NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT 249

PEAK-HOUR TRAFFIC SIGNAL WARRANT

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **249**

PEAK-HOUR TRAFFIC SIGNAL WARRANT

R. DAVID HENRY and JAY H. L. CALHOUN
JHK and Associates,
Alexandria, Virginia

AND

RONALD C. PFEFER and ROBERT K. SEYFRIED
Northwestern University Traffic Institute
Evanston, Illinois

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

OPERATIONS AND TRAFFIC CONTROL
TRAFFIC FLOW, CAPACITY, AND MEASUREMENTS
(HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. SEPTEMBER 1982

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 249

Project 3-20A FY '80
ISSN 0077-5614
ISBN 0-309-03419-1
L. C. Catalog Card No. 82-51075

Price: $7.60

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

Each report is reviewed and processed according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Special Notice

The Transportation Research Board, the National Academy of Sciences, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America.

FOREWORD

By Staff
Transportation
Research Board

This report will be of special interest to state, county, and city traffic engineers having responsibility for installing traffic signals. Governmental agencies and national committees (e.g., the National Advisory Committee on Uniform Traffic Control Devices) that develop signal warrants will also be interested in the research findings. A new peak-hour traffic signal warrant is proposed for use at locations having heavy traffic flows of short duration (e.g., an industrial plant exit). The basis for the proposed warrant includes (1) a comparative evaluation of previously suggested peak-hour warrants, (2) traffic characteristics data collected at over 200 intersections, and (3) engineering judgment regarding the perceived need for a signal.

The need to install or remove a traffic signal is often difficult to determine and substantiate without a nationally accepted, objective, easily understood warrant. Many factors need to be considered in making a decision, and the use of a warrant ensures that the traffic-related aspects receive appropriate evaluation and also results in more consistent applications. Widely used traffic signal warrants are found in the *Manual on Uniform Traffic Control Devices* (MUTCD), but these warrants do not cover the need for a traffic signal due to unique peak-hour conditions (e.g., industrial plant exits).

Several peak-hour warrants had been proposed but had not been verified in regard to the acceptability of the underlying assumptions and the actual numerical values. Individual states have developed and are using their own variations of this type of warrant, but the need for a nationally accepted warrant remains. The objective of this research was to evaluate and verify the peak-hour warrant suggested by the Signals Subcommittee of the National Advisory Committee on Uniform Traffic Control Devices (NAC) and the peak-hour warrant developed as part of NCHRP Project 3-20. A recommendation with supporting documentation and justification was desired for adoption of either of the two previously proposed warrants or an alternative warrant.

Traffic performance data were collected at over 200 intersections in six cities, and the researchers also evaluated the ability of the two warrants to provide the same conclusion regarding the need for a signal as would be determined through engineering judgment based on observation of the intersection. Following the comparative evaluation of the previously proposed warrants, a new warrant was developed. The form of the warrant is easily understood by the nonprofessional and facilitates application by minimizing the amount of data to be collected.

At the time of publication, the warrant proposed herein has not been considered, approved, or adopted by the NAC. Therefore, readers should check the current policy of the NAC in regard to the acceptability of this warrant. Also, although the results of this research provide an objective approach to determining the need for a traffic signal, the reader is reminded that, in applying this or any other warrant, care must be taken to take unique site conditions and considerations into account.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 3-20A by JHK & Associates and the Northwestern University Traffic Institute. JHK & Associates was the contractor for this study. The work was undertaken at the Traffic Institute under a subcontract with JHK & Associates.

R. David Henry, Senior Associate, and Jay H. L. Calhoun, Senior Transportation Engineer, at JHK & Associates, were co-principal investigators. Ronald C. Pfefer, Associate Director of Research and Development, and Robert K. Seyfried, Senior Transportation Engineer, at the Northwestern University Traffic Institute, also authored portions of the report and provided invaluable aid in the statistical analysis of the data.

An important component of the research was the field studies. Appreciation is expressed to the following persons who gave their time and knowledge in aiding in the identification of candidate intersections for study: Richard B. Nassi, City Traffic Engineer, Tucson, Arizona; William R. Bain, Traffic Engineering Supervisor, Phoenix, Arizona; Dennis E. Royer, Transportation Engineer, Denver, Colorado; Bhupen N. Patel, City Traffic Engineer, Hartford, Connecticut; Joseph M. Thomas, Jr., Deputy Director, Bureau of Traffic Engineering, Atlanta, Georgia; Michael Errico, Chief, Bureau of Transportation, Prince Georges County, Maryland; Kay Colpitts Traffic Engineer, Montgomery County, Maryland; Joseph M. Durkee, Traffic Engineer, Arlington County, Virginia; David R. Gehr, Regional Transportation Engineer, Virginia Department of Highways and Transportation; and Charles E. Kenyon, Traffic Director, Alexandria, Virginia.

Substantial contributions to this research were also made by the engineers of JHK & Associates who performed the data collection effort. They include: Mary L. Gallagher; Stephen L. Bolduc; Louis G. Neudorff; James C. Gray; and Stephen D. Hetrick.

PEAK-HOUR TRAFFIC SIGNAL WARRANT

SUMMARY

Several peak-hour warrants for traffic signal installation have been developed and are in everyday use. These peak-hour warrants are typically applied at intersections in the proximity of large industrial parking lots to determine whether traffic signals should be installed.

For the most part, each existing warrant is used only in one state. Examples include the warrants used in Texas, Pennsylvania, Illinois, and Missouri among others. Unfortunately, none of these warrants have been extensively validated.

Canditate Warrants

Two warrants, however, have generated nationwide interest. The warrant suggested by the Signals Subcommittee of the National Advisory Committee (NAC) on Uniform Traffic Control Devices, referred to as the NAC warrant, is one. The peak-hour warrant developed as a part of NCHRP Project 3-20, referred to as the NCHRP warrant, is the other.

The NAC warrant has two elements, a volume element and a delay element. The volume warrant element is based on critical combinations of main street and cross street volumes during the peak hour (any four consecutive 15-min periods) of the average day. This element is based on work done by Herman E. Haenel of the Texas Highway Department and was developed on the basis of a normalized traffic volume distribution over time.

The delay element of the NAC warrant indicates that signal control can be justified when the side street delay equals or exceeds 4 veh-hr for a one-lane approach, and 5 veh-hr for a two-lane approach, provided that there is at least a minimum volume on the side street and that the total number of vehicles entering the intersection exceeds a minimum value.

The warrant is satisfied when the conditions previously noted are met, or the plotted point representing the vehicular demand on the main and side streets falls above a warrant curve. A reduction of the warrant values for high-speed roads (40 mph or higher) and for isolated communities is considered with a second curve with less stringent warrant criteria.

The NCHRP peak-hour warrant was developed by KLD Associates as a part of NCHRP Project 3-20. It is based on the assumption that queue instability (growing without bound) is the primary factor justifying a traffic signal installation during a peak period of congestion. The queue instability assumption is based on the fact that as demand approaches capacity on an approach controlled by a STOP sign, the probability of queue instability (growing without bound) increases markedly. Such instability reflects a breakdown in intersection control and must be prevented.

The NCHRP warrant was designed to identify the need for a signal when there is an intensive period of congestion extending over a relatively short period of time as characterized by: (1) a high level of delay experienced by side street vehicles controlled by a STOP sign; and (2) unstable queue growth on the side streets.

The relationship between queue and delay was examined using a queue discharge model. It was further assumed, based on a survey response, that intensive congestion was equivalent to a mean delay of 57 sec per vehicle. Furthermore, the analysis indicated that the onset of unstable queue behavior occurred when there was a mean queue length of 4 vehicles. For the peak hour, therefore, the total delay on that approach would be approximately equal to 4 veh-hr per hour.

Approach

A primary thrust of this research, therefore, was to determine which of the two candidate warrants is better, and if neither accurately reflects the need for signalization based on peak-hour demand, to develop a new warrant. The basic means of investigation used in this research was to collect a wide variety of field measures (i.e., turning movement counts, stopped-time delay, percent of vehicles stopping, queue length, etc.) to determine how these measures compare at intersections meeting the candidate warrants.

The major contribution of the study is the field measures of delay and queue length at 217 intersections in six widely separated metropolitan areas. A total of 817 25-min observations were obtained. For each 25-min observation, a field engineer made a value judgment of whether the intersection would have operated "better" under STOP-sign control or under signal control.

With the combination of the direct measures (volume, delay, queue, etc.) and the judgment of the field engineer, it was possible to test the two candidate warrants against each other as well as against the embedded assumptions that were used to develop the candidate warrants.

The NAC warrant curves are intended to represent iso-delay curves of 4 veh-hr for one-lane approaches and 5 veh-hr for two-lane approaches. To determine whether this, in fact, was achieved, the total approach delay was averaged for all observations at nonsignalized intersections with two-lane approaches that experienced main street and cross street demand volumes within limits approximating the warrant curve.

Although fewer than 2 percent of the data base met these selection criteria, a total of 16 observations, the fact that these observations averaged only 144 veh-min (2.4 veh-hr) is important. The assumption that observations within the volume region would reflect 5 veh-hr of delay is obviously incorrect.

The analysis testing of the embedded assumptions in the NCHRP warrant showed a much better consistency between the results and the assumptions. This analysis used average approach delay (vehicle-minutes per vehicle), total approach delay (vehicle-minutes), and queue length.

Because these measures were found to be highly correlated, it was desirable to select one for further analysis. Emphasis was placed on the queue measure for two reasons:

1. Total delay is derived from queue measures by factoring in time, and thus, as noted previously, it is simply another way of expressing average queue.
2. A lay person can more readily grasp the significance of queue length than of vehicle-minutes (or vehicle-hours) of delay, and thus, the queue concept provides a more universal means of communications. To actually realize this communications benefit, surrogate phrases would likely have to be used. Rather than average queue, "number of cars backed up" may be a more easily recognizable term.

Based on these analyses, queue length was found to be the optimum direct measure with a threshold value of 4.0 vehicles. That is, a signal is considered warranted when the average queue is 4.0 or more vehicles in length. Notice that this measure is independent of intersection geometrics but can only be applied on nonsignalized locations. For signalized locations, it is recommended that another measure, conflicts, which is derived from an intersection turning movement study, be used. A threshold value of 350 was recommended for the conflicts measure.

A new peak-hour warrant based on queue length for STOP-sign-controlled intersections and conflicts for signal-controlled intersections is recommended for inclusion into the Manual of Traffic Control Devices.

CHAPTER ONE

INTRODUCTION AND APPROACH

BACKGROUND

As noted in the original Research Problem statement, "... The need for a traffic signal warrant based on peak-hour conditions has been identified...." Several peak-hour warrantes have been developed and are in everyday use. For the most part, each warrant is used only in one state. Examples include the warrants used in Texas, Pennsylvania, Illinois, and Missouri, among others. Unfortunately, none of these warrants has been validated beyond the state in which they are used.

Two warrants, however, have generated nationwide interest. The warrant suggested by the Signals Subcommittee of the National Advisory Committee (NAC) on Uniform Traffic Control Devices, referred to as the NAC warrant, is one. The peak-hour warrant developed as a part of NCHRP Project 3-20, referred to as the NCHRP warrant, is the other.

A primary thrust of this research, therefore, was to determine which of the two candidate warrants is better, and if neither accurately reflects the need for signalization based on peak-hour demand, to develop a new warrant. The basic means of investigation used in this research was to collect a wide variety of field measures (i.e., turning movement counts, stopped-time delay, percent of vehicles stopping, queue length, etc.) to determine how these measures compare at intersections meeting the candidate warrants.

Unfortunately, there is no definitive agreement within the traffic engineering professional community of when it is "better" to have a signal installed. Worse yet, there is little agreement as to which measure should be used to evaluate the performance of the intersection. To address these issues, empirical analyses of data collected at a large number of intersections, both signalized and nonsignalized, which have geometric and demand characteristics that would make them candidates for meeting a peak-hour traffic signal warrant, were conducted.

In essence, the research was directed towards identifying which measures of effectiveness that could be observed in the field can be used to determine when an intersection is operating "better" under signal control than under STOP-or YIELD-sign control. If this measure can be defined and if a threshold value above which a signal should be installed can be developed, a definition of "better" would be obtained.

Before delving into the analytical procedures employed to investigate the characteristics of the peak-hour delay warrant, it is helpful to consider the real world situations for which the warrant is intended to apply. In general, the problem can be considered in the abstract by stating it in terms of time and demand.

Peak-Hour Problem

The peak-hour problem may be characterized as having two dimensions, time and demand. In the time dimension, the key characteristic is duration, nominally 1 hr.

At the typical intersection, there are usually 2 peak hours each day where need for signal control is greatest. At locations subject to application of a peak-hour warrant, there is ordinarily only 1 hr per day (during heavy discharges).

The demand dimension is generally characterized by a large, short-term increase in the approach volumes on one or more approaches to the intersections in question.

The abstract representation of the peak-hour problem is a potential framework from which an objective analysis procedure could be developed. However, it is probably more useful to consider the peak-hour problem in less abstract terms that are much more recognizable in the real world.

The classical peak-hour problem occurs at an intersection that is heavily impacted by its proximity to a large industrial parking lot. During the early stages of the project, it was thought the peak-hour problem would also be common at such locations as regional shopping centers, where a peak-hour problem would manifest itself during certain days of the week. Additional examples were expected to be found in the proximity of institutions such as churches, hospitals, and schools.

The actual field experience did not confirm these expectations. Only two general conditions were found to be common in the six cities where field measurements were made. The first was the industrial parking lot, as expected; the second was conditions found at intersections that were impacted by commuter traffic. Unfortunately, with the exception of the demand volume characteristic, no other attribute of these commuter-impacted intersections was identified that could be used as an aid in identifying them as potentially meeting a peak-hour warrant.

Demand Profile

The major premise on which the need for a peak-hour warrant is based is that situations exist in which there are relatively short-lived delays to vehicles on the side street approach to an intersection, but that these delays are sometimes of an intolerable length. A signal, therefore, may be warranted on the basis of the amount of delay incurred during this transient period even though it may not be warranted on the basis of one of the existing warrants in the MUTCD.

The duration and extent of these delays are highly variable. They may be of extremely short duration, but with a high average delay per vehicle during that period; or they may extend over a longer period, but have a considerably smaller average delay per vehicle.

Figures 1 through 4 illustrate the variation in the volume distributions that might be found at intersections that could conceivably fall into the application area of a peak-hour warrant. In each case, the volume distributions are from the highest volume side street approach and a signal is not warranted under the existing volume warrants in the MUTCD.

Figure 1 represents a case in which the volumes are not highly peaked. This is typical of a volume distribution on a major arterial street. Figure 2 represents a highly peaked condition, with 23 percent of the 24-hr volume occurring in the peak hour. The peak volume in Figure 2 is higher than that found in Figure 1, but volumes during the remaining hours are much less. The approach in Figure 2 may far exceed the "tolerable" limits of delay whereas the approach in Figure 1 may not. A peak-hour warrant would conceivably justify a traffic signal at the latter but not at the former.

Figures 3 and 4 indicate other typical volume distributions for locations with greater than average peaking characteristics. At these locations, the peak hour usually ranges between 16 and 25 percent of daily volume for average conditions. Driveways from office and industrial complexes may have as high as 50 percent of the daily volume in one direction in the peak hour.

This study has taken the position that examining the peak hour alone is sufficient and that the primary purpose of such a warrant is to eliminate conditions with "intolerable" delays, if such conditions exist for 1 hr or more.

PREVIOUS RESEARCH

During recent years, there were three major studies that contained findings directly related to the peak-hour traffic-signal warrant problem:

1. "Assembly, Analysis, and Application of Data on Warrants for Traffic Control Signals," by Paul C. Box and Associates for Signals Committee National Joint Committee on Uniform Traffic Control Devices, March 1967 (Box–Alroth Study).
2. "Traffic Signal Warrant for Heavy Traffic Volumes Occurring During Short Periods of Time," by Wilbur Smith and Associates for West Virginia Department of Highways, April 1975 (Wilbur Smith Study).
3. "Traffic Signal Warrants," by KLD Associates, Inc. for the National Cooperative Highway Research Program, Transportation Research Board, National Research Council, December 1976 (KLD Study).

Each of these studies has contributed significant knowledge to the peak-hour signal problems. A brief summary of each of the findings pertaining to the peak-hour warrant issue is provided in the following.

Box–Alroth Study

In preparation of a revision of the MUTCD in 1966, the signal committee of the NJCUTD recognized a need for review of the existing warrants. Since publication of the 1964 edition of the Manual, widespread research and individual study have gone into traffic elements that potentially affect warrant values. The scope of this study was defined as:

1. The search for and collection of all information and data presently available in the literature on intersectional traffic volumes, vehicle headways, gaps in traffic streams, gap acceptance, etc., and any other factors that should be considered in establishing warrants for traffic control signals.
2. The preparation of a bibliography of the information collected in (1) above.
3. The grouping, consolidation and coordination of the information gathered to allow the establishment and/or intelligent review of warrants for traffic control signals.
4. The preparation of suggested factors and considerations to be included in warrants for traffic control signals, and suggested numerical values thereof.

The methodology was specified as a thorough search for existing data, the review and combination of the available data, and at least suggestions on factors applicable to signal warrants.

The study resulted in observations, opinions, findings, and conclusions several of which are excerpted below:

- If the construction "warrant" for a highway improvement can logically use the 30th highest hour concept, surely similar rationale can be applied to traffic signals. The urban weekday park-hour occurs some 250 times a year, and the combined AM and PM peak-hours occur 500 times a year. Why should signal warrants use the eighth highest hour of the weekday, which typically occurs some 2000 times a year? Similarly, five hours on a Saturday or Sunday would roughly equate to the weekday peak-hour.
- Satisfactory and nationally accepted standards for treat-

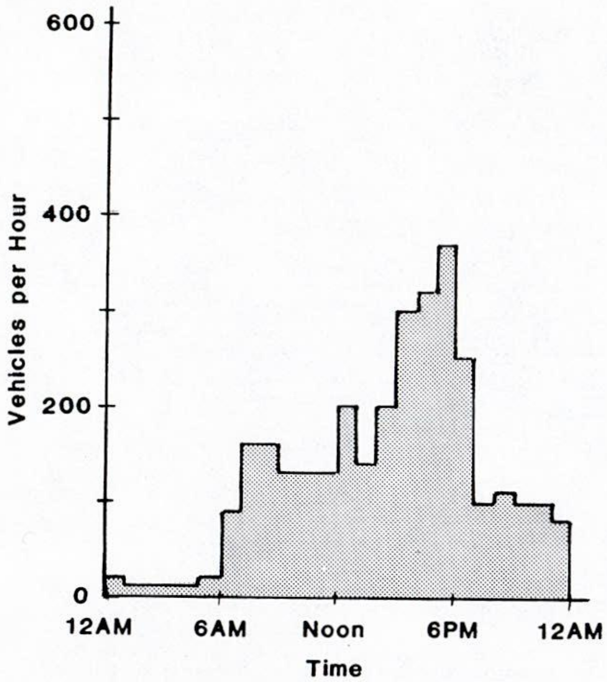


Figure 1. Moderated peaked demand profile.

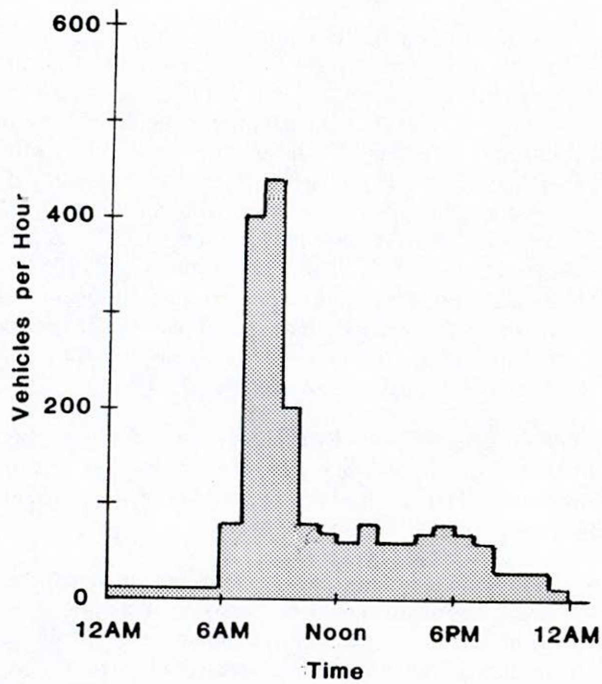


Figure 2. Highly peaked demand profile.

