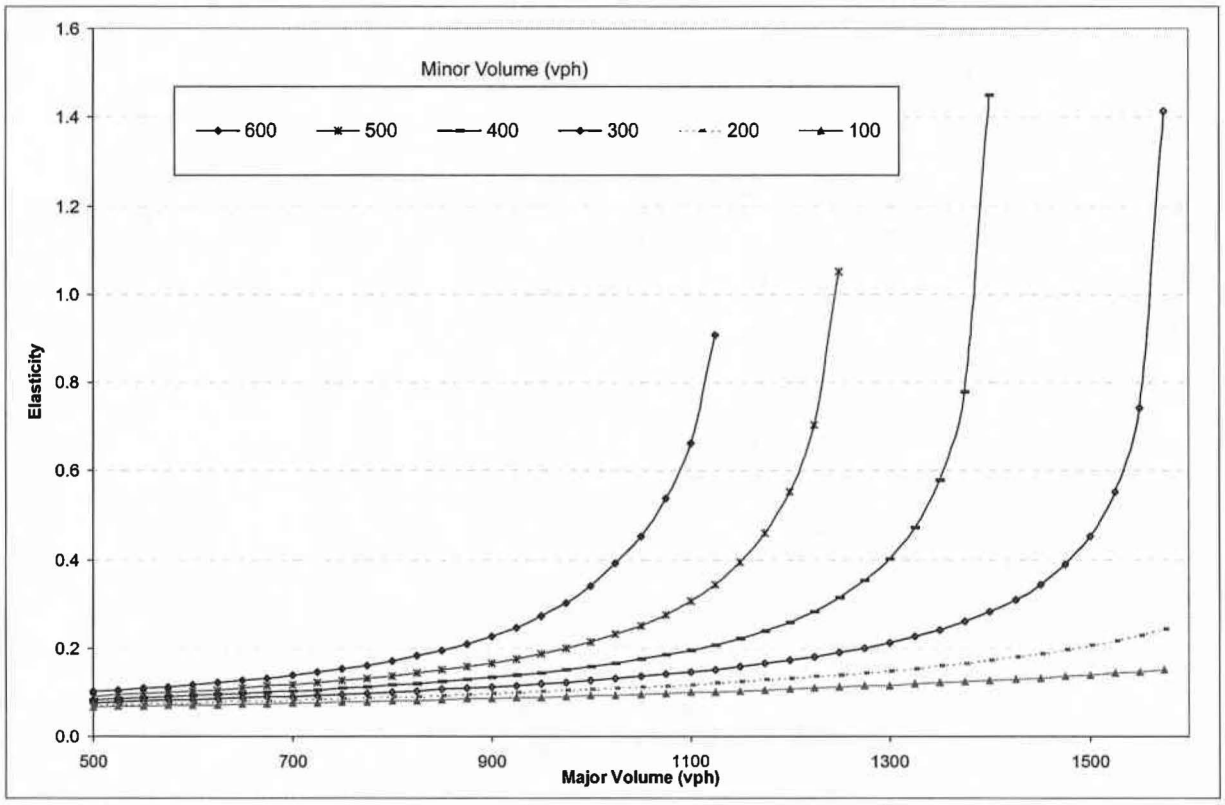


Figure 5. Multivariate Sensitivity Analysis

This figure indicates that as the total volume entering the intersection increases, the sensitivity of the intersection operations related to the increase in heavy vehicles also increases. However, the relationship is not linear. For relatively low volume combinations, heavy vehicles do not impact intersection operations significantly. As volume combinations increase, the impact of heavy vehicles related to intersection operations begin to take effect. It is not until the volume combinations reach a significant level that the impact of heavy vehicles becomes a concern. Likewise, at these levels, the intersection should already be signalized, and therefore, the question of signalization becomes a moot point.

The areas of concern in Figure 5 are volume thresholds defined in the volume-based warrants (i.e., Warrant 1 - Minimum Vehicular Volume, Warrant 2 - Interruption of Continuous Traffic, Warrant 8 - Combination of Warrant, Warrant 9 - Four Hour Volume, Warrant 10 - Peak Hour Delay, Warrant 11 - Peak Hour Volume, and Warrant 12 - Traffic Actuated Signals). A discussion of heavy vehicle effects on each of these warrants (categorized as defined above) follows.

Warrant 1 - Minimum Vehicular Volume

According to the survey results, TxDOT most frequently uses warrant 1. The results of the survey show that it was the primary warrant used to justify signalization during the time period from 1995 to, and including, 1997 (28 percent). Other states and cities used this warrant even more than TxDOT (44 and 36 percent, respectively). Without a doubt, this warrant is the primary warrant used to justify signalization.

The volume thresholds established for this warrant are shown in Table 35. Regardless of the geometry of the intersection, the major volume threshold is 500 to 600 vph while the minor volume threshold is 150 to 200 vph. For conditions such as high speed approaches or intersections in isolated communities with populations less than 10,000, these thresholds can be reduced to 70 percent of the requirement. Using these thresholds and Figure 5, it is apparent that at such low volumes, heavy vehicles do not impact intersection operations significantly. The elasticity values calculated for these volume combinations are also shown in Table 35. Using the average of the elasticity values (0.0724), the effect of heavy vehicles on warrant 1 volume thresholds can be quantified in terms of heavy vehicle percentages. That is, for every 1.00 percent increase in heavy vehicles at the volume combinations established for warrant 1, the total intersection delay will increase by 0.0724 percent.

Table 33. Volume Thresholds for Warrant 1

Geometry		Volume		Elasticity
Major	Minor	Major	Minor	
1	1	500	150	0.0687
2 or more	1	600	150	0.0734
2 or more	2 or more	600	200	0.0764
1	2 or more	500	200	0.0712

Warrant 2 - Interruption of Continuous Traffic

The TxDOT survey results indicated that this warrant was used 16 percent of the time to warrant signals in the last three years. The warrant applies to operating conditions where the traffic volume on a major street is so heavy that traffic on a minor intersection street suffers excessive delay or hazard in entering or crossing the major street. This purpose differs from warrant 1 which is intended for application where the volume of the intersecting traffic is the principle reason for consideration of signal operation. Because warrant 2 focuses on excessive delay and higher major street volumes, the effect of heavy vehicles should be more pronounced than for warrant 1.

The volume criteria for warrant 2, excluding reduction exceptions, and respective elasticity values are displayed in Table 34. As expected, with the higher volumes associated with warrant 2, the sensitivity of heavy vehicles is somewhat greater. However, the difference is not significant.

Averaging the elasticity values over the range of volume combinations results in an elasticity value of 0.0804. As before, this value can be used to estimate the effect of heavy vehicles on intersection operations at volume levels indicative of a marginally warranted intersection based on warrant 2. This effect can be estimated such that for every 1.00 percent increase in heavy vehicles at the volume combinations established for warrant 2, the total intersection delay will increase by 0.0804 percent.

Table 34. Volume Thresholds for Warrant 2

Geometry		Volume		Elasticity
Major	Minor	Major	Minor	
1	1	750	75	0.0755
2 or more	1	900	75	0.0830
2 or more	2 or more	900	100	0.0855
1	2 or more	750	100	0.0774

Warrant 8 - Combination of Warrants

This warrant was originally developed to be used with warrants 1, 2, or 3. However, the 1988 national MUTCD modified warrant 3 and consequently, eliminated the use of warrant 3 to satisfy the requirements for this warrant. The Texas MUTCD still allows for the consideration of warrant 3 when attempting to satisfy the warranting criteria under this warrant. Even with these key differences, TxDOT, other state DOTs, and cities use this warrant to justify signalization at about the same rate. TxDOT used this warrant for primary justification on 4 percent of the signals installed on the state system between 1995 and 1997. Likewise, other DOTs also used this warrant 4 percent of the time. Cities responding to the survey used this warrant on 5 percent of their signal installations.

According to the Texas MUTCD, warrant 8 is intended to be used when no single warrant is met but where two or more of warrants 1, 2, or 3 are satisfied to the extent of 80 percent or more of the stated values. This warrant is then a reduction factor for the volume combinations in warrants 1 and/or 2. As such, it requires fewer entering vehicles to satisfy the warrant than warrants 1 or 2 require. As shown in Figure 5, the impact of heavy vehicles decreases with decreasing the total entering vehicles. Also, the analyses of the Minimum Volume and the Interruption of Continuous Traffic Warrants (warrants 1 and 2, respectively) demonstrated that at the volume thresholds required to satisfy each warrant, the impact of heavy vehicles, was practically negligible. Because this warrant requires even fewer vehicles to satisfy the criteria, and it has been determined that with fewer entering vehicles the impact of heavy vehicles is decreased, the overall impact of heavy vehicles will be even less than it was for the volume thresholds in warrants 1 or 2.

Warrant 10 - Peak Hour Delay

The Peak Hour Delay Warrant is not commonly used to warrant signalization. According to the results of the survey, TxDOT has used this warrant once during a three-year time frame (from 1995 to 1997). Other jurisdictions use this warrant just as infrequently as TxDOT (for states, the results were 2 percent and cities were 1 percent).

The Manual indicates that this warrant is intended for application where traffic conditions are such that for one hour of the day minor street traffic suffers undue delay in entering or crossing the street. Conditions that must be met for this warrant to be satisfied for one hour (any four consecutive 15-minute periods) of an average weekday are listed below:

- The total delay experienced by the traffic on one minor street approach (one direction only) controlled by a Stop sign equals or exceeds four vehicle-hours for a one-lane approach and five vehicle hours for a two-lane approach, and
- The volume on the same minor street approach (one direction only) equals or exceeds 100 vph for one moving lane of traffic or 150 vph for two moving lanes and
- The total entering volume serviced during the hour equals or exceeds 800 vph for intersections with four (or more) approaches or 650 vph for intersections with three approaches.

Using the highest minor approach values calculated earlier, the minimum criteria to satisfy this warrant were applied to the data. The volume combinations where the criteria were satisfied were recorded. This was completed for a range of heavy vehicle percentages from 0 to 20, using a stepping increment of 10 percent. The results are plotted in Figure 6.

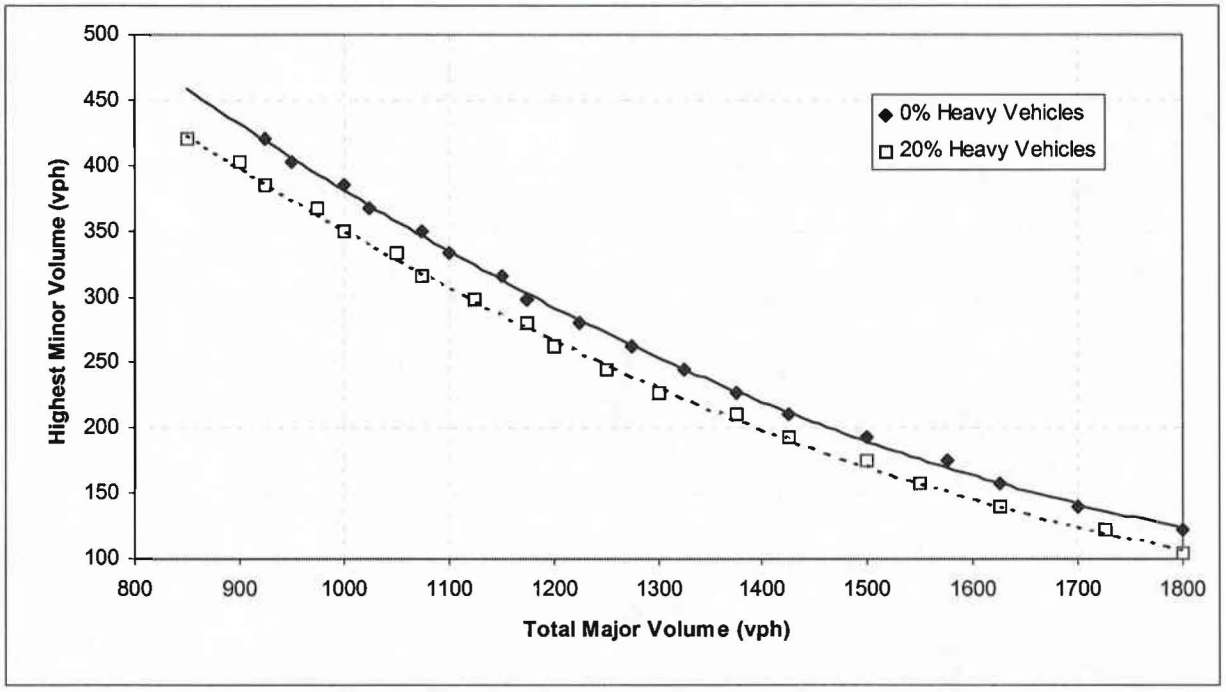


Figure 6. Heavy Vehicle Effect On Peak Hour Delay Warrant

Figure 6 shows the impact of heavy vehicle considerations under the warranted volume combinations determined from the criteria set forth by the Manual in regards to the Peak Hour Delay Warrant. The top line represents the volume combinations that would need to be present to warrant signalization under the Peak Hour Delay Warrant (given the intersection configuration and assumptions discussed earlier in this chapter). The bottom line represents the same as the top with the addition of heavy vehicle considerations.

Warrants 9, 11, and 12 – Four Hour Volume, Peak Hour Volume, and Traffic Actuated Signals

The survey results indicate that these warrants are the second most popular set of warrants used to justify signalization (the most popular set of warrants is the main discrete volume based warrants, i.e., 1 and 2). Table 35 summarizes the use of these warrants.

Table 35. Use of Variable Volume Based Warrants

Agency	Warrant No.			Total
	9	11	12	
TxDOT	3	12	19	34
States	4	7	0	11
Cities	9	11	0	10

As discussed earlier, TxDOT has been using an additional warrant not contained in the national Manual. This warrant, Traffic Actuated Signals (warrant 12), is used when warrants 1 through 11 cannot be satisfied but where unpredictable peak hour(s) may occur on either the total of both major approaches or the highest of the minor approach. This warrant, as indicated by the high percentage shown in Table 35, has become the second most used by TxDOT to justify signalization. Comments received formally and informally indicate that engineers around the state feel that it is too easily satisfied and should be adjusted with higher thresholds.

The Peak Hour and Four Hour Warrants (warrants 11 and 9) are similar to warrant 12 in that they are based on variable volume thresholds. For all three warrants, plotted points representing vehicles per hour are plotted on warrant curve figures. If the points fall above a predetermined line (based on intersection configuration), then the warrant is met. Because of the similarity of these warrants, they have been classified together. The analysis of these warrants will focus on only one – the Peak Hour Warrant. This warrant has been chosen to represent the group for several reasons. First is that it is the most commonly used warrant within the group that is common to all jurisdictions. Second, it is very similar in intention to the Actuated Traffic Signal Warrant. Last, despite its name, the Peak Hour Warrant is based on delay fundamentals. This warrant is meant to be applied to intersections where short bursts in traffic demand exist. These areas include industrial park entrances, school campuses, shopping centers, and the like. Because of the characteristics associated with these types of facilities, heavy vehicles can routinely be included in the mix of vehicles during the peak periods. Consequently, the effect of heavy vehicles on the Peak Hour Volume Warrant is crucial in the development of recommended practices.

The goal of this analysis was to determine the effect of heavy vehicles at two-way stop controlled intersections operating at volume levels similar to the thresholds found in the Peak Hour Volume Warrant. Different values of intersection delay were calculated as the heavy vehicle percentage was stepped through a range of values (0 to 20 percent of the total traffic entering the intersection) for each major and minor volume combination defining the signalization threshold for a one-lane - one-lane geometric combination. Remaining variables were kept constant throughout this process. Two measures of effectiveness were used to determine two unique elasticity values. The first was total intersection delay, and the second was the maximum minor approach delay. Table 36 summarizes the results.

Table 36. Sensitivity Analysis of Peak Hour Volume Warrant

MUTCD Peak Hour Volume Warrant Threshold for Signalization*		Total Intersection Delay (sec/veh)		Elasticity (E_d)	Minor Approach Delay (sec/veh)		Elasticity (E_d)
Major (vpd)	Minor (vpd)	No HVs	20% HVs		No HVs	20% HVs	
500	424	5.618	6.221	0.051	11.12	12.41	0.055
538	400	5.478	6.072	0.051	11.51	12.85	0.055
600	376	5.456	6.074	0.054	12.51	14.02	0.057
700	326	5.169	5.779	0.056	13.94	15.7	0.059
738	300	4.898	5.475	0.056	14.29	16.08	0.059
800	281	4.842	5.437	0.058	15.56	17.59	0.061
900	240	4.501	5.077	0.060	17.41	19.78	0.064
1000	200	4.064	4.598	0.062	19.36	22.06	0.065
1100	174	3.868	4.405	0.065	22.15	25.42	0.069
1200	151	3.678	4.217	0.068	25.42	29.4	0.073
1300	131	3.504	4.046	0.072	29.28	34.14	0.077
1400	117	3.483	4.064	0.077	34.39	40.59	0.083
1500	105	3.509	4.144	0.083	40.73	48.75	0.090
1600	100	3.855	4.647	0.093	50.25	61.67	0.102
Note: For a 1 Lane-1 Lane intersection configuration							

The elasticity values for both the total intersection delay and the minor approach delay are relatively low, ranging from 0.05 to 0.09 and about 0.6 to 0.10, respectively. A primary reason for these low sensitivity values is as before – the volumes required to warrant signalization are relatively low. Being such, the addition of heavy vehicles with poorer operating characteristics and larger physical sizes has negligible effects on the operations at the intersection. From these values, it appears that the introduction of heavy vehicles into the traffic stream composition, at least for levels up to and including 20 percent, does not significantly impact the operations of the intersection.

In further analysis of heavy vehicles and their impact on the Peak Hour Volume Warrant, Figure 7 shows total intersection delay plotted for each combination of major-minor volumes shown

in Table 36. The Peak Hour Volume Warrant curve for geometry consisting of one-lane and one-lane was also plotted on this figure for comparison.

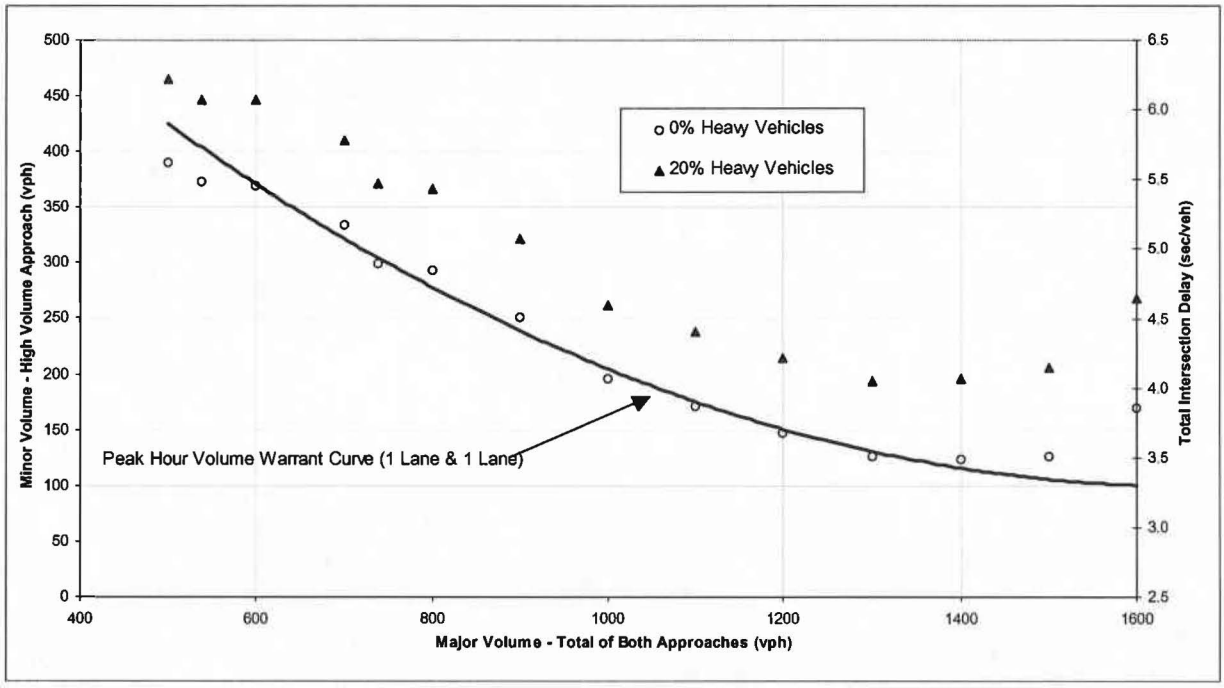


Figure 7. Average Total Intersection Delay for Different Heavy Vehicle Percentages

Figure 7 indicates the difference in total intersection delay between two conditions – one where special provisions for heavy vehicles are neglected (in other words, they are treated as a passenger car) and another where heavy vehicles are accounted for through the adjustment of critical gap and follow-up times. Volume combinations were chosen to coincide with the intersection configuration assumptions (i.e., one-lane - one-lane) such that marginally warranted conditions existed. The secondary y-axis (total delay) was adjusted vertically to match the warrant curve. Interestingly, the warrant curve that defines the threshold of signalization coincides very well with total intersection delay. This is fortunate for it provides a nice comparison of the difference between accounting for heavy vehicles and neglecting their impact. The difference is the total intersection delay caused by a 20 percent composition of heavy trucks in the vehicle stream. At 1,000 vph on the major and 200 vph on the minor (assuming one vehicle equals one vehicle regardless of vehicle type), total intersection delay is about at the warrant threshold. This is true for most all cases of volume combinations. However, with the same volume combinations, but accounting for heavy vehicles with the critical gap and follow-up time adjustments, the total intersection delay increases slightly. If the warranting curve were based on total intersection delay, then the impact of heavy vehicles appears to affect the curve position.

CHAPTER 6
ACCIDENT CONSIDERATIONS

Early in the project, the Project Director, TxDOT Advisory Panel, and researchers evaluated the feasibility of potential considerations for the inclusion of fatal accident criteria into the warranting procedures. A significant amount of research has been focused on this very issue and is summarized in chapter 3. The conclusion of this previous work is that results aimed at assessing the safety impacts of signalization remain inconclusive. Moreover, an NCHRP study (NCHRP Project 17-16, *Accident Warrant for Traffic Signals*) was recently initiated which specifically focuses on developing an improved accident warrant based on a better understanding of the safety impacts of signalization. Because the effort of this NCHRP project is so closely related to the accident severity concern herein, and both the money and time available to conduct a thorough analysis are greater for the NCHRP project, the Project Director, Advisory Panel, and researchers determined that the focus of this TxDOT project on accident severity inclusions into the warranting procedures should be lessened. The work that was conducted included a review of the literature and coordination of activities with the contracting agency responsible for NCHRP Project 17-16 (23). This chapter summarizes the coordination of activities and work accomplished to date as part of this NCHRP effort.