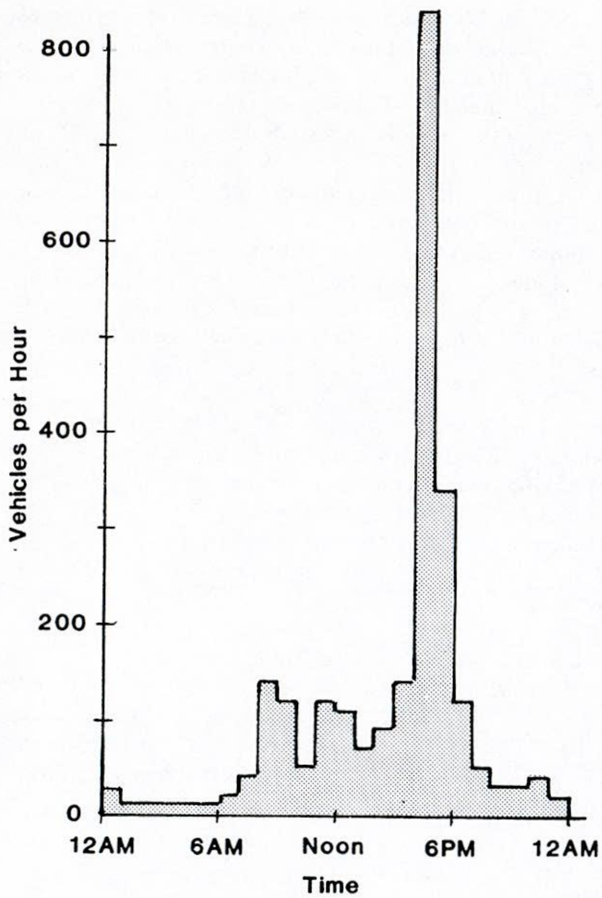


Figure 3. Typical high-peak, high-volume demand profile.

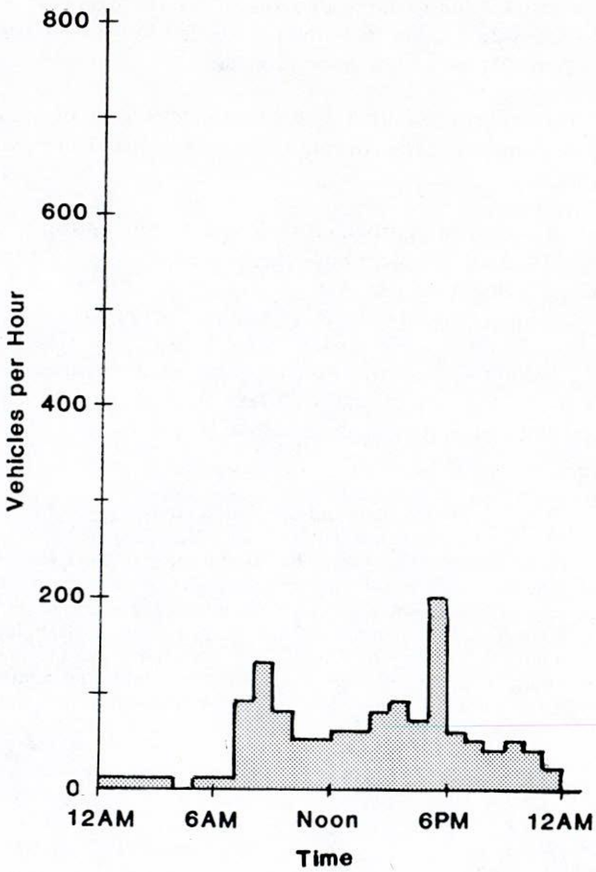


Figure 4. Typical high-peak, low-volume demand profile.

ing short-burst traffic control demands have not been established. The typical high-volume industrial driveway, the drive-in theater exit and even certain shopping centers may exhibit this characteristic. These are troublesome areas, and the hiring of off-duty police officers is not necessarily the best answer. For example, the use of officers at suburban or semi-rural locations typical of drive-in theaters and newer industrial developments may be hazardous. The major route speeds tend to be higher, and the peak demands frequently occur during hours of darkness. Signal control may be far preferable because of its higher visibility. It can be warranted if peak-hour concepts are accepted.

Other points made by Box and Alroth include the concept of flashing operation when side street demand is less than a threshold and single lane approaches should not be signalized when widening is possible.

- Another consideration in signal warrants may be the specification of signal type. As an example, perhaps semi-actuated signal control should never be allowed at a factory exit, unless interconnected as part of a progressive route system. The logic should be self-evident, since an isolated semi-actuated controller cannot sense major route flow, and hence cannot properly balance the exit needs with the major route needs.
- An additional element to be resolved in setting a peak-hour delay warrant is minimum side-street volume. As pointed out in the discussion on delay warrants in other countries, some minimum is needed to prevent absurd installations from being requested.

The report concluded with a tentative peak-hour warrant based on delay. The warrant contained the following as factors:

- Number of approaches under stop sign control.
- Total vehicle-hours of delay.
- Minimum vehicle volume.
- Type of signal control (fixed-time, actuated).

In addition, the warrant suggested flashing operation when delay to side street traffic is less than 60 percent of the warrant values for two consecutive hours. The actual wording is as follows:

> From the limited field and simulation studies performed to date, a tentative value of 3.0 vehicle hours delay is suggested for a peak-hour warrant. This would apply to total waiting time for two side-street approaches under two-way Stop sign control. If only one approach is involved (such as from a "T" intersection or a commercial driveway) a value of 2.0 vehicle hours might be appropriate. If the intersection to be studied is under three or four-way Stop control, appropriate adjustments should be made in total delay values and minimum volumes.

This warrant is summarized in Table 1.

Table 1. Peak-hour warrant, Box–Alroth.

Number of Approaches(1)	Vehicle Hours Delay(2)	Min Veh Vol.(3)	Type of Allowable Control by Peak Hour Factor (4)		
			0.3 or less	0.31 to 0.50	over 0.50
1	2.0	100	FA(5)	SA or FA	any
2	3.0	100	FA	SA or FA	any
3	4.0	300	FA	SA or FA	any
4	4.0	400	FA	any	any

(1) When a single approach, or one leg with over 60 percent of common phase entering traffic, has less than two moving lanes, the warrant test may not be applied without first adding a second lane by parking prohibition for at least 100 ft on approach and departure sides or by widening, provided such widening is not physically impractical due to restricted built-up right-of-way, or other major physical barriers such as bridge abutments.

(2) Waiting time delay, measured by 15-sec queue count, at 15-minute intervals during the peak traffic hour of a typical weekday, or five hours of a Saturday or Sunday.

(3) Entering volume from minor leg or legs, during same period as delay study.

(4) The entering volume of (3) above, divided by four times the highest 15-min volume of the one or two lowest volume approaches which would operate on the same signal phase.

(5) FA = full-actuated type control.
SA = semiactuated type control.
These limitations apply only where the location will not be progressively timed as part of a signal system on one of the routes.

NOTE: To determine flashing needs, the peak-hour volume of (3) above, should be divided by the eight highest hours volume. If the percentage thus found is 20 percent or greater, delay studies should also be conducted at other lower volume hours. Flashing operation should be used during hours when STOP sign delay measurements show less than 60 percent of the peak hour delay warrant for at least two consecutive hours.

Wilbur Smith Study

The purpose of this project was to develop a warrant that could be used to determine the need for traffic signals at isolated intersections subject to short-duration heavy-volume peaking characteristics. A warrant of this type was established based on volume-delay counts obtained at selected typical intersections and comparable date from other research and simulation studies in West Virginia. Moreover, the warrant values have been tested using similar data from other locations.

Not all intersection configurations and conditions were included in the field samples. Consequently, the warrant values presented in this report were viewed as tentative. It was recommended that additional field tests be undertaken.

The tentative peak-hour delay warrants for traffic signals developed in this research study contained the following as factors:

- Type of intersection (three-way "T" or four-way).
- Number of lanes on the side street approach.
- Minimum total intersection volume.
- Minimum highest side street volume.
- Minimum total delay to side street traffic.
- Percent of left-turn from the main street and left-turn delay.

The actual criteria are given on Table 2.

This warrant was similar but not identical to that developed by Box and Alroth. An important recommendation from the Wilbur Smith analysis was that one-lane minor street approaches should be widened to two lanes (if physically feasible) before application of the warrant test.

KLD Study

The objectives of this study were to evaluate the adequacy

Table 2. Peak-hour warrant from Wilbur Smith study.

Type of Intersection	Number of Approach Lanes On Minor Street	Signal Warrant Values		
		Major Street Volume (Vehicles per Hour)	Minor Street Volume (Vehicles per Hour)	Minor Street Total Delay (Vehicle Hours)
3-Way T	1	750	150	2.0
4-Way +	1	800	200	3.0
3-Way T	2	750	400	4.5
4-Way +	2	800	500	5.0

of the existing traffic signal warrants published in the Manual on Uniform Traffic Control Devices (MUTCD) and to evaluate the need for revised or additional warrants.

The research included the following activities: (1) review and survey of current practices; (2) empirical studies of traffic operations; (3) statistical analysis of accident data; (4) application of a microscopic traffic simulation model; (5) application of analytical models; (6) development of recommended traffic signal warrants; (7) preliminary warrant evaluation survey; and (8) design of warrant verification study.

Of the ten warrants defined in the KLD study, the Peak-Hour Warrant is the one of major interest. This warrant was developed using estimates of intersection capacity provided by the simulation study and assumptions concerning the stability characteristics of traffic on side streets controlled by stop signs as indicated by the queue-theoretic models. A description excerpted from NCHRP Project 3-20 report follows.

> The Peak-Hour Volume Warrant was designed to assess short-term demands to determine whether a traffic signal is warranted. The primary factor is queue stability. It is based on the assumption that as demand approaches capacity on an approach controlled by a STOP sign, the probability of queue instability (growing without bound) increases markedly. Such instability reflects a breakdown in intersection control and must be prevented. The criterion adopted indicates a need for a traffic signal to be installed whenever the saturation ratio of traffic demand to capacity on a side street approach exceeds 0.8, for a period of one hour.
>
> The above criterion will allow the mean delay experienced by side street vehicles to substantially exceed 25 seconds during the relatively short period of one hour, so long as the queue remains stable. The actual delay experienced varies with conditions. According to queueing theory, the mean queue at a saturation ratio of 0.8 is approximately four vehicles.

One other criterion applied to the Peak-Hour Volume Warrant is that no signal will be installed unless the side street volume equals or exceeds 100 vph (150 vph for a two-lane approach).

Although the warrant has only two criteria, the saturation ratio exceeds 0.8 and a minimum side street volume, the actual execution of the warrant procedures calls for the use of graphs that reflect geometric conditions (number of main and cross street lanes, one-way or two-way operation) and combinations of main and side street volumes. In addition, it is necessary to convert observed side street demand to effective side street volumes based on correction tables for percent trucks and percent right turns. A complete description of the warrant is provided in Appendix A.

EXISTING WARRANTS

The concept of a peak-period warrant is not new. In fact, the 1948 MUTCD contained an explicit warrant for traffic-actuated signalized intersections:

> 3. Peak-Hour Volumes.—When signal control is required at an intersection during only a small part of the day, such as during peak traffic hours, traffic-actuated signals may be installed if economically justified, since they will not unduly delay traffic at other times.

Although neither the 1961 addition nor the 1971 edition of the MUTCD contained explicit provisions for peak-hour warrants, several states have recognized the need for a peak-hour warrant and have developed warrants that are used in their respective jurisdictions. The current MUTCD does, however, recognize a warrant for a demand condition that is of direct duration.

> . . . . 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 any five hours of a Saturday and/or Sunday. . . .

The important element included in this warrant is the time duration—1 hr per day and 5 hr per week. Another interesting aspect of this warrant is that it is independent of intersection geometrics.

Brief descriptions of the peak-hour warrants used in several states are provided as follows. Brief descriptions of the two candidate warrants, the NAC Peak-Hour Warrant and the NCHRP Peak-Hour Warrant, are also given.

EXISTING PEAK-HOUR WARRANTS

The Texas Highway Department has conducted a considerable amount of work developing a peak-period warrant. The Texas Peak Period Warrant is actually a series of warrants covering 1-, 2-, and 4-hr periods. Numerical values used in this warrant were developed based on the values currently used in the MUTCD. The curves for shorter time periods were constructed on a basis of a normalized traffic volume distribution over time. That is, if historical records have shown the traffic in the nth highest hour to be, on the average, k times the traffic in the eighth highest hour, the curve for the nth highest hour is the base curve translated by factor k. This approach is the basis for the NAC peak-hour traffic signal warrant which is one of the two candidate warrants evaluated in this research program.

The Commonwealth of Pennsylvania has adopted a similar warrant, the salient difference being that consideration is given to pedestrian volumes. Illinois has a commercial-industrial warrant that is based on multipliers to be applied to either the volume or the interruption warrant stated in the MUTCD. A similar approach, the use of multipliers to be applied to the MUTCD warrant values, is also taken by the State of Missouri. In both Illinois and Missouri, a minimum of 2 hr during which the warrant must be met is specified.

CANDIDATE WARRANTS

There were two candidate warrants to be evaluated and verified in this research project, the NAC warrant and the NCHRP warrant.

NAC Warrant

The NAC warrant has two elements, a volume element and a delay element. The volume warrant element is based on critical combinations of main street and cross street volumes during the peak hour (any four consecutive 15-min periods) of the average day. This element is based on work done by Herman E. Haenel of the Texas Highway Department and was developed on the basis of a normalized traffic volume distribution over time.

The delay element of the NAC warrant indicates that signal control can be justified when the side street delay equals or exceeds 4 veh-hr for a one-lane approach, and 5 veh-hr for a two-lane approach, provided that there is at least a minimum volume on the side street and that the total number of vehicles entering the intersection exceeds a minimum value.

The warrant is satisfied when the conditions previously noted are met, or the plotted point representing the vehicular demand on the main and side streets falls above a warrant curve. A reduction of the warrant values for high-speed roads (40 mph or higher) and for isolated communities is considered with a second curve with less stringent warrant criteria.

The actual NAC warrant is provided in Appendix A.

NCHRP Warrant

The NCHRP peak-hour warrant was developed by KLD Associates as a part of NCHRP Project 3-20. It is based on the assumption that queue instability is the primary factor justifying a traffic signal installation during a peak period of congestion. The queue instability assumption is based on the fact that as demand approaches capacity on an approach controlled by a STOP sign, the probability of queue instability (growing without bound) increases markedly. Such instability reflects a breakdown in intersection control and must be prevented. The criterion adopted therefore indicated a need for a traffic signal installation whenever the saturation ratio of traffic demand to capacity on a side street approach exceeds 0.8 for a period of 1 hr.

Through simulation it was also shown that the mean delay experienced by side street vehicles would substantially exceed 25 sec. The NCHRP warrant was designed to identify the need for a signal when there is an intensive period of congestion extending over a relatively short period of time as characterized by: (1) a high level of delay experienced by side street vehicles controlled by a STOP sign; and (2) unstable queue growth on the side streets.

The relationship between queue and delay was examined using a queue discharge model. It was further assumed, based on a survey response, that intensive congestion was equivalent to a mean delay of 57 sec per vehicle. Furthermore, the analysis indicated that the onset of unstable queue behavior occurred when the ratio of demand to capacity on an approach approximated 80 percent. This was determined to be the equivalent of having a mean queue of 4 vehicles. For the peak hour, therefore, the total delay on that approach would be approximately equal to 4 veh-hr per hour.

The full NCHRP peak-hour warrant is provided in Appendix A.

PROJECT OBJECTIVES

Two specific objectives were addressed in this research study:

1. To evaluate and verify the peak-hour warrant suggested by the Signals Subcommittee of the National Advisory Committee on Uniform Traffic Control Devices (NAC) and the peak-hour warrant developed as part of NCHRP Project 3-20.
2. 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.

APPROACH

An initial review of the problem showed that a great deal of original research had been directed towards the problem, but that there had been little research based on field observations of traffic flows at intersections during peak-hour conditions. The approach taken by the research team, therefore, was based on a pragmatic, empirical analysis of data collected at as many different locations as possible within the scope of the budget. The procedures used to collect these data are described in Appendix C. The final research plan placed heavy emphasis on field data collection preceded by a carefully structured data requirements analysis. The actual reduction of the peak-hour data was structured using three distinct approaches; the simulation approach, the intuitive approach, and the direct measure approach.

The *simulation* approach attempted to examine the validity of the volume/delay relationships of both the NAC and the NCHRP warrants. An issue with the NAC warrant is whether both the delay and volume elements are necessary. With the NCHRP warrant, the issue is related to the impacts of percent of right turns from the side street and percent of truck traffic.

The *intuitive* approach involved following the candidate warrant criteria for using the NAC and the NCHRP criteria separately for each 25-min observation period and comparing the results (a signal is or is not warranted) with a field engineer's judgment of whether the intersection would have operated better with or without a traffic signal during each 25-min period.

The *direct measure* approach involved the formulation of alternative criteria that can be measured directly in the field and that are, either explicitly or implicitly, embedded in the NAC and the NCHRP warrants.

These approaches were designed as a check against one another as well as the proposed warrants, and were developed using the same extensive set of field data. These approaches are amplified in the following.

Simulation

There are several functional relationships that were derived through the use of simulation and analytical models during the conduct of the NCHRP 3-20 project. These include the following:

- Through vehicle equivalence for right-turn traffic.
- Relationship of main and side street volumes to total intersection delay.
- Relationship of main and side street volumes to average delay on STOP-sign-controlled approaches.

It was planned to study these relationships by comparing the predicted parameter (say, delay per vehicle) with actual measured parameters for comparable demand and geometric conditions. Once the verification process was completed, it was planned to extrapolate these parameters through the use of the simulation model to obtain data in regions not observed with actual field measurements.

Model

To investigate these issues, a simulation model, STOPSIGN, was developed. STOPSIGN simulates the operation of a one- or two-lane STOP-sign approach to a "T" intersection using a simple queueing model. It is a menu-driven program written in Applesoft BASIC. Where feasible, variable names have been retained. The program is structured, with most modules corresponding to a menu selection or a utility used by one or more other modules.

STOPSIGN assumes Poisson arrivals on the STOP approach (i.e., exponential headway distribution). The gap which any particular vehicle will accept is log-normally distributed. The headway on the main street has a shifted exponential distribution. The parameters of the latter two distributions are user-modifiable. When two approach lanes are present, it is assumed that all traffic in the left lane will turn left, and all traffic in the right lane will turn right. The lanes are modeled independently, so a long "gap" simulated for left-turn traffic will not necessarily be present for right-turn traffic at that particular time.

STOPSIGN calculates stop-line occupancy (percent of time occupied), average queue (including first car in queue), queue remainder at end of simulation, total number served, average wait time, and average delay including acceleration/deceleration. When two lanes are specified, separate statistics will be provided for each.

The final version of STOPSIGN produced results similar to the results of models by Thommason & Wright, Kell, and UTCS-1, as shown on Figure 5.

Results

Unfortunately, the results of any one run were highly variable. This was thought to be due, at least in part, to the random number generator. Because of the problems of wide variability of the results given identical input values, and because the other two approaches were showing definite signs of being more productive, additional simulation runs were not conducted.

Intuitive

In the evolution of traffic engineering, engineering judgment has long played a dominant role. Intuition was, at first, the only criterion available to the engineer for determining whether certain traffic control devices, such as traffic signals, should be installed. When the need for additional traffic control devices became prevalent, so did the need for a more quantitative and systematic basis for determining applications. The development of these systematic guidelines has partially, but far from completely, eliminated the need for the traffic engineers' intuition and judgment.

The development of the proposed peak-hour signal warrants has followed somewhat the same pattern. Situations were identified in which a traffic signal was obviously needed, but which did not satisfy any of the existing warrants. The peaking nature of traffic demand is a consistent feature of these situations. The intuitive approach, therefore, capitalizes on the fact that the engineer has a "sense" of when a problem exists that has a solution through the use of a traffic signal.

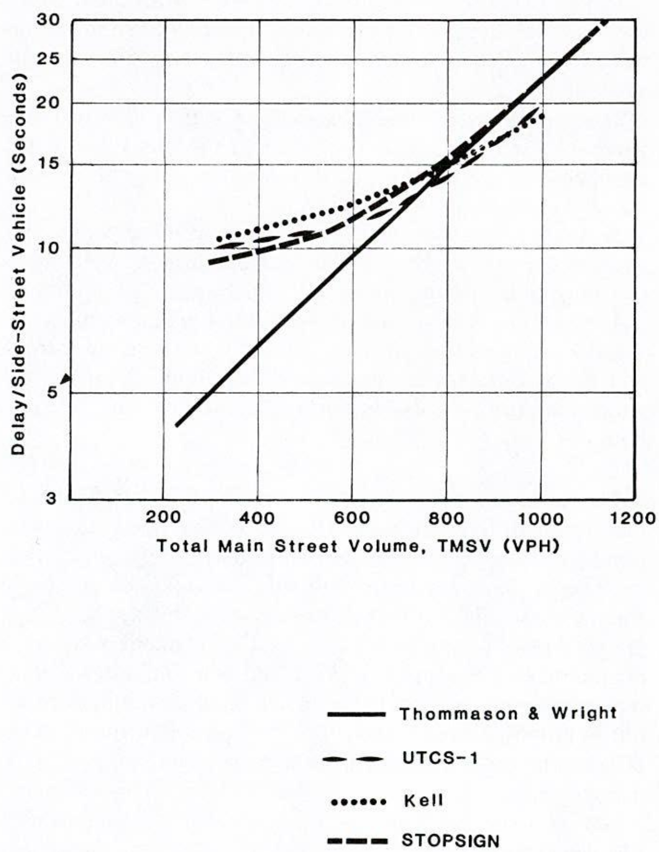


Figure 5. Comparison of other simulation models with STOPSIGN.

Ideally, the traffic engineer's "sense" of when a signal is necessary should closely match the results of following the prescribed signal warrant criteria. If it does not, there are two possibilities: either the engineer's "sense" is correct and the warrant is in error, or the warrant is correct and the traffic engineer's "sense" is wrong. The intuitive approach assumes that, in general, the former is true. Using this approach, both signalized and nonsignalized intersections were analyzed.

The warrant evaluation criteria used in the intuitive approach is the value judgment of the JHK field engineer as to whether the intersection would operate more effectively under signal control or under STOP-sign control. This decision was made for each 25-min observation of the data collection period. Thus, a direct comparison between an engineer's intuition and various derived and observed measures was possible. Problems anticipated with this approach were related to potential bias of one or more of the field engineers.

Direct Measure

Whereas the intuitive approach strictly considers the judgmental appropriateness of a signal, the direct measure approach determines the appropriateness on a quantitative basis. Through the formulation of an objective function and the collection of field data, this approach determines whether an intersection meets the requirements of the hypothetical warrants. The direct measure approach included the following:

1. *Total side street delay*—The signal is warranted when the total side street delay exceeds a threshold. Comparisons were made for thresholds varying between 0 and 800 veh-min per hour.
2. *Average side street delay*—The signal is warranted when the average delay to each vehicle exceeds a threshold. Comparisons were made for thresholds varying between 0 and 200 sec per vehicle.
3. *Average queue*—The signal is warranted when the average queue exceeds a threshold. Comparisons were made for thresholds varying between 0 and 10 vehicles in queue.
4. *Conflict*—The signal is warranted when conflict (a variable representing potential conflicts between side street and main street traffic) exceeds a threshold. Comparisons were made for thresholds varying between 0 and 800 per hour.

These comparisons were made for the full data base and for subsets of the data base. The subsets included stratification by traffic control (signal or no signal) and by geometrics (number of lanes on major and side streets). The comparisons were made with decisions reached by applying the NCHRP peak-hour warrant criteria, the judgment of the field engineer, and by applying the NAC warrant criteria. The direct measure approach produced results complementing the intuitive approach and ultimately provided the foundation for the recommended peak-hour warrant.

PROJECT DATA BASE

The project data base exists in three different formats, one of which is physical, the other two are machine readable. A great deal of thought and care was expended in developing this data base with the expectations that this effort will benefit not only this current research, but would also provide a valuable data base for other researchers.

Physical Format

The physical portion of the data base includes all the forms, photographs, and worksheets that relate to an individual intersection. This includes an intersection data sheet that describes the basic type of intersection control (the signal phasing if signalized), a sketch of the intersection, and space for comments for the field engineer. The packet also includes two photographs, nominally 3½ x 5 in., of each approach to the intersection. One photograph was taken approximately 100 ft upstream from the intersection and shows the intersection geometrics in detail, while the second photograph was taken further back, a distance ranging from 400 to 800 ft, to show the general geometrics on the approach to the intersection. Worksheets used to compute the intersection delay and percent stopping, as well as turning movement counts and classification worksheets, are included. Each intersection was identified with a three-digit number. The first digit is a code for each city. The other two digits identify the intersection within the city. For example, numbers from 100 to 199 represent intersections in Atlanta.

Magnetic Format

In order to conduct the analyses with the variables contained in this data base, it was necessary to code the data into a machine readable format. For convenience in manipulating the data, the data were actually coded into two different data bases for reasons described below. One of these is the Creative Computer Applications Data Management System (DMS). This data base management system was chosen for two primary reasons. First, the principal investigator was familiar with the syntax and capabilities of the system and felt that it would provide a useful means for manipulating the large amount of data to be analyzed. The second, and perhaps more important reason, is that the data stored using this system are accessible from other programs. That is, the format of the records in the file is described in the documentation making it possible to write software which accesses the file created by DMS for further manipulation. In fact, this was an absolute necessity as the data were analyzed using a statistical analysis package that required the data in yet another format. It was possible by using DMS, however, to write a straightforward program that converted the data from the data base format to that required by the statistical analysis package.

The third format is that required by the other data base management package used in this research, DB MASTER. The work involved in recording the data base into the DB MASTER format, approximately two technician-days, was justified by two attributes of DB MASTER that are impossible with the DMS package. The first of these is the ability to count the number of records that meet a specified complex criteria. For example, DB MASTER was used to generate a listing of all records of observations where the intersection delay was greater than 240 min, the intersection was signalized, and the criteria of the NCHRP warrant were not met. This query capability provided the means to rapidly access the relative importance of a number of the variables in the data base early in the analysis phase.

The second capability of DB MASTER that was felt to be a major contribution to the analysis is the report generating capability. An example of this is provided in the listing shown in Appendix B, Database.

CHAPTER TWO

FINDINGS

The results of the analysis of the data base are presented in this chapter. The chapter includes three major topics. The first is an overview of the factors that were used to describe the physical conditions and traffic flows that were observed and measured at each of the 241 intersections included in the study.

The second topic explores the differences between the two candidate warrants, the NAC warrant and the NCHRP warrant. The third topic relates the field measures to each of the two candidate warrants as well as to the observations of the professional engineer.

Table 3. Number of intersections and observations by city.

City	Number of Intersections	Number of 25-Minute Observations
Atlanta	41	163
Denver	26	95
Hartford	36	152
Phoenix	30	126
Tucson	30	88
Washington	78	193
Totals	241	817

FIELD OBSERVATIONS

The data were collected in six cities where JHK maintains offices. The selection of these cities allowed the data to be collected under the supervision of a permanent JHK engineer. For the most part, observations of the peak-demand periods for candidate intersections required approximately 2 hr during the peak period. The peak-period observations were conducted at 241 intersections in the six cities. More intersections were observed in the Washington area than in the other five cities because of the location of the co-principal investigators in the Washington office which allowed cost-effective data collection activities. The number of 25-min observations as well as the number of intersections in each city are given on Table 3.

With the assumption that many intersections would exhibit demands that would manifest themselves quickly and be dissipated within the hour, four observations were conducted at each intersection. It was planned that the first 25-min observation be timed so that the measures would be taken before the peak-period demand occurred. The second 25-min period was timed to be coincident with the peak demand for that intersection. The third 25-min period was intended to measure the decay of the queue from the peak-demand period, and the fourth 25-min period was a measure of the traffic flow after the peak demand had passed. In many cases, only three observations were required because, by virtue of an empty parking lot, it was obvious that the demand had dissipated.

Geometrics and Traffic Control

Of the 241 intersections, there were 124 cross intersections, 116 "T" intersections, and one intersection that fit neither description. This yielded a total of 413 observations at cross intersections, 400 observations at "T" intersections, and 4 observations at the "other" intersection.

In the data base, there were 115 intersections that were controlled by STOP signs, 126 intersections that were controlled by traffic signals, and 3 intersections that were controlled by police officers during at least one observation period. This yielded a total of 368 STOP-sign control observations and 444 traffic-signal control observations. These classifications are summarized in Tables 4 and 5.

At the onset of the study, it was anticipated that many more observations would be obtained at locations controlled by police officers. In practice, however, this was found not to be the case in the six cities in which the data were collected. There were only five observations at intersections with police control. This was an unexpected finding because the identification of officer-controlled intersections was anticipated to be one of the primary means for identifying candidate peak-hour locations for data collection. In fact, the first question asked of the traffic engineers in the six cities where data were collected was a request for a listing of intersections where officers controlled traffic flow during peak

Table 4. Number of intersections by intersection geometrics and traffic control device.

Traffic Control	Geometric Classification			
	Cross	"T"	Other	Total
Stop	42	72	1	115
Signal	82	44	0	126
Total	124	116	1	241

Table 5. Number of observations by intersection geometrics and traffic control device.

Traffic Control	Geometric Classification			
	Cross	"T"	Other	Total
Stop	136	228	4	368
Signal	277	167	0	444
Police	0	5	0	5
Total	413	400	4	817

periods. The scarcity of observations with officer control is an unfortunate occurrence because this form of traffic control is prevalent in a number of locations throughout the country.

Another stratification of the data base that is useful in interpreting the results is a comparison of the number of observations for each category of number of lanes on the main street and side street and whether the intersection is signalized or not. Tables 6 and 7 indicate that in the data base intersections of the higher geometric type are more likely to be signalized than those of a lower geometric type. There were only eight observations at signalized intersections with one lane on the main street and one lane on side street. For the most part, there was an adequate number of observations in most cells to allow statistical testing.

A factor to keep in mind is that the "number of lanes" is the number on each approach, not the roadway. In other words, a one-lane approach on the main street actually describes a two-lane, two-way roadway. In the detailed analysis, it was found to be convenient to group all multilane approaches into one category. The resulting number of observations is given in Table 8.

Left-Turn Geometrics

A separate left-turn lane for the main street traffic turning onto the side street was investigated to determine the effects of the geometric conditions. From Table 9, it can be seen that a separate left-turn lane was more common as the number of lanes on the main street increased.

There was also concern as to whether the separate left-turn lanes were more prevalent at "T" intersections than at cross intersections. Table 10 indicates a trend to the reverse of this situation. Of importance, however, is the fact that the left-turn geometric variations were adequately represented for both the "T" and cross intersection categories.

Main Street Speed Limits

The number of observations by speed limit category are given in Table 11. Of interest here is that a large majority of the observations (approximately 90 percent) fall within the range of 30 mph to 45 mph.

Table 6. Number of observations at STOP-sign-controlled intersections by number of lanes.

Cross Street	Main Street		Total
	1	2 or More	
1	84	98	182
2 or more	50	136	186
Total	134	234	368

Table 7. Number of observations at signal-controlled intersections by number of approach lanes.

Cross Street	Main Street		Total
	1	2 or More	
1	8	55	63
2 or more	46	335	381
Total	54	390	444

Table 8. Number of observations in major categories by number of lanes.

Cross Street	Main Street		Total
	1	2 or More	
1	92	153	245
2 or more	96	471	567
Total	188	624	812

Proximity to Other Signalized Intersections

A final descriptive stratification of the data base concerned the proximity of signalized intersections to the candidate intersection. Seventy percent of the observations were made at candidate intersections that were within 2,000 ft of another signalized intersection. Details are given in Table 12.

Data Summary

The foregoing has provided an overview description of the characteristics of the intersections at which the peak hour observations were made. It is important to emphasize that these intersections were not selected at random, but rather each intersection was chosen specifically because it was suspected of being a prime candidate for a peak-hour warrant. Thus, insofar as practical, it was determined that the intersection did not meet one of the existing warrants in the MUTCD, that it exhibited a peak period demand pattern, and that local traffic engineers (both JHK & Associates resident engineers and public agency traffic engineers) felt that the intersection would likely meet a peak period warrant.

ANALYSIS

Analysis of the data was conducted in six distinct steps:

- NAC/NCHRP assumptions.
- Criteria comparisons.
- Engineer's judgment.
- Intuitive analysis.
- Direct measure analysis.
- Other factors.

First, direct comparisons were made between the NAC and NCHRP warrants to ascertain areas of differences between the warrants. Next, the NAC criteria and the NCHRP criteria were applied to each 25-min observation using applicable data. This resulted in a total of 817 applications of the NAC warrant criteria and 817 applications of the NCHRP warrant criteria.

A key element in this research approach is the exercise of the judgment of the field engineer for each 25-min observation as to whether the intersection would have operated better with STOP-sign control or with signal control. A major concern was of a possible bias of one or more of the observers, and, therefore, this issue is examined.

Given the results of the applications of the NAC warrant criteria and the NCHRP warrant criteria, the intuitive analysis is conducted.

Following the intuitive analysis is the analysis of the direct measures. This is done in a straightforward manner by determining the number of observations that agree between a standard and a field measure threshold. For example, the NCHRP warrant criteria were used as one of the standards and queue was used as one of the direct measures. A queue threshold of 3.5 vehicles was one of the thresholds used. As given in Table 13, there are two possible correct cells with the implication that a direct measure of queue of less than 3.5

Table 9. Number of observations by left-turn geometrics and by number of main street approach lanes.

Number of Main Street Lanes	Left Turn Geometrics		Total
	No Separate Lane	Separate Lane	
1	124	68	192
2	203	256	459
3+	47	119	166
Total	374	443	817

Table 10. Number of observations by left-turn geometrics and by type of intersection.

Type of Intersection	Left Turn Geometrics		Total
	No Separate Left Turn Lane	Separate Left Turn Lane	
Cross	135	282	417
T	239	161	400
Total	374	443	817

Table 11. Number of observations by speed limit category.

Main Street Speed Limit (MPH)	Number of Observations
25 or less	62
30 or 35	406
40 or 45	320
50 or 55	29
Total	817

Table 12. Number of observations by traffic signal proximity and traffic control type.

Traffic Control	Nearest Signal		Total
	2000 ft	2000 ft	
Stop Sign	257	111	368
Signal	308	136	444
Police	3	2	5
Total	568	249	817

Table 13. NCHRP warrant criteria versus queue.

Queue	No Signal	Signal
3.5	Correct	Beta Error
3.5	Alpha Error	Correct

Truck Percentage	Percent of Samples
1.4	71.8
1.5-3.4	16.3
3.5-5.4	6.1
5.5-7.4	2.0
7.5-9.4	1.4
9.5	2.4
Total	100%

Table 14. Percentage of trucks on side street approaches.

vehicles indicates that a signal should not be installed. There are also two possible wrong cells. These have been designated as Alpha and Beta errors. In any given error level, that is, where the sum of the Alpha plus Beta errors is a constant, it is desirable to minimize the Alpha error because it is considered the more grevious. In other words, if the "standard" is assumed correct (the NCHRP warrant criteria in the example), the Alpha error implies the justification of a non-warranted signal. The Beta error, while also undesirable, would simply result in a potentially beneficial signal not being justified.

The direct measure analysis consists of comparisons of the standards (the NCHRP warrant, the NAC warrant, and the field engineer's judgment) against threshold values of the field measures (average approach delay, vehicle-minutes per hour; conflict, a measure of potential conflicts described later; and average queue length, number of vehicles).

The final step of the analysis was to ascertain the impact of potential parameters on the procedure. The parameters considered were proximity to signalized intersections, left-turn lane geometrics, main street speed, and type of intersection.

NAC/NCHRP Assumptions and Criteria Comparisons

Both the NAC warrant and the NCHRP warrant are presented in graphical form with a curve of main street versus side street volumes for each of several different combinations of number of lanes on the main street and side street. The NCHRP warrant, however, applies two factors to adjust the side street demand volumes, a truck factor and a right-turn factor.

Truck Factor

The proposed NCHRP peak-hour warrant includes a process that accounts for the percentage of trucks in the traffic stream on the side street. As described in Appendix A, one truck is considered as operationally equivalent to two passenger cars, and this "equivalent" volume is used as input to the next stage.

A review of the data collected at 817 side street approaches showed that the vast majority of approaches had very low truck percentages. Table 14 indicates that of the 817 25-min observations periods sampled by this study, approximately 72 percent had truck percentages of less than 1.4, and nearly 90 percent had percentages less than 3.4. The highest truck percentage found was 23 percent. Only 2.4 percent of the sampling periods had truck percentages of 10 or more. The mean percentage of trucks at these candidate intersections under peak-hour demand conditions was found to be 2.0 percent.

The foregoing is not surprising when one considers the nature of traffic at locations that are candidates for peak-hour signals. Many of these locations have extremely peaked volumes because of the high proportion of commuters in the traffic stream. Commuters tend to drive passenger vehicles as opposed to trucks, as defined in this study. This indicates that the magnitude of truck traffic at 90 percent of the peak-hour candidate locations ranges from zero to approximately 4 percent.

Another factor considered in reviewing the impact of trucks is how this is accounted for in the warrant criteria. It was found that the impact of the percentage of trucks on the outcome is small, particularly considering the range of typical truck percentages. For each 1 percent of trucks in the traffic stream, the side street volume threshold to satisfy the peak-hour warrant is reduced by 1 percent. This is shown graphically in Figure 6. An approach with 10 percent trucks

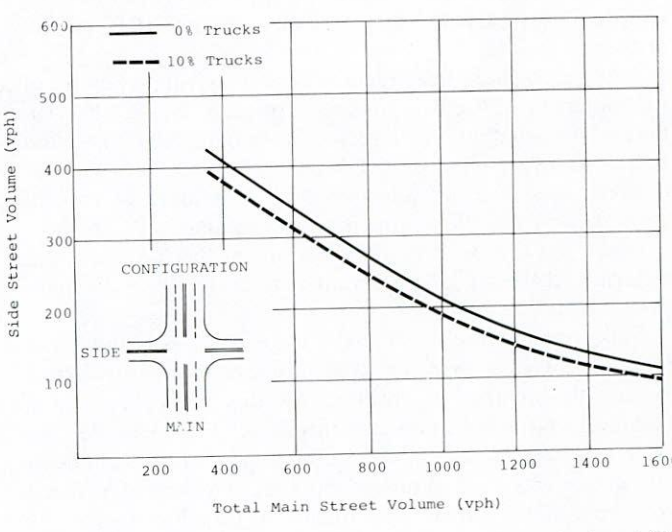


Figure 6. Comparison of NCHRP peak-hour warrants for 0 and 10 percent trucks.

would require 10 percent less total volume on the side street to satisfy the warrant than with no trucks. Even this 10 percent level, which has been demonstrated to be rare, is considered small in view of the fact that the statistical error in the measurement of total traffic volumes is often within this range.

This analysis indicates that there is little need to include the percentage of trucks in the process for determining when the peak-hour warrant is satisfied. Only in rare cases, when truck volumes are unusually high, does the truck factor need to be considered. Therefore, it is suggested that the percentage of trucks not be required in the general application of the warrant. This would eliminate one additional step in computations, and more importantly, relieves the warrant process of the need to collect costly vehicle classification data.

Right-Turn Factor

The percentage of right turns on the side street approach is a major factor included in the currently proposed NCHRP peak-hour warrant. It is not considered in the NAC warrant. A rationale supporting this factor in the warrant is that right turns are made more easily (fewer conflicting movements) than are through or left-turn movements. In general, right-turn delay is related to the gap distribution of those vehicles approaching from the left on the main street, while through and left-turn movements are impacted by the combined gap distribution for both directions of main street flow. When considering both directions of flow, there are fewer acceptable gaps and, thus, more delay to those having to cross both streams.

The data collected in this study have verified the importance of the right-turn factor in the determination of peak-hour warrants. There is a wide range in turn percentages at candidate intersections, and the effect of this variation significantly impacts the threshold at which a signal is warranted.

Figure 7 shows how the percentage of right turns affects the volume threshold for a basic geometric configuration in the currently proposed NCHRP peak-hour warrant. Also plotted on this graph is the NAC volume curve. As indicated, an increase in the percentage of right turns increases the volume threshold for which a signal is warranted. Two observations may be derived from this figure. First, the NAC warrant curve is similar to the NCHRP curves; and, second, the NAC warrant is more lenient than the NCHRP warrant for all ranges of percent right-turn traffic.

With slightly different geometrics, two lanes on the main street approaches and one lane on the side street approach, the shape of the curves changes somewhat as shown on Figure 8. With these geometrics, the NAC provides the more stringent criteria over much of the range of main street volumes and percent right turns.

Figure 9 shows the NAC and NCHRP warrant curves for intersections with two lanes on both the main street and side street. The pattern shown on this figure is similar to that

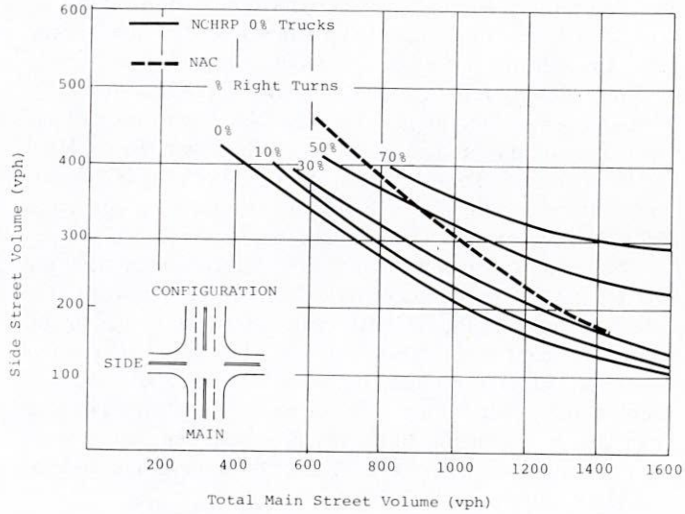


Figure 8. Comparison of NAC and NCHRP peak-hour warrants — two-lane and one-lane approaches.