NCHRP Project 17-16, *Accident Warrant for Traffic Signals*

Research Agency:	Bellomo-McGee Inc.
Principal Investigator:	Hugh McGee
Completion Date:	March 31, 1999
Funds:	$300,000
NCHRP Staff:	B. Ray Derr

Project Abstract

Traffic signals are often seen by the public and elected officials as a cure-all for operational and safety problems at intersections. Although signals have been used for many years, very little is actually known about their impact on safety. The accident experience warrant in the MUTCD (one of 11 warrants that set minimum thresholds for considering installation of a traffic signal) is not well supported and does not consider accident severity. The MUTCD specifies that an engineering study "should indicate a traffic signal will improve the overall safety and/or operation of the intersection" before a signal is installed; however, there are no tools to help the traffic practitioner determine the likely impact on safety from installing a traffic signal. Past studies have yielded contradictory results and suffered from a number of serious deficiencies. Sometimes changes in traffic conditions can eliminate the need for an existing traffic signal. Practitioners need a way to analyze the safety impact of removing such a signal. This information can be used to alleviate the public concern that usually blocks signal removal.

Introduction

Currently, the Accident Warrant is satisfied when:

1) Adequate trial of less restrictive remedies fails; AND
2) Five accidents involving personal injury or property damage of the type susceptible to correction by signal control are observed in a twelve month period; AND
3) Traffic volumes meet at least 80 percent of the specified in the Minimum Vehicular Volume Warrant, the Interruption of Continuous Traffic Warrant, of the Minimum Pedestrian Volume Warrant; AND
4) The signal will not seriously disrupt traffic.

The fundamental thrust of the accident warrant is the observation of five accidents in a twelve month period that are of the type "susceptible to correctable" by signal control. Several concerns have arisen with the context of the current warrant. The five-accident threshold is not well supported by modern studies of intersection safety and is not grounded in logical and defendable research. Its history has been traced back as far as the 1935 MUTCD where it can be found almost verbatim. Previous studies investigating the accident threshold have yielded contradictory results and have not provided a definitive tool for engineers to investigate the safety impacts from signal installation/removal. Developing an improved accident experience warrant to resolve this problem is the primary objective of the research being conducted under NCHRP Project 17-16. To this end, the project researchers will accomplish the objective by providing model(s) to estimate the safety impacts on installing or removing traffic signals. The research entails a two-phase work plan. The first phase deals primarily with acquiring and reviewing recent literature, developing a data collection plan, and delivering an interim report. This phase also includes a presentation of research findings at the 1997 summer meeting of the National Committee on Uniform Traffic Control Devices. At the end of Phase I is the submission of a revised work plan and budget for the remaining tasks. To develop the plan, it is necessary to define the study variables of concern and to identify potential accident databases that contain such data. Phase II entails execution of the work plan, developing the accident models, recommending an accident warrant for the MUTCD, and delivering a final report of the research results.

Work Plan

The objectives of this project are to develop an improved accident warrant for traffic signals and to provide a model(s) to estimate the safety impacts of installing or removing traffic signals. Research includes the following tasks:

1. Review previous research, evaluating accident experience at signalized intersections and those controlled by stop signs. Identify the issues and challenges in assessing the safety impacts of traffic signals and developing an accident warrant. Such challenges include accounting for unreported accidents, jurisdictional differences in accident reporting requirements and procedures, inaccuracy in reported accidents, definition of the types of accidents correctable by a traffic signal, high accident levels that do not accurately reflect the mean accident rate, and data-collection sample sizes needed for accurate estimation. Identify accident data sources that may be suitable for this project.

2. Considering the issues and challenges identified in task 1, develop a data-collection and analysis plan suitable for the tasks 5 and 6 development work.
3. Prepare an interim report that includes the information developed in tasks 1 and 2 and a revised work plan and budget for the remaining tasks.
4. Execute the approved data-collection plan.
5. Develop a model(s) to estimate the number, severity, and types of accidents expected at signalized and stop-controlled intersections and the changes expected from installation or removal of a traffic signal. Estimates should include confidence limits. The model(s) should consider different intersection characteristics (e. g., approach and turning volumes, intersection geometry, proximity to other signalized intersections, control type, signal phasing, regional differences, and area type).
6. Using the task 5 model, identify the conditions under which signal installation or removal is likely to improve or degrade safety and the types of accidents most affected. Recommend an improved accident warrant and related material suitable for inclusion in the MUTCD. The recommendations must be credible, definitive, and defensible.
7. Prepare a final report documenting the research results, presenting the task 6 model and showing how it could be used with other analysis tools to assess the desirability of signal installation or removal. The recommended revisions to the MUTCD and justification for them should be included as an appendix.

Coordination Activities

Several activities were coordinated with project NCHRP 17-16 throughout the span of this project. Literature was shared, various questions of the survey were developed to expedite potential data sources for the NCHRP project, data from the survey was shared, and frequent updates were made to ensure reduction of duplicating efforts.

Current Status

The researchers made a brief presentation on the project to the Signals Technical Committee of the NCUTCD on June 25, 1997. The task 3 interim report was approved by the panel in September 1997. The researchers have begun pilot testing the data collection procedure in Maryland and Virginia and are diligently trying to locate data collection sites.

The interim report is available for loan from the NCHRP. Tentatively, the project is expected to be completed on time (i.e., March 31, 1999). This information was obtained on July 17, 1998.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

The goal of this project was to evaluate various considerations for inclusion into the traffic signal warranting process. The following objectives, which were based on the project goal, were developed to address specific concerns related to the warranting process:

1. To determine if, and possibly how, heavy vehicle considerations can be incorporated into existing traffic signal warrants or as part of a new warrant, and
2. To coordinate research efforts with the NCHRP Project 17-16 research team with respect to accident severity issues and to provide an update to Project 17-16 at the termination of this project.
3. To identify concerns about emergency signal installations at locations not clearly defined in the MUTCD.
4. To develop an additional document that will be used by engineers throughout the Department to provide more consistency in the warranting analysis procedures.

The activities conducted in an effort to meet these objectives have been presented in this report. Based on this work, the following conclusions and recommendations are made.

CONCLUSIONS

Traffic Signal Warrants

- The public and elected public officials generally view traffic signals as a cure-all for intersection operational and safety concerns.
- The first warrants were developed in the late 1920s and 1930s. They have evolved with each new edition of the MUTCD. Currently, there are 11 warrants in the national MUTCD and 12 in the TxMUTCD. The proposed national warrants for the MUTCD 2000 are essentially the same as the current warrants, just combined to create fewer total warrants.
- Neither the current warrants nor the proposed warrants contain provisions for heavy vehicles or accident severity concerns. The current warrants are written with somewhat vague language. The Manual indicates that an engineering study should be conducted showing that the installation of a traffic signal will improve operations and/or safety. The Manual implies that sound engineering judgement should be used when conducting signal warrant analyses.
- The Minimum Volume Warrant (warrant 1) is the most commonly used warrant to justify signalization. During the time period from 1995 to 1997, TxDOT used this warrant 28 percent of the time. Other state DOTs and cities used this warrant 44 and 36 percent of the time, respectively.
- A section of the survey addressed the adequacy of the current traffic signal warrants. Slightly over half of the responding engineers feel that the current warrants do not need to be modified. Furthermore, most feel that no new warrants are needed. The main concerns conveyed through the comments were that more stringent criteria are needed for

the volume based warrants, and that the Accident Experience Warrant needs to be modified.

Heavy Vehicles

- Of the previous work related to the inclusion of heavy vehicle considerations into the warranting procedures, only one report recommends the practice. The recommendation comes in the form of a passenger car equivalency (PCE) value. The suggested PCE is one truck or bus on the side street approach is equivalent to two passenger cars.
- Considering the operations of heavy vehicles at unsignalized intersections, special provisions are made for the impact caused by heavy vehicles. Modifications are made to capacity and delay estimates based on adjustments of the base critical gap and follow-up time default values. These adjustments are based on the percentage of heavy vehicles with respect to the intersection type and vehicular movement.
- The introduction to the warrants describes advance data required to determine the necessity for signal installation and to furnish necessary data for the proper design and operation of a signal found to be warranted. Included in this description of data are vehicular volumes classified by vehicle type. In the survey, a question was directed to obtain an estimate of the percentage of counts that contain classification data. The results indicate that most agencies do not consistently classify counts. TxDOT does 26 percent of the times. Other state DOTs and cities classify vehicles 28 and 18 percent of the time, respectively.
- TxDOT, state DOTs, and city engineers from around the country were asked their opinion concerning the inclusion of heavy vehicles into the warranting analysis. The results were consistently mixed, with about one-third indicating no, one-third indicating uncertain, and the remaining third answering yes.
- For the volume levels contained in the current warrants, heavy vehicles do not impact intersection operations significantly as shown by the analyses conducted in chapter 5.

Accident Severity Issues

- The previous research related to accident impacts of signalization results in inconclusive findings.
- The Accident Experience Warrant (warrant 6) is the only warrant that considers accidents. It is vaguely worded and based on accident threshold criteria that are not well supported by modern studies of intersection safety.
- When engineers were asked about the use of accident severity for recent warrant analyses, most indicated that it was not formally incorporated into the analyses, but high profile fatal accidents certainly caused more pressure for signalization than other accidents. Furthermore, when asked which accidents engineers consider "susceptible to correction by traffic control," a wide variety of responses were provided.
- Agencies were asked if accident severity should be incorporated into the warranting procedures. Without a doubt, most feel that this is not a good idea.
- The National Cooperative Highway Research Agency (NCHRP) has recently started Project 17-16, *Accident Warrant for Traffic Signal*. The objectives of this project are to

develop an improved accident warrant for traffic signals and to provide a model(s) to estimate the safety impacts of installing or removing traffic signals.

Emergency Signal Considerations

- Sections 4E-18 through 4E-21 of the MUTCD provide discussion pertaining to emergency signals. Emergency signals may be installed at locations that do not meet the warrants. They may be installed where there is direct access from a building which houses the emergency vehicle.
- Specific concerns related to this project dealt with intersections at hazardous chemical plants (common along the Gulf Coast), industrial parks, and military bases where the cargo is sometimes unknown but potentially hazardous.
- The engineers who returned surveys were split on this issue. About half felt that considerations may be necessary for other conditions, while the other half felt that emergency signals are meant to provide travel time benefits to emergency vehicles and, as such, no further provisions should be considered. Additionally, some engineers expressed the concern that at locations such as chemical plants, industrial parks, and military bases, if volumes do not meet warrants such as the Peak Hour Volume Warrant, then consideration of these locations would be adding exceptions to the warrants and increasing the complexity in terms of application.

Electronic Survey

- In addition to mailing hard copies of the survey, it was also available through the Internet. This was an experimental process used to assess the feasibility of conducting paperless surveys.
- The web page where the survey resided received 85 "hits."
- Eight fully completed surveys were received through the Internet. One was from TxDOT, three from other state DOTs, and four from cities.

RECOMMENDATIONS

- The results of this project show that there is no need to account for heavy vehicles when conducting traffic signal analyses. At the threshold volumes of the warrants, heavy vehicle percentages up to 20 percent do not significantly affect the results. Heavy vehicles do have a significant impact at higher volumes, but the volumes are so high that the intersection would have met one or more warrants based on passenger cars alone. Those districts that are conducting counts for warranting analyses by obtaining axle counts and dividing by two are effectively lowering the warrant volume thresholds. Many complaints were received from the districts indicating that the current volume thresholds were too easily satisfied. This procedure for determining vehicle counts should be discontinued as funds are available to update the counting equipment to include equipment that can count and classify. An alternative that may be viable until updated equipment can be purchased is to perform manual counts.
- Currently, no changes should be made to the way accidents are evaluated in terms of warranting criteria. However, consideration should be given to recommendations that will

result from NCHRP Project 17-16. This is perhaps the most comprehensive and focused efforts pertaining to accident severity issues related to the Accident Experience Warrant. A new Accident Experience Warrant will be forthcoming when the project terminates (scheduled for March 31, 1999).

- One of this project's main objectives was to identify concerns about emergency signal installations at locations not clearly defined in the MUTCD. Locations of focus were at entrances/exits to hazardous chemical plants, industrial parks, and military bases. Input from engineers around the country was split. Several concerns were addressed in regards to the possible inclusion of additional exceptions to the warrants and the negative impacts that these may cause by allowing more intersections to be signalized that are not warranted based on safety or efficiency reasons. Other concerns were that the emergency signal exception is based on the philosophy that emergency vehicle response time is the main justification for this exception, and as such, additional exceptions should not be considered or used. Another frequently expressed concern was that engineering judgement is called for in the MUTCD and is particularly important when considering the impacts of signalization. Some engineers would rather see the current level of engineering judgement maintained in the warrant analysis rather than providing more conditions that may allow a signal to be warranted when, in fact, it is against the engineer's belief that a signal would improve the safety and/or the efficiency of the intersection.
- Based on the results of the survey responses, it appears that when given the option, engineers prefer paper versions of surveys rather than electronic versions. However, there may be other factors involved that were not studied (since this was a very minor objective of this research). For instance, perhaps the engineer does not have access to the Internet, or maybe the awareness tasks were not encompassing enough. Consequently, it is recommended that surveys continue to be disseminated by traditional means such as mailings. Additional sources may be provided, such as the Internet, they but should not be relied on as the main vehicle in which responses will be received.
- Sound engineering judgement is a prerequisite for any transportation official conducting signal warrant analyses. Additional requirements include a thorough knowledge of the warranting procedures as well as interpretations of the language of the warrants. As such, an additional document has been developed as part of this project that addresses many of the issues that have typically been left to interpretation. The document is intended to improve the consistency of the warranting process (5).

CHAPTER 8
IMPLEMENTATION

INTRODUCTION

The current traffic signal warrants have been developed to define the ***minimum*** conditions under which further consideration of a traffic signal is appropriate. Appropriateness is assumed to be in terms of improved safety or efficiency. Simply meeting the warranting criteria does not mean that a signal is justified at a given location. There are many factors that impact the results of a warrant analysis. One such is the many interpretations can be made with regard to the current language of the warrants. This project investigated several warrant considerations. As a result of the findings and the determined need for more consistent warranting procedures, the researchers prepared a supplemental document (TxDOT Research Report 3991-2, Guidelines for Conducting a Traffic Signal Warrant Analysis) to clarify interpretations and improve the consistency of the warranting process.

The guideline was developed to provide transportation officials with detailed information about conducting a traffic signal warrant analysis. It addresses many of the issues that have typically been left to interpretation and is intended to improve the consistency of the warranting process.

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APPENDIX A

SUMMARY OF SURVEY RESULTS

This appendix provides a summary of the responses from both the TxDOT traffic engineers' survey, summarized in the first section of this appendix, and the state and city DOT survey, summarized in the second section. Each section provides a sample of the survey instrument and a summary of the answers and comments. Both surveys were mailed to the traffic engineers in their respective jurisdictions. The surveys were also available electronically through the world wide web.

SURVEY OF TXDOT DISTRICT TRAFFIC ENGINEERS

The Texas Department of Transportation is jurisdictionally divided into 25 districts. Each District, further divided into area jurisdictions, maintains the highways in their districts, including roadway construction, maintenance, and improvements. The districts are also responsible for traffic control devices including traffic signals. On the state-maintained roadway network, these districts are responsible for determining the need of traffic signals, and, if deemed necessary, then they are also responsible for the design, operation, and maintenance of these signals. The engineer typically responsible for overseeing the warrant analysis and designing, installing, maintaining, and operating warranted signals is the Director of Transportation Operations or the Area Engineer.

Survey Instrument Design

The research team, with the assistance of the Advisory Panel, developed a seven page survey that addressed the warranting analysis within the state of Texas. Three of the questions solicited general information about the district, their total number of signals, and type of signals. The next six questions focused on determining which warrants are mostly used to justify signal installation. The following ten questions pertained to the warranting criteria and which criteria were used most frequently when conducting signal warrant analyses. Two questions were then directed toward obtaining information about the need for warrant modifications or the inclusion of a new warrant(s) in the MUTCD. The last six questions dealt with potential warrants and were focused on soliciting comments on the two primary objectives of the research project – considerations to include heavy vehicles and accident severity into the warranting process. A copy of the survey is provided on the following pages.

TRAFFIC SIGNAL WARRANT SURVEY

The current traffic signal warrants define minimum criteria that should be met before installation of a traffic signal can proceed. Oftentimes, the public fails to understand these warrants and request a signal on the basis of criteria not in the current warrants. Two such considerations are school buses and fatal accidents. The Texas Transportation Institute (TTI) is conducting a research project for the Texas Department of Transportation (TxDOT) to determine the feasibility of including school bus and/or fatal accident considerations in the traffic signal warranting procedure. Please answer the following questions about your district's traffic signal warranting procedures.

Some of the questions may ask for information that is not available or which would require a significant effort to determine. For these questions, please provide your best estimate. **The survey should not take more than 15 to 20 minutes to complete.**

You may use the back of the survey or additional pages, if necessary. Please return the survey to Paul Carlson at TTI by September 5, 1997. A mailing label is attached for your convenience. Responses to this survey will be treated confidentially. If you have any questions, please contact Paul Carlson at (409) 845-6004. Thank you for your assistance.

PART I - GENERAL INFORMATION

1. Please provide the following information so we may contact you at a later date.

Name:		Telephone:	
District:		Fax:	
Position:		Email:	

2. How many signalized intersections is your agency responsible for?

Type of Control	Number
Fixed-Time	
Semi- or Fully-Actuated	
Total	

Are these values estimates (❑) or actual counts (❑)?

3. What percentage of the signals in question 2 are coordinated? _____

Is this value an estimate (❑) or an actual count (❑)?

PART II - TRAFFIC SIGNAL WARRANTS UTILIZED

3. Does your district use signal warrants that are different from those in the 1980 Texas MUTCD?

   ❑ Yes ❑ No ❑ Uncertain

   If yes or uncertain, please enclose a copy.

   Comment: _____

4. From 1/1/93 to 12/31/95, please indicate the percentage of each warrant utilized to install or upgrade signalization. In cases where more than one warrant was met, please specify the warrant that was primarily justified.

   Are these values estimates (❑) or actual percentages (❑)?

WARRANT	PERCENTAGE OF SIGNALIZATIONS OVER LAST 3 YEARS
1 - Minimum Vehicular Volume	
2 - Interruption of Continuous Traffic	
3 - Minimum Pedestrian Volume	
4 - School Crossings	
5 - Progressive Movements	
6 - Accident Experience	
7 - Systems	
8 - Combination of Warrants	
9 - Four Hour Volumes	
10 - Peak Hour Delay	
11 - Peak Hour Volume	
12 - Volumes for Actuated Signals	
13 - Other	

   Comment: _____

6. How many signals were installed in your district between 1/1/93 and 12/31/95? _____

   Is this value an estimate (❑) or an actual count (❑)?

   Comment: _____

7. Of these locations, how many had geometric improvements added as part of the upgrade? _____

   Is this value an estimate (❑) or an actual count (❑)?

   Comment: _____

8. How many existing signal installations were upgraded between 1/1/93 and 12/31/95? _____

   Is this value an estimate (❑) or an actual count (❑)?

   Comment: _____

9. How many signals were removed in your district between 1/1/93 and 12/31/95? _____

   Is this value an estimate (❑) or an actual count (❑)?

   Comment: _____

PART III - WARRANTING CRITERIA

10. Please indicate the vehicular volume data your agency typically obtains for initial warrant analysis.

    Duration of counts: ❑ 24 hours ❑ 16 hours ❑ Highest 8-hour
    ❑ Highest 4-hour ❑ Peak hour ❑ Peak 15-minute

    Is the volume duration checked above determined from:

    - ❑ hourly volume counts from a single day?
    - ❑ an average of hourly volume counts over multiple days?
    - ❑ other: _____

11. Does your agency classify these volume data as part of the warrant analysis process?

❑ Yes ❑ No If yes, indicate the classifications used:
❑ Heavy trucks ❑ Light trucks ❑ Passenger cars
❑ Buses ❑ Motorcycles ❑ Bicycles

How do you use this data? _____

12. Are turning movements collected as part of the warrant analysis process?

❑ Yes ❑ No

How do you use this data? _____

13. Is vehicle delay measured as part of the warrant analysis process?

❑ Yes ❑ No

If yes, at what percentage of intersections? _____
What justifies delay measurement at some intersections over others? _____

14. What criteria does your agency use to determine when a pedestrian volume count is needed for warrant analysis?

15. Does your agency classify these pedestrian data by age? ❑ Yes ❑ No

If so, indicate the age categories used:
❑ Under 13 years ❑ 13 - 60 years ❑ Over 60 years
Other: _____

How do you use this data? _____

16. Is pedestrian delay measured as part of the warrant analysis process? ❑ Yes ❑ No

If yes, at what percentage of intersections? _____
What justifies delay measurement at some intersections over others? _____

17. Does your agency consider 85th-percentile speeds to reduce the minimum volume warrants?

❑ Yes ❑ No

Comment: _____

18. Does your agency consider accident data when conducting a warrant analysis?

❑ Yes ❑ No If yes: ❑ by frequency (e.g., number per time period)
❑ by type (e.g., side-swipe, rear-end, etc)
❑ by severity (e.g., fatal, injury, or PDO)

How do you define "accidents susceptible to correction by traffic signal control?" _____

If severity is considered, how? _____

19. Does your agency consider other traffic or geometric characteristics when conducting a warrant analysis?

❑ Yes ❑ No

If yes, please indicate: _____

PART IV - WARRANT MODIFICATION

20. Should the existing warrants in the national MUTCD be modified? ❑ Yes ❑ No

If yes, please specify your recommendations for such modifications: _____

21. Is there a need for a new warrant(s)? ❑ Yes ❑ No

If yes, please describe: _____

PART V - POTENTIAL WARRANTS

22. Should accident severity be incorporated into the accident warrant?

❑ Yes ❑ No ❑ Uncertain

Comment: _____

23. If the accident warrant is modified to include accident severity, how should it be done?

❑ Weighted based on severity of accidents (i.e., fatal, injury, and PDO)
❑ Other: _____

If weighted, indicate the weights you would recommend.

_____ Fatal accidents
_____ Injury accident
_____ Property Damage Only accidents (mark an ✗ if these are not to be included)

Comment: _____

24. Should vehicle type (i.e., passenger car, heavy truck, bus, etc.) be considered in the warrants?

❑ Yes ❑ No ❑ Uncertain

Comment: _____

25. If the MUTCD warrants are modified to include vehicle type, how should it be done?

❑ Equivalency factors
❑ Minimum number of heavy vehicles/buses to meet the reduced volume criteria in existing warrants
❑ Other: _____

Comment: _____

26. The MUTCD contains provisions for the installation of emergency traffic signals (section 4E-18) at locations that do not meet the standard warranting procedure. Similar reservations have been proposed within the scope of this project and are listed below. Indicate the situations in which you feel reservations from the standard signal warranting procedures may be granted.