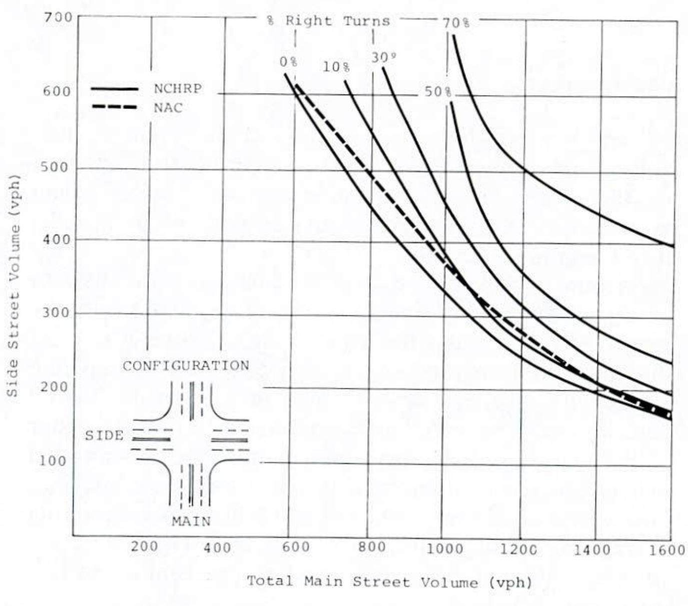


Figure 9. Comparison of NAC and NCHRP peak-hour warrants — two-lane approaches.

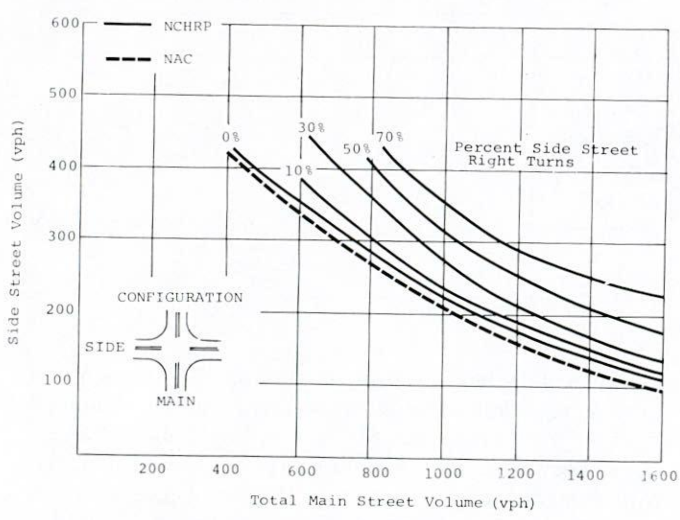


Figure 7. Comparison of NAC and NCHRP peak-hour warrants — one-lane approaches.

shown on Figure 7, with the NAC warrant in all cases being the less stringent criteria, except when the right-turn percent is zero.

Because of the impact of the right-turn percentage on the NCHRP criteria, a more detailed examination was conducted. Table 15 gives the frequency distribution of the percentage of right turns for the 817 samples in the data base. The mean percentage for one-lane approaches is 51, while the mean for two-lane approaches is slightly lower at 38 percent.

There is a remarkably even distribution of right-turn percentages over the entire range of 0 to 100 percent for approaches with one lane. The distribution is skewed toward the lower percentages for approaches of two or more lanes. In both cases the percentage is higher than the average that most engineers are used to dealing with for an average condition. This again is due to the particular types of sites selected for inclusion in the data base. Typically, they are local or collector streets opening onto an arterial, so that much of the side street traffic would be expected to turn.

From this review of the NAC and NCHRP warrants, it would appear that in general, the NAC warrant criteria would result in more signals being justified than the NCHRP warrant criteria. To test this assumption, both the NAC warrant criteria and the NCHRP warrant criteria were applied to all 817 observations. The results are given in Table 16.

The values displayed on this table clearly indicate that the NCHRP is the more rigid criteria. Thirty-eight percent of the observations met the NCHRP criteria for installing a signal, and 54 percent met the NAC criteria. This table also shows a relatively high agreement between the two criteria; 83 percent of the observations, 370 not met and 307 observations met, are in agreement. In the disagreement cells, there were 134 observations where the NAC criteria were met and the NCHRP criteria were not met.

This analysis shows that the two candidate warrants are distinctly different and that the NCHRP warrant is the more stringent of the two.

Observer Bias

There was considerable concern that one or more individual field engineers who were making the decision as to whether the intersections would operate "better" with STOP-sign control or signal control was more lenient or strict than the group as a whole.

An initial review of the data showed that observations with average queue lengths ranging from 1 to 4 vehicles were the more difficult ones to judge. That is, when the queue was less than one, all observers judged the intersections to operate better with STOP-sign control; with queues greater than 4 vehicles, most observations were judged to operate better with signal control. To focus on how the observers fared in making judgments in the critical range, a subset of the data base was created that contained all observations where the average queue ranged from 1 to 4 vehicles. There were 396 records in this subset, approximately 48 percent of the records in the data base.

The number of judgments that each field engineer made in each category is arrayed, by city, on Table 17. A chi-square test was conducted to test the hypothesis that the two variables were independent; that is, there was no significant observer bias. Using the data arrayed on Table 17 as the contingency table, a chi-square score of 3.3 was calculated. With 5 degrees of freedom and a 5 percent level of confidence, a chi-square score of 11.1 or higher is required to reject the null hypothesis. It was concluded, therefore, that there was no significant observer bias.

Table 15. Frequency of percent right turns on side street approaches.

Percent Right Turns	One Lane (%)	Two Lanes (%)
0-10	10	15
11-20	8	13
21-30	10	15
31-40	12	16
41-50	11	9
51-60	8	9
61-70	10	11
71-80	8	6
81-90	10	4
91-100	13	2
Total	100%	100%

Table 16. Number of observations meeting NCHRP criteria versus those meeting NAC criteria.

NAC Criteria	NCHRP Warrant Criteria		
	Not Met	Met	Total
Not Met	370	6	376
Met	134	307	441
Total	504	313	817

Table 17. Number of observations ($1 \leq$ queue ≤ 4) by control device by city.

City	"Better" Traffic Control Device		
	Stop Sign	Signal	Total
Atlanta	40	37	77
Denver	20	25	45
Hartford	30	28	58
Phoenix	23	36	59
Tucson	24	29	53
Washington	49	55	104
Total	186	210	396

Using this same 396 record subset of the data base, another table was constructed. Table 18 gives the average queue and standard deviation of the observations that were judged better for STOP-sign control and for those that were judged better for signal control. There are two observations relevant to this table. First, there is remarkable agreement in the averages for both classes in the six cities. Second, and more important, this table suggests that a possible threshold for signal justifications using queue would be between 1.5 and 2.5.

Intuitive Comparisons

The intuitive analysis as first proposed was predicated on the assumption that the reality that a signal was or was not actually installed would be a good indication of the actual need. Of course, there is no way of knowing whether the "need" which justified the signal installation was at all related to the peak-period demand.

To investigate this approach, two tables were developed showing the relationship between type of traffic control and the NCHRP criteria (Table 19), and type of traffic control and the NAC criteria (Table 20) As can be seen in both tables, the association between the warrant criteria being met and a signal being installed is in evidence, but the association is not strong.

There are several instances where the percentage of disagreements between existing control and warrant criteria is high. For example, 37 percent of the observations differed from the NCHRP warrant with existing signalized intersections being prevelant. Approximately 39 percent of the observations differed from the NAC warrant. Of these, half were STOP-sign locations that warranted a signal and half were signals that were not warranted.

Because this approach did not appear to offer much promise, a slightly different approach was taken involving comparisons between the warrant criteria and the decisions of the field engineers.

Preliminary analysis of the differences between the NAC and the NCHRP warrant criteria indicated that the percent right-turn factor appeared to account for most of the difference. To test this, each observation was subjected to both the NAC warrant criteria and the NCHRP warrant criteria neglecting the percent right-turns factor. The results of this are given in Table 21.

This table shows that of the 817 observations, there were 788 agreements—96 percent—and only 29 cases where the criteria disagreed. Of these 29, 27 were in the cell indicating that the modified NCHRP criteria were met and the NAC criteria were not met. From this effort it was concluded that when the right-turn factor of the NCHRP warrant is neglected, the two criteria are very similar, with the NAC criteria being slightly more stringent.

The next comparison involved subjecting each 25-min observation to the actual NCHRP warrant criteria and comparing the results to the NAC criteria results. This effort is depicted in Table 22. The magnitude of the differences between the NAC and NCHRP candidate begins to emerge from the data given in Table 22.

As with previous comparisons, the number of observations where the criteria agree is high—677 observations out

Table 18. Average queue length for observations judged "better" for STOP-sign control and for signal control.

City	Stop Sign		Signal	
	Average	Std. Dev.	Average	Std. Dev.
Atlanta	1.50	0.60	2.63	1.03
Denver	1.45	0.51	2.69	0.74
Hartford	1.47	0.54	2.50	0.82
Phoenix	1.30	0.40	2.50	0.87
Tucson	1.47	0.31	2.35	0.63
Washington	1.83	0.57	2.54	0.77

Table 19. Comparison of NCHRP warrant versus traffic control device.

Traffic Control	NCHRP Warrant	
	Not Met	Met
Stop Sign	285	83
Signal	216	228
Police	3	2
Total	504	313

Table 20. Comparison of NAC warrant versus traffic control device.

Traffic Control	NAC Warrant	
	Not Met	Met
Stop Sign	213	155
Signal	162	282
Police	1	4
Total	376	414

Table 21. Comparison of NCHRP warrant criteria without RT factor versus NAC warrant criteria.

NAC Criteria	NCHRP Criteria (without RT Factor)		
	Not Met	Met	Total
Not Met	349	27	376
Met	2	439	441
Total	351	466	817

Table 22. Comparison of NCHRP warrant criteria versus NAC warrant criteria.

NAC Criteria	NCHRP Criteria		
	Not Met	Met	Total
Not Met	370	6	376
Met	134	307	441
Total	504	313	817

Table 23. NAC criteria versus engineer's judgment.

Engineer's Judgement	NAC Criteria		
	Not Met	Met	Total
Not Met	322	117	439
Met	54	324	378
Total	376	441	817

of 817 (83 percent). But the cell of major disagreement, NAC criteria met and NCHRP criteria not met, accounts for practically all of the difference, 16 percent. From this it was concluded that while the criteria agreed most of the time (83 percent), the area of disagreement clearly shows that the NCHRP is the more stringent criteria.

The next step is to compare both candidate criteria with the judgment of the field engineer. The results of these comparisons are given in Table 23 for the NAC warrant criteria and Table 24 for the NCHRP warrant criteria. An interesting coincidence is that both tables show 646 observations in agreement (79 percent).

An examination of the two nonagreement cells in both tables shows a definitive reversal of patterns. That is, the NAC warrant is definitely less stringent than the engineer's judgment as evidenced by the fact that the NAC criteria were met 117 times when the engineer judged the intersection to operate better with STOP-sign control. Conversely, the NCHRP criteria are more stringent than the engineer's judgment. (Independent research has developed the following comparisons between engineer's judgment and the warrants, separated by existing control type. This was done using the data base presented in Appendix B.

Comparison of "Best" Traffic Control at Stop-Sign-Only Locations

	Better Traffic Control	
	Stop Sign	Signal
NAC	213	155
Judgment	273	95
NCHRP	285	83

Comparison of "Best" Traffic Control at Signalized Locations

	Better Traffic Control	
	Stop Sign	Signal
NAC	162	282
Judgment	166	278
NCHRP	216	228

It is interesting to note that engineering judgment closely matched the NCHRP warrant at sign locations and NAC warrant at signalized locations. Perhaps the NCHRP warrant (4 veh-hr delay) is a good indicator of need for peak-hour signal and NAC warrant (25 veh-hr) is a good threshold for converting to flashing operation. Unfortunately, neither time nor budget was available to pursue this issue as part of this project.)

Table 24. NCHRP criteria versus engineer's judgment.

Engineer's Judgement	NCHRP Criteria		
	Not Met	Met	Total
Not Met	386	53	439
Met	118	260	378
Total	504	313	817

Table 25 is a summary of the number of observations relating each of the three criteria (NAC, NCHRP, and judgment) to an implied optimum traffic control device. The relative differences among the three criteria are readily seen from this table. The NAC warrant is the least stringent, indicating that 441 observations should be signalized (54 percent). The engineer's judgment qualified 378 observations (46 percent) for signalization; while the NCHRP criteria only indicated 313 observations (38 percent) for signalization. The engineer's judgment appears to offer an exact middle ground between

Table 25. Traffic control versus signal criteria.

Criteria	Traffic Control	
	Stop Sign	Signal
NAC	376	441
Judgement	439	378
NCHRP	504	313

the two candidate criteria, qualifying 8 percent fewer than the NCHRP and 8 percent more than the NAC for signalization.

This was an unexpected (and undesirable) result as it was hoped that the engineer's judgment would validate one or the other of the candidate warrants.

Direct Measures

As described in Appendix C, Data Collection Procedures, a number of field measures of performance were observed during each 25-min period. At this point in the study, three of these measures are relevant; total approach delay (vehicle-minutes per hour), average approach vehicle delay (vehicle-seconds per vehicle), and average queue (vehicles in queue).

It should be noted that these measures are highly correlated with each other and, in fact, total approach delay and average queue are virtually identical measures. For example, an average queue of 2 vehicles for 1 hr is, in fact, 2 veh-hr of delay. To avoid working with decimals, the principal investigator chose to express delay in terms of vehicle-minutes. Thus, the 2 veh-hr would be expressed as 120 veh-min of delay in this study.

NAC Warrant Measures

The NAC warrant curves (see App. A) are intended to represent iso-delay curves of 4 veh-hr for one-lane approaches and 5 veh-hr for two-lane approaches. To determine whether this, in fact, was achieved, the total approach delay was averaged for all observations at nonsignalized intersections with two-lane approaches that experienced main street and cross street demand volumes within limits approximating the warrant curve. These limits are shown on Figure 10.

The results of these tabulations are given in Table 26. Fewer than 2 percent of the data base met these selection criteria—a total of 16 observations. In spite of the few observations lying exactly within the boundary conditions, the fact that these observations averaged only 144 veh-min (2.4 veh-hr) is important. The assumption that observations within the volume region would reflect 5 veh-hr of delay is obviously incorrect. Similar analyses for other combinations of numbers of main and side street lanes showed similar results. Based on these actual field measures, it was concluded that the curves contained in the NAC warrant represented delay conditions substantially less than that stated in the verbal description of the warrant.

NCHRP Warrant Measures

Because of the confounding impact of the right-turn factor, an analysis of the NCHRP warrant similar to that described above was not possible. Instead, a stepwide multiple regression analysis was used to determine whether it was possible to predict total delay (or queue) as a function of the following:

1. Number of lanes on the main street.
2. Number of lanes on the cross street.
3. Main street volume.
4. Side street volume.
5. Percent right turn.

Because the anticipated curve was not expected to be linear, a good fit was not anticipated. The purpose was to achieve a sense of the magnitude of the impact of each of the variables. As expected, the curve fit was not good. With all variables included in the equation, the R-square statistic was 0.24. Of interest is the amount of the variance explained by each variable.

When the variables (including the intercept), which were not significantly different from zero, were removed, three remained: number of lanes on the side street, main street volume, and side street volume. The R-square statistic remained 0.24. With these variables, 16 percent of the variance was explained by the side street volume, 5 percent by the main street volume, and 3 percent by the number of lanes on the side street. Although not possible within the time and budget constraints of this study, pursuing multiple regression using linear transforms and other nonlinear techniques appears to be a fruitful avenue of research.

Conflict Analysis

Although the right-turn factor did not prove significant within the context of linear multiple regression, it was felt that this factor was important and should be investigated further using a surrogate measure, conflict.

Conflict (conflict analysis as defined and used in this study is separate and distinct from the Traffic Conflicts technique developed by General Motors Research Laboratories), which is fully described in Appendix B, is based on the number of potential conflicts between vehicles on the main street and vehicles on the side street. There are three primary attributes of conflict. First, it is simple, being derived by multiplying and adding data normally available from a classical turning movement count. Second, it is independent of any traffic control device, and therefore, can be used at signalized intersections (direct measures of delay and queue can only be used as a warrant at nonsignalized locations because the variables are directly influenced by signal timings). Third, it explicitly accounts for right-turning traffic in a manner similar to the correction factors included in the NCHRP warrant.

The conflict measure was used in two different procedures. One procedure used conflict as a dependent variable with queue as the independent variable in a simple linear regression. This was done using all observations in the data base at nonsignalized intersections (NOSIG). The results were poor. A correlation coefficient of 0.56, an R-square statistic of 0.32, and a standard error estimate of 188 were found. This procedure was abandoned in favor of the second procedure.

The second procedure that involved the conflict measure was an analysis of the conflict threshold that provided the optimum agreement with two criteria, the field engineer's

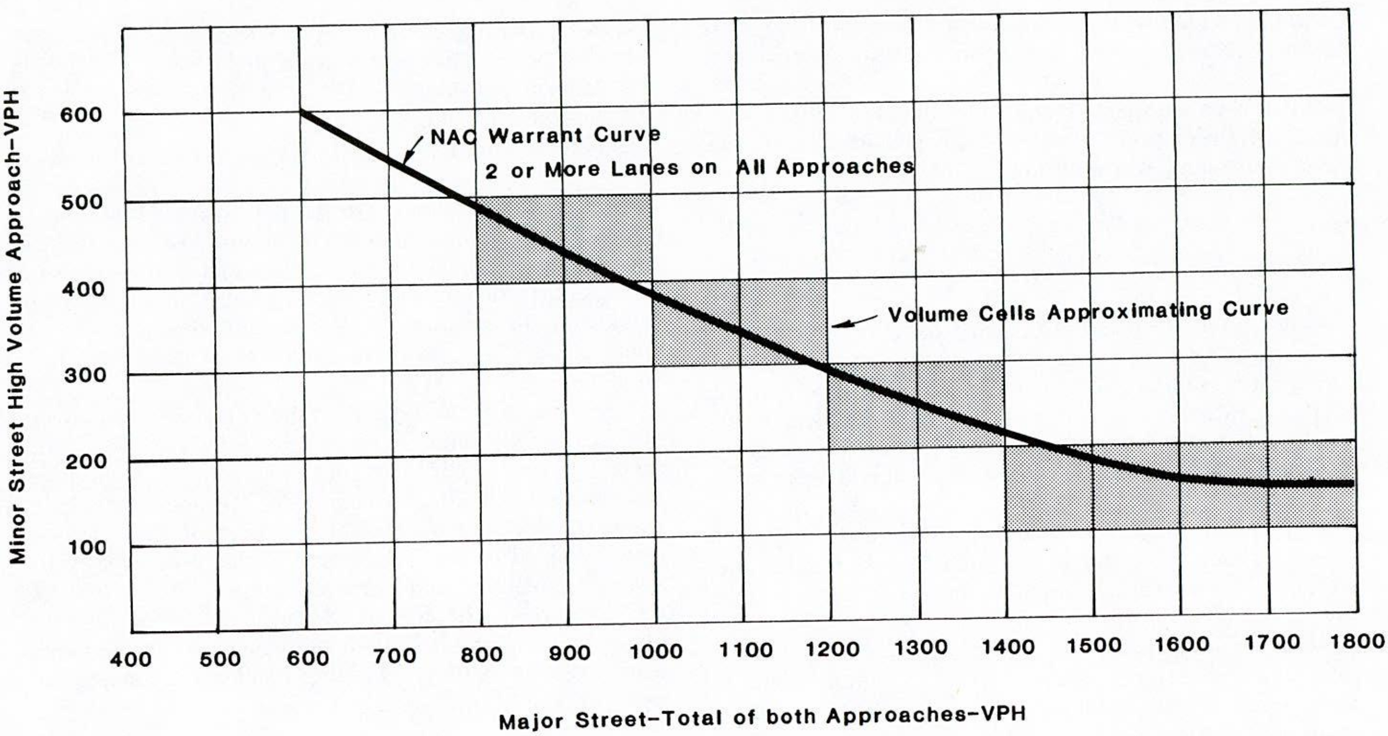


Figure 10. Volume cells used to approximate NAC warrant thresholds.

Table 26. Observed total two-lane approach delay within volume ranges.

Volume		Number of Observations	Average Total Delay (Veh-Min)
Main Street	Side Street		
800-1000	400-500	1	54
1000-1200	300-400	4	209
1200-1400	200-300	5	89
1400	100-200	6	162
Total	-	16	144

judgment and the NCHRP warrant criteria. Because this threshold procedure is used in following sections, it is explained in detail.

The threshold comparison is based on the comparison matrix previously introduced and shown again on Figure 11.

Thus, a conflict threshold may be set at any value, say 200 for example, then that value may be used as a decision point. Observations with conflict measures equal to or greater than 200 meet the criteria, whereas conflicts less than 200 do not meet the criteria. For each observation, this decision based on conflicts may be compared to the decision of the field engineer with four possible outcomes (cells) as shown on Figure 11.

CONFLICT THRESHOLD	ENGINEER'S JUDGEMENT	
	Not Met	Met
Not Met	Correct	Beta Error
Met	Alpha Error	Correct

Figure 11. Comparison matrix.

Two of these cells are correct cells; that is, both measures are in agreement—either the criteria are met or they are not met. Two of the cells are ''error'' cells; that is, the measures are in disagreement with one another.

In this analysis, the engineer's judgment, and subsequently the NCHRP warrant criteria, are used as standards against which the the conflicts measure is evaluated. Of the two types of errors, one is more detrimental than the other. This one has been designated an alpha error. This error occurs when the candidate criteria declare a signal warranted and, for the same observation, the standard (either the engineer's judgment or the NCHRP criteria) declares the signal not warranted. The beta error is the reverse condition. The alpha error is the more critical error because if the candidate criteria are adopted, a large error would result in a high proportion of signals being justified when, in fact, they should not be warranted.

Emphasis on the alpha error may be justified from a cost standpoint—unnecessary signals are as expensive to install and maintain as warranted signals. There is a second reason, however, for the emphasis on the alpha error. Many traffic engineers feel that the current warrants are too lenient and another warrant will simply lead to additional unncecessary signals. Emphasis on the alpha error is to address this issue by reducing to a practical minimum the probability of making the error of stating that a signal should be installed when in fact it should not be installed.

The basic threshold analysis incremented candidate threshold values of conflict from 0 to 800 in 25 unit steps to see what value would prove to have the best combination of percent correct and minimum alpha error. The results of the threshold analysis for conflicts are plotted on Figure 12 for the comparison against judgment and on Figure 13 for comparison against NCHRP warrant criteria.

On Figure 12, the maximum percent correct was found to be 84 percent with conflict equal to 250. Because the corresponding alpha error was high, 9 percent, the optimum value selected was a conflict value of 300 with corresponding percent correct of 82 percent and an alpha error of 6 percent.

On Figure 13, the results showed an optimum percent correct of 87 percent with an alpha error of only 4 percent with the conflict equal to 350. This was considered an extremely valuable finding because conflict is easier to measure and apply than the NCHRP warrant criteria and yields results that are very similar.

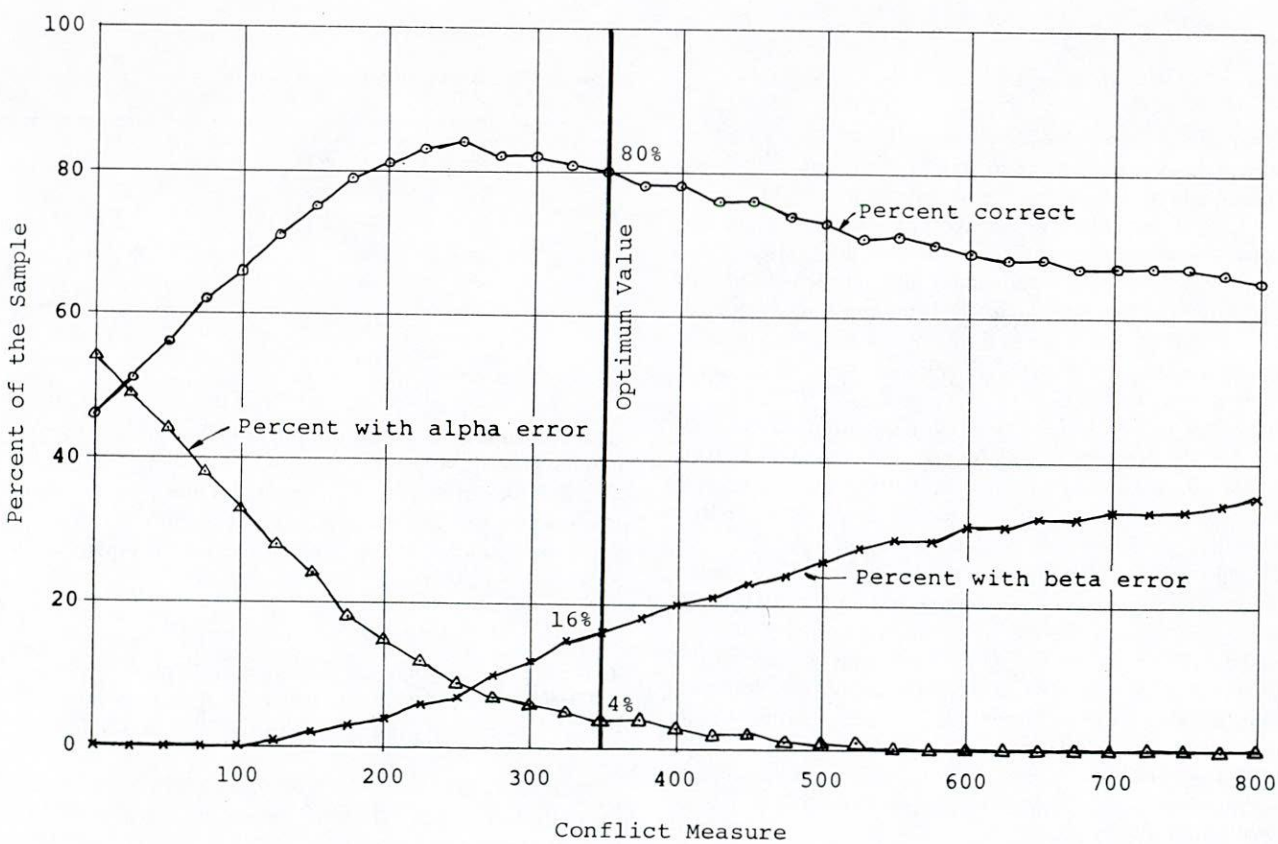


Figure 12. Threshold analysis—conflict (full data base—judgment).

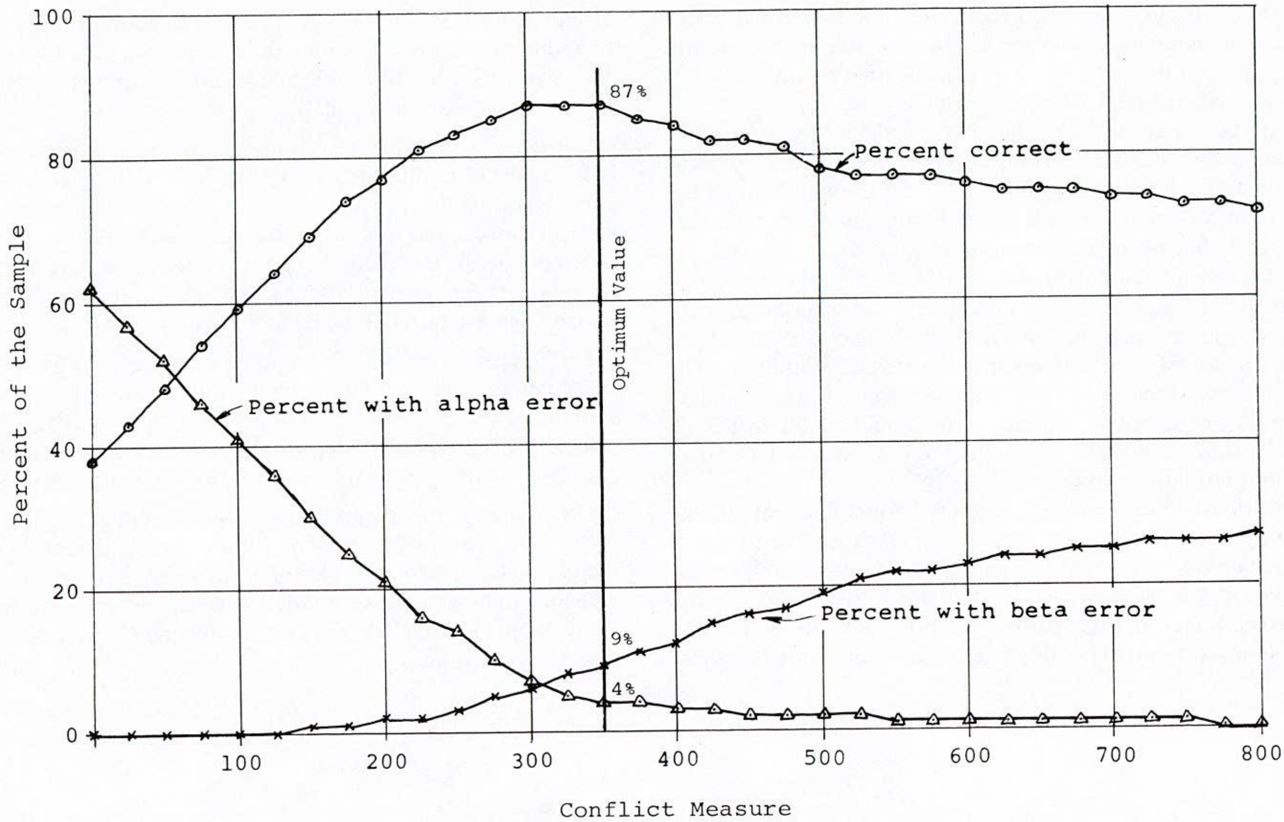


Figure 13. Threshold analysis—conflict (full data base—NCHRP).

Delay and Queue

Other direct measures included in the analysis are total approach delay, average queue, and average approach delay. As noted previously, all three measures are highly correlated. The relationship between average delay and queue was studied with five subsets of the data base: all nonsignalized observations (NOSIG); one lane on all approaches (NOSIG 11); two or more lanes on the main street, one lane on the side street (NOSIG 21); one lane on the main street, two or more lanes on the side street (NOSIG 12); and two or more lanes on both streets (NOSIG 22).

Summary statistics of the regression equations are given in Table 27. Although the correlation coefficients are relatively high, the regression equations are far from precise as indicated by the relatively large standard error of estimates, particularly the 34 sec for the NOSIG 22 data set.

To gain a better insight into this relationship, a scatter diagram was prepared of all data points in the NOSIG 22 category that had measured queue ranging from 1 to 12 vehicles. This plot is shown in Figure 14. As can be seen on this diagram, there is a positive correlation between average approach delay and queue length, but there is obviously quite a bit of scatter of the data.

The relationship between total delay and queue was found to be much stronger. Using linear regression, the following equation was derived:

$$\text{Total delay} = 1.5 + 54.9 \times \text{queue}$$

Table 27. Regression summary average delay versus queue.

Database Subset	Number of Observations	Correlation Coefficient	Slope	Intercept	Standard Error (sec)
NOSIG11	84	.82	10.4	10	16
NOSIG12	50	.97	7.2	7	6
NOSIG21	98	.90	6.7	18	13
NOSIG22	136	.84	8.6	7	34
NOSIG	368	.85	8.1	11	24

where: total delay is measured in vehicle-minutes and queue is measured in vehicles.

The R-square statistic for this equation was found to be 0.99. Because a t test on the intercept being different from zero was not significant at the 5 percent level, the equation could be simplified to:

$$\text{Total delay} = 55 \times \text{queue}$$

This equation also has an R-square statistic of 0.99.

Because these two measures are so highly correlated, emphasis was placed on queue measures for two reasons:

1. Total delay is derived from queue measures by factoring in time, and thus, as noted previously, it is simply another way of expressing average queue.
2. A lay person can more readily grasp the significance of

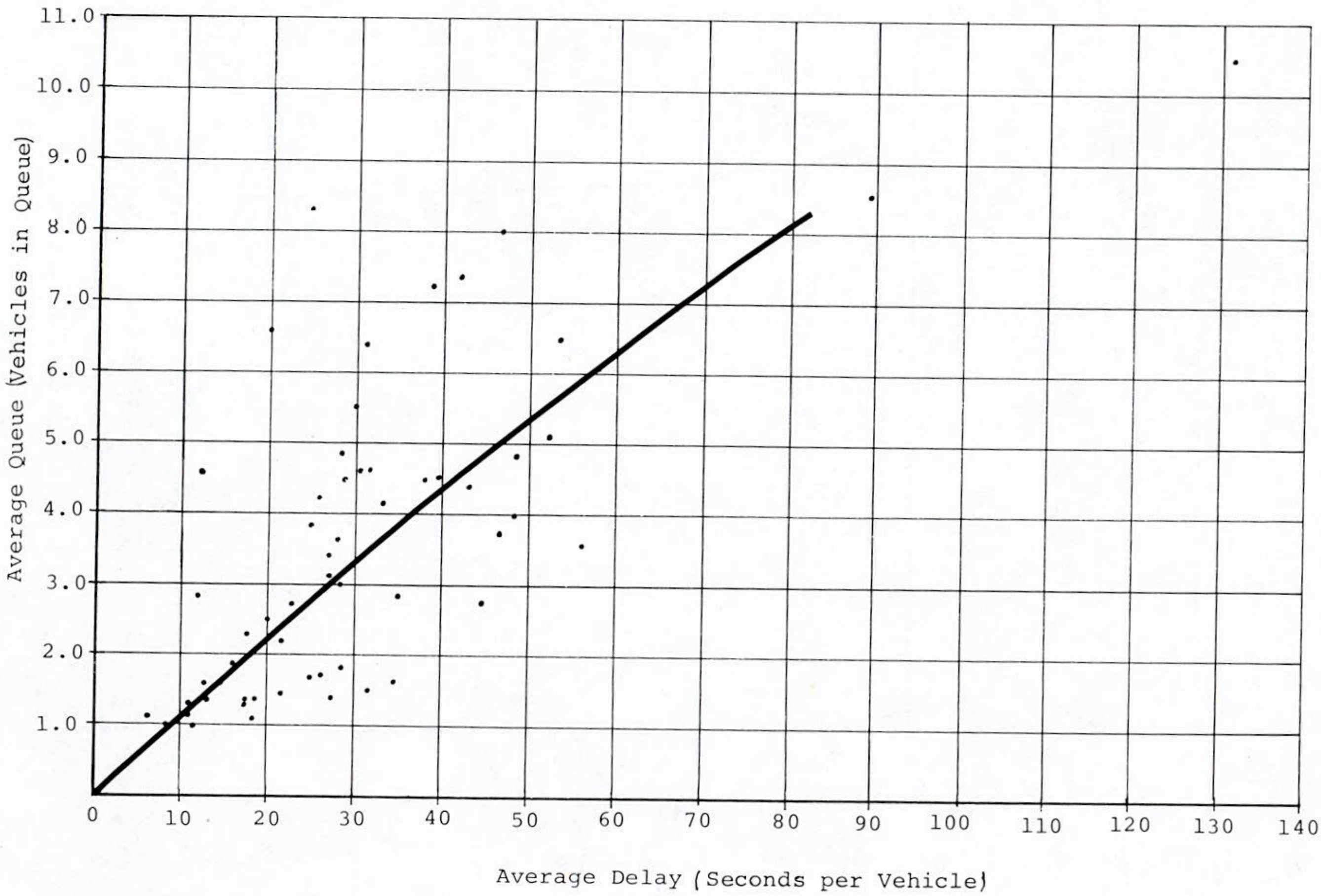


Figure 14. Average queue length vs. average delay.

number of vehicles in queue than vehicle-minutes (or vehicle-hours) of delay, and thus the queue concept provides a more universal means of communications. To actually realize this communications benefit, surrogate phrases would likely have to be used. Rather than average queue, "number of cars backed up" may be a more easily recognized term.

Threshold Analysis

As with the conflict measure, the measures of average delay, total delay, and queue were analyzed using the threshold comparison technique previously described. This process proved extremely valuable and in collaboration with the results of previous research by Box and Alroth, Wilbur Smith Associates, and KLD Associates provided the foundations for a new peak-hour warrant.

Average Delay. Average side street delay thresholds were generated from zero to 200 sec per vehicle and compared to the engineer's judgment and the NCHRP warrant criteria. The results of percent correct, percent with alpha errors, and the percent with beta errors were plotted for visual analyses. These data are shown on Figures 15 and 16, respectively, for judgment and NCHRP criteria. Notice that these data are for the NOSIG subset of the data base since delay at signalized intersections is significantly impacted by signal timing. On Figure 15, an optimum at 50 sec per vehicle with 81 percent correct and a 3 percent alpha error was selected.

With the NCHRP comparison, a slightly higher optimum of 60 sec per vehicle was selected. This optimum produced 75 percent correct comparisons with a 6 percent alpha error. This was a significant finding because it corroborated earlier assumptions used to formulate the NCHRP warrant as well as the results of a polling of engineers who attended a Peak-Hour Warrant Seminar conducted as a part of this study, as described in Appendix D.

Although average delay provided some valuable insight, this measure suffers from two problems. It is relatively difficult to compute when compared to the more simple average queue, and it produces a very flat percent correct threshold curve. It was expected that other measures would produce more peaked maximums.

Total-Delay. The threshold analysis procedure using total side street delay rather than average delay was completed next. Comparisons with judgment are shown on Figure 17 and comparisons with the NCHRP warrant criteria are shown on Figure 18.

These figures show extremely encouraging results. There was 92 percent agreement between total delay and engineer's judgment with an alpha error of 1 percent when the total delay threshold was set at 200 veh-min. An optimum of 225

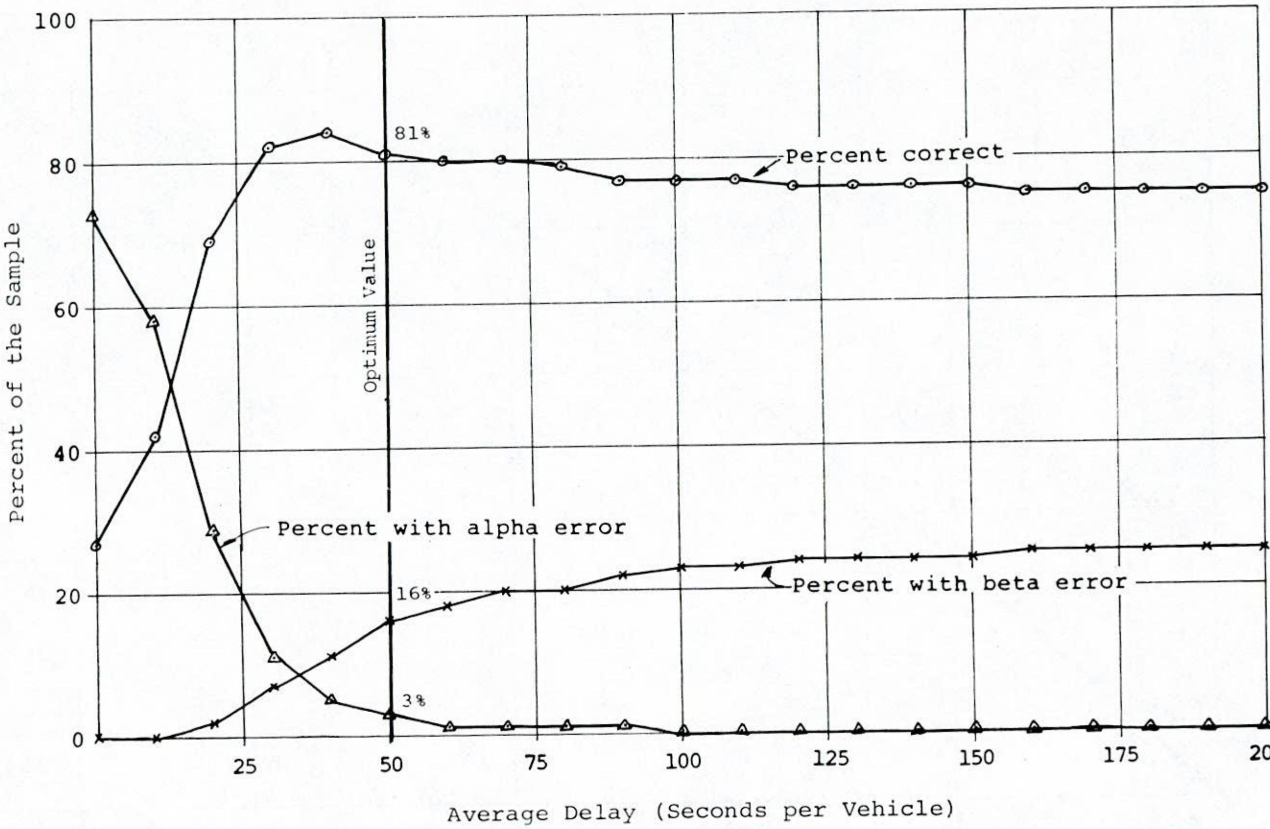


Figure 15. Threshold analysis —ave-delay (NOSIG—judgment).