- ❑ Hazardous chemical plants adjacent to major roadways using fleets of heavy vehicles for transportation
- ❑ Industrial parks entrances with high peak traffic intersecting major roadways
- ❑ Military bases intersecting major roadways that frequently transport unknown but potentially hazardous cargo
- ❑ Other: _____
- ❑ No other exception should be provided

Comment: _____

27. A task to be conducted as part of this research project will involve TTI collecting data at problem intersections where signalization is not warranted using the warrants in the TxMUTCD but engineering judgement would otherwise justify further consideration. The sites we are looking for include intersections with excessive school bus and/or heavy vehicle volumes. Also of concern are sites where trucks transporting hazardous chemicals frequently use an intersection. Please provide a list of these types of intersections in your district.

Intersection #1	Intersection #2	Intersection #3

Please return the survey to the following address. Thank you for your time.

Paul Carlson
Texas Transportation Institute
Texas A&M University System
College Station, TX 77843-3135

Phone: (409) 845-6004
Fax: (409) 845-9761
E-mail: paul-carlson@tamu.edu

Participating Districts

A total of 19 of the 25 TxDOT districts were represented in the sample of completed surveys. Table A-1 summarizes the participating districts.

Table A-1. TxDOT Districts and Areas Participating in Survey

District	District Number	District	District Number
Amarillo	04	Laredo	22
Atlanta	19	Lufkin	11
Beaumont	20	Odessa	06
Bryan	17	Paris	01
Childress	25	San Angelo	07
Corpus Christi	16	San Antonio	15
Dallas	18	Tyler	10
El Paso	24	Waco	09
Fort Worth	02	Wichita Falls	03
Houston	12		

Survey Results

The following section details the responses from the districts. It is important to remember that due to multiple responses, many of the cumulative percentages sum over 100 percent.

2. How many signalized intersections is your district responsible for?

Type of Control	Number	Average
Fixed-Time	360	26
Semi- or Fully-Actuated	2583	136
Total	2943	155

Based on a 37 percent estimation

3. What percentage of the signals in question 2 are coordinated?

37%

Based on a 42% estimation

4. Does your district use signal warrants that are different from those in the 1980 Texas MUTCD?

   Yes - 0% No - 100% Uncertain - 0%

   Comments:
   - For "flashing beacon" warrants, we use 5.6% of the ADT.

5. From 1/1/93 to 12/31/95, please indicate the percentage of each warrant utilized to install or upgrade signalization. In cases where more than one warrant was met, please specify the warrant that was primarily justified.

WARRANT	PERCENTAGE OF SIGNALIZATIONS OVER LAST 3 YEARS
1 - Minimum Vehicular Volume	28
2 - Interruption of Continuous Traffic	16
3 - Minimum Pedestrian Volume	0
4 - School Crossings	2
5 - Progressive Movements	3
6 - Accident Experience	7
7 - Systems	4
8 - Combination of Warrants	4
9 - Four Hour Volumes	3
10 - Peak Hour Delay	2
11 - Peak Hour Volume	11
12 - Volumes for Actuated Signals	19
13 - Other	0

Comments:
- By far the "Actuated" warrants will meet more times than other warrants. Most of our studies for the past three years are to upgrade to "closed loop" systems.
- Percentages are for four intersections: two for new installation and two upgrades.
- All our warrant studies were performed by an individual who retired over a year ago; therefore we cannot give you good usable data for the time period mentioned.
- Most of these signals met more then one warrant.

6. How many signals were installed in your district between 1/1/93 and 12/31/95?

   486 - Total
   29 - Average
   Based on a 56% estimation

   Comments:
   - New Installation

7. Of these locations, how many had geometric improvements added as part of the upgrade?

   62 - Total
   5 - Average
   Based on a 39% estimation

8. How many existing signal installations were upgraded between 1/1/93 and 12/31/95?

   618 - Total
   36 - Average
   Based on a 56% estimation

   Comments:
   - To "closed loop" system
   - Downtown was actuated
   - Four of the intersections did not require a new warranting study by traffic operations in Austin.

9. How many signals were removed in your district between 1/1/93 and 12/31/95?

   22 - Total
   2 - Average
   Based on a 28% estimation

   Comments:
   - Removed because of change in roadway to expressway type facility.
   - Actually relocated an installation when school and post office relocated down the highway.

PART III - WARRANTING CRITERIA

10. Please indicate the vehicular volume data your district typically obtains for initial warrant analysis.

Duration of counts:	56% - 24 hours	17% - 16 hours	28% - Highest 8-hour
	6% - Highest 4-hour	0% - Peak hour	0% - Peak 15-minute

Is the volume duration checked above determined from:

67% - hourly volume counts from a single day?
17% - an average of hourly volume counts over multiple days?
22% - other:
- ♦15-minute counts over two days
- ♦counters set to 24-hours – from that we use 16 hours (7:00 am to 10:00 pm)
- ♦To determine highest 8-hour
- ♦15-minute
- ♦15-minute intervals

11. Does your district classify these volume data as part of the warrant analysis process?

26% - Yes 74% - No If yes, indicate the classifications used:

22% - Heavy trucks	0% - Light trucks	28% - Passenger cars
0% - Buses	0% - Motorcycles	0% - Bicycles

How do you use these data?
- ♦ We don't typically classify, but we have on occasion, when marginally warranted.
- ♦ IAW TMUTCD
- ♦ Adjustments to timing may be made to accommodate commercial vehicle traffic.
- ♦ Traffic signal timing

12. Are turning movements collected as part of the warrant analysis process?

39% - Yes 61% - No

How do you use these data?
- ♦ Traffic signal phasing and timing
- ♦ Sometimes - depending on approach lane designations
- ♦ Determine need for left-turn channelization and signal timing
- ♦ It will depend on the configuration of the intersection and its surroundings.
- ♦ To determine phasing and splits
- ♦ IAW TMUTCD
- ♦ Normally, this data is collected only if the counts marginally pass the warrants.

13. Is vehicle delay measured as part of the warrant analysis process?

    26% - Yes 74% - No

    If yes, at what percentage of intersections? 42%

    What justifies delay measurement at some intersections over others?

    - Normally this data is collected only if the counts marginally pass the warrants.
    - TTI delay formula
    - The amount of delay
    - Vehicular volumes

14. What criteria does your district use to determine when a pedestrian volume count is needed for warrant analysis?

    - Knowledge of location
    - Number of pedestrians
    - If near a school, or if downtown business district
    - Pedestrians are counted at every intersection along with the vehicular volume data.
    - Word of mouth
    - N/A
    - If an intersection is known to have pedestrian traffic, then we conduct a pedestrian volume count along with the vehicle.
    - If there are stores in the area or any public gathering place
    - When requested from a school system
    - It is recommended by our Austin Division that pedestrian signals be installed when an occasional pedestrian is present. Volume counts only occur if there are numerous pedestrians using the crossing.
    - Usually install; pedestrian signal on warranted traffic signals
    - School Zone X-walk
    - We seldom do pedestrian counts. If they are done, it is usually near a school or in a downtown area.
    - When the intersection is near a school & the traffic warrants did not meet
    - When no other warrant is met & pedestrians are present, then a ped. vol. count is conducted.
    - When a study is requested by a city near a school or other pedestrian traffic generator

15. Does your district classify these pedestrian data by age?

    12% - Yes 87% - No

    If so, indicate the age categories used:
    6% - Under 13 years 0% - 13 - 60 years 0% - Over 60 years
    Other: ♦Elem. school/junior-high school/older

    Comments:
    - ♦ Schools
    - ♦ TMUTCD
    - ♦ Vehicle volume and speed is a big factor.

16. Is pedestrian delay measured as part of the warrant analysis process?

    29% - Yes 71% - No

    If yes, at what percentage of intersections? 8%

    What justifies delay measurement at some intersections over others?

    - ♦ TMUTCD
    - ♦ Schools
    - ♦ Vehicle volume and speed is a big factor.

17. Does your district consider 85th-percentile speeds to reduce the minimum volume warrants?

    79% - Yes 21% - No

    Comments:
    - ♦ By using the 85th% speeds, the required warrant may drop to rural.
    - ♦ Do not use this as standard for warranting traffic signals.
    - ♦ We take a close look on the accident history.

18. Does your district consider accident data when conducting a warrant analysis?

    100% - Yes 0% - No If yes: 84% - by frequency (e.g., number per time period)
    68% - by type (e.g., side-swipe, rear-end, etc)
    26% - by severity (e.g., fatal, injury, or PDO)

    How do you define "accidents susceptible to correction by traffic signal control?"

    - ♦ Five right angle accidents per year
    - ♦ Right angle and/or turning maneuver
    - ♦ Right angle accidents
    - ♦ Angle accident, opposite direction accident, severity

- Right-angle and left-turn accidents are susceptible to correction by signal control.
- Right angle
- Primarily right-angle
- Side swipe
- When vehicles are approaching at an angle, going same direction, or going opposite direction as defined in master accident decoding manual
- By time of day and speed
- Right angle turning movement
- An accident which may have been avoided by the use of a signal to assign right-of-way
- Right angle
- Accident analysis
- We look at right-angle accidents as "accidents susceptible to correction by traffic signal control." We will also consider 1 veh straight 2 veh left if we consider installing protected left turn signal indications.
- Right angle accidents
- Angle or turning accidents
- Right-angle, left-turns. A vehicle accident with opposing traffic

If severity is considered, how?

- Severity may indicate other needed improvements, such as geometric improvements or speed reductions.
- Number
- On how many fatal accidents at the location
- Severity is considered at marginally warranted signals.
- Fatalities coupled with number of accidents get greater scrutiny.

19. Does your district consider other traffic or geometric characteristics when conducting a warrant analysis?

79% - Yes 21% - No

Comments:

- Vehicle counts thru- free right turns are excluded from approach volume. Minor street approach has to be at least a dedicated city street.
- Sight distance, lane designation & condition of signing & marking
- Build-up area if near school. Sight restrictions to try to eliminate
- Spacing of existing signals and locations of intersections on rural roadways
- The intersection layout must be able to support signal operation
- Sight distance, geometry overall
- If other traffic control devices have been placed before to help out a problem
- Sight distance vertical and horizontal curve
- Roadway alignment, speed
- "Engineering judgement" overall condition of each intersection
- Topography and traffic generators

- Geometrics is always considered. We look at skew of the road, turning lanes, and the advantages/disadvantages of directional islands.

PART IV - WARRANT MODIFICATION

20. Should the existing warrants in the Texas MUTCD be modified?

    26% - Yes 74% - No

    Comments:
    - The systems warrant is difficult to understand & the actual warrant requirements are too low.
    - Not that we know of
    - Warrant No. 12 allows intersections to meet warrant - needs to be based on higher volumes. Once a warrant is met, traffic signal is installed in our district even though engineering judgement says otherwise.
    - Consideration should be given to total number of accidents and not just correctable ones by a traffic signal installation.
    - For signals near schools, school bus routes

21. Is there a need for a new warrant(s)?

    18% - Yes 82% - No

    Comments:
    - Guidelines for new proposed intersections with projected counts
    - Possibly consider a minimum of three fatal accidents in three to five years or some other similar type combination
    - Fatalities at intersections where there are no signals are big media stories. It is hard to defend why a signal cannot be installed because the intersection does not meet the warrants.

PART V - POTENTIAL WARRANTS

22. Should accident severity be incorporated into the accident warrant?

    32% - Yes 68% - No 22% - Uncertain

    Comments:
    - We already have an accident warrants; we do not need another.
    - All information certainly wouldn't hurt but uncertain about warrants
    - Engineering judgement with guidelines for accident correction based on type and not severity. Accident types can be the same with severity being different. Frequency of severe accidents should be considered.
    - Severity is a judgement call by the local officials and also speed of vehicles which may not be indicative of the need for a signal
    - Alcohol-related accidents should not count toward meeting the warrant.
    - If there is not enough volume to support the signal, people tend to disregard the signal.

- ♦ Number of fatal and personal injuries should be considered.
- ♦ I think when a number of fatalities over a number of years should impact the warrant more

23. If the accident warrant is modified to include accident severity, how should it be done?

37% - Weighted based on severity of accidents (i.e., fatal, injury, and PDO)
22% - Other: ♦$ amount used in safety projects also can be used, but all of these accidents has to be correctable (right angle accidents)
♦PDO accidents should not be considered.
♦Weighted based on fatal and injury accidents only
♦A combination of accidents and minimum vehicle volume

If weighted, indicate the weights you would recommend.

56% - Fatal accidents
41% - Injury accident
27% - Property Damage Only accidents

Comments:
- ♦ There should be a required volume; we have several "rural" intersections where fatalities occur where it would not be beneficial to install a traffic signal.
- ♦ Uncertain

24. Should vehicle type (i.e., passenger car, heavy truck, bus, etc.) be considered in the warrants?

17% - Yes 39% - No 44% - Uncertain

Comments:
- ♦ Trucks and buses move slower thru intersections; don't know how this should be considered.
- ♦ Only by EQ vehicle count
- ♦ Some locations may not meet existing warrant requirements. Locations where heavy trucks enter the highway (such as a plant) combined with other geometric issues may need to be addressed.
- ♦ The HCM considers % trucks to determine LOS – perhaps it should also be considered when justifying a traffic signal.

25. If the MUTCD warrants are modified to include vehicle type, how should it be done?

42% - Equivalency factors
28% - Minimum number of heavy vehicles/buses to meet the reduced volume criteria in existing warrants
17% - Other: ♦Do not know
♦Uncertain

Comments:

- ♦ Develop two separate warrants using the above criteria. Equivalency factors would be used first with minimum numbers used if equivalency factors did not produce needed volumes.

26. The MUTCD contains provisions for the installation of emergency traffic signals (section 4E-18) at locations that do not meet the standard warranting procedure. Similar reservations have been proposed within the scope of this project and are listed below. Indicate the situations in which you feel reservations from the standard signal warranting procedures may be granted.

    28% (5) - Hazardous chemical plants adjacent to major roadways using fleets of heavy vehicles for transportation
    22% (4) - Industrial parks entrances with high peak traffic intersecting major roadways
    28% (5) - Military bases intersecting major roadways that frequently transport unknown but potentially hazardous cargo
    58% (10) - No other exception should be provided
    0% - Other

    Comments:
    - ♦ Most motorists fail to stop when indication changes to red because of the constant or always green or flashing yellow indication (Emergency traffic signals).
    - ♦ Section 4E-18 addresses emergency traffic signals for "Emergency" vehicles.

27. A task to be conducted as part of this research project will involve TTI collecting data at problem intersections where signalization is not warranted using the warrants in the TxMUTCD but engineering judgement would otherwise justify further consideration. The sites we are looking for include intersections with excessive school bus and/or heavy vehicle volumes. Also of concern are sites where trucks transporting hazardous chemicals frequently use an intersection. Please provide a list of these types of intersections in your district.

Intersection #1	Intersection #2	Intersection #3

SURVEY OF STATE AND CITY TRAFFIC ENGINEERS

In addition to the TxDOT district survey, the other 49 states and 152 of the largest cities in the U.S. were also surveyed. The cities were identified using census data for 1994, estimated from the 1990 census data. Over the years, TTI has developed and maintained a database of state traffic engineers. This database was used to identify the state traffic engineers. The city engineers were identified through a variety of means but most commonly through the use of the ITE Directory and phone calls to city hall. Most of the state and city surveys that were returned appeared to have been passed down from the state/city traffic engineer to a more appropriate person – one who perhaps performed the signal warranting analyses on a more regular basis.

Survey Instrument Design

Like the TxDOT district survey, the research team, with the assistance of the Advisory Panel, developed a seven page survey that addressed the warranting analysis. However, instead of focusing on Texas' warranting procedure (which contains 12 warrants compared to 11 of the national MUTCD), the state and city traffic engineers' survey was developed based on the procedures outlined in the national MUTCD. Five of the questions solicited general information about the agency, their total number of signals, and type of signals. The next six questions focused on determining which warrants are mostly used to justify signal installation. The following ten questions pertained to the warranting criteria and which criteria were used most frequently when conducting signal warrant analyses. Two questions were then directed toward obtaining information about the need for warrant modifications or the inclusion of a new warrant(s) in the MUTCD. The last five questions dealt with potential warrants and were focused on soliciting comments on the two primary objectives of the research project – considerations to include heavy vehicles and accident severity into the warranting process. A copy of the state and city survey is provided on the following pages.

STATE AND CITY TRAFFIC ENGINEER
TRAFFIC SIGNAL WARRANT SURVEY

The current traffic signal warrants define minimum criteria that should be met before installation of a traffic signal can proceed. Oftentimes, the public fails to understand these warrants and request a signal on the basis of criteria not in the current warrants. Two such considerations are school buses and fatal accidents. The Texas Transportation Institute (TTI) is conducting a research project for the Texas Department of Transportation (TxDOT) to determine the feasibility of including school bus and/or fatal accident considerations in the traffic signal warranting procedure. Please answer the following questions about your district's traffic signal warranting procedures.

Some of the questions may ask for information that is not available or which would require a significant effort to determine. For these questions, please provide your best estimate.

You may use the back of the survey or additional pages, if necessary. Please return the survey to Paul Carlson at TTI by September 5, 1997. A mailing label is attached for your convenience. Responses to this survey will be treated confidentially. If you have any questions, please contact Paul Carlson at (409) 845-6004. Thank you for your assistance.

PART I - GENERAL INFORMATION

1. Please indicate your jurisdictional type: ❑ City ❑ State

2. What is the populations of your city/state? _____

   Is this value an estimate (❑) or an actual count (❑)?

3. Please provide the following information so we may contact you at a later date.

Name:		Telephone:	
Agency:		Fax:	
District/Dept:		Email:	
Position:			

4. How many signalized intersections is your agency responsible for?

Type of Control	Number
Fixed-Time	
Semi- or Fully-Actuated	
Total	

Are these values estimates (❑) or actual counts (❑)?

5. What percentage of the signals in question 4 are coordinated? _____

   Is the value an estimate (❑) or an actual percentage (❑)?

PART II - TRAFFIC SIGNAL WARRANTS UTILIZED

6. Does your state use signal warrants that are different from those in the 1988 national MUTCD?

   ❑ Yes ❑ No ❑ Uncertain

   If yes or uncertain, please enclose a copy.

   Comment: _____

7. From 1/1/93 to 12/31/95, please indicate the percentage of each warrant utilized to install or upgrade signalization. In cases where more than one warrant was met, please specify the warrant that was primarily justified.

   Are these values estimates (❑) or actual percentages (❑)?

WARRANT	PERCENTAGE OF SIGNALIZATIONS OVER LAST 3 YEARS
1 - Minimum Vehicular Volume	
2 - Interruption of Continuous Traffic	
3 - Minimum Pedestrian Volume	
4 - School Crossings	
5 - Progressive Movements	
6 - Accident Experience	
7 - Systems	
8 - Combination of Warrants	
9 - Four Hour Volumes	
10 - Peak Hour Delay	
11 - Peak Hour Volume	
12 - Volumes for Actuated Signals	
13 - Other	

   Comment: _____

8. How many signals were installed in your state between 1/1/93 and 12/31/95? _____

   Is this value an estimate (❑) or an actual count (❑)?

   Comment: _____

9. Of these locations, how many had geometric improvements added as part of the upgrade? _____

   Is this value an estimate (❑) or an actual count (❑)?

   Comment: _____

10. How many existing signal installations were upgraded between 1/1/93 and 12/31/95? _____

    Is this value an estimate (❑) or an actual count (❑)?

    Comment: _____

11. How many signals were removed in your state between 1/1/93 and 12/31/95? _____

    Is this value an estimate (❑) or an actual count (❑)?

    Comment: _____

PART III - WARRANTING CRITERIA

12. Please indicate the vehicular volume data your agency typically obtains for initial warrant analysis.

    Duration of counts: ❑ 24 hours ❑ 16 hours ❑ Highest 8-hour
    ❑ Highest 4-hour ❑ Peak hour ❑ Peak 15-minute

    Is the volume duration checked above determined from:

    - ❑ hourly volume counts from a single day?
    - ❑ an average of hourly volume counts over multiple days?
    - ❑ other: _____

13. Does your agency classify these volume data as part of the warrant analysis process?

❑ Yes ❑ No If yes, indicate the classifications used:
❑ Heavy trucks ❑ Light trucks ❑ Passenger cars
❑ Buses ❑ Motorcycles ❑ Bicycles

How do you use this data? _____

14. Are turning movements collected as part of the warrant analysis process?

❑ Yes ❑ No

How do you use this data? _____

15. Is vehicle delay measured as part of the warrant analysis process?

❑ Yes ❑ No

If yes, at what percentage of intersections? _____
What justifies delay measurement at some intersections over others? _____

16. What criteria does your agency use to determine when a pedestrian volume count is needed for warrant analysis?

17. Does your agency classify these pedestrian data by age? ❑ Yes ❑ No

If so, indicate the age categories used:
❑ Under 13 years ❑ 13 - 60 years ❑ Over 60 years
Other: _____

How do you use this data? _____

18. Is pedestrian delay measured as part of the warrant analysis process? ❑ Yes ❑ No

If yes, at what percentage of intersections? _____
What justifies delay measurement at some intersections over others? _____

19. Does your agency consider 85th-percentile speeds to reduce the minimum volume warrants?

❑ Yes ❑ No

Comment: _____

20. Does your agency consider accident data when conducting a warrant analysis?

❑ Yes ❑ No If yes: ❑ by frequency (e.g., number per time period)
❑ by type (e.g., side-swipe, rear-end, etc)
❑ by severity (e.g., fatal, injury, or PDO)

How do you define "accidents susceptible to correction by traffic signal control?" _____

If severity is considered, how? _____

21. Does your agency consider other traffic or geometric characteristics when conducting a warrant analysis?

❑ Yes ❑ No

If yes, please indicate: _____

PART IV - WARRANT MODIFICATION

22. Should the existing warrants in the national MUTCD be modified? ❑ Yes ❑ No

If yes, please specify your recommendations for such modifications: _____

23. Is there a need for a new warrant(s)? ❑ Yes ❑ No

If yes, please describe: _____

_____

_____

PART V - POTENTIAL WARRANTS

24. Should accident severity be incorporated into the accident warrant?

❑ Yes ❑ No ❑ Uncertain

Comment: _____

_____

_____

25. If the accident warrant is modified to include accident severity, how should it be done?

❑ Weighted based on severity of accidents (i.e., fatal, injury, and PDO)
❑ Other: _____

_____

_____

If weighted, indicate the weights you would recommend.

_____ Fatal accidents
_____ Injury accident
_____ Property Damage Only accidents (mark an ✗ if these are not to be included)

Comment: _____

_____

_____

26. Should vehicle type (i.e., passenger car, heavy truck, bus, etc.) be considered in the warrants?

❑ Yes ❑ No ❑ Uncertain

Comment: _____

_____

_____

27. If the MUTCD warrants are modified to include vehicle type, how should it be done?

- ❑ Equivalency factors
- ❑ Minimum number of heavy vehicles/buses to meet the reduced volume criteria in existing warrants
- ❑ Other: _____

Comment: _____

28. The MUTCD contains provisions for the installation of emergency traffic signals (section 4E-18) at locations that do not meet the standard warranting procedure. Similar reservations have been proposed within the scope of this project and are listed below. Indicate the situations in which you feel reservations from the standard signal warranting procedures may be granted.

- ❑ Hazardous chemical plants adjacent to major roadways using fleets of heavy vehicles for transportation
- ❑ Industrial parks entrances with high peak traffic intersecting major roadways
- ❑ Military bases intersecting major roadways that frequently transport unknown but potentially hazardous cargo
- ❑ Other: _____
- ❑ No other exception should be provided

Comment: _____

Please return the survey to the following address. Thank you for your time.

Paul Carlson
Texas Transportation Institute
Texas A&M University System
College Station, TX 77843-3135

Phone: (409) 845-6004
Fax: (409) 845-9761
E-mail: paul-carlson@tamu.edu

Participating States

A total of 27 of the 49 additional states besides Texas returned completed surveys. From one of the states, six district engineers returned completed surveys. This brought the total number of completed surveys from states besides Texas to 32. Table A-2 summarizes this representation.

Table A-2. States Participating in Survey

State	Population	Number of Responses	State	Population	Number of Responses
Arkansas	2,000,000 [A]	1	New York	17,990,455	1
Colorado	3,500,000 [A]	1	North Carolina	7,500,000 [A]	1
Delaware	800,000 [A]	1	North Dakota	650,000 [A]	1
Florida	14,411,563 [B]	6	Ohio	10,600,000 [A]	1
Georgia	no response	1	Oklahoma	3,300,000 [A]	1
Idaho	no response	1	Oregon	3,100,000 [A]	1
Indiana	5,544,159	1	Pennsylvania	11,000,000 [A]	1
Iowa	2,776,755	1	Rhode Island	1,003,000	1
Kansas	2,478,099	1	South Dakota	700,000 [A]	1
Maryland	6,000,000 [A]	1	Vermont	600,000 [A]	1
Michigan	no response	1	Virginia	6,500,000	1
Mississippi	3,000,000 [A]	1	Washington	4,500,000 [A]	1
Montana	856,057	1	West Virginia	2,000,000	1
New Mexico	1,600,000 [A]	1			

Notes: A: Estimated value provided on survey
B: Indicates state population

Survey Results

The following section details the responses from only the states. The city responses are summarized separately and following this section. Once again, it is important to remember that due to multiple responses, many of the cumulative percentages sum over 100 percent.

4. How many signalized intersections is your state responsible for?

Type of Control	Number	Average
Fixed-Time	8332	439
Semi- or Fully-Actuated	34277	1224
Total	55509 *	1791

Based on a 72 percent estimation

Note: The total is higher than expected due to a state not provided classification of signals, but rather, a total number of signals.

5. What percentage of the signals in question 4 are coordinated?

53%
Based on a 72% estimation

6. Does your state use signal warrants that are different from those in the 1988 national MUTCD?

Yes - 6% No - 91% Uncertain - 3%

Comments:

- Not different but formatted on LOTUS with minor editorials
- We do utilize spacing criteria as well.
- Indiana MUTCD warrants are similar to federal warrants. Right-turn-on-red reductions are actively used. Additionally we have warrants for special generators and new facilities. Normally #1, 2, or 3 must be met to signalize.
- Not really except a modification to the Accident Warrant in our supplements. We do not require 80% of warrant 1,2, or 3 to be met. However, the warrants are occasionally ignored.
- We have one signal warrant, and some other minor differences. See the "ADT Volume Warrant" on page E-5 of the attached Engineering and Traffic Studies.

7. From 1/1/93 to 12/31/95, please indicate the percentage of each warrant utilized to install or upgrade signalization. In cases where more than one warrant was met, please specify the warrant that was primarily justified.

WARRANT	PERCENTAGE OF SIGNALIZATIONS OVER LAST 3 YEARS
1 - Minimum Vehicular Volume	44
2 - Interruption of Continuous Traffic	27
3 - Minimum Pedestrian Volume	0
4 - School Crossings	2
5 - Progressive Movements	0
6 - Accident Experience	6
7 - Systems	1
8 - Combination of Warrants	5
9 - Four Hour Volumes	4
10 - Peak Hour Delay	2
11 - Peak Hour Volume	7
12 - Volumes for Actuated Signals	0
13 - Other	1

Comments:

- Policy changed in 10/95 to allow signals under warrants 10 and 11
- 82% of the above warrants satisfied two or more warrants
- We generally do not install a signal that does not meet warrants 2, 9, and 11. We like for all intersections to meet warrant 1. We occasionally install for warrant #4 (schools) or warrant #6 (crashes).
- Most of our signal installation because of warrants # 1, 2, 9, and 11.
- MD SNA does not use (allow) Warrant #11.
- This is considering all signals statewide.
- Majority of intersections met warrants 1, 2, 8, 9, and 11
- Unknown – Primarily we want to see warrant 1, 2, 8, or 9 met. See attached guidelines.
- Mostly warrants 1 & 2. Warrants 8 & 9 are often used. Others are occasionally used. Accident related signal installations are typically warranted under a warrant other than 6.
- Majority justified through warrants 1 & 2, but recent increase justification in MUTCD warrants 10 & 11

8. How many signals were installed in your state between 1/1/93 and 12/31/95?

   2936 - Total
   109 - Average
   Based on a 76% estimation

   Comments:
   - Although this is an actual count, it is from fiscal year 6-30-93 to fiscal year 6-3-96, so we called it an estimate.
   - This includes emergency signals and flashing beacons.
   - This estimate is for new signal installations and does not include revised signals.
   - 6 KDOT signals – 45 others installed by KDOT and later turned over to cities
   - This figure is only for those signals maintained and operated by the NDDOT.
   - Approximately 25 new ones
   - This includes two emergency signals and one intersection control beacon.

9. Of these locations, how many had geometric improvements added as part of the upgrade?

   705 - Total
   25 - Average
   Based on a 79% estimation

   Comments:
   - Geometric improvements were done at two existing signalized locations.
   - Installation or modification within roadway improvement job

10. How many existing signal installations were upgraded between 1/1/93 and 12/31/95?

    5991 - Total
    221 - Average
    Based on a 76% estimation

    Comments:
    - This includes emergency signals and flashing beacons. Many were upgraded with computerized signal system components only.
    - This figure is only for those signals maintained and operated by NDDOT.
    - These are upgrades of signal installations, not including loop replacement projects which number about 20-30 per year.
    - We do not keep the dates on upgrades of traffic signal locations.

11. How many signals were removed in your state between 1/1/93 and 12/31/95?

    169 - Total
    9 - Average
    Based on a 41% estimation

    Comments:
    - ♦ Past experience shows that trying to remove a signal is political suicide.
    - ♦ Most were relinquished to local control-not physically removed. Local public input often results in state/local cooperation that allows the signal to remain where the state alone would remove it.
    - ♦ See comment for Question #8.

PART III - WARRANTING CRITERIA

12. Please indicate the vehicular volume data your district typically obtains for initial warrant analysis.

    Duration of counts: 34% - 24 hours 19% - 16 hours 31% - Highest 8-hour
    6% - Highest 4-hour 12% - Peak hour 12% - Peak 15-minute

    Is the volume duration checked above determined from:

    56% - hourly volume counts from a single day?
    9% - an average of hourly volume counts over multiple days?
    41% - other:
    - ♦1-5 day machine count, 6 hr manual count: 7-10 am, 3-6 pm
    - ♦Counts are taken with machines for 24 hours and manually counted for eight hours over a two day period.
    - ♦Highest 10-hour turning movement We collect data in 15 min. intervals.
    - ♦Hourly or 15 minute interval counts from 6A to 6P. Typically other hours are counted when conditions indicate the added data would be more representative of the location.
    - ♦For signal studies, we typically obtain a 13-hour count (6am - 7 pm).
    - ♦Actual traffic counts in 15-minute intervals usually from 2:00 pm to 10:00 pm one day and from 6:00 am to 2:00 pm the following day.
    - ♦Hourly for two days
    - ♦10-12 hours of counts on a single weekday
    - ♦Hourly volume counts from two separate days (8 hours per day)
    - ♦Smoothed ADT and an 8-hour count from 7-11 am and 2-6 pm.
    - ♦7- hour turning movement count typically 7-9, 11-1, 3-6. Normally taken one day mid-week.
    - ♦12-hour manual turning movement counts
    - ♦Complete 24 hours counts for usually a total of 48 hours.

13. Does your state classify these volume data as part of the warrant analysis process?

29% - Yes 71% - No If yes, indicate the classifications used:

28% - Heavy trucks	14% - Light trucks	24% - Passenger cars
21% - Buses	3% - Motorcycles	3% - Bicycles

How do you use these data?

- For informational purposes
- As a general rule, we do not make vehicle classification counts as part of a traffic signal study. On a case by case basis, we make classification counts.
- All trucks and buses are included together. This data is used in the highway capacity analysis.
- "Passenger Car"= single rear-tire/ "Truck"= dual rear tires General Information only
- We typically would not use this data with the analysis for the warrant but would incorporate it in the justification for signalization (i.e., capacity).
- We do usually note school buses, in limited cases trucks (> loaded pickup).
- To adjust the volumes and for engineer's review of data.
- We would if the case required it .
- We would if we believe there is a problem related to trucks vs. cars.
- When TT truck values are high

14. Are turning movements collected as part of the warrant analysis process?

97% - Yes 3% - No

How do you use these data?

- Manual counts are used to adjust machine counts to match the manual counts.
- Input into warrant analysis program
- Warrants are not based on machine counts but are on manual turning movements, especially if left-turn volumes are extremely heavy.
- Used in evaluating warrant criteria.
- Only TMC data is used for volume warrants.
- To determine turning % for possible discounting on right-turn volume and determining conflicting traffic demands
- We use the eight hours of counts for the eleven MUTCD warrants.
- We evaluate right turns, free right turns as per MUTCD for side streets to determine if they should be involved; we do capacity analysis to determine delays, and we use in design for geometrics involving storage.
- We get information of side street right turn traffic to assess if it should be adjusted for the signal warrants.
- Consideration of need for turn arrows or lanes, Right-turn-on-red volumes are often reduced from raw data numbers before analysis.
- If a signal is close to being warranted, right turns are evaluated and may be excluded since right turns on red are allowed in most cases.
- To see number of right turns & to calculate existing delay

- Adjust warrant volumes for right and left turns which could not benefit by signalization (reduce approach volume).
- Used to help justify additional traffic lanes, the need for separate signal phases, and in intersection capacity analysis.
- For capacity analysis studies
- We specifically look at number of left turns and cross movements from side streets in comparison to MUTCD. We also evaluate need for auxiliary lanes.
- To determine needs for channelization and phasing
- For signal timings
- Remove right turns from approach volumes - use left turns for phase analysis
- Only use it to look at volume of right-turns.
- Determine whether to use right turns (or a % of) analysis
- See answer #12.
- For peak hour input into HCM; time of day variance % of left & right turning vehicles.
- Turning movements are collected; however, this information is not used to warrant the signal.
- Justification of exclusive turn phase

15. Is vehicle delay measured as part of the warrant analysis process?

    64% - Yes 36% - No

    If yes, at what percentage of intersections? 43%

    What justifies delay measurement at some intersections over others?

- PA - Minor street traffic, for one hour of one day, suffers undue delay in entering or crossing the major street.
- Observation of queues (e.g., waiting to make left turn)
- When warrants are not met but judgement indicates signal may be warranted, a delay study will be done.
- Amount of traffic and access points
- Where the volume of traffic on the side street approach turning left or crossing major street marginally meet MUTCD
- NY - Several regional offices that are located in highly congested parts of the state conduct vehicle delay studies.
- For new installation where other warrants have not been met but indications are that motorists are having major delays.
- They may meet warrants but may not want to install for reason such as: other signals close by, high % of right turns, existing LOS good.
- When other warrants are not met
- Specific side street complaints/observed problems. Note: Obtaining vehicle delay during peak hours is required (or strongly recommended) as part of signal study.
- Complaints of delays vary. The delay warrant is very rarely satisfied.
- Field review indicates that the delay appears to be significant and should be measured.

- We do a delay study at all full intersection studies done by a consultant. In-house studies include delay if complaint related a delay problem.
- N/A
- When volumes are reached for warranting signal but crashes are not significant - delay may or may not decide installation.
- If intersection meets warrant 2 volumes but not warrant 1, then delay becomes an issue.
- Only when and after other warrants are checked and conditions apply

16. What criteria does your state use to determine when a pedestrian volume count is needed for warrant analysis?

- Actual pedestrian counts taken when it has been requested to evaluate pedestrian involvement
- Visual observation normally during the turning movement count
- When intersection is near a school or a known pedestrian crossing location
- Demographics. If area is conducive for pedestrian activity.
- We routinely do a pedestrian count during all TMCs
- The location (the beach area or downtown), also the request itself, may indicate pedestrian activity as the concern.
- We perform for all warrants analysis.
- We typically make an effort to note any pedestrian movements on a routine basis.
- When adult pedestrians are expressed in the request and when it involves a school
- Pedestrians are counted as a part of all studies.
- Nearby pedestrian generators (mall/transit), citizen request, or typically, our 13-hour volume count also automatically includes peds.
- When warrants 3 & 4 may be met
- Except for school crossings, we seldom do.
- Observation of intersection
- Pedestrians are usually included in our 16 hour counts.
- Judgement - If we believe that there is significant pedestrian activity, then we'll conduct analysis.
- When engineering experience or requests indicate pedestrian movements are particularly high at study locations
- Engineering judgement, pedestrian / bicycle counts and movement priorities, problems and alternatives are all considered.
- We do a pedestrian count for every count we do for warranting a .
- Engineering judgement
- Don't have criteria for this.
- Routinely, pedestrians are counted when turning movements are collected.
- Political pressure
- Not typically done, all of our intersections are arterials in suburban or rural settings. The two major metropolitan areas are not currently under our control. Will be looking at this warrant in the future under multi-model issues.
- If a request for pedestrian signals is received, or if it is known the area is in a high ped. location, at or near school/school crossings
- None

- Every Engineering and Traffic Study pertaining to the justification of a traffic control signal, emergency traffic signal, flashing beacon or lane use control signals.

17. Does your state classify these pedestrian data by age?

    23% - Yes 77% - No

    If so, indicate the age categories used:
    14% - Under 13 years 3% - 13 - 60 years 3% - Over 60 years
    Other: ♦We only do age for school crossings and other special studies.

18. Is pedestrian delay measured as part of the warrant analysis process?

    17% - Yes 83% - No

    If yes, at what percentage of intersections? 10%

    What justifies delay measurement at some intersections over others?

    - Unless it is to warrant signal data, it is used to design ped crossing and signals for each leg of intersection
    - For school X-ings, we do gap studies.
    - School locations
    - School crossings at signalized locations

19. Does your state consider 85th-percentile speeds to reduce the minimum volume warrants?

    100% - Yes 0% - No

    Comments:
    - As per MUTCD, measured only when speed limit is near 40 mph
    - We take a close look on the accident history.
    - However, if the speed limit is less than the 85th percentile, the speed limit is used.
    - We use a 70% warrant when the arterial speed (85th percentile) exceeds 40 mph.
    - Posted speed most often used.
    - 40MPH - as per MUTCD
    - We use actual speed limits which approximate 85th percentile speed.
    - Per MUTCD 70% factors
    - We base it primarily on operating speed and not existing speed limit. This involves actual speed measurement at a large proportion of our intersection review. This is typical for us since we are a state highway agency.
    - Follow MUTCD
    - We perform a speed study with every traffic signal warrant analysis.
    - If posted 35 mph, then measure 85% speed – if posted < 35 mph, then no reduction taken – if posted > 35 mph, then take reduction

- Generally not an issue. When it is necessary, we do a spot speed study.
- Normally the posted speed limit is used unless it is felt to be unreasonable. A spot speed check is then done to determine the 85th percentile speed.
- Based on posted speed limits

20. Does your state consider accident data when conducting a warrant analysis?

97% - Yes 3% - No If yes: 76% - by frequency (e.g., number per time period)
83% - by type (e.g., side-swipe, rear-end, etc)
28% - by severity (e.g., fatal, injury, or PDO)

How do you define "accidents susceptible to correction by traffic signal control?"

- Right angle
- Case by case basis, but an example would be angle accident, some rear end collisions, etc.
- Angle type accidents
- Right angle, left turns versus opposing throughs only if protected arrows will be used.
- Angle and/or left turn
- Those that can potentially be corrected by a signal. Primarily angle crashes but may include left turns if a phase is added.
- Angle and left turn
- By type - angles and left turns
- Those where the allocation of right of way which a signal creates, we mitigate the accident.
- Usually we consider accidents that are correctable by traffic signal control, the angle type, and left turn if the left turn is improved by proposed signal phasing.
- Generally right angle accidents. If left turn arrows are being considered, restrictive arrows may "correct" turn type accidents.
- Angle and most left-turn accidents.
- Angle accidents
- Right angle, left turn primarily
- Right angle type
- Usually right angle. Sometimes left turns.
- Accidents which would likely not occur if a traffic signal was in place. For example, a signal would eliminate many right angle type collisions.
- Primarily accidents involving vehicles or main streets and side streets colliding at right angles.
- Those typically assumed to be preventable by traffic signal control such as left-turning accidents with protected phasing
- Entering at angle accidents
- Right-angle and sometimes left-turn if a left-turn phase would be part of the signal phasing.
- Typically angle-type accidents
- Same as MUTCD warrant #6
- Engineering judgement typically angle accidents. Each accident is individually reviewed.
- An accident at 90 degree angles, e.g. NB, vehicle hits EB vehicle
- No clear definition
- Yes, all reportable accidents.

If severity is considered, how?

- Only in that it's an indicator of a more serious problem
- Yes, we consider not only the intersection's accident rate but also the intersection's injury rate and the number of fatal accidents.
- PDO vs Injury is considered but not weighted.
- In b/c calculations
- Sometimes, a fatal can push a nearly warranted over the edge.
- Qualitative look to judge "how hard they are crashing." Severity does not change volume factors for the supplemental accident warrant.
- No, we look at severity, but this is not a criteria by itself.
- N/A
- Only look at injury and fatals as they relate to cause.
- Reviewed as part of accident investigation. All fatals are reviewed, and sometimes this leads to a warrant analysis.
- Only by weight for benefit to cost ratio

21. Does your state consider other traffic or geometric characteristics when conducting a warrant analysis?

73% - Yes 27% - No

Comments:

- Sight distance and functional class; gap acceptance from side street. Right turns are factored out in proportion to delay.
- If circumstances indicate or an engineering study shows problems in sight distance or sloping distance.
- Geometric improvements are reviewed as an alternate to signal installation even if warrants are met.
- One or more lane approaches, slip lanes, left turn lanes, etc. are all factors.
- Need to know impact of right turns on side street traffic. How much could turn RTOR if a signal were installed.
- Access to nearby signalization intersections
- We look at the geometry of the intersection and the width of the side street.
- Free right turning lanes, auxiliary lanes are typically considered.
- Generally our focus is on vehicular volume and accidents; however, we do try and look at these factors together and at any pertinent independent factors that good engineering judgement would require, such as sight distance and our ability to physically correct it.
- A condition diagram is prepared for each location. Sight distances are reviewed.
- In lieu of or in addition to signal for safer operations. Any and all options are to be identified when conducting an intersection/signal study.
- Sight distance, grade
- Number of lanes if left turn lanes are existing
- Approach lanage considers turning movements and adjustment to approach volume for analysis.

- Sight distance, adjacent signals for arterial progress in analysis.
- We have a progressive movement warrant which deals with coordinated signals.
- Need for turn lanes and whether they may solve the problem. Also, consider grades, sight distance, proximity of signals, interconnecting street system, level of service of approach and intersection.
- Sight distances, alignments, R/R crossings, nearby access movements, progression, local support, land use issues, transportation plans, access management issues
- Always consider geometries, lane configurations, relative location to other signalized and non-signalized intersections, parking, affected driveways, businesses, etc.
- Geometrics and sight distance
- Geometric improvements, if possible, may assist with congestion management issues that a warranted signal cannot alleviate.

PART IV - WARRANT MODIFICATION

22. Should the existing warrants in the National MUTCD be modified?

43% - Yes 57% - No

Comments:

- Two conditions: 1) left turn volume warrant, and 2) high speed facility warrant
- The peak hour warrant should be removed. The 100 veh/hr requirement qualifies too many locations such as fast food restaurants and banks.
- Left-turn warrant - high volume streets with a large left-turn volume and minor side street volumes
- Peak hour and interruption warrants should require a measured delay before applying volume criteria.
- Lose #8,9,10,11. Make #6 more specific. Also, most of our signals are put in under reduced warrants 1 & 2 (which can be relatively easy to meet). Suggest that warrants 1 & 2 stand as is, and that reduced warrants not be used.
- Personal opinion of writer is that some consideration of delay should be given. If a number of vehicles are observed to travel thru an intersection without a signal, there is minimal delay, and minimal crash history, why is a signal needed?
- 1) Have reduction allowed related to travel speed (i.e., 10%). The reason being introduction of traffic signal control on high speed facilities has higher potential to cause accidents. 2)The accident criteria "Adequate trial" should be softened.
- Warrants 9 and 11 should be deleted.
- Increase side street threshold in urban areas.
- Should be modified but question is how much. NAC has a draft of revised warrants quite well developed and ready for "new" MUTCD.
- Warrant 2 should include a clear definition of excessive delay and hazardous conditions. Example; Average Delay of 40 secs/veh is considered excessive. Three or more accidents correctable by signal in a 12 month period is considered a hazardous condition.