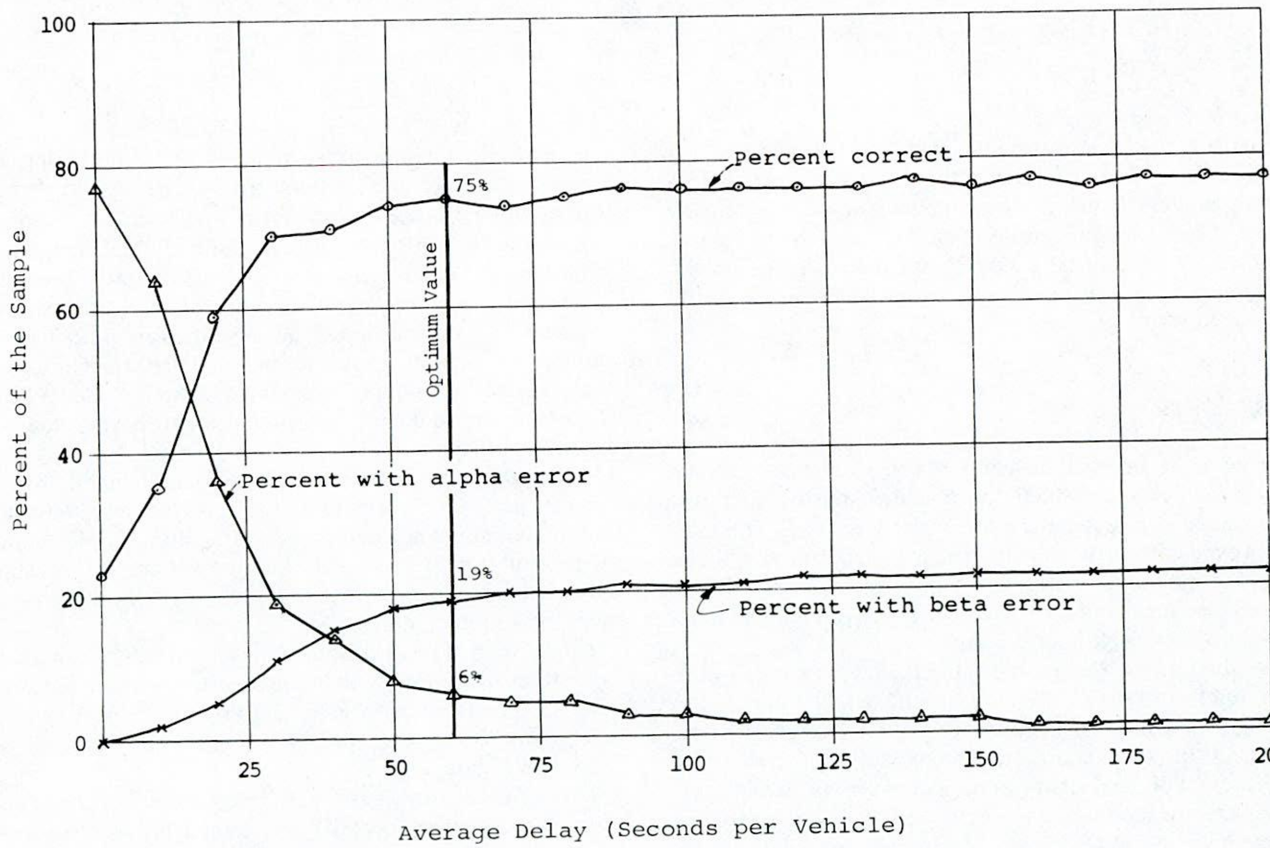


Figure 16. Threshold analysis —ave-delay (NOSIG—NCHRP).

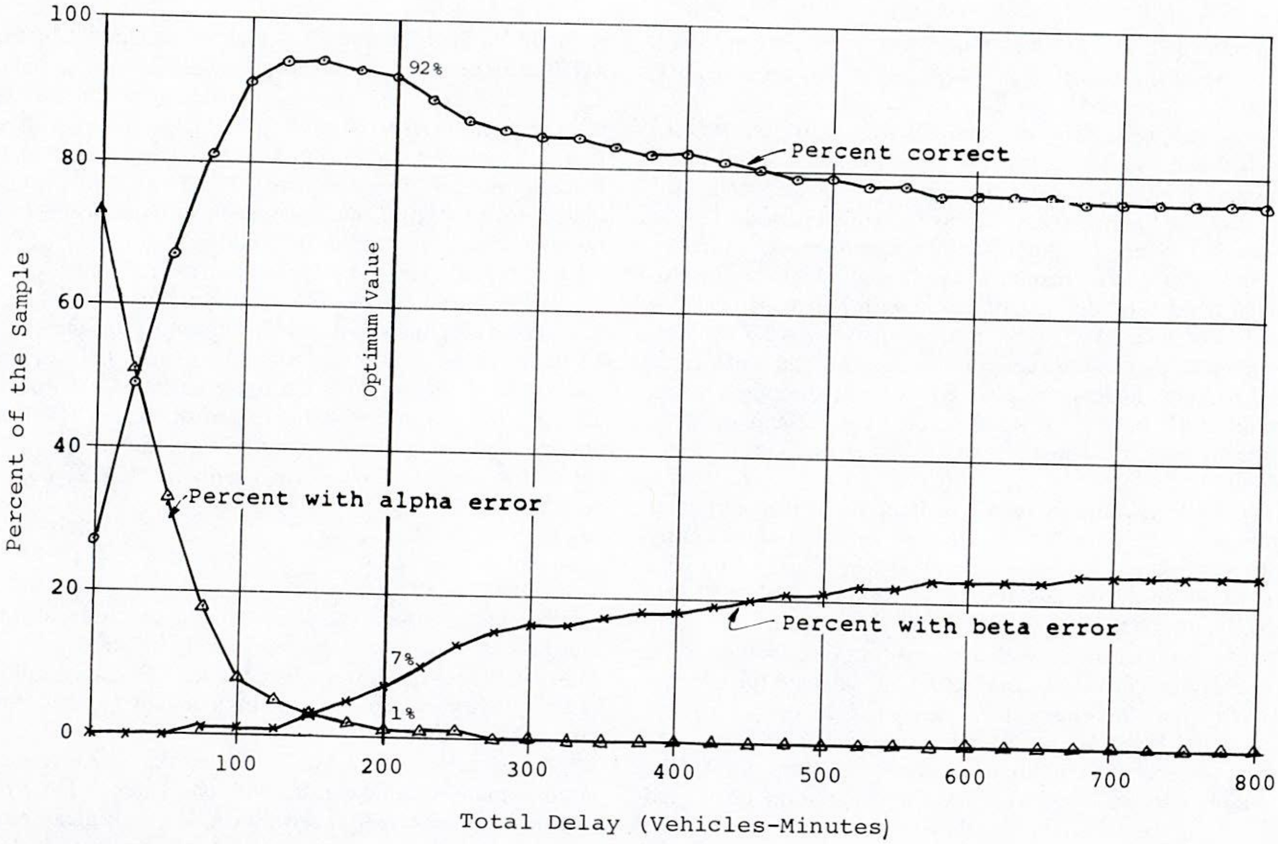


Figure 17. Threshold analysis—tot-delay (NOSIG—judgment).

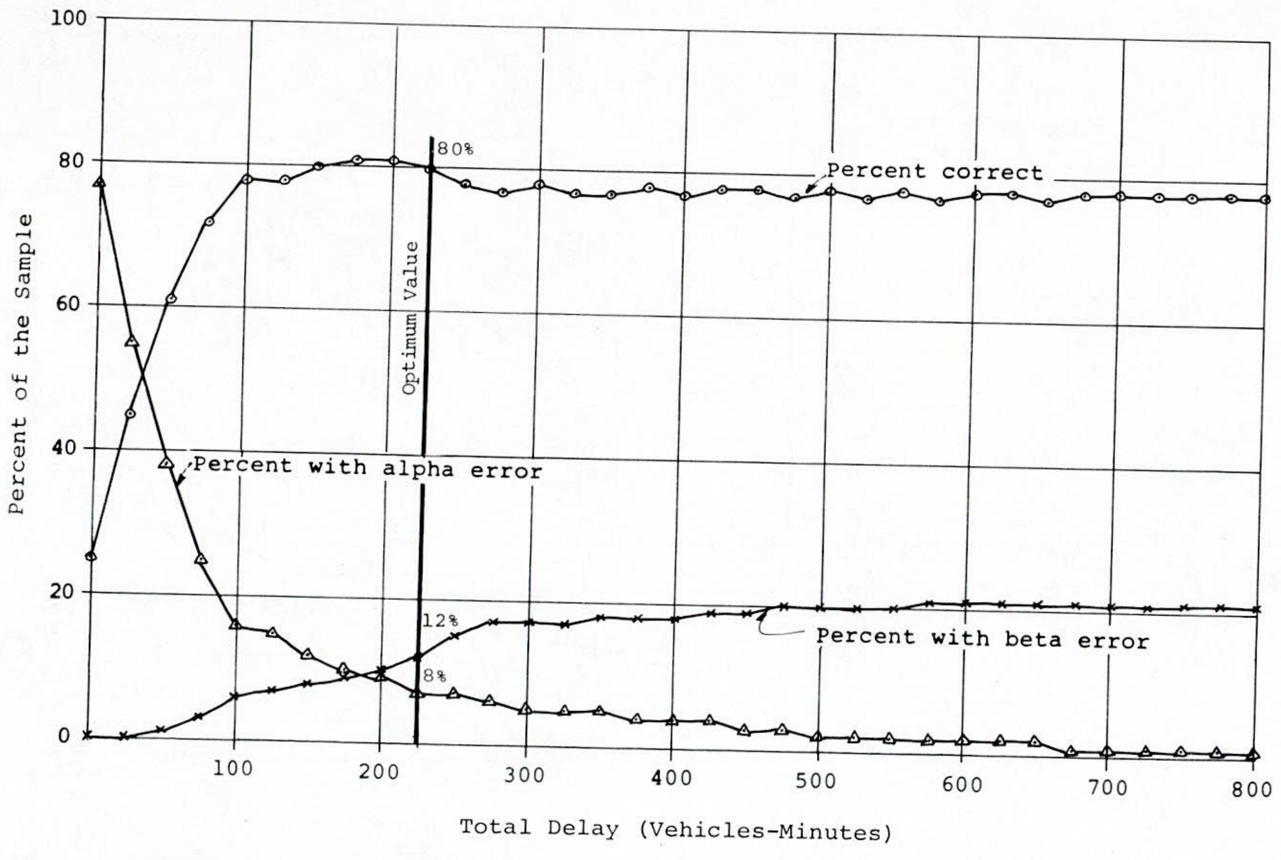


Figure 18. Threshold analysis—tot-delay (NOSIG—NCHRP).

veh-min (3.75 veh-hr) was found with an 8 percent alpha error when the comparisons were made with the NCHRP criteria.

Average-Queue. The threshold analysis procedures were applied in a manner identical to the previous analyses using average queue. Average queue is the average number of vehicles on the approach during the study period. This is measured using the point sample technique described in Chapter Three. The results were virtually identical to those found using total delay. Compared with judgment, an optimum was selected when the average queue was 3.5 vehicles yielding 93 percent correct comparisons with an alpha error of 1 percent. Against the NCHRP criteria, an optimum was found at 4.0 vehicles with 80 percent correct and an alpha error of 8 percent. These curves are shown on Figures 19 and 20.

Direct Measure Summary. To be assured that particular subsets of the data base would not result in significantly different optimum locations than that which was found with the NOSIG portion, similar data were plotted for NOSIG 11, NOSIG 12, NOSIG 21, and NOSIG 22.

Several conclusions were drawn from these analyses. The close agreement between the optimum selected for average delay (using both engineer's judgment of 50 sec per vehicle and NCHRP's 60 sec per vehicle) with previous assumptions tends to reinforce confidence in the threshold process. The virtually identical results obtained using total delay and queue confirms the fact that they are highly correlated and, in fact, are identical measures.

On the basis of the foregoing analyses, queue was selected as the recommended direct measure with a threshold value of 4.0 vehicles. That is, a signal is considered warranted when the average queue is 4.0 or more vehicles in length. Notice that this measure is independent of intersection geometrics but can only be applied to nonsignalized locations. For signalized locations, it is recommended that conflicts be used as the direct measure with a threshold value cf 350.

The average queue of 4.0 vehicles was recommended primarily because it equates to 4 veh-hr of delay—a value that has appeared consistently in the literature during the last 15 years as a suitable criterion for a peak-hour warrant. The value of conflicts was chosen primarily for parallelism. That is, the 4 vehicles coincided with the NCHRP comparison optimum, therefore the 350 conflict measure was selected because it also coincided with the NCHRP comparison optimum.

Regression Analysis

Attempts at estimating delay using geometrics, volumes, and percent right turns showed that the relationship among these variables is extremely complex. Several additional studies were conducted to attempt to achieve a better understanding of the mechanism.

Another subset of the data base was created. Observations at nonsignalized intersections with two lanes or more on all approaches that experienced total side street delay ranging from 210 to 270 veh-min (3.5 to 4.5 veh-hr) were included.

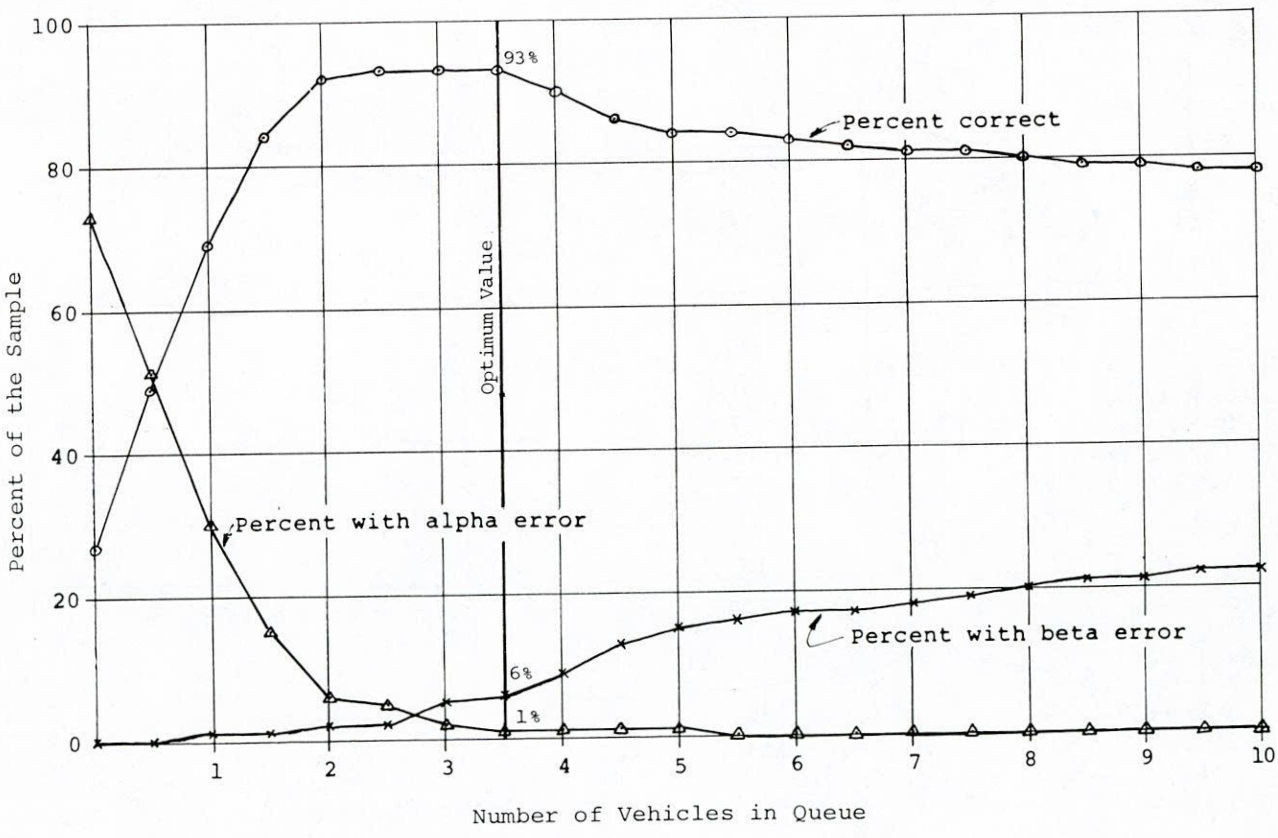


Figure 19. Threshold analysis—ave-que (NOSIG—judgment).

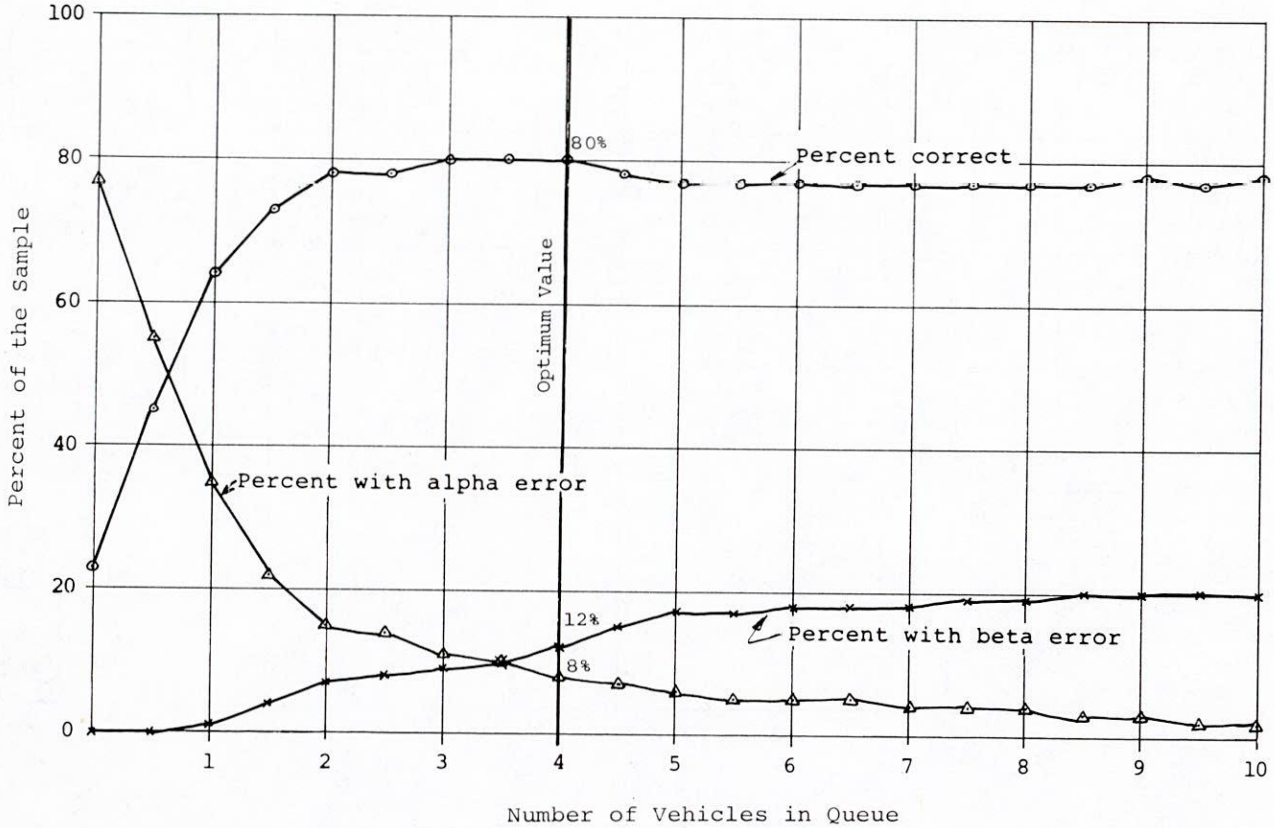


Figure 20. Threshold analysis—ave-que (NOSIG—NCHRP).

The main street and side street volumes are plotted on Figure 21.

The significance of this plot is that the minimum observed side street volume that resulted in at least 210 veh-min of delay was 279 vph. Because both candidate warrants have minimum side street volume criteria lower than this, this plot suggests a value of 250 vph may be more appropriate.

Another concern was the impact of the following factors: type of intersection (cross or "T"), protected left-turn lane for turns from the main street on to the side street (did or did not exist), speed posted on the main street (less than 40 mph or greater than 40 mph); proximity of other signalized intersections (less than 200 ft or greater than 2000 ft).

A subset of the data base was created that included all observations at nonsignalized intersections. The foregoing factors were transformed from the format in the original data base to the binary format described above. A stepwise multiple regression was performed to measure the impact of these variables.

The results were inconclusive. With all variables in the equation, the R-square statistic was 0.37. However, one variable, conflict, accounted for approximately 33 percent of this variance. The remaining variables, therefore, only account for a maximum of 5 percent. The proximity of adjacent signalized intersections explained virtually none of the variance and were eliminated from the equation. The geometric type appeared to account for 2 percent; the main street speed and left-turn lane appeared to account for 1 percent.

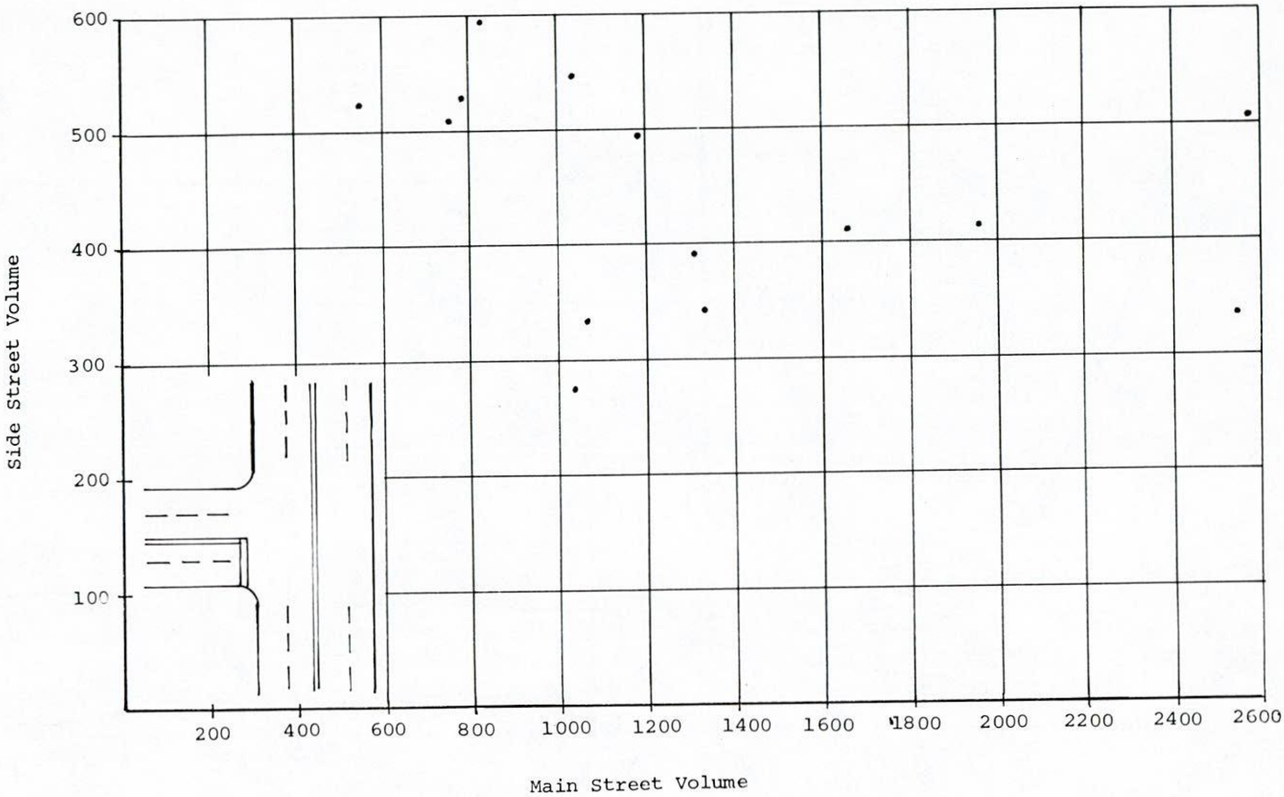


Figure 21. Nonsignalized intersections with total delay ranging from 210 to 270 veh-min.

CHAPTER THREE

INTERPRETATION, APPRAISAL, AND APPLICATION

A brief interpretation of the findings as related to the candidate NAC and NCHRP warrants is provided in this chapter. This is followed by a description of a proposed new warrant that is based on a direct measure of queue.

NAC WARRANT

The NAC warrant graph was found to represent delay values much less than the 4 (one-lane approach) and 5 (two-lane approach) veh-hr of delay referenced in the verbal description of the warrant.

The reason for this, as postulated by the research team, is that this warrant was not developed with the intent of identifying signal installation criteria for a peak-period demand condition wherein the peak hour may be 25 percent of the average daily traffic (ADT). Instead, it suspected that this criterion was intended to be applied to locations that exhibited a more normal temporal variation of demand volumes, say 10 to 12 percent during the peak hour.

For example, by making the assumption that the eighth highest hour experienced 5.3 percent of ADT and the highest hour experienced 10.6 percent of the ADT, then if the "highest" hour exceeded two times the warrant value, the eighth highest hour would also exceed the warrant and the signal would be justified. Thus, this approach would appear to be more directly related to reducing the amount of data required than to identifying a true need based on peak-hour demand conditions.

This may explain why the data points based on field observations in the region of the NAC warrant curve (based on side and main street volumes) actually resulted in average measured delays of approximately half those stated in the verbal description of the warrant.

NCHRP WARRANT

The NCHRP warrant criteria proved to be the most stringent of the three criteria that were compared; the NAC warrant, the engineer's judgment, and the NCHRP warrant. The only real problems that were found involving the NCHRP warrant were related to the procedures used in the warrant.

The warrant was distributed to a group of traffic engineers along with data for a hypothetical problem. The group was asked to follow the NCHRP warrant procedures and then comment on the method. Details of this meeting are provided in Appendix D.

In particular, the following problems were noted:

- Confusion between equivalent side street volume (Qss) and Effective Side Street Volume (ESSV) on Tables A-2 through A-5.
- The need to interpolate and extrapolate the ESSV values in Tables A-2 through A-5.
- The need to use one of four different graphs and which graph to use if the geometric condition was not represented. For example, a one-lane main-street approach with a two-lane side street was found to be common in this field study but was not accounted for in the graphs.

From a positive perspective, the assumptions embedded in the simulation that was used to develop the NCHRP warrant were found to be extremely consistent with those measured in the field.

In the KLD approach to developing a peak-hour warrant, the primary factor used was queue stability. It was reasoned that as demand approaches capacity at a STOP-sign-controlled intersection, the probability of queue instability increases markedly. As this condition reflects a breakdown in intersection control, it must be avoided. The criterion adopted, therefore, indicated a need for signal control when the demand-to-capacity ratio exceeded 0.80 for a period of 1 hr. Application of queuing theory was used to transform this criterion to a mean queue of 4 vehicles.

In essence, this research study found that there was general agreement between the engineer's opinion of when an intersection would operate "better" under signal control and the application of the warrant procedure. Because queue is very simple to measure in the field and because this direct measure avoids the problems of using the correct curve, interpreting tables, and so forth, the conclusion of the research team was to formulate a new warrant that would be based on a direct measure of queue.

PROPOSED PEAK-HOUR WARRANT

The proposed peak-hour warrant is intended for application at intersections that are subjected to heavy traffic demands for a relatively short period.

For nonsignalized intersections, the peak-hour warrant is satisfied when, for at least 1 hr per day, 5 days per week, the traffic demand on the highest minor street approach results in an average queue of 4, or more, vehicles based on a field study of queue. The procedure to determine queue is described in the following.

For signalized intersections, the peak-hour warrant is satisfied when, for at least 1 hr per day, 5 days per week, the conflict measure equals or exceeds 350, and the highest side street approach volume is equal to or greater than 200 vph.

The conflict measure is calculated from the following equation:

$$C = \frac{(RB + LB)(SSL) + RB\ (SSR)}{1{,}000}$$

where:

C = conflict measure;
RB = right-bound traffic;
LB = left-bound traffic;
SSL = side-street left-turn traffic;
SSR = side-street right-turn traffic.

The RB traffic and the LB traffic include both the through and left-turn movements. The SSL traffic includes through traffic if the intersection is not a "T" type. Traffic from any other approach to the intersection is not used in the conflict measure. The movements are shown diagramatically on Figure 22.

The conflict measure was formulated to intentionally ignore left and right turns from the main street. The intent was to present an equation with as few factors as possible. Although other formulations and manipulations of intersection turning movement data may prove superior to the equation suggested herein, each formulation would have to be calculated and processed against the other variables (queue, delay, and etc.) to determine if, in fact, the new formulation is superior.

QUEUE STUDY

The principal objective of the Intersection Delay Study is to collect data on the approach to a signalized intersection such that an accurate estimate of approach delay per vehicle can be made.

A step-by-step approach should be followed in the design of the study. The following elements must be considered:

1. Select intersection approach to be studied—the major side street approach must be determined.
2. Select time period to be studied—the peak period must be determined.
3. Select length of study period—a minimum of 60 point samples must be taken. This represents a 15- or 13-min

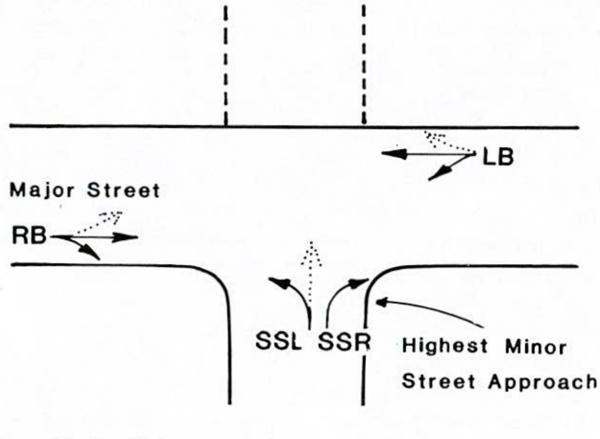


Figure 22. Conflict movements.

period, depending on the interval between samples used. It is recommended that lengths of studies be either 60, 90, or 120 point samples.

4. Determine cycle length—for each proposed study period, the cycle length of pretimed or the background cycle of system control is determined. If the cycle length cannot be determined in advance of the study, it must be determined in the field just prior to performing the study.

5. Determine interval between samples—if a signal is operating in a pretimed or system mode, use a 13-sec interval for cycle lengths of 45, 60, 75, 90, 105, 120, 135, or 150 sec. For all other cycle lengths in a pretimed or system mode, use a 15-sec interval between samples. For all traffic actuated signals not operating in a system, use a 15-sec interval.

6. Determine means for obtaining volume count—a volume count must be taken simultaneously with the delay study if measures of performance are to be calculated on a per vehicle basis. A simple count of total volume using either an observer or some type of mechanical counter can be conducted.

The step-by-step procedure for performing the delay study is as follows:

- Step 1—Upon arrival at the site, find an observation point which ensures that a good view of stopped queues is available.
- Step 2—If a doubt exists as to traffic signal timing, perform a check by using a stopwatch to time three signal cycles, from end of green on the main street to the next end of green on the main street. If all three cycles conform to a cycle length of 45, 60, 75, 90, 105, 120, 135, or 150 sec, a 13-sec interval between samples is used. If not, a 15-sec interval is used.
- Step 3—If more than one person is used for the delay study, the crew chief assigns specific lanes of the approach to each person. Then, at each sampling point, each delay observer records the number of stopped vehicles in those lanes for which he is responsible.
- Step 4—Each observer fills out the general information at the top of the data sheet.
- Step 5—At the proper time of day, the crew chief begins the study by starting the stopwatch in motion. At the same instant, he signals to all other persons that the study period has begun.
- Step 6—At time zero of the study, no point sample is taken. At the end of the first interval, which occurs at either 13 or 15 sec, each observer notes the number of vehicles stopped at that instant and records this number on the data sheet. Each successive sampling point is identical in operation in that the delay observer notes and records the number of vehicles stopped at the instant the interval ends. Observers are instructed not to try to guess what the value of any sample they miss might be, but rather to leave the box(es) blank.
- Step 7—At the end of the required number of samples, the crew chief signals to all others that the study has ended and reads the study timer to obtain the total elapsed time of the study. This time is noted on the data sheet under "Comments." It is important that the signal at the beginning and at the end of the study be given exactly at the zero point and the final sampling point, respectively, so that all observers can begin and end their count at the proper time.

Instructions to observers as to which vehicles are included in the sample of stopped vehicles at each sampling point are as follows:

- A vehicle with locked wheels (no motion) is counted.
- A vehicle that had previously come to a stop and is creeping (at the instant a point sample is taken) in a stopped queue which is not discharging from the intersection is classified in the following manner: it is considered as "stopped" if a gap of less than or equal to 50 ft (15 m) or about three car lengths, exists between it and the vehicle in front of it; it is considered to be "moving" (and thus is *not* counted in the point sample of stopped vehicles) if the gap to the next vehicle is greater than 50 ft (15 m).

Two additional points are important. First, when two persons are used to perform the Delay Study it is recommended that they stand relatively close together so that an audible cue from the crew chief can be heard by both. If it becomes absolutely necessary for one delay observer to move away from the other, a prearranged system of audible or visual cues is used to signal each sampling point.

Second, the delay observers should be made aware of the fact that the most difficult point to sample is just after the traffic signal has turned green and the front end of a stopped queue is moving. The observer should make a mental note of all vehicles that are stopped at the instant of the sampling point. Then the observer can take a few seconds to count all of these vehicles.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

Two specific conclusions have been drawn from the findings of this study. First, the existing NAC and NCHRP warrants, while appearing to be similar, are distinctly different. The NCHRP warrant is the more stringent of the two. Of the 817 observations made during this study, the NAC warrant qualified 54 percent of them for signalization, while the NCHRP warrant qualified only 38 percent of them.

Of perhaps greater importance, however, was the finding that the NAC warrant criteria based on the graphical representation violated the embedded assumptions. That is, the stated warrant criterion was 4 veh-hr (5 veh-hr on multilane approaches) of delay. Actual observations with main street and minor street volumes corresponding to the warrant curve measured delay averaging 2.0 to 2.5 veh-hr per hour.

The second conclusion was that both the NAC and NCHRP warrants, as evaluated, were found to be relatively difficult to use, primarily based on the data requirements. The NAC warrant requires traffic engineers to collect volume data and use graphs based on the number of lanes on the main and side streets, the main street speed limit, and the surrounding community size. The NCHRP warrant requires that turning-movement counts that are classified as to vehicle type be conducted and the results compared to a series of graphs based on the number of lanes on the main and side streets, percentage of right-turning vehicles, and percentage of trucks.

Because of these issues, a new peak-hour traffic-signal warrant was deemed necessary and was developed as part of this project. The warrant is described in the preceding chapter.

To be effective, a warrant must accurately predict when a signal should be installed and it must be easy to use. The proposed peak-hour warrant was developed to meet both of these requirements. There was a strong relationship between this warrant and an engineer's judgment of whether or not a signal should be installed so it is an accurate predictor.

It is also easy to use. The peak-hour warrant proposed herein requires that, for an unsignalized location, an observer record queues on the side street approach during the peak period and that a side street volume count be conducted during the same period. If both the minimum volume and average queue thresholds are exceeded, the location meets the requirements of the warrant.

If the intersection is presently signalized, a turning-movement count must be conducted during the peak hour. From these data, the conflict measure is calculated. Only if both the minimum volume and conflict thresholds are exceeded does the warrant indicate that a signal is justified at that location.

One of the primary goals of this project was to collect field data to verify a peak-hour warrant. This was done by collecting many different types of data at more than 200 intersections and for more than 800 25-min observation periods. These data are presented in Appendix B and offer the opportunity for future research into such topics as flashing versus stop-and-go intersection control modes and saturation flow rates of STOP-sign-controlled approaches.

No additional research is recommended with respect to the peak-hour warrant issue. The approach used in NCHRP 3-20, which was based primarily on simulation, and the approach used in this study, which was based primarily on field observations, have given the same general result. That is, a traffic signal would significantly improve intersection operation when an average queue of 4, or more, vehicles is present for a period of 1 hr.

At issue is a comparison between the NCHRP procedure and the queue measuring procedure proposed herein. The queue measuring procedure was recommended primarily because the necessary field studies can be conducted by one person, while the need for turning movement and classification data as input to the NCHRP procedure dictates the need for at least two persons to conduct the necessary field studies.

The second point is that queue—average number of cars waiting at the STOP-sign—is a concept readily explained to the lay person, and thus should enable the traffic engineer to readily communicate the technical warrant requirements to the general public.

Two additional findings of the analysis are related to percentage of trucks and the impact of right turning traffic from the side streets.

This study showed that there is little need to include the percentage of trucks in the process for determining when the peak-hour warrant is satisfied. Only in rare cases, when truck volumes are unusually high, does the truck factor have an impact. Therefore, it is suggested that the percentage of trucks not be required in the general application of the warrant. This would eliminate one additional step in computations and, more importantly, relieves the warrant process of the need to collect costly vehicle classification data.

The data collected in this study have verified the importance of the right turn factor in the determination of peak hour warrants. There is a wide range in turn percentages at candidate intersections, and the effect of this variation significantly impacts the threshold at which a signal is warranted.

APPENDIX A

NAC AND NCHRP WARRANTS

NAC PEAK-HOUR WARRANT

Warrant 9 Peak-Hour Delay and Volume Warrants

The peak-hour delay and volume warrants are intended for application where traffic conditions are such for one hour of the day that minor street traffic suffers undue delay or hazard in entering or crossing the main street.

The peak-hour delay warrant is satisfied when the conditions given in the table exist for one hour (any four consecutive 15-minute periods) of an average weekday.

Table - Peak-Hour Delay Warrant

The peak-hour delay warrant is met when:

1. The total delay experienced by the traffic on a side street 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 side street approach 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 this hour equals or exceeds 800 vph for intersections with four (or more) approaches or 650 for intersections with three approaches.

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 vehicles per hour on the higher volume minor street approach (one direction only) for one hour (any four consecutive 15-minute periods) on an average day falls above the curve in Figure A-1 for the existing combination of approach lanes.

When the 85-percentile speed of 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 peak-hour volume requirement is satisfied when the plotted point referred to above falls above the curve in Figure A-2 for the existing combination of approach lanes.

NCHRP PEAK-HOUR WARRANT

Engineering Data Required

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 its proper design and operation. The following definitions apply:

- If the existing control at an intersection is a two-way STOP (or YIELD sign), then the major street approaches are those that are not controlled. The side street approaches are those that are controlled by a sign.
- If the existing control at an intersection is a three- or four-way STOP sign, or if the intersection is not controlled with any device, then the major street approaches are those servicing a combined (total of both directions) Average Daily Traffic (ADT) that is higher than the combined ADT of the competing approaches. These competing approaches servicing the lower ADT are the side street approaches. If the respective values of combined ADT on the competing streets are comparable, then the engineer must exercise his judgement to classify the approaches as major and side streets.
- For a tee intersection, the approach constituting the "stem" of the tee is the side street approach.

The required data should include:

1.1 The number of vehicles entering the intersection in each hour from each approach during eight hours of a representative day. The eight hours selected should ordinarily contain the greatest percentage of the 24-hour traffic. If it is not possible to identify these eight hours, then data should be collected over 12 consecutive hours.

1.2 Vehicular volumes for each traffic movement from each approach, classified by general vehicle type (heavy trucks, passenger cars and light trucks, and public transit vehicles), during each 15-min period of eight (or 12) hours considered in Paragraph 1.1.

1.3 Pedestrian and bicycle volume counts on each crosswalk during the same periods as the vehicular counts in Paragraph 1.2 above and also during hours of highest pedestrian/bicycle volume. Where young or elderly persons need special consideration, the pedestrians or bicycle riders may be classified by general observation and recorded by age groups as follows:

a. under 13 years
b. 13 to 60 years
c. over 60 years.

Detailed pedestrian and bicycle counts are not required if total volume crossing the major street is well below 100 per hour.

1.4 The 85-percentile speed of free-flowing vehicular traffic on the major street approaches beyond the influence of any intersection control. This data shall be collected during at least three of the hours considered in Paragraph 1.1. Each value of speed should reflect a different range of major street volumes.

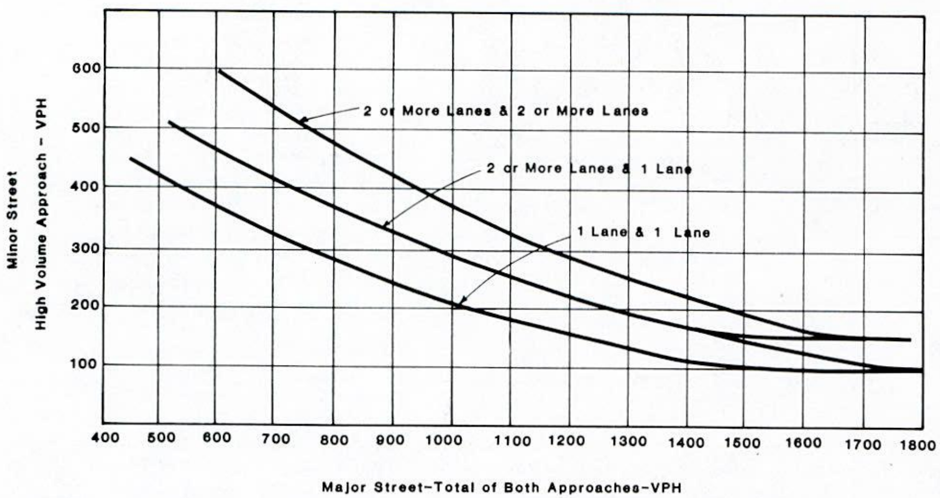
1.5 A condition diagram showing details of the physical layout, including such features as intersection geometry, channelization, grades, sight-distance restrictions, bus stops and routings, parking conditions, pavement markings, distance to nearest signals and adjacent land use.

1.6 A collision diagram showing intersection accident experience by type, direction of movement, severity and time of day for at least two years.

1.7 Measurement of delay in queue should be undertaken for all side street approaches only when the intersection configuration does not adhere to those defined for the Vehicular Volume Warrants. The methodologies recommended in "A Technique for Measurement of Delay at Intersections" by W. R. Reilly, et al. shall be applied.