23. Is there a need for a new warrant(s)?

17% - Yes 83% - No

Comments:
- Need a way to keep the politicians out of engineering.
- Side distance problem / vertical or horizontal minimum signal spacing warrant
- See #22
- Better application of existing
- Left-turn volume

PART V - POTENTIAL WARRANTS

24. Should accident severity be incorporated into the accident warrant?

7% - Yes 65% - No 28% - Uncertain

Comments:
- Accident severity usually is a result of higher speed limits; therefore, consideration should be given to another factor for say, SL > 50 mph.
- Many accidents result of careless motorists, and enforcement would enhance warranted corrections.
- One fatal accident could cause an intersection to meet a warrant where no existing warrant is satisfied.
- Do not fit into syndrome of "how many deaths or even one death justifies a signal." This is knee jerk reaction; base decision or sound engineering principles not emotion.
- There are too many factors that lead to severity besides traffic control (speed, safety restraints used, driver error, etc.). A severity warrant would favor the high-speed intersections, which for other reasons are not ideal candidates for signalization.
- It should be a consideration but not a special warrant.
- If you say "yes," you will get a segment of the public which will throw you a statement like "How many people have to be killed before you install a signal" in your face more often than you already hear it now.
- Believe this belongs as an item in determining a priority list.
- Opinion of this writer is that severity consideration must be carefully applied. With history of crashes, perhaps a signal should be installed. But one severe crash with no other crash history may not be a good reason to install a signal although local opinion may support a signal
- Severity should be on the justification side not on the warrant side of the engineering analysis. Also accidents will be just as severe after the signal is installed, by type. It is very difficult to get an accident severity that is statically significant.
- The public believes every fatal crash was caused not by driver error but by something wrong with the road or the lack of a traffic signal or other device.
- Fatals are a rare event that cannot be predicted. The type of crash is more important because we may be able to control certain types.

- Crash severity is an uncertain call. Sometimes a minor crash may result in a fatality, while a major one might not. A lot depends on the age and health of the driver and the response time of the EMT crew. We already consider the severest form of crashes (right angles) to warrant signalization.

25. If the accident warrant is modified to include accident severity, how should it be done?

58% - Weighted based on severity of accidents (i.e., fatal, injury, and PDO)
76% - Other:
- Should not be used. Even though a crash is minor, the potential could be there for more serious injuries or fatalities. This is where engineering judgement should be used.
- Develop statewide average for different types of facilities and compare to intersection being studied.
- It should be weighted on severity potential of the accident type potentially correctable by a traffic signal.
- Combination including severity type consideration
- Considered in conjunction with injury and fatality rate
- Benefit/cost
- Should not be done

If weighted, indicate the weights you would recommend.

43% - Fatal accidents
33% - Injury accident
30% - Property Damage Only accidents

Comments:
- No recommendation for weighing accidents.
- Feel this is totally unnecessary
- Uncertain of weight; I would take average count for each type of accidents and then devise a rate. However, one spectacular fatality could really skew the results in favor of a signal whereas an intersection with many minor PDO type accidents would never qualify for a signal.
- In FL, we only get a small portion of PDO crash reports. Crash data does not really give a true picture of crash problem because we only get a portion of crashes; some go unreported and some reports are unintelligible.

26. Should vehicle type (i.e., passenger car, heavy truck, bus, etc.) be considered in the warrants?

29% - Yes 39% - No 32% - Uncertain

Comments:
- If truck traffic is high but volumes to not meet minimums, delay should be high enough to warrant signal.
- I do believe that trucks may need special consideration as related to available gaps when accessing a busy roadway.

- ♦ School buses, tractor trailers making left turns have problems stacking in the median of divide roads and, therefore, may have problems getting into main line traffic without a signal.
- ♦ Could use weighting PCE as per HCM.
- ♦ It maybe a factor when considering transit malls and/or corridors crossing general roadways.
- ♦ Passenger car equivalents
- ♦ As a consideration but not as a separate warrant
- ♦ High percentages of heavy trucks can cause additional delay on the side streets since they require larger gaps in the major street traffic.

27. If the MUTCD warrants are modified to include vehicle type, how should it be done?

38% - Equivalency factors
14% - Minimum number of heavy vehicles/buses to meet the reduced volume criteria in existing warrants
10% - Other: ♦MT-An occupancy equivalence between passenger cars and transit vehicles.
♦Emergency signals are installed for Fire and EMS Stations.
♦A signal warrant is supposed to be a comprehensive engineering study - not a "cookbook" of numbers. Each intersection should be evaluated on its own merits. If trucks are a problem, then they should be looked at and assumptions made on their impact.

Comments:
- ♦ PCE should be stated in report.
- ♦ The FDOT has adopted our own procedure for warranting emergency signals.
- ♦ Heavy vehicles on the side street and making left turns from the major rd. to the minor rd. should be given more weight than the major rd. thru trucks/buses.

28. The MUTCD contains provisions for the installation of emergency traffic signals (section 4E-18) at locations that do not meet the standard warranting procedure. Similar reservations have been proposed within the scope of this project and are listed below. Indicate the situations in which you feel reservations from the standard signal warranting procedures may be granted.

26% - Hazardous chemical plants adjacent to major roadways using fleets of heavy vehicles for transportation
23% - Industrial parks entrances with high peak traffic intersecting major roadways
23% - Military bases intersecting major roadways that frequently transport unknown but potentially hazardous cargo
10% - Other: ♦Fire stations
♦This matter should not be specific. It should be general as in Ohio.

40% - No other exception should be provided

Comments:
- ♦ Exceptions should not be added. We recommend manual control of intersection.

- Engineering judgement by a competent traffic engineer should preclude the need for this type warrant.
- We will consider an emergency signal installation if certain criteria are satisfied. Attached is a copy of the worksheet.
- In our opinion, whenever the cargo is hazardous, such as proposed in the three scenario above, then access to the street should be gained through manually flagged operation. Traffic signal control is far from infallible. It has a potential of a false sense of security for the vehicle operator.
- The Indiana MUTCD warrant 10 partially addresses this. Land use is generally not a factor in application of warrants.
- 4E-18 is not applicable to these situations.
- Special interests will continue to seek reservations from standard procedures. Minimum specific volumes should be basis to meet any reduced volume criteria.
- Our military bases use military policemen to control the intersection.
- Most of these locations probably will qualify for a signal under the current warrants, so the idea is mostly a mental exercise with little affect on reality. Also, the facility could apply for a permit signal if they thought a signal was really needed.
- Use engineering judgement.
- Note - we treat private entrances as an intersection, i.e., if industrial park entrance above meets an existing warrant, then it is signalized; however, in our case, cost is borne by private concern (all costs, installation, utility bill, & maintenance).
- Warrants for emergency signals should be included. We use warrants developed by NY state for these installations.
- The Ohio manual reads, "A traffic study by a traffic engineer shall be the only basis for the installation of a signal unless at least one of the warrants specified in this manual is met."

Participating Cities

The cities selected to send surveys to had to have an estimated population (1994) of over 100,000. The Populations Distribution and Populations Estimates Branches of the U.S. Bureau of the Census were used to obtain the 1994 estimates. A total of 209 cities were identified. However, addresses of some cities were not readily available at the time of mailing. Consequently, a total of 152 surveys were sent to cities across the U.S. Of these, 50 fully completed surveys were returned. Table A-3 summarizes this representation.

Survey Results

The following section details the responses from only the cities. It is important to remember that due to multiple responses, many of the cumulative percentages sum over 100 percent.

4. How many signalized intersections is your city responsible for?

Type of Control	Number	Average
Fixed-Time	6285	174
Semi- or Fully-Actuated	12386	263
Total	18671	397

Based on a 23 percent estimation

5. What percentage of the signals in question 4 are coordinated?

72%
Based on a 53% estimation

Table A-3. Cities Participating in Survey

City	Population	City	Population
Abilene, TX	113,000 [A]	Pittsburgh, PA	380,000 [A]
Albuquerque, NM	no response	Plano, TX	200,000
Amarillo, TX	170,000 [A]	Reno, NV	160,000
Beaumont, TX	114,000	Sacramento, CA	350,000 [A]
Chula Vista, CA	156,148	San Bernardino, CA	182,000
Columbia, SC	120,000 [A]	San Francisco, CA	755,300 [A]
Columbus, OH	760,000 [A]	San Jose, CA	875,000
Edmonton, Canada	621,000 [A]	Santa Ana, CA	330,000 [A]
Fremont, CA	190,000 [A]	Santa Clarita, CA	143,000
Garland, TX	200,000 [A]	Scottsdale, AZ	175,000 [A]
Glendale, CA	180,000 [A]	Simi Valley, CA	105,000 [A]
Hampton, VA	141,000 [A]	Stockton, CA	230,000
Henderson, NV	145,000 [A]	Tallahassee, FL	130,000 [A]
Irving, TX	165,000 [A]	Tampa, FL	285,000 [A]
Knoxville, TN	175,000 [A]	Toledo, OH	330,000 [A]
Lakewood, CO	136,000 [A]	Topeka, KS	130,000 [A]
Lancaster, CA	123,197	Westlake Village, CA	8,000
Los Angeles, CA	3,500,000 [A]	Wichita, KS	300,000 [A]
Louisville, KY	700,000 [A]	Winston-Salem, NC	165,000 [A]
Lubbock, TX	185,000 [A]	Anchorage, AK	250,000 [A]
Montgomery, AL	200,000 [A]	Dept. of Public Works, NH	108,000
Norfolk, VA	280,000 [A]	Gwinnett County, GA	480,000 [A]
Omaha, NE	335,000 [A]	Pasadena Public Works, CA	135,240
Overland Park, KS	130,000	Pueblo DOT, CO	101,252
Palmdale, CA	115,000	Salem Public Works, OR	120,000 [A]

Notes: A: Estimated value provided on survey

6. Does your city use signal warrants that are different from those in the 1988 national MUTCD?

Yes - 24% No - 71% Uncertain - 5%

Comments:

- The City of Chula Vista as a Charter City has developed their own City Council adopted warrants based on those contained in the State of California Department of Transportation Traffic Manual (Caltrans).
- Caltrans warrants, based on MUTCD
- Gwinnett County Conflict Warrant, Copy of 'T' and 'X' intersection warrant (attached). Reference: ITE 1994 Compendium of Technical Paper, pg 37.
- California Department of Transportation warrants that are based on MUTCD warrants
- We use warrants, but have a two justification process. #1 data (counts, accidents) compared with warrants and if one or more warrants is met, proceed to AL; #2 field observation and delay study. If prepared delay is 40 or more seconds, signal is justified; if
- We continue to use warrants 1, 2, and 8 from the pre-1988 MUTCD, that is we continue to add major st. left-turn volumes to minor st. volumes where left-turn phasing would be used
- Mandated by state law
- Caltrans St. Manual - basically the same as MUTCD
- We use 1980 Texas MUTCD as revised (we have thru revision No. 5 dated 3-31-94 plus Erratic Notification of revision No. T dated 12-1-94) - one hr warrant not used. Four hr warrant excludes ½ of minor street right turns.
- In San Francisco, the California Department of Transportation "Traffic Manual" is used as a guide. It varies slightly from the MUTCD.

7. From 1/1/93 to 12/31/95, please indicate the percentage of each warrant utilized to install or upgrade signalization. In cases where more than one warrant was met, please specify the warrant that was primarily justified.

WARRANT	PERCENTAGE OF SIGNALIZATIONS OVER LAST 3 YEARS
1 - Minimum Vehicular Volume	36
2 - Interruption of Continuous Traffic	21
3 - Minimum Pedestrian Volume	2
4 - School Crossings	2
5 - Progressive Movements	2
6 - Accident Experience	11
7 - Systems	1
8 - Combination of Warrants	5
9 - Four Hour Volumes	9
10 - Peak Hour Delay	1
11 - Peak Hour Volume	11
12 - Volumes for Actuated Signals	0
13 - Other	3

Comments:

- Fourteen signals installed by developers as part of sub-division improvements and/or street widening, i.e., two lane roadway widened to six lane prime arterial. We do not use warrant #12 and did not do studies on development signals.
- Other-mid block ped signals at bike trail crossings
- Other - political
- 1989 to 1991- The percentage should be similar for the 1993 to 1995 percent. Reference: ITE 1991 Compendium of Technical Papers, pg 163.
- General funded signals must meet two warrants or more - usually #1 and #2, plus either #6 or #8. About 2/3 or these meet #6. Developer-funded signals need only meet warrant #11. Signals built for freeway ramps do not require warrant studies.
- Difficult to track down reasons. 5, 7, 9, 10, 11 were not used, and generally are not here. Six is most important to me. Four is used some, as are 1, 2 & 8 but do not always mean a signal is needed, if there is a coordinated signal system where nearby signals create gaps and accidents are low.
- In most cases, multiple warrants were used to justify signals. The percentages listed indicate percent of total number of warrants that were used for justifying all of the signals constructed

during this three year time frame. Where multiple warrants were used, it would be very difficult to determine which was the primary warrant.

- We don't install signals that only meet one (1) warrant. The signal needs to meet warrant #1 or #2 plus #6 or #8 to justify. This is if public funds or politics doesn't come into play.
- At least five warrants were met at each intersection where a signal was installed.
- The above percentages indicate the approximate % of how many signals satisfied that warrant.
- Most intersections satisfied either 1 or 2 and 6.
- All (something) more than are warrant.
- We have used pedestrian volumes and school crossing but not in the last 5-6 yrs. We use all the three warrants marked to compare on all signal warrants run. No one necessarily has more weight. Usually when volumes meet, accidents also meet (in our case).
- Most times warrants 1 and 2 are met, warrants 9 and 11 will also be met. I am not familiar with warrant 12.

8. How many signals were installed in your city between 1/1/93 and 12/31/95?

763 - Total
17 - Average
Based on a 45% estimation

Comments:

- Some required for development
- Assume you mean new traffic signal intersections
- Twelve were constructed by state dept. of transportation as part of construction of roads. 85-87% were all freeway ramps intersecting surface streets.
- All have been signal upgrades. One new signalized intersection will be installed within the next few months.
- We typically install 10 signals per year.

9. Of these locations, how many had geometric improvements added as part of the upgrade?

346 - Total
9 - Average
Based on a 49% estimation

Comments:

- Of these locations, most had geometric improvements as a result of the realignment and construction of The Embarcadero.
- Primarily involved new signals at major traffic generators w/ new drives
- Striping was modified at each location by installing marked crosswalks.
- Most of these locations were fully improved. Didn't count the new freeway ramps as improvements.
- These signals were installed as part of the improvement of major street widening projects.

10. How many existing signal installations were upgraded between 1/1/93 and 12/31/95?

    1623 - Total
    38 - Average
    Based on a 55% estimation

    Comments:
    - We upgrade approximately four intersections per year.
    - Communications/signal coordination software/controller upgrade
    - Loop detection added, additional signal faces added, etc. (physical changes only)
    - We upgrade signals every year, from just installing new controller and cabinet to total refreshing of the infrastructure; however, very few of these are checked for warrants.
    - Left turn arrow additions and special phase configurations
    - Includes: addition of lt. phasing - 28, installation of option for preempt - 12, longer mastarms-3, installation of loops and ped buttons - 8, rebuild signals - 5, additional lt. lane and loop - 4.
    - Does not include controller equipment upgrades, detector upgrades, or minor upgrades.
    - Upgrades include controller change-out locations - Electro-mechanical to NEMA
    - These were due to accidents that gave us a good opportunity to upgrade.
    - This estimate is within plus or minus five upgrades.
    - Conversions from diagonal span to mast-arm
    - Control boxes were replaced at approx. 100 signals in this time period as part of a central control system upgrade project.

11. How many signals were removed in your city between 1/1/93 and 12/31/95?

    61 - Total
    4 - Average
    Based on a 21% estimation

    Comments:
    - These all come out of the downtown area.
    - These signals were temporarily installed for construction projects and were removed upon completion of construction.
    - This doesn't include a handful of signals removed due to freeway construction (moved to nearby locations in most cases).
    - Tried to remove ~6 in 1992, but too much public controversy.
    - 24 hr. flash operation

PART III - WARRANTING CRITERIA

12. Please indicate the vehicular volume data your city typically obtains for initial warrant analysis.

Duration of counts:	65% - 24 hours	2% - 16 hours	20% - Highest 8-hour
	14% - Highest 4-hour	20% - Peak hour	6% - Peak 15-minute

Is the volume duration checked above determined from:

80% - Hourly volume counts from a single day?
16% - An average of hourly volume counts over multiple days?
20% - Other:
- ♦Our counts are 48 hour counts with each hour broken into 4-15 min. periods. Highest hours are taken from 7-8am, for example, while peak hour may be from 7:15 to 8:15 depending on the actual traffic. Both days are added together and averaged to get the high.
- ♦15 min. counts for 2 hours am & 2 hours pm on one day
- ♦We use 12 hr. manual volume counts from a single day.
- ♦We normally obtain both an automatic count (24 hr) and a manual count (6 peak hours).
- ♦Make tube counts for 2-3 weekdays & are tabulated by 15 minute periods.
- ♦8-hour turn count w/ peds. count occurs on 2 days - pm day 1 & am day 2.
- ♦13 hour turning movement counts from 6:00 am till 7:00 pm
- ♦We count by 15 minute increments for twelve hours (usually 7:00a.m to 7:00p.m.) on one day. This is a turning movement count.
- ♦15 min. counts for a single day
- ♦12 hours
- ♦Each location is considered based on 1) past counts &/or 2) familiarity with location as to whether a four peak hrs. turning movement or 24 hr. approaches count might be more worthwhile.
- ♦Often we will get 8 hour counts to start, but meeting warrants 1 and 2 is difficult with only 8 hours of data.
- ♦24 hour machine counts, educated guesses, 10 minute counts, estimates from nearby locations, or other agencies counts

13. Does your city classify these volume data as part of the warrant analysis process?

18% - Yes 82% - No If yes, indicate the classifications used:

16% - Heavy trucks	2% - Light trucks	18% - Passenger cars
8% - Buses	0% - Motorcycles	8% - Bicycles

How do you use these data?
- ♦ Signal timing
- ♦ Signal timing
- ♦ To obtain % of truck traffic of statistic, nothing else
- ♦ We check with the MUTCD warrants. If any of the warrants are met, then we conduct a turning movement count for 9 hours.
- ♦ Only use classifications when anticipate some unusual percentage or condition - rarely occurs.
- ♦ Bicycles and peds are counted separately from motor vehicles.
- ♦ Peak hours determined from counts
- ♦ Classification data is used exclusively for street design and pavement section determination and is not a criteria for traffic signal installation.

14. Are turning movements collected as part of the warrant analysis process?

73% - Yes 27% - No

How do you use these data?

- Document percent of side street right turns which are taken out of the analysis
- To study for left turn phasing and determine signal timing
- Turning movements are used to determine left turn phasing requirements and signal timing but not for initial installation warrants.
- Overall traffic volume/left turn phase (protected/perm) on selected studies only
- Sometimes-depending on location
- Maybe - depends on consideration for turn indications
- Depends on intersection. Data used for timing and protected turn analysis.
- Perform delay analysis using highway capacity software
- 1). If signal request is due to main line left turn into a site against opposing traffic e.g., freeway on ramp. 2). If side street has two lanes and left turn traffic may generate enough traffic to be analyzed as one-lane instead of two-lane.
- We still include left turns in warrants #1 & #2 where separate left turn phasing is appropriate.
- Engineering judgement used to subtract right turn volumes, determine # or lanes to use when left turn lanes exist.
- Engineering judgement used to subtract right turn volumes, determine # or lanes to use when left turn lanes exist.
- Turning volumes are analyzed to see if left turn phasing is needed or if right turn volumes should be included in volumes used to justify a signal.
- If tube counts well below warrants, no turning movement counts are made. May count if high percentage of right turns is expected.
- Not used in analysis, except to assess whether geometric improvements would relieve "need" for signalization
- We verify 24-hr tube counts, look for pedestrians, conflicts, and trends. We might subtract right turns if high.
- We look a right turn volumes. If a traffic signal is installed, counts are used for signal phase selection.
- For minor street approach, we do warrant analysis based on existing approach plus possible revisions to approach. Also, we look at % of each movement (right turn, straight, left turn) to decide how many lanes to use the analysis.
- Use for installation of left turn and right turn bays
- To determine left turn warrants, right turn lane needs, or signal overlays, etc.
- 1)see #6 2)Capacity analysis 3)left turn arrow determination
- Signal timing, if warranted based upon 24 hour/15 min counts and/or accident data.
- To determine the need for separate left-turn phases.
- To discount for right turns. We take the % of vehicles which could get a gap of 6 sec in the main line and discount the right turn by this %.

- To, for example, consider the installation of a new signal with a protected left turn phase.

15. Is vehicle delay measured as part of the warrant analysis process?

    34% - Yes 66% - No

    If yes, at what percentage of intersections? 58%

    What justifies delay measurement at some intersections over others?

    - If parts 2 and 3 of warrant 10 are met, then a delay study is done.
    - When considering new signal installations, we analyze all applicable warrants (i.e., those which address a real or perceived problem). To justify the installation of a signal, we try to meet as many warrants as possible, though this varies from engineer to engineer since meeting one warrant is all that is required.
    - If delay warrant is likely to be only one met, it is studied, and if warrants are met but need in unclear, delay will be measured;p otherwise delay is not measured.
    - When peak hour delay warrant being considered and/or signal is marginally warranted based upon volumes.
    - 1)observation 2)perhaps numerous citizen complaints 3)accident frequency
    - Percentage is very small. Warrant 10 is peak hour delay warrant. If engineer, through reviewing volume data and observation of intersection, believes warrant 10 will not be met, then delay data is not collected. Delay data is usually only collected as a way to set priority between two intersections that clearly meet only one or more signal warrants.
    - We first prioritize studies, then do delay studies at the top 20 locations.
    - Has been used to assist in warranting when problem exists for which stop signs are not appropriate.
    - Based on counts, # of lanes, & observations. Delay measured when suspected to be in question or to prioritize installations.
    - Field investigations which reveal long queues, particularly for left & right turns.
    - Sometimes do traffic modeling to estimate delay, but do not measure it.
    - We calculate delay but do not use it in warranting locations for signals.
    - Delay measured only if appears significant. Have never had a location come close to satisfying warrant #10.
    - If warrant analysis indicates one of warrants may be met, we do a vehicle delay study during peak hours; delay must be equal to or greater than 40 seconds to justify signal
    - Budget and staff time is not available for this.
    - Do all intersections
    - Geometrics
    - It is one of the warrants that is studied at all locations (see warrant #10).
    - Volumes to warrant on warrant #2 or #10.

16. What criteria does your city use to determine when a pedestrian volume count is needed for warrant analysis?

- Pedestrian counted in T.M.C.
- Warrant #3 is a "Minimum Pedestrian Volume" warrant which requires pedestrian counts for the 8 highest traffic hours at each intersection.
- If the count falls within 10 percent of the warrant condition per MUTCD/Caltrans Traffic Manual or if it is an intersection in high pedestrian activity area
- Usually a school in close proximity or a retail outlet (mall) that may generate peds.
- City council direction
- Any evidence of pedestrian activity
- Pedestrian generators near intersection
- Not aware of any recent signal installations where pedestrian volumes were a factor.
- Very limited area has high enough pedestrian volume to be considered (downtown)
- Based on special request. Pedestrians are rarely an issue in Gwinnett County.
- Land development, citizen complaints, past history
- Estimation only or actual observations during peak times
- If the request for a signal is pedestrian-oriented or for a school-related problem
- Engineering judgement.
- We always count peds.
- Pedestrian volumes always too low, not generally needed for analysis. Sometimes do gap studies to determine if a signals are needed for peds.
- Field investigations are always done to check for unusual conditions - peds are one condition that is checked.
- Peds. are always counted as part of our normal 12-hour turning movement count.
- When it is obvious that there is a lot of peds - 100 peds per hour is a lot
- Pedestrian volumes are normally included in manual count. If the individual request is for a signal near a school, we will adjust hours for the manual count to include school age pedestrians.
- Familiarity with location, location relative to schools
- Always performed as part of turn count
- Citizen requests, school crossing or two major traffic generators across from each other.
- If there is a school crossing
- When intersection appears to have high pedestrian activity that may satisfy warrant #3.
- None
- Site specific conditions - pedestrian volumes rarely approach warranting criteria.
- Pedestrian volume count is collected for all intersections for which signal warrant analysis is done.
- Warrant #3 is used as is. This is a rare warrant that we use to justify a signal.
- Past visual observations
- Nature of problem & character of surroundings
- Location of intersection; school zones, downtown area
- Not done except for school crossings.
- Pedestrian volume are always counted with our manual counts.
- Peds counted routinely with 4 hr. turning movement studies -generally not classified by age as usually they are very few in #.
- When requested or when there is a reasonable chance the amount of pedestrian may be significant.

- When enough complaints about the need for a pedestrian signal are received
- Presence of a school near the intersection
- Experience/land usage/part of turning movement count data
- Pedestrian counts are obtained if we are going to try to meet warrant three, or to determine the need for a warranted signal, or to determine if pedestrian phones should be added
- Available pedestrian volume data and judgement
- General familiarity w/area and traffic
- Our department uses a signal rating system to calculate the priority of a new signal at an intersection. This rating system considers vehicular volumes, pedestrian volumes, accidents, major flow data, coordination, stops, and unusual conditions.
- When the request is specific that pedestrians are having hard time crossing a heavily traveled walkway, and no gap is a variable for safe x-way

17. Does your city classify these pedestrian data by age?

    24% - Yes 76% - No

    If so, indicate the age categories used:

    24% - Under 13 years 16% - 13 - 60 years 14% - Over 60 years

    Other: ♦Elementary/Middle school/High school/Adult/Senior
    ♦Under & over 16
    ♦Adult and school age students.

Comments:

- To determine high pedestrian activity areas
- To set pedestrian crossing time
- For school crossing warrants evaluation or guard crossing warrants
- We assume that all peds are of school-age at locations on "official routes to school".
- To further justify a new signal - if a large # of children or elderly
- Primarily to get a sense of how the intersection is being used by pedestrians. If ped counts are high, signal may be justified based on ped volume warrant.
- Usually relevant to crossing guard locations or signal operation (e.g., right turns on red allowed, separate LT. phases, etc.)
- To calculate walking speed
- To determine if a location satisfies for a signal installation under the "traffic signal for school" warrant in the State of California, Dept. of Transportation Traffic Manual.
- School crossings primarily
- See if signal pedestrian heads/phasing might be welded as part of new signal installations
- Schools

18. Is pedestrian delay measured as part of the warrant analysis process?

    8% - Yes 92% - No

    If yes, at what percentage of intersections? 6%

What justifies delay measurement at some intersections over others?

- The need to interrupt vehicular traffic for pedestrian crossing is the primary purpose of this warrant. Not based on pedestrian delay as much as providing protection.
- If request for signal is school related
- Complaint's general environment, e.g., business area with pedestrian activity may be comparatively (in-city) heavy
- Gap analysis may be performed for school crossings.
- But do gap studies near schools, old folks homes, etc.
- Schools

19. Does your city consider 85th-percentile speeds to reduce the minimum volume warrants?

80% - Yes 20% - No

Comments:
- This is one difference between the MUTCD and the "Traffic Manual." The "Traffic Manual" does not contain language to reduce the minimum volume warrants.
- Typically use speed limit
- Generally used via less restrictive 4 hr. warrant curve when intersection involves an arterial - usually posted at 40 mph, & 85th percentile is above 40 mph
- We use the speed limit if it is a high speed. Of course, the speed limit is suppose to be around the 85th percentile unless there are unusual conditions.
- Sometimes
- We use current radar speed studies to determine if a local is "urban" or "rural"
- In warrants 1, 2, and 3, the urban/rural determination is based on prevailing or 85th percentile speeds.

20. Does your city consider accident data when conducting a warrant analysis?

100% - Yes 0% - No If yes: 80% - by frequency (e.g., number per time period)
82% - by type (e.g., side-swipe, rear-end, etc)
31% - by severity (e.g., fatal, injury, or PDO)

How do you define "accidents susceptible to correction by traffic signal control?"

- Right angle and left turn
- Right angle, left turn
- For warranting purposes, we use only "right angle" accidents, i.e., accidents involving a vehicle from each street in which the right-of-way control was violated. Left turn accidents are a factor - already whether to install a left turn phase from existing or planned signal.
- Right angle collisions. We know rear ends usually increase upon installation of a signal. But we do look at all accidents at a given intersection.
- Typically right angle, or left turn depending on intersection geometry
- Generally we use broadside as the key to correction by signal control, turn movements for left turn studies.

- Right angle & left turns
- Angle, a turning if the signal could have prevented it
- Generally right angle
- Right-angle, left-angle
- Those that are considered right-angle or turning movement accidents
- Broadsides involving either vehicles traveling at right-angles or one vehicle hitting a left turning vehicle.
- We generally look at angle accidents. Specific police reports will occasionally be read to determine which ones a signal may have prevented.
- By left turn or right angle accidents
- Right angle
- Accidents susceptible to correction are generally those which can be prevented by assigning the right-of-way more clearly.
- Right angle

If severity is considered, how?

- In ranking formula
- PDO, injury & fatal
- The accident experience warrant is satisfied when "five or more reported accidents of types susceptible to correction by traffic signal control have occurred within a 12-month period, each accident involving a personal injury or property damage to an...."
- Not considered
- In the assignment of priority points
- "engineering judgement"
- As a tool to establish priority among intersections which meet one or more signal warrants
- Only to establish immediacy of installation - many locations warrant a signal, but it does not necessarily make sense to actually install it.
- By number and type
- No precise formula, usually most relevant in prioritization. Since city is growing rapidly, we also look at growth trends, undeveloped area , the site, etc.
- We usually include fatal and injury accidents only. We use 3 for no. of accidents during recent 12 month period. LAPD does not take accident reports for all PDO accidents. Therefore, we use fatal and injury info only along with reduced warrant requirement.
- No
- Severity is considered when ranking locations that have met signal warrants.
- Reportable accident
- No
- To prioritize installation warranted signal
- Spectacular collisions get public & political attention - but not within the warrant analysis
- Six fatals over two years
- The accident number is the number of accidents reported with over $500 of damage.

21. Does your city consider other traffic or geometric characteristics when conducting a warrant analysis?

71% - Yes 40% - No

Comments:

- Sight distance
- See warrant #12 "Special Conditions."
- Sight distance
- Skewed intersections
- e.g. intersection offset in median for L.T.
- Limited sight distance
- Sight distance
- Sight distance, conflict warrant, T or X intersection (geometry)
- Is there a sight distance restriction that cannot be restricted -- (there will probably be an angle-accident problem with this situation).
- Sight distance, number of lanes
- We consider roadway classification (major routes - warrant 7), proximity to schools or parks (warrant 4), issues of access (added points for landlocked neighborhoods).
- Sight distance is important - AASHTO.
- Volume
- Overall site conditions, i.e, proximity to railroad tracks, driveways, other signals, etc.
- Every location also analyzed in the field for any unusual conditions that might justify the installation of a signal. These conditions are then noted in the authorization report.
- Visibility, growth anticipated, any characteristic which may be impacted. Whether other controls or geometric changes are more appropriate.
- Some geometric conditions are not conducive to pole placement. Also, correction of poor geometric conditions may relieve need for signal.
- We look at pavement markings, sign control (visibility, condition, & placement), channelization, roadway lighting and surface.
- Sight distance
- Visibility - but only to establish immediacy of installation - many locations warrant a signal, but it does not necessarily make sense to actually install it.
- Geometric: "T" intersections, one way streets, locations relative to adjacent signals along both streets, planned roadway improvements, right turn lanes. Traffic: growth rate, high concentrations of young drivers or elderly drivers.
- Street offset, other signals in area, or general problems that might exist. (Driveways, traffic generators, etc.).
- Sight distance, roadway design
- Time of year - school vs non-school, day of week-generally no counts on atypical days-Monday or Friday & weekends, holidays hours of the day - if prior info is available may count atypical hours
- If a right-turn lane will help or left-turn lane, we will take this into consideration
- Volume of trucks/geometric improvement cost/need for improvements
- We look at inadequate site distances when conducting our studies and adjust our right turn discounting accordingly.
- Future traffic growth

- For example, improving transit operation is considered to warrant a signal, as is to improve ingress/egress at new developments. Sight distance is a possible consideration on the steep hills of San Francisco.

PART IV - WARRANT MODIFICATION

22. Should the existing warrants in the national MUTCD be modified?

39% - Yes 61% - No

Comments:

- The volumes required to install traffic signals cannot be met all the time; political pressure is there if the council person get pressured from constituents.
- Modifications based on (1) severity of accidents (2) heavy pedestrian activity mid-block
- I think trucks should be considered in some situations.
- If prevailing good judgment (especially backed by reliable data) from traffic engineering profession recommends modification. No specific recommendations except to know if all current warrants are used & if not used, consider removal.
- Not wild about the peak hour warrant; it makes it easy to justify a signal at just about any location.
- For warrants 1 & 2, provide for a reduction in warranting volume for speed over 40 mph. This reduction to 70% of standard is too large of a reduction to do in a single step. There would be two steps in the reduction speed less than 40 (standard), speed 40 to 50 (85% of standard),and speeds over 50 (70% of standard).
- There should be a classification in the traffic volume justification, to justify a traffic signal based on a traffic split. For ex., if you had 500 vph on both streets for an eight hour period.
- Need to look at delay based warrants
- I think the volumes for warrant #2 are too low. Almost any side street could meet it.
- Peak hour w/ speed reduction allows warrants to be met too easily.
- Should be more specific in identifying pros & cons of signal installation and impact on individual movements. Also, consider impacts over entire day.
- In large urban areas, 8 hr. requirements for volume warrants should be reduced to 6 hrs., and accident warrant may need to be modified if reporting system does not include PDOs.
- Throw out 9-11. Not sure what 12 is. More clarification on removing right turners. More clarification on when to treat as 1 or 2 lane approach if left turn lanes exist. Make allowances for when nearby signals create gaps. Address T-intersections which seem to operate better with no opposing traffic for side street lefts.
- Need some way to factor in left-turns from major to minor streets.
- Have seen proposed changes - reducing from 11 to 7 warrants. Have not thoroughly
- The accidents warrant uses a raw number of five correctable accidents; an accident rate would be more appropriate; we get numerous suggestions each year that school buses and trucks should get passenger car equivalents to increase count to compensate form.
- Consider difference between X and T intersection-there are 32 conflict points at an X intersection but only 6 at T intersection. The warrants should be different. Consider the right turn volume not being necessary for signal warrant. Ignoring RT's is only advised in the MUTCD. Consolidate warrants 5 and 7. Consider median refuge for certain level of side street traffic.
- Remove the four hour volume warrant

- Traffic warrant volumes may be too low resulting in many warranted signals. Give some guidance on when emergency signals should or should not be installed by establishing minimum threshold criteria.

23. Is there a need for a new warrant(s)?

29% - Yes 71% - No

Comments:
- Emergency signals. See comments on #22.
- A warrant does a better job looking at the available gaps in traffic for the side street. Gaps are too hard and laborious to measure, so a substitute for a gap warrant. Let the warrant really address the operational characteristic.
- Severe sight distance combined with either high speed and/or high traffic volume
- If existing warrants cannot be molded to include other issues (e.g., large vehicles), then new warrants may not be needed.
- An engineering judgement warrant that would factor in issues such as restricted access, land use decisions, or other not covered by existing warrants.
- Modify existing warrants.
- Possible special warrant for shopping centers or developments. Also warrant for removal.
- Delay based
- Fatalities should not justify a signal installation.
- The Texas MUTCD warrant 12 (8 hr & 2 hr warrants for actuated signals) is a good warrant that should be considered.
- Trucks start up delay
- As mentioned in item 22, either the existing warrants must be modified or new warrant be added to consider these factors.

PART V - POTENTIAL WARRANTS

24. Should accident severity be incorporated into the accident warrant?

22% - Yes 47% - No 31% - Uncertain

Comments:
- Severity is a function of speed which is already incorporated into the volume warrants.
- Accident severity is considered, though no specific provisions are made for fatalities.
- The problem with incorporating an accident warrant is that the question, "How many people have to die before you put in a signal?" will have an answer, and that answer may not be zero. The correct answer to this question if there is one, should continue to be zero.
- By formal measure?? - perhaps best left to engineering judgement
- To some degree, it already is because minor accidents frequently are not reported. The difference between an injury & fatal can be nothing more than the age of the person or use of a seat belt.

- ♦ Politically, severe accidents often lead to pressure for action. In most cases though, the intersection meets one or more existing warrants, but we have been unable to obtain funding.
- ♦ I can give intersections that have had severe accidents, but I would never place a signal there, & I have locations that still have severe accidents with a signal installed. Therefore, I see severe accidents as not being remedied by signals unless there are a lot of them.
- ♦ The difference in severity is often due to factors not related to signal control. For example, wearing a seatbelt or not wearing a seatbelt on a small car hit by a pickup compared with two passenger cars colliding.
- ♦ A fatal accident may be counted as 2 accident?
- ♦ Multiple severe injuries may indicate a sight distance or perception problem.
- ♦ Too many variables to consider like driver experience, vehicle condition etc. alcohol drug related.
- ♦ Not normally applicable in an urban environment. Maybe in rural environment.
- ♦ Primarily for prioritization. Investigation into potential impact of signal and accidents causes should be clear. Should be very cautious of drawing too many conclusions from one or a few accidents. Also consider trends.
- ♦ Only if reporting agency (police, hwy patrol, etc.) does not include every type of accident (PDOs) - Then numerical requirement (5) should be lowered (?). Otherwise, severity is probably not important (although severity can be extremely important from a political viewpoint,
- ♦ Conditions that contribute to accidents may not have any bearing on severity. Severity usually a result of speed.
- ♦ Too hard to standardize degrees of severity or to determine degree from our summary accident histories.
- ♦ "Severity" can be difficult to quantify - dependent upon age (and "health") of both vehicle and driver. Would be difficult to get consistent/detailed information from our accident database.
- ♦ However, existing raw # of 5 should be changed to a rate (per million vehicles). Solving "fender benders" is just as important – they may lend to a more severe type of accident.
- ♦ Severity is subjective, e.g., we just had a slow speed collision which resulted in a fatality because of the age and condition of the victim.
- ♦ Severity of a collision may be due to factors unrelated to signal warrants. For example, the use of safety equipment.
- ♦ If we do not watch ourselves, we'll be building more monuments to acts of idiocy. Severity is an issue of chance. The greater the severity, generally, the greater the acts of idiocy - carelessness.
- ♦ We pull accidents over $500 of damage. With today's cars, minor fender benders cause $500 of damage.

25. If the accident warrant is modified to include accident severity, how should it be done?

56% - Weighted based on severity of accidents (i.e., fatal, injury, and PDO)

12% - Other: ♦We pull accidents over $500 of damage. With today's cars minor fender benders cause $500 of damage.

♦High speed impacts vs. Low speed. Typically will have a correlation to severity.

♦A fatality at an unsignalized intersection usually requires signalization for political reasons.
♦Degree of actual collision, i.e., amount of energy dissipated as a result of the crash -- this means higher speed accidents will always get high severity and low speed accidents is always a low severity.
♦N/A
♦Only as if cautious as indicated in #24
♦Increase #s if only PDO
♦Cost to the community measure

If weighted, indicate the weights you would recommend.

54% - Fatal accidents
30% - Injury accident
17% - Property Damage Only accidents

Comments:
- Not just on severity; should weight by likely signal impact
- Should be careful not weighted so that a fatality controls the whole analysis
- One or two fatals should not justify a signal. There should still be a minimum volume included, and all other means to solve problems should be tried first. Signal should always be last device tried.
- See above comments
- May need to change the threshold.
- A traffic engineer and/or civil engineer should be capable of judgement & thought.
- If property damage & fatals are summed, we'll be getting a clearer picture of what is serious & what is merely a fender bender due to inattentive driving.

26. Should vehicle type (i.e., passenger car, heavy truck, bus, etc.) be considered in the warrants?

24% - Yes 44% - No 32% - Uncertain

Comments:
- Trucks have very low involvement in numbers relative to the total, but have a disproportionately high number of major injury & fatalities to the automobile drivers that they tangle with.
- School buses only
- Maybe specific locations after considering speed, visibility, AADT, # of lanes, turn lanes, etc., alt. routes
- Trucks and other bigger vehicles may be converted to an equivalent of passenger cars
- We get requests every year for this.
- Buses and heavy trucks do have a significant impact on flow.
- Trucks need a much higher "acceptable gap" to enter a busy street. from a stop controlled minor street.
- In some rare cases, vehicle type may be important (i.e., trucks).
- Should be left to engineer

- ♦ This is an engineering judgement consideration. A signal may be installed when warrants are not met.
- ♦ Probably heavy trucks based on percentage (if over 10%, reduce #s). Trucks have different accel. / decel. characteristics.
- ♦ Trucks and buses have different vehicle characteristics that can increase the need for a traffic signal, etc., longer time to get started from stop
- ♦ Type of vehicle is more significant as a factor as part of traffic on the minor street than for the angled street.

27. If the MUTCD warrants are modified to include vehicle type, how should it be done?

46% - Equivalency factors
25% - Minimum number of heavy vehicles/buses to meet the reduced volume criteria in existing warrants
14% - Other: ♦We have used bus occupancy rates to convert bus volumes into an equivalent vehicular volume.
♦When minor street approach for left or straight movement has a heavy vehicle that exceeds a specified threshold (actual # on % of total), then a reduced volume criteria would apply
♦Should be left to engineer
♦Unsure
♦Weight factors
♦Alt. routes should also be considered.
♦Percent of heavy vehicles should be include and an adjustment made but I don't necessarily agree that existing numbers should be lowered. They should first be increased for the warrants in general and allow factored reduction based on the percent of heavy vehicles.

Comments:
- ♦ This is an issue for detection & timing if a signal is installed, assuming that it is warranted.
- ♦ Consideration as to whether the median refuge will support the long vehicle
- ♦ Not sure I like #2; it would be signal to revised ped warrant #3
- ♦ Recommend that this be treated as a special condition to be left to the discretion of the engineer. Possibly provide some general guidance.

28. The MUTCD contains provisions for the installation of emergency traffic signals (section 4E-18) at locations that do not meet the standard warranting procedure. Similar reservations have been proposed within the scope of this project and are listed below. Indicate the situations in which you feel reservations from the standard signal warranting procedures may be granted.

40% - Hazardous chemical plants adjacent to major roadways using fleets of heavy vehicles for transportation
40% - Industrial parks entrances with high peak traffic intersecting major roadways
30% - Military bases intersecting major roadways that frequently transport unknown but potentially hazardous cargo
14% - Other: ♦Entrances/exits to exclusive bus transit

- ♦See below
- ♦Fire stations and maybe hospital entrances
- ♦Adjacent to school
- ♦Schools
- ♦Study location on a case by case basis

35% - No other exception should be provided

Comments:

- ♦ It can be accomplished with advance warning signage/flashing beacons. Give more defined parameters for placement of emergency signals. Nearly all facilities want them, and it is hard to say "No" without some established standards, not merely generalities.
- ♦ Situations above usually have uniformed traffic control. If the industrial park has enough vol - the warrant is met.
- ♦ These sound reasonable, but what might be deemed similar...what precedents does this set?
- ♦ These signals should operate in flash mode when not used by hazardous or special vehicle.
- ♦ Emergency vehicles have a special need because of the time factor involved (need for a fast and safe access into traffic stream of busy roadway). Too many signals get installed now that are not justified. Additional exceptions would open the flood gates to more unjustified signals.
- ♦ As mentioned, have installed signals for "political/economic" reasons...
- ♦ We have warrants for peak hour traffic (9 and 11).
- ♦ Uncertain. No real need for that here.
- ♦ I would have no objections to special warrants for these situations. However, I would hope that most traffic engineers would be able to authorize signals under these conditions even if the "official" warrants were not satisfied.
- ♦ Due to acceleration/deceleration characteristics
- ♦ Most of the aforementioned criteria appear to cause other warrants to be met.
- ♦ Recommend that special conditions be left to the discretion of the engineer. There are an infinite number of special cases that will have to be individually addressed.
- ♦ A good reason for exception is that signals that are located where there is not the usual high volumes to meet warrants violate the driver expectancy. I think most of the above reasons can be handled by signage or warning beacons.
- ♦ Emergency vehicles have to enter the intersection quickly and safely to save lives and property. The above vehicles only have to enter safely and could wait for gaps in traffic as long as necessary to do so.

APPENDIX B

CURRENT TEXAS MUTCD WARRANTS

CURRENT TRAFFIC SIGNAL WARRANTS

This section provides the actual language of the Texas MUTCD sections addressing the twelve traffic signal warrants. In general, the language of these warrants is the same as contained in the 1988 National MUTCD. However, the Texas MUTCD contains an additional warrant (Warrant 12) and there has been language added to some of the warrants. In this section, the additional language from the Texas MUTCD that is not contained within the National MUTCD is distinguished using a different font.

Warrant 1, Minimum Vehicular Volume (4C-3)

The Minimum Vehicular Volume warrant is intended for application where the volume of intersecting traffic is the principal reason for consideration of signal installation. The warrant is satisfied when, for each of any 8 hours of an average day, the traffic volumes given in Table 11 exist on the major street and on the higher-volume minor street approach to the intersection. An "average" day is defined as a weekday representing traffic volumes normally and repeatedly found at the location.

Table B-1. Minimum Vehicular Volumes for Warrant 1

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)	Vehicles per hour on higher-volume minor-street approach (one direction only)
Major Street	Minor Street		
1	1	500	150
2 or more	1	600	150
2 or more	2 or more	600	200
1	2 or more	500	200

These major-street and minor-street volumes are for the same 8 hours. During those 8 hours, the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours.

When the 85-percentile speed of major-street traffic exceeds 40 mph in either an urban or a rural area, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the Minimum Vehicular Volume warrant is 70 percent of the requirements above.

Warrant 2, Interruption of Continuous Traffic (4C-4)

The Interruption of Continuous Traffic warrant applies to operating conditions where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay

or hazard in entering or crossing the major street. The warrant is satisfied when, for each of any 8 hours of an average day, the traffic volumes given in the table below exist on the major street and on the higher-volume minor street approach to the intersection, and the signal installation will not seriously disrupt progressive traffic flow.

Table B-2. Minimum Vehicular Volumes for Warrant 2

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)	Vehicles per hour on higher-volume minor-street approach (one direction only)
Major Street	Minor Street		
1	1	750	75
2 or more	1	900	75
2 or more	2 or more	900	100
1	2 or more	750	100

These major-street and minor-street volumes are for the same 8 hours. During those 8 hours, the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours.

When the 85-percentile speed of major-street traffic exceeds 40 mph in either an urban or a rural area, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the Interruption of Continuous Traffic warrant is 70 percent of the requirements above.

Warrant 3, Minimum Pedestrian Volume (4C-5)

A traffic signal may be warranted where the pedestrian volume crossing the major street at an intersection or mid-block location during an average day is:

100 or more for each of any four hours; or
190 or more during any one hour.

The pedestrian volume crossing the major street may be reduced as much as 50 percent of the values given above when the predominant pedestrian crossing speed is below 3.5 feet per second.

In addition to a minimum pedestrian volume of that stated above, there shall be less than 60 gaps per hour in the traffic stream of adequate length for pedestrians to cross during the same period when the pedestrian volume criterion is satisfied. Where there is a divided street having a median of sufficient width for the pedestrian(s) to wait, the requirement applies separately to each direction of vehicular traffic.

Where coordinated traffic signals on each side of the study location provide for platooned traffic which result in fewer than 60 gaps per hour of adequate length for the pedestrians to cross the street, a traffic signal may not be warranted.

This warrant applies only to those locations where the nearest traffic signal along the major street is greater than 300 feet and where a new traffic signal at the study location would not unduly restrict platooned flow of traffic. Curbside parking at non-intersection locations should be prohibited for 100 feet in advance of and 20 feet beyond the crosswalk.

A signal installed under this warrant should be of the traffic-actuated type with push buttons for pedestrians crossing the main street. If such a signal is installed within a signal system, it should be coordinated if the signal system is coordinated.

Signals installed according to this warrant shall be equipped with pedestrian indications conforming to requirements set forth in other sections of this Manual.

Signals may be installed at non-intersection locations (mod-block) provided the requirements of this warrant are met, and provided that the related crosswalk is not closer than 150 feet to another established crosswalk. Curbside parking should be prohibited for 100 feet in advance of and 20 feet beyond the crosswalk. Phasing, coordination, and installation must conform to standards set forth in this Manual. Special attention should be given to the signal head placement and the signs and markings used at non-intersection locations to be sure drivers are aware of this special application.

Warrant 4, School Crossing (4C-6)

A traffic control signal may be warranted at an established school crossing when a traffic engineering study of the frequency and adequacy of gaps in the vehicular traffic stream as related to the number and size of groups of school children at the school crossing shows that the number of adequate gaps in the traffic stream during the period when the children are using the crossing is less than the number of minutes in the same period (sec. 7A-3).

When traffic control signals are installed entirely under this warrant:

a. Pedestrian indications shall be provided at least for each crosswalk established as a school crossing.
b. At an intersection, the signal normally should be traffic-actuated. As a minimum, it should be semi-traffic-actuated, but full actuation with detectors on all approaches may be desirable. Intersection installations that can be fitted into progressive signal systems may have pretimed control.
c. At non-intersection crossings, the signal should be pedestrian actuated, parking and other obstructions to view should be prohibited for at least 100 feet in advance of and 20 feet beyond the crosswalk, and the installation should include suitable standard signs and pavement markings. Special police supervision and/or enforcement should be provided for a new non-intersection installation.

Warrant 5, Progressive Movement (4C-7)

Progressive movement control sometimes necessitates traffic signal installations at intersections where they would not otherwise be warranted, in order to maintain proper grouping of vehicles and effectively regulate group speed. The Progressive Movement warrant is satisfied when:

1. On a one-way street or a street which has predominantly unidirectional traffic, the adjacent signals are so far apart that they do not provide the necessary degree of vehicle platooning and speed control, or
2. On a two-way street, adjacent signals do not provide the necessary degree of platooning and speed control and the proposed and adjacent signals could constitute a progressive signal system.

The installation of a signal according to this warrant should be based on the 85-percentile speed unless an engineering study indicates that another speed is more desirable.

The installation of a signal according to this warrant should not be considered where the resultant signal spacing would be less than 1000 feet.

Warrant 6, Accident Experience (4C-8)

The Accident Experience warrant is satisfied when:

1. Adequate trial of less restrictive remedies with satisfactory observance and enforcement has failed to reduce the accident frequency; and
2. Five or more reported accidents, of types susceptible to correction by traffic signal control, have occurred within a 12-month period, each accident involving personal injury or property damage apparently exceeding the applicable requirements for a reportable accident; and
3. There exists a volume of vehicular and pedestrian traffic not less than 80 percent of the requirements specified either in the Minimum Vehicular Volume warrant, the Interruption of Continuous Traffic warrant, or the Minimum Pedestrian Volume warrant; and
4. The signal installation will not seriously disrupt progressive traffic flow.

Any traffic signal installed solely on the Accident Experience warrant should be semi-traffic-actuated (with control devices which provide proper coordination if installed at an intersection within a coordinated system) and normally should be fully traffic-actuated if installed at an isolated intersection.

Warrant 7, Systems Warrant (4C-9)

A traffic signal installation at some intersections may be warranted to encourage concentration and organization of traffic flow networks. The Systems Warrant is applicable when the common intersection of two or more major routes: (1) has a total existing, or immediately projected, entering volume of at least 1000 vehicles during the peak hour of a typical weekday and has five year projected traffic volumes, based on an engineering study, which meet one or more of warrants 1, 2,

8, 9, and 11 during an average weekday; or (2) has a total existing or immediately projected entering volume of at least 1000 vehicles for each of any five hours of a Saturday and/or Sunday.

A major route as used in the above warrant has one or more of the following characteristics;

1. It is part of the street or highway system that serves as the principal network for through traffic flow;
2. It connects areas of principal traffic generation;
3. It includes rural or suburban highways outside, entering or traversing a city;
4. It has surface street freeway or expressway terminals;
5. It appears as a major route on an official plan such as a major street plan in an urban area traffic and transportation study.

Warrant 8, Combination of Warrants (4C-10)

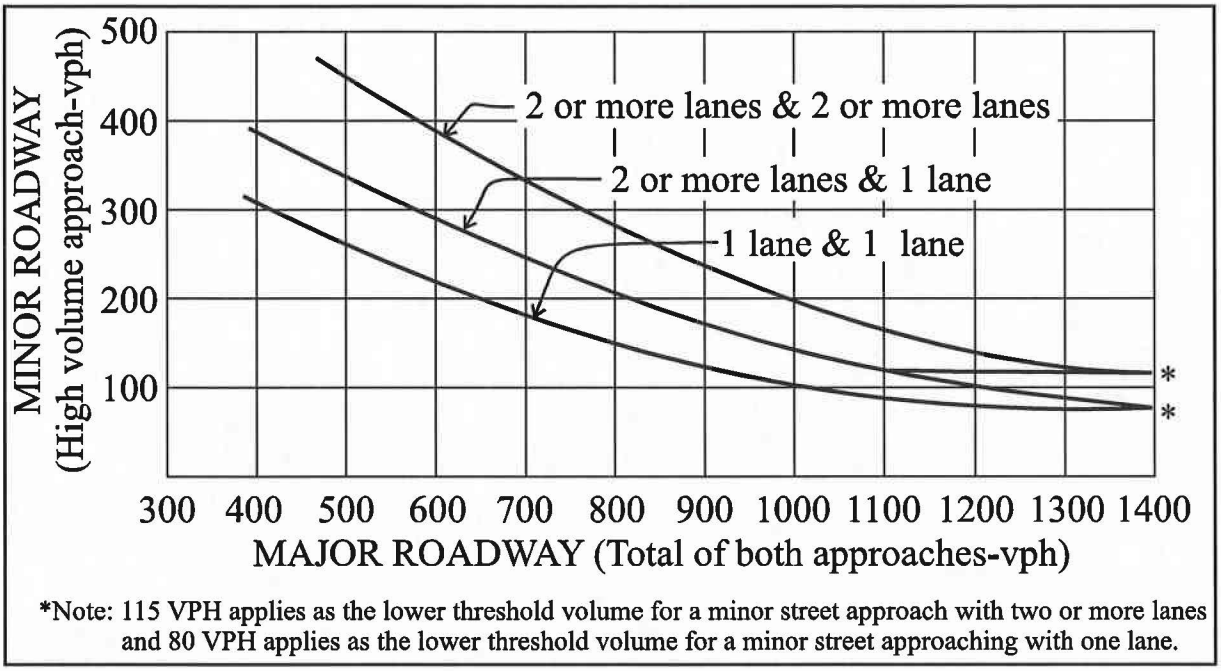
In exceptional cases, signals occasionally may be justified where no single warrant is satisfied but where two or more of Warrants 1, 2, and 3 are satisfied to the extent of 80 percent or more of the stated values.

Adequate trial of other remedial measures which cause less delay and inconvenience to traffic should precede installation of signals under this warrant.

Warrant 9, Four Hour Volume (4C-10.1)

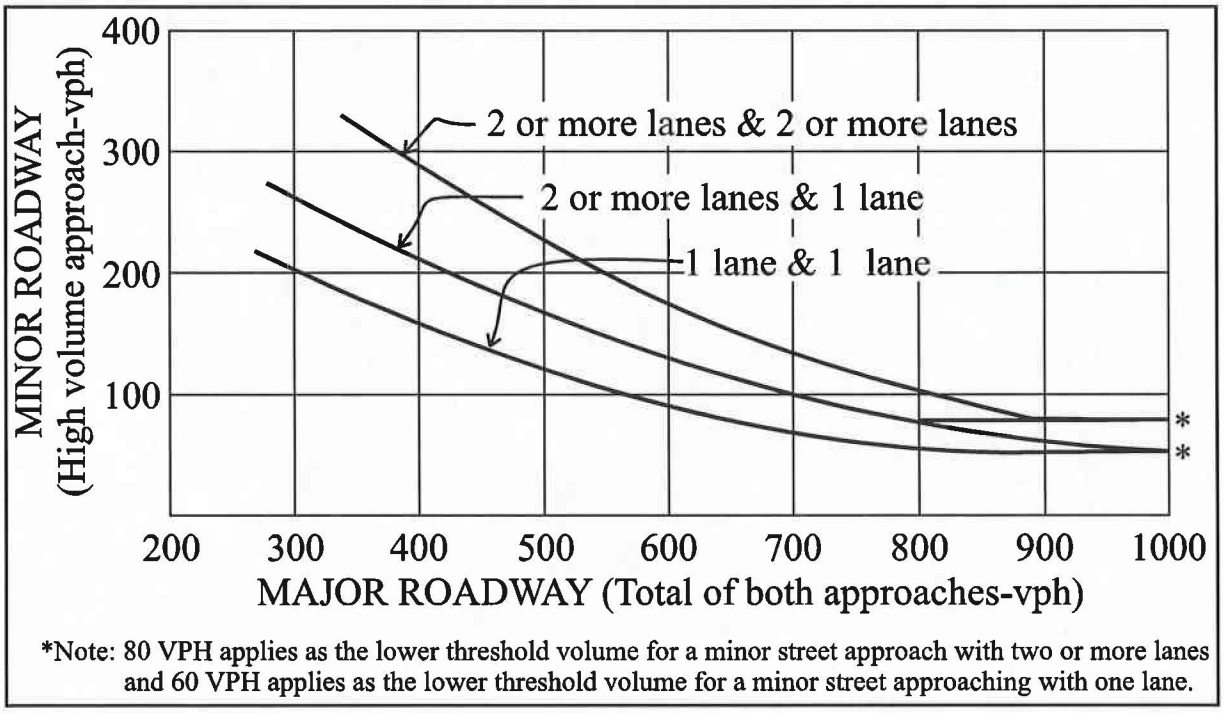
The Four Hour Volume Warrant is satisfied when each of any four hours of an average day the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher volume minor street approach (one direction only) all fall above the curve in Figure 1 for the existing combination of approach lanes.

When the 85th percentile speed of the major street traffic exceeds 40 miles per hour or when the intersection lies within a built-up area of an isolated community having a population less than 10,000, the four hour volume requirement is satisfied when the plotted points referred to fall above the curve in Figure 2 for the existing combination of approach lanes.



*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 approaching with one lane.

Figure B-1. Four Hour Volume Warrant



*Note: 80 VPH applies as the lower threshold volume for a minor street approach with two or more lanes and 60 VPH applies as the lower threshold volume for a minor street approaching with one lane.

Figure B-2. Reduced Four Hour Volume Warrant

Warrant 10, Peak Hour Delay (4C-10.2)

The Peak Hour Delay Warrant is intended for application where traffic conditions are such that for one hour of the day minor street traffic suffers undue delay in entering or crossing the major street. The Peak Hour Delay Warrant is satisfied when the conditions given below exist for one hour (any four consecutive 15-minute periods) of an average weekday.

The Peak Hour Delay Warrant is met when:

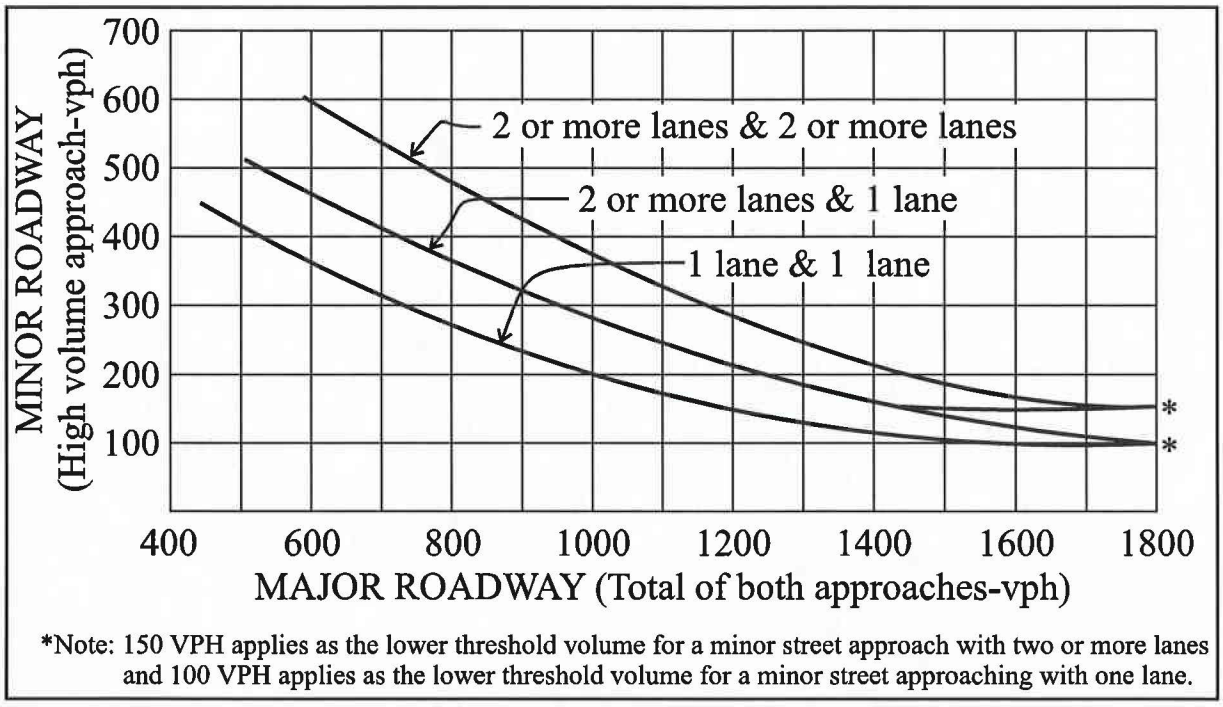
1. The total delay experienced by the traffic on one minor street approach (one direction only) controlled by a STOP sign equals or exceeds four vehicle-hours for a one-lane approach and five vehicle hours for a two-lane approach, and
2. The volume on the same minor street approach (one direction only) equals or exceeds 100 vph for one moving lane of traffic or 150 vph for two moving lanes, and
3. The total entering volume serviced during the hour equals or exceeds 800 vph for intersections with four (or more) approaches or 650 vph for intersections with three approaches.

Warrant 11, Peak Hour Volume (4C-10.3)

The Peak Hour Volume Warrant is also intended for application when traffic conditions are such that for one hour of the day minor street traffic suffers undue traffic delay in entering or crossing the major street.

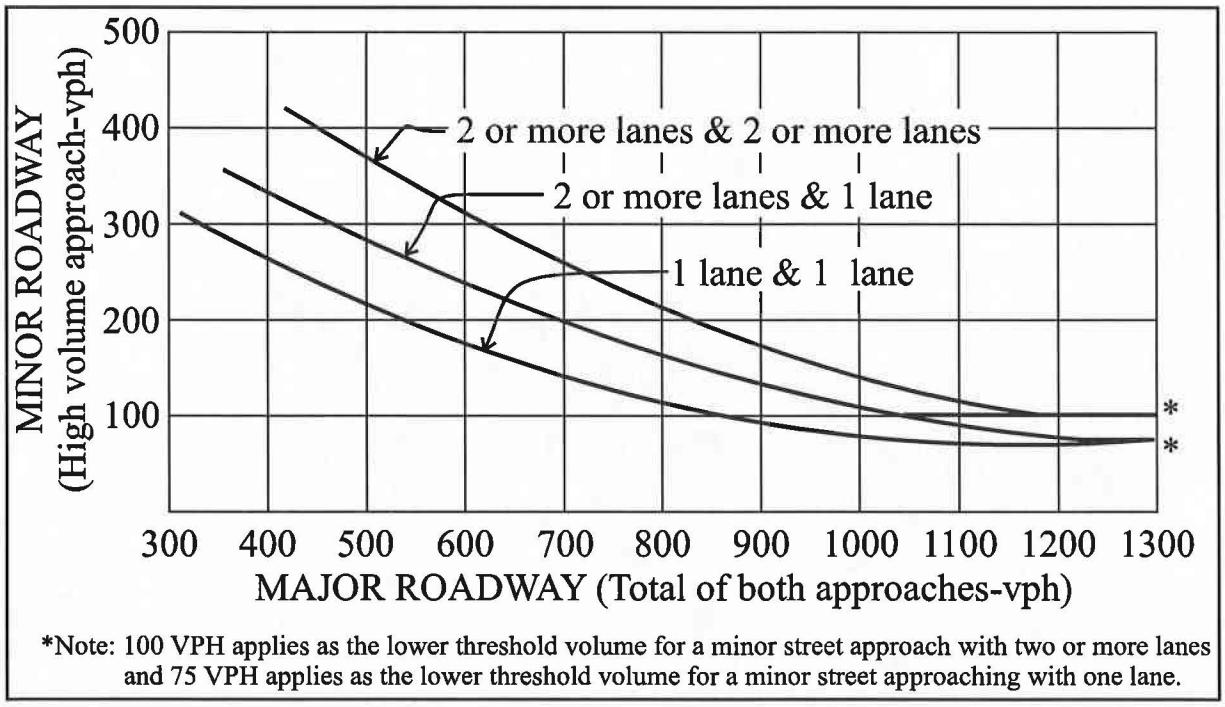
The Peak Hour Volume Warrant is satisfied when the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicle per hour of the higher volume minor street approach (one direction only) for one hour (any four consecutive 15-minute periods) of an average day falls above the curve in Figure 3 for the existing combination of approach lanes.

When the 85th percentile speed of major street traffic exceeds 40 mph or when the intersection lies within a built-up area of an isolated community having a population less than 10,000, the peak hour volume requirement is satisfied when the plotted point referred to above falls above the curve in Figure 4 for the existing combination of approach lanes.



*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 approaching with one lane.

Figure B-3. Peak-Hour Volume Warrant



*Note: 100 VPH applies as the lower threshold volume for a minor street approach with two or more lanes and 75 VPH applies as the lower threshold volume for a minor street approaching with one lane.

Figure B-4. Reduced Peak Hour Volume Warrant

Warrant 12, Warrant Volumes for Traffic Actuated Signals (4C-10.4)

The warrant volumes for traffic actuated signals are intended for application where the volume of intersecting traffic may not completely satisfy the requirements of warrants 1 through 11, but where unpredictable peak hour or hours may occur either on the total of both approaches of the major street or on the high volume approach of the minor street.

Traffic actuated signal installation is considered justified if any one of the two following conditions exist:

1. For each of any eight hours of the average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher volume minor street (one direction only), all lie above the applicable curve in Figures 5 and 6. The major street and minor street volumes are for the same eight hours.
2. For each of any two hours of the average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher volume minor street (one direction only), all lie above the applicable curve in Figures 7 and 8. The major street and minor street volumes are for the same two hours.

When the 85th percentile speed of major street traffic exceeds 40 mph either in an urban or rural area, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, rural warrant curves should be utilized.

If a decision is reached to install traffic actuated control equipment, the use of full-actuated, rather than semi-actuated equipment, should be considered. The inherent design of the semi-actuated equipment tends to penalize the traffic on the major roadway, as no intelligence is transmitted to the controller relating to the vehicular volume on the major roadway.

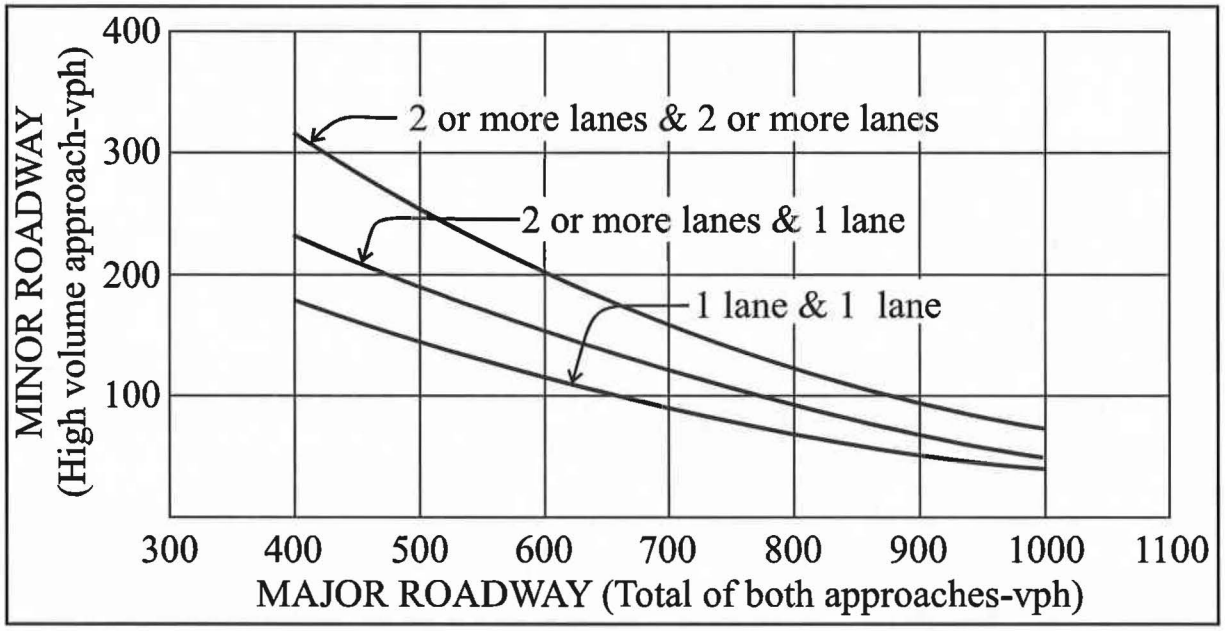


Figure B-5. Urban, Eight-Hour Traffic Actuated Warrant

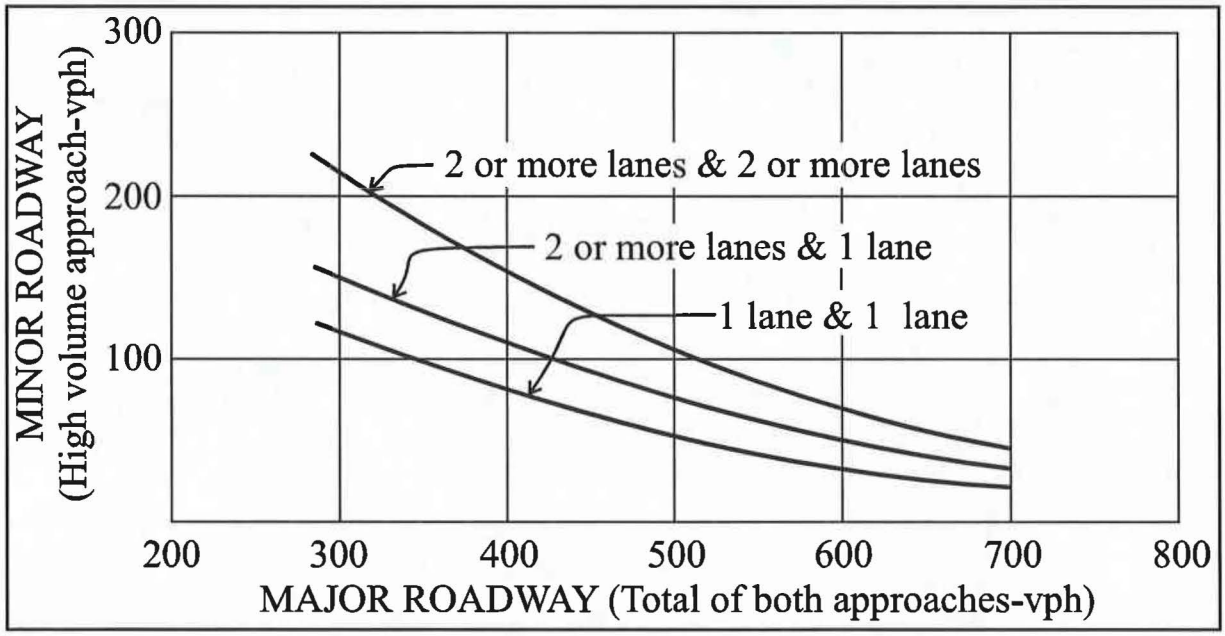


Figure B-6. Rural, Eight-Hour Traffic Actuated Warrant

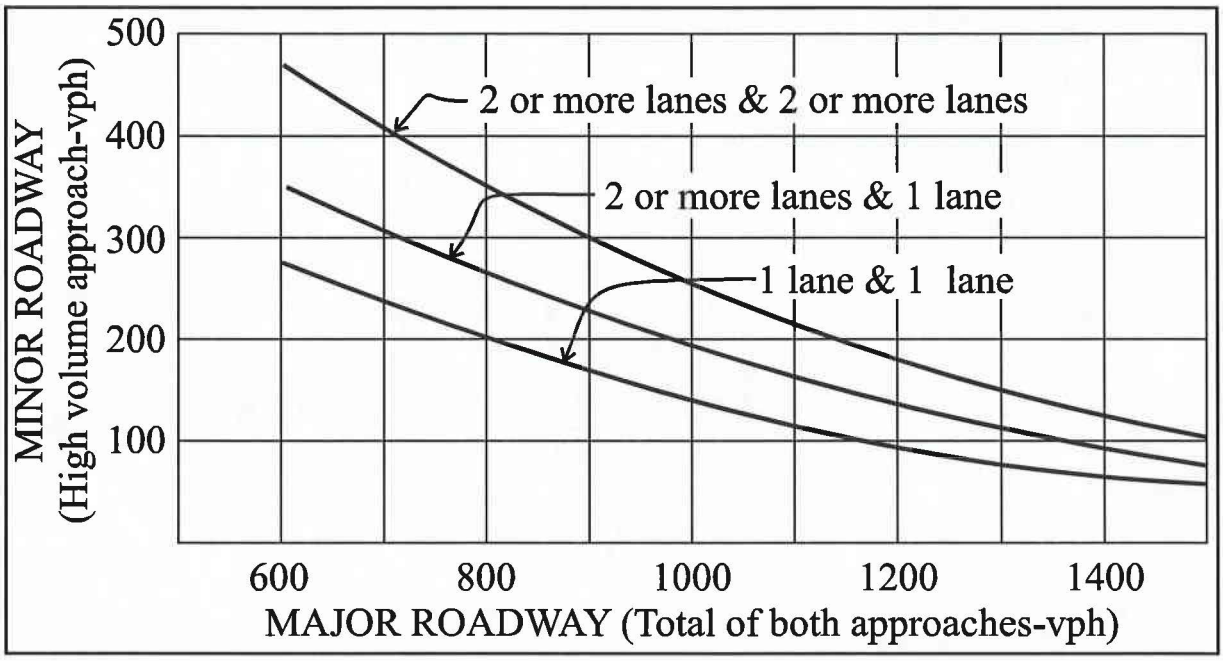


Figure B-7. Urban, Two-Hour Traffic Actuated Warrant

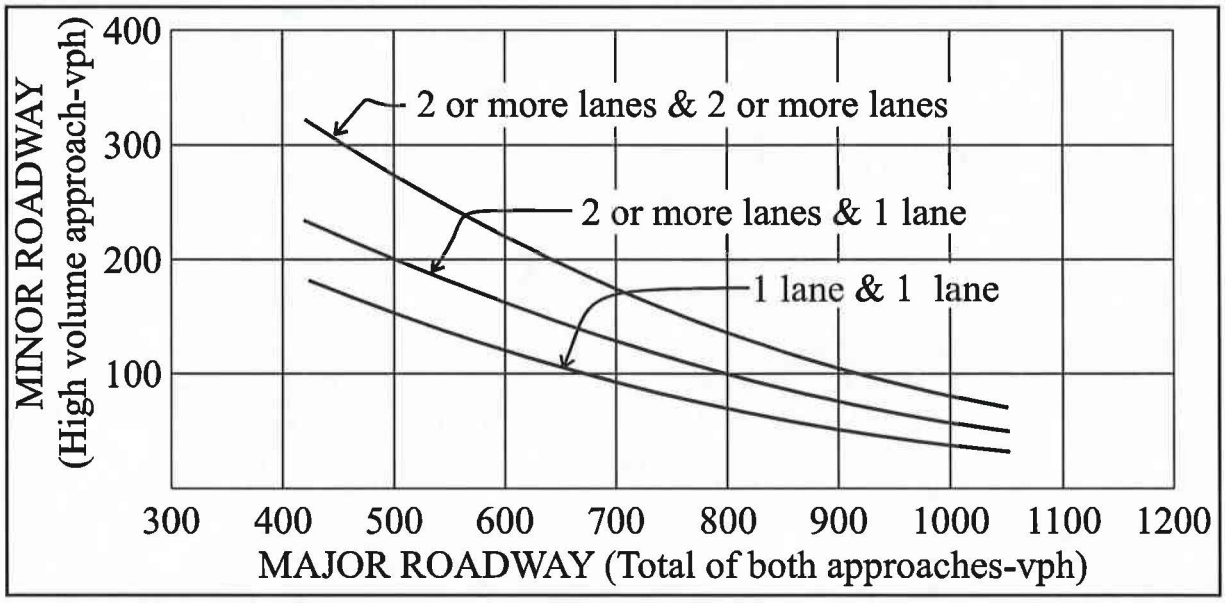


Figure B-8. Rural, Two-Hour Traffic Actuated Warrant

APPENDIX C

PROPOSED NATIONAL WARRANTS

PROPOSED TRAFFIC SIGNAL WARRANTS

Continuing advances in technology have and will continue to produce changes in the highway, the vehicle, and in driver proficiency. Accordingly, portions of the system of control devices in the MUTCD will require updating. The National Committee on Uniform Traffic Control Devices (NCUTCD) is currently taking on the massive task of rewriting the MUTCD to meet the demands that have developed since the last edition was published in 1988. The proposed MUTCD is scheduled to be released in the year 2000.

Section 4C of the proposed MUTCD lists seven warrants for justifying a highway traffic control signal installation. The number of national warrants would be reduced from eleven warrants to seven warrants. This is in response to the FHWA receiving a number of complaints concerning the number and complexity of the current warrants. The following is a brief summary of how the proposed warrants were reduced:

1. The interruption of continuous traffic warrant will be combined with the new warrant number 1 entitled, "Eight Hour Vehicle Volume Warrant."
2. The school crossing warrant will be placed in section 7D.4 of the Manual.
3. Warrant 8 will be incorporated into warrant 1.
4. The Peak Hour Delay Warrant will be included in warrant 3.

The results of these efforts are the seven warrants listed below. This section describes each of these warrants.

- Warrant 1 - Eight-Hour Vehicular Volume
- Warrant 2 - Four-Hour Vehicular Volume
- Warrant 3 - Peak Hour
- Warrant 4 - Pedestrian Volume
- Warrant 5 - Coordinated Signal System
- Warrant 6 - Accident Experience
- Warrant 7 - Roadway Network

In addition to reducing the number and complexity of the warrants, the proposed MUTCD also contains other significant changes. Among them is the formatting. The NCUTCD have eliminated inconsistent and ambiguous language, such as "it is desirable that," "shall preferably be," "may be required," "may be justified," "shall be permitted," "it is necessary that," "normally should," and "is intended for use." The current guidelines proposed by the NCUTCD to reformat the MUTCD classifies the language in the Manual into four categories: standard, guidance, option, and support, as shown in Table 13.

Table C-1. Reformatting Guidelines for the Proposed MUTCD

Heading	Description	Typical Phrases
STANDARD:	Mandatory actions, which are required without exceptions or with exceptions so noted, under this heading.	Shall, shall mean, shall be satisfied, shall consist
GUIDANCE:	Advisory usage, recommended but not mandatory with deviations allowed where engineering judgement indicates the deviation to be appropriate.	Should, should be used, should be considered, should be given
Options:	Includes those procedures and devices which are allowed but carry no recommendation or mandate. The user is free to use or refrain from their use.	May, may be used, may be considered
SUPPORT:	Includes all introductory or explanatory language. It may occur before, within, or after any heading, but shall be clearly marked as "Support."	Is, are, warrants, considered, required [1]
Notes: [1] Support words may be used provided there is no intention of mandating, recommending, or authorizing any procedure or device under this heading.		

Warrant 1, Eight Hour Vehicular Volume (4C-2)

SUPPORT:

The Minimum Vehicular Volume, Condition A, is intended for application 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 where the traffic volume on a major roadway is so heavy that traffic on a minor intersecting roadway suffers excessive delay or hazard in entering or crossing the major roadway.

STANDARD:

The need for a traffic control signal shall be considered if one of the following conditions exist for each of any 8 hours of an average day.

1. The vehicles per hour given in both of the 100 percent columns of condition A in Table 14 exist on the major roadway and on the higher volume minor roadway approaches, respectively, to the intersection.
2. The vehicles per hour given in both of the 100 percent columns of condition B in Table 14 exist on the major roadway and on the higher volume minor roadway approaches, respectively, to the intersection.

In applying each condition, the major roadway and minor roadway volumes shall be for the same 8 hours. On the minor roadway, the higher volume shall not be required to be on the same approach during each of these 8 hours.

Option:

If the posted or statutory speed limit or the 85th-percentile speed on the major roadway exceeds 65 km/h (40 mph), or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the traffic volumes in the 70 percent columns in Table 14 may be used in place of the 100 percent columns.

STANDARD:

The need for a traffic control signal shall be considered if both of the following conditions exist for each of any 8 hours of an average day:

1. The vehicles per hour given in the 80 percent columns of Condition A in Table 14 exist on the major roadway and on the higher volume minor roadway approaches, respectively, to the intersection.
2. The vehicles per hour given in the 80 percent columns of Condition B in Table 14 exist on the major roadway and on the higher volume minor roadway approaches, respectively, to the intersection.

These major roadway and minor roadway volumes shall be for the same 8 hours for each condition; however, the 8 hours satisfied in Condition A shall not be required to be the same 8 hours satisfied in Condition B. On the minor roadway, the higher volume shall not be required to be on the same approach during each of the 8 hours.

Table C-2. Warrant 1. Eight-hour Vehicular Volume

	Number of lanes for moving traffic on each approach		Vehicles per hour on major roadway (total of both approaches)			Vehicles per hour on higher-volume minor-roadway approach (one direction only)		
Condition A Minimum Vehicular Volume	Major roadway	Minor roadway	100%[a]	80%[b]	70%[c]	100%[a]	80%[b]	70%[c]
	1	1	500	400	350	150	120	105
	2 or more	1	600	480	420	150	120	105
	2 or more	2 or more	600	480	420	200	160	140
	1	2 or more	500	400	350	200	160	140
Condition B Interruption of Continuous Traffic	Major roadway	Minor roadway	100%[a]	80%[b]	70%[c]	100%[a]	80%[b]	70%[c]
	1	1	750	600	525	75	60	53
	2 or more	1	900	720	630	75	60	53
	2 or more	2 or more	900	720	630	100	80	70
	1	2 or more	750	600	525	100	80	70

Notes:
[a] Basic minimum hourly volume.
[b] Used for combination of conditions A and B after adequate trial of other remedial measures.
[c] May be used when the major roadway speed exceeds 65 km/h (40 mph) or in an isolated community with a population of less than 10,000.

GUIDANCE:

The combination of Conditions A and B should be applied only after adequate trial of other less restrictive alternatives that could cause less delay and inconvenience to traffic has failed to solve the traffic problems.

Warrant 2, Four-Hour Vehicular Volume (4C-3)

SUPPORT:

The Four-Hour Vehicular Volume Warrant conditions are intended to be applied where the volume of intersecting traffic is the principal reason to consider installing a traffic control signal.

STANDARD:

The need for a traffic control signal shall be considered if, for each of any 4 hours of an average day, the plotted points representing the vehicles per hour (vph) on the major roadway (total of both approaches) and the corresponding vph on the higher volume minor roadway approach (one direction only) all fall above the applicable curve in Figure 1 for the existing combination of approach lanes. On the minor roadway, the higher volume shall not be required to be on the same approach during each of these 4 hours.

Option:

If the posted or statutory speed limit or the 85th-percentile speed on the major roadway exceeds 65 km/h, or the intersection lies within the built-up area of an isolated community having a population of less than 10,000, Figure 2 may be used in place of Figure 1.

Warrant 3, Peak Hour (4C-4)

SUPPORT:

The Peak Hour Warrant is intended for use at locations where traffic conditions are such that for a minimum of 1 hour of an average day, the minor-roadway traffic suffers undue delay when entering or crossing the major roadway.

STANDARD:

This warrant shall be applied only in unusual cases. Such cases include, but are not limited to, office complexes, manufacturing plants, industrial complexes, or high-occupancy vehicle facilities that attract or discharge large numbers of vehicles over a short time. The need for a traffic control signal shall be considered if the criteria in either of the following two categories are met:

1. If all three of the following conditions exist for the same 1 hour (any four consecutive 15-minute periods) of an average day:
   a. The total delay experienced by the traffic on one minor-roadway approach (one direction only) controlled by a STOP sign equals or exceeds: 4 vehicle-hours for a one-lane approach; or 5 vehicle-hours for a two-lane approach, and
   b. The volume on the same minor-roadway approach (one direction only) equals or exceeds 100 vph for one moving lane of traffic or 150 vph for two moving lanes.
   c. 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.
2. The plotted point representing the vehicles per hour on the major roadway (total of both approaches) and the corresponding vehicles per hour on the higher-volume minor-roadway approach (one direction only) for 1 hour (any four consecutive 15-minute periods) of an average day falls above the applicable curve in Figure 3 for the existing combination of approach lanes.

Option:

If the posted or statutory speed limit or the 85th-percentile speed on the major roadway exceeds 65 km/h, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, Figure 4 may be used in place of Figure 3 to satisfy the criteria in the second category of the standard.

Warrant 4, Pedestrian Volume (4C-5)

SUPPORT:

The minimum pedestrian volume conditions are intended for application where the traffic volume on a major roadway is so heavy that pedestrians experience excessive delay or hazard in crossing the major roadway. The warrant given in Section 7D.4 is applicable where the fact that school children cross the major roadway is the principal reason to consider installing a traffic control signal.

STANDARD:

The need for a traffic control signal at intersections or mid-block crossings shall be considered if both of the following criteria are met:

a. The pedestrian volume crossing the major roadway at an intersection or mid-block location during an average day is 100 or more for each of any 4 hours or 190 or more during any 1 hour.
b. There are fewer than 60 gaps per hour in the traffic stream of adequate length to allow pedestrians to cross during the same period when the pedestrian volume criterion is satisfied. Where there is a divided roadway having a median of sufficient width for pedestrians to wait, the requirement applies separately to each direction of vehicular traffic.

The Pedestrian Volume Warrant shall not be applied at locations where the distance to the nearest traffic control signal installation along the major roadway is less than 90 meters, unless the new traffic control signal will not restrict the progressive movement of traffic.

A traffic control signal installation justified by both this warrant and a traffic engineering study shall be equipped with pedestrian signal heads conforming to requirements set forth in Chapter 4E of this manual.

GUIDANCE:

If a traffic control signal installation is justified by both this warrant and a traffic engineering study:

a. If installed within a signal system, the traffic control signal installation should be coordinated.
b. At an intersection, the traffic control signal installation should be traffic-actuated and should include pedestrian detectors. As a minimum, it should have semi-actuated operation, but full actuation operation with detectors on all approaches may be considered.
c. At non-intersection crossings, the traffic control signal should be pedestrian-actuated, parking and other sight obstructions should be prohibited for at least 30 m (100 ft) in advance of and at least 6 m (20 ft) beyond the crosswalk, and the installation should include suitable standard signs and pavement markings.

Option:

The pedestrian volume crossing the major roadway may be reduced as much as 50 percent if the average crossing speed of pedestrians is less than 1.1 meters per second. A traffic control signal

installation may not be needed at the study location if adjacent coordinated traffic control signal installations consistently provide gaps of adequate length for pedestrians to cross the roadway, even if the rate of gap occurrence is less than one per minute.

Warrant 5, Coordinated Signal System (4C-6)

SUPPORT:

Progressive movement in a coordinated signal system sometimes necessitates installing traffic control signal installations at intersections where they would not otherwise be needed in order to maintain proper platooning of vehicles.

STANDARD:

The need for a traffic control signal shall be considered if one of the following criteria is met:

a. On a one-way roadway or a roadway that has traffic predominantly in one direction, the adjacent traffic control signal installations are so far apart that they do not provide the necessary degree of vehicle platooning.
b. On a two-way roadway, adjacent traffic control signal installations do not provide the necessary degree of platooning, and the proposed and adjacent traffic control signal installations will collectively provide a progressive operation.

GUIDANCE:

The Coordinated Signal System Warrant should not be applied where the resultant spacing of traffic signal installations would be less than 300 m (1,000 ft).

Warrant 6, Accident Experience (4C-7)

SUPPORT:

The Accident Experience Warrant conditions are intended for application where the severity and frequency of accidents are the principal reasons to consider installing a traffic control signal.

STANDARD:

The need for a traffic control signal shall be given consideration if all of the following criteria are met:

a. Adequate trial of less restrictive alternatives with satisfactory observance and enforcement has failed to reduce the accident frequency.
b. Five or more reported accidents, of types susceptible to correction by traffic control signal have occurred within a 12-month period, each accident involving personal injury or property damage apparently exceeding the applicable requirements for a reportable accident.
c. The vehicles per hour given in both of the 80 percent columns of Condition A in Table 14 (see Section 4C.2), or in both of the 80 percent columns of Condition B in Table 14 exist on the major roadway and on the higher-volume minor-roadway approach, respectively, to the intersection, or the vph in both of the 80 percent columns of Condition B in Table 14 exist on the major roadway and on the higher-volume minor-roadway approach, respectively, to the intersection, or the volume of pedestrian traffic is not less than 80

percent of the requirements specified in the pedestrian volume warrant. These major-roadway and minor-roadway volumes shall be for the same 8 hours. On the minor roadway, the higher volume shall not be required to be on the same approach during each of the 8 hours.

Warrant 7, Roadway Network (4C.8)

SUPPORT:

Installing a traffic control signal at some intersections may be justified to encourage concentration and organization of traffic flow on a roadway network.

STANDARD:

The need for a traffic control signal shall be considered if the common intersection of two or more major routes meets one or both of the following criteria:

a. The intersection has a total existing, or immediately projected, entering volume of at least 1,000 vph during the peak hour of a typical weekday and has 5 year projected traffic volumes, based on an engineering study, that meet one or more of warrants 1, 2, and 3 during an average weekday.
b. The intersection has a total existing or immediately projected entering volume of at least 1,000 vph for each of any 5 hours of a non-normal business day (Saturday or Sunday).

A major route, as used in this warrant, shall have one or more of the following characteristics:

a. It is part of the roadway or highway system that serves as the principal network for through traffic flow.
b. It includes rural or suburban highways outside, entering, or traversing a city.
c. It appears as a major route on an official plan, such as a major roadway plan in an urban area traffic and transportation study.