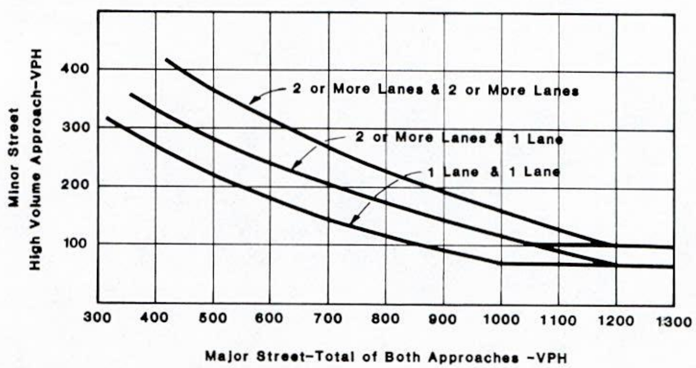
PRELIMINARY CONSIDERATIONS

Traffic control signals should not be installed unless one or more of the proposed traffic signal warrants are met. Data should be obtained by means of engineering



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 A-1. 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 A-2. Peak Hour Volume Warrant

(Community Less than 10,000 Population or Above 40 MPH on Major Street) studies and related to the requirements set forth in the warrants. If these requirements are not met, a traffic signal should neither be put into operation nor continued in operation (if already installed).

When a traffic signal is warranted, prior consideration should be given to viable alternatives. Widening of one or more side street approaches may be preferred as an alternative to signalization. In urban areas, the widening sometimes may be effected by eliminating parking in the vicinity of the intersection. Other alternatives include modifications in channelization, speed zoning, improved lighting, advance warning signs, geometric improvements, and alterations to satisfy sight distance requirements. It should be determined whether a new signal installation would have a disruptive effect on an existing progressive signal system. For any fixed-time signal installation, consideration should be given to placing the signal on flashing operation during those periods of at least four consecutive hours when the appropriate Vehicular Volume Warrant is not satisfied.

If it is determined that a traffic signal installation represents the best solution, the signal and all related traffic control devices and markings should be installed according to the standards set forth in the Manual on Uniform Traffic Control Devices (MUTCD). Signal indications should be properly phased. If the new signal is part of a progressive system, all traffic signals should be properly coordinated. Adequate supervision should be given to the operation and maintenance of the signal and all of its related devices. The traffic signal operation should be selected on the basis of engineering study and judgement.

Warrants for Traffic Signal Installation

The investigation of the need for traffic signal control should consist of the applicable warrant procedures as specified in Table A-1.

Volume Adjustments

Approach volumes are adjusted according to the following:

1. Select one of the (at least) eight hours of data collected to determine the value of Total Major Street Volume (TMSV), i.e., sum of both approaches if two-way traffic is serviced.
2. For each such hour note the total volume of traffic on each side street approach (SSV), the associated percentage of right-turn movements (P_R) and the volume of truck and bus traffic (Q_T).
3. For each side street approach, calculate the "equivalent" volume, $Q_{ss} = SSV + Q_T$, which states that one truck/bus is equivalent to two passenger cars.

Intersection Classification Notation

The following intersection notation scheme is used:

1. The major street approaches and side street approaches each service one through lane of traffic (2222).
2. The major street approaches each service two through lanes of traffic; the side street approaches each service one through lane (4222).
3. The major street approaches and side street approaches each service two through lanes of traffic (4242).
4. The major street approaches each service three through lanes of traffic; the side street approaches each service one through lane of traffic (6222).

Peak-Hour Warrant

A traffic signal is warranted if one (or more) point(s) plotted on the Warrant Diagram lies within the shaded region labelled, "PEAK-HOUR WARRANT SATISFIED." When a value of TMSV exceeds 1600 vph, a traffic signal is warranted if the associated value of HSSV exceeds 100 vph for a one-lane side street approach.

A traffic signal installed under this warrant should be either semi- of full-traffic-actuated as determined by the responsible engineer.

Table A-1

Application of Specified Traffic Signal Warrants

Warrant	Data Required	Applicable Conditions
1. Vehicular Volume 2. Peak-Hour	Sections 1.1, 1.2, 1.5	Right-angle intersections with 3 (tee) or 4 approaches. Major street may have a total width of 2, 4 or 6 lanes. Each side street approach has one lane. For the case where the major street has a total of 4 lanes, side street approaches with 2 lanes are also considered.
3. Hazard	Sections 1.1, 1.2, 1.4	
4. Delay	Sections 1.1, 1.2, 1.5, 1.7	Intersection configurations which are skewed, offset, have 5 or more approaches, or otherwise differ from those desired above. That is, warrants 1-3 are not applicable.
5. Pedestrian 6. School Crossing	Sections 1.1, 1.2, 1.3, 1.5	All intersection configurations. Warrants 1-3 or 4 must have been applied earlier and have not been satisfied.
7. Accident Experience	Sections 1.1 through 1.6	All intersection configurations. All applicable warrants listed above must have been applied earlier and have not been satisfied

Table A-2

Impact of Right-Turn Movements: Configuration 2222*

Equivalent Side Street Volume Q_{ss}	Effective Side-Street Volumes (ESSV) for Indicated Right-Turn Percentages (P_R)							
	10	20	30	40	50	60	70	80
100	90	80	70	-	-	-	-	-
140	130	120	110	100	80	-	-	-
180	170	160	150	140	120	100	80	-
220	210	200	190	170	140	110	100	90
260	250	240	230	210	190	170	150	120
300	280	260	250	240	220	210	190	160
340	310	240	270	260	250	230	220	200
380	350	320	290	280	270	260	250	240
420	390	360	330	310	290	280	270	270

(Rounded to multiples of 10)

*Also 2122,2211,2111

Table A-3

Impact of Right-Turn Movements: Configuration 4222*

Equivalent Side Street Volume Q_{ss}	Effective Side-Street Volumes (ESSV) for Indicated Right-Turn Percentages (P_R)							
	10	20	30	40	50	60	70	80
100	90	80	70	-	-	-	-	-
140	130	120	110	90	80	-	-	-
180	170	150	140	120	100	80	-	-
220	200	180	160	140	120	100	80	-
260	250	230	210	190	160	130	80	-
300	290	270	250	230	200	180	150	100
340	330	320	310	290	250	220	200	170
380	370	360	350	330	300	270	250	220
420	410	400	390	370	340	320	290	270

(Rounded to multiples of 10)

*Also 4122,4211,4111

Table A-4

Impact of Right-Turn Movements: Configuration 4242*

Equivalent Side Street Volume Q_{ss}	Effective Side Street Volumes (ESSV) for Indicated Right-Turn Percentages (P_R)							
	10	20	30	40	50	60	70	80
120	110	100	90	-	-	-	-	-
200	190	180	170	160	130	-	-	-
280	260	250	230	220	200	160	-	-
360	340	310	290	270	240	210	130	-
440	370	350	330	310	290	250	200	-
520	420	370	340	330	310	300	240	120
600	500	410	380	360	340	320	300	240
680	570	480	400	380	370	350	330	280

(Rounded to mulitples of 10)

*Also 4142,4221,4121

Table A-5

Impact of Right-Turn Movements: Configuration 6222*

Equivalenced Side Street Volume Q_{ss}	Effective Side Street Volumes (ESSV) for Indicated Right-Turn Percentages (P_R)							
	10	20	30	40	50	60	70	80
100	90	80	70	-	-	-	-	-
140	130	120	110	100	90	80	-	-
180	170	160	140	120	100	80	-	-
220	210	200	180	160	130	100	-	-
260	250	240	220	190	160	130	90	-
300	290	280	260	230	200	160	120	80
340	330	320	300	270	240	200	160	120
380	370	360	340	310	270	240	200	140
420	410	400	380	350	310	280	240	190

(Rounded to multiples of 10)

*Also 6122,6211,6111

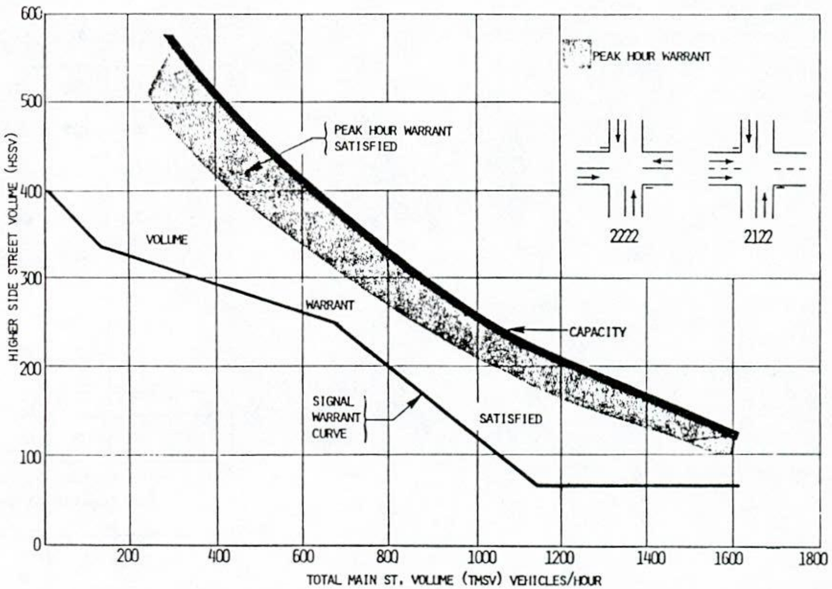


Figure A-3. Vehicular Volume and Peak- Hour Volume Warrant Diagram for the 2222, 2122, 2211 and 2111 Intersection Configurations

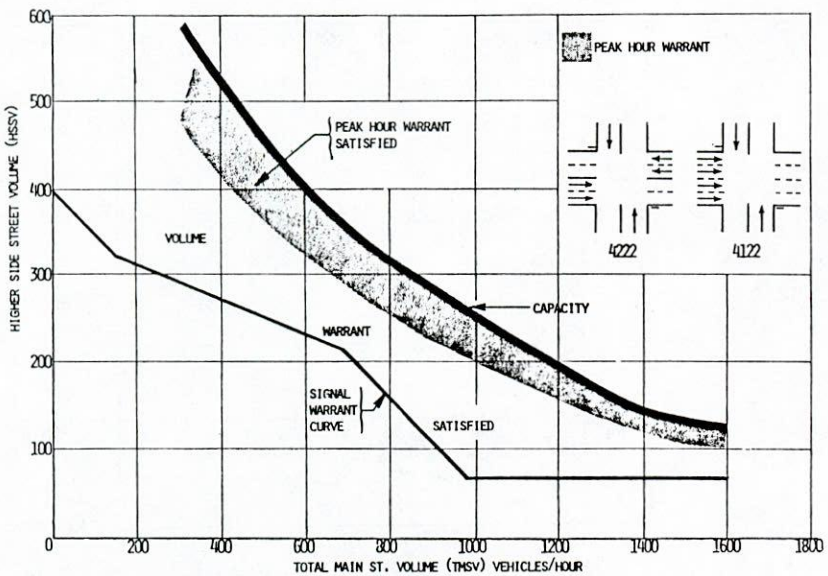


Figure A-4. Vehicular Volume and Peak-Hour Volume Warrant Diagram for the 4222, 4122, 4211 and 4111 Intersection Configurations

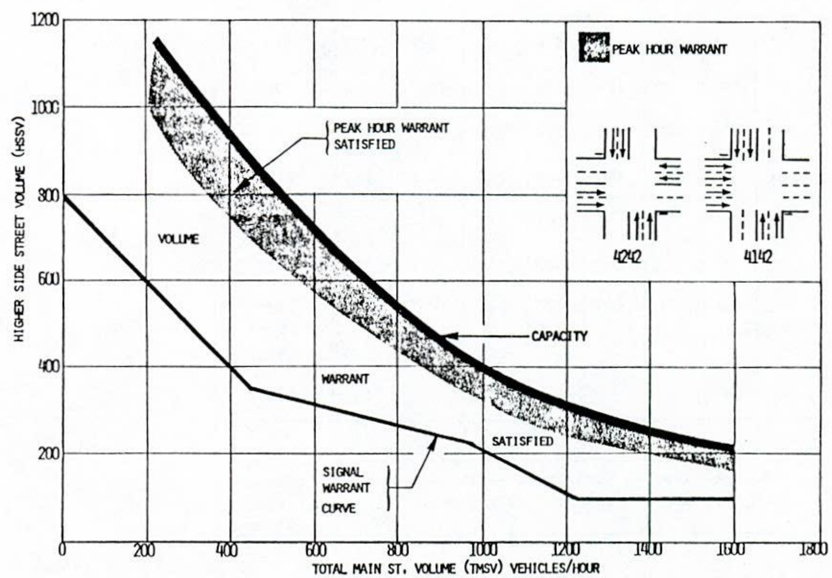


Figure A-5. Vehicular Volume and Peak-Hour Volume Warrant Diagram for the 4242, 4142, 4221 and 4121 Intersection Configurations

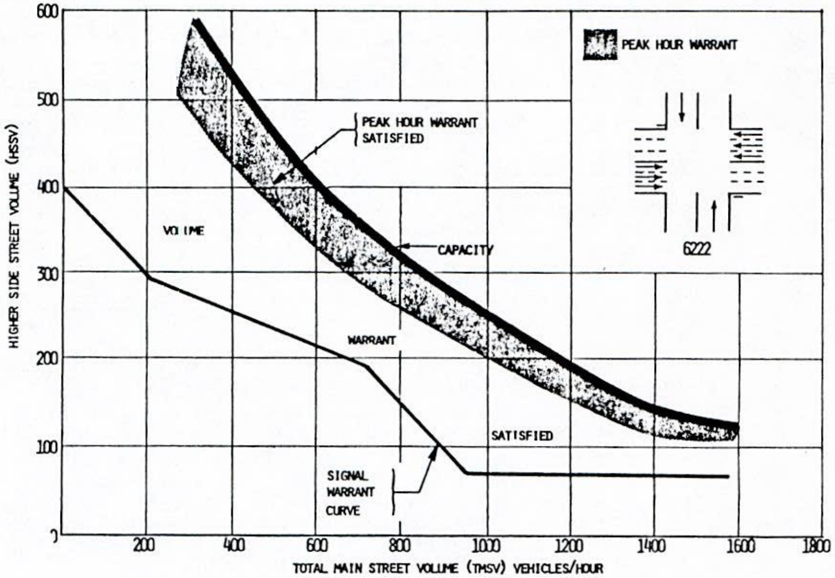


Figure A-6. Vehicular Volume and Peak-Hour Volume Warrant Diagram for the 6222, 6122, 6211 and 6111 Intersection Configurations

APPENDIX B

DATABASE

The general format of the magnetic media databases is basically one record per observation. Each record, therefore, represents the traffic volumes, intersection approach delay, average queue, and so forth observed during each 25-minute observation period. In addition, each record contains variables describing the intersections, such as the number of lanes on the main and cross streets, speed limits on a main street, and whether it was signalized or not. In the paragraphs below, a description of the codes used in the database is provided. This is followed by a description of the intersections included in the peak-hour database.

DATABASE CODES

These codes applied to the database that was used for the study. In general, all field entries were numeric. The allowable range for each field is shown in parentheses after the field name.

I/S-NUM (101-699) - This is the intersection identification number. The first digit identifies the city as follows:

1 - Atlanta,
2 - Denver,
3 - Hartford,
4 - Phoenix,
5 - Tucson, and
6 - Washington.

The remaining two digits uniquely identifies each intersection.

OBS-NUM (1-9) - Each observation consists of a 25-minute field study of the traffic flows at the intersection. There are normally four consecutive observations at each intersection.

IS-TYPE (1-3) - Each intersection is classified into one of three categories as follows:

1 - Normal cross intersection;
2 - "T" Intersection (study approach is the stem leg); and,
3 - Other intersections with special geometrics.

LANES-MS (1-3) - Number of through lanes in each direction on the main street approaches.

LANES-SS (1-3) - Number of lanes on the side street approach.

LT-LANE (0 or 1) - A "0" indicates that there are no separate left turn lanes on the main street. A "1" indicates that there is at least one separate left turn lane.

TRAFFIC CONTROL (0-2) - A "0" indicates that the intersection is not signalized, a "1" indicates that the intersection is signalized, and a "2" indicates that the intersection was under police control.

MS-SPEED (0-4) - The posted speed limit on the main street is coded as follows:

0 - Unknown or not posted,
1 - 25 MPH, 30 MPH or 35 MPH,
2 - 40 MPH or 45 MPH, and
3 - 50 MPH or 55 MPH.

SIG-RITE (0-3) - The distance to the nearest signal to the right (when looking at the intersection from the study approach) is coded as follows:

1 - 2000 feet or less;
2 - from 2000 to 4000 feet, and
3 - more than 4000 feet.

SIG-LEFT (0-3) - The distance to the nearest signal to the left and is coded as described above.

MS-VOL (0-9999) - The total main street (two-way) traffic expressed as an hourly flow rate (VPH) that was counted during the study period.

SS-APVOL (0-9999) - The side street study approach traffic expressed as an hourly flow rate (VPH) that was counted during the study period.

PCT-RT (0-100) - The percent of sidestreet traffic turning right during the 25-minute observation period.

TOTALVOL (0-9999) - The total traffic entering the intersection during the study period expressed as an hourly flow rate (VPH).

CLV-VPH (0-9999) - The sums of the Critical Lane Volumes for the intersection were calculated for each period using the hourly flow rates described above.

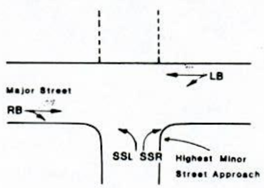
CONFLICT (0-9999) - This is a measure of the potential conflicts at an intersection and is calculated using the following equation:

$$C = \frac{(RB + LB)(SSL) + RB\ (SSR)}{1000}$$

where:

C = Conflict measure
RB = Rightbound traffic
LB = Leftbound traffic
SSL = Side street left turn traffic
SSR = Side street right turn traffic

The "RB" traffic and the "LB" traffic include both the through and left turn movements. The "SSL" traffic includes any through traffic if the intersection is not a "T" type as shown below. All other traffic that may enter the intersection is ignored.



PCT-STOP (0-100) - This value is simply the percentage of vehicles on the study approach that were stopped before entering the intersection. Notice that for STOP sign controlled intersections, the PCT-STOP value is not relevant. The actual field measures of percent stopping traffic was conducted only at signalized intersections.

TOT-DELA (0-9999) - This value is the total approach delay measured during each observation period. The value is normalized to an hourly figure to enable comparisons. The units used are vehicle-minutes per hour of delay.

AVE-DELA (0-999) - Another statistic that is indicative of intersection performance is the average delay per vehicle. The units used here are seconds per vehicle.

QUEUE (0.0-9.9) - Closely related to the total approach delay is average queue. This is simply the average number of vehicles in queue on the study approach to the intersection during each 25-minute observation period.

JUDGEMENT (0 or 1) - During each observation period, the engineer-supervisor made a value-judgement as to whether the intersection would have operated better with a signal or without a signal. The results of this judgement are coded here. A "0" indicates that the intersection would have operated better without signal control and a "1" indicates that a traffic signal would have improved the situation.

NAC Warrant (0 or 1) - For each observation, the criteria expressed in the NAC warrant were followed to determine whether the criteria were satisfied for that observation. A "0" indicates that the criteria was not satisfied, a "1" indicates that a signal is warranted.

NCHRP Warrant (0 or 1) - Similarly, the NCHRP warrant criteria were applied and the results were coded - a "0" indicating that the warrant was not met, a "1" indicating that the warrant was met.

2/24/81 FINAL REPORT PAGE 1

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON-FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
1	101	1	1	4	4	2	0	1108	238	264	100	41	11	1	0
2	101	2	1	4	4	2	0	751	312	234	100	60	12	1	0
3	101	3	1	4	4	2	0	857	171	147	100	31	11	1	0
4	101	4	1	4	4	2	0	378	85	32	100	6	4	0	0
5	102	1	1	3	4	2	1	168	405	67	80	111	16	2	0
6	102	2	1	3	4	2	1	120	423	51	73	99	14	2	0
7	102	3	1	3	4	2	1	74	261	19	83	92	21	2	0
8	102	4	1	3	4	2	1	41	206	8	86	72	21	1	0
9	103	1	2	3	2	2	1	2474	223	488	84	152	41	3	1
10	103	2	2	3	2	2	1	2729	364	790	64	205	34	4	1
11	103	3	2	3	2	2	1	2400	374	708	75	175	28	3	1
12	103	4	2	3	2	2	1	2537	235	519	81	124	32	2	1
13	104	1	1	3	2	2	1	3088	79	185	67	29	22	1	0
14	104	2	1	3	2	2	1	3345	124	332	75	38	18	1	0
15	104	3	1	3	2	2	1	3762	516	1513	77	312	36	6	1
16	104	4	1	3	2	2	1	3381	180	491	68	40	13	1	1
17	105	1	2	3	2	2	1	3164	55	145	100	31	34	1	0
18	105	2	2	3	2	2	1	3839	142	427	88	78	33	1	1
19	105	3	2	3	2	2	1	4054	142	430	78	71	30	1	1
20	105	4	2	3	2	2	1	3662	69	217	70	52	45	1	0
21	106	1	2	2	2	2	1	1388	468	367	78	192	25	4	1
22	106	2	2	2	2	2	1	1394	619	483	82	316	31	6	1
23	106	3	2	2	2	2	1	1294	514	396	65	210	25	4	1
24	106	4	2	2	2	2	1	1073	413	277	64	96	14	2	1
25	109	1	1	2	2	2	1	1849	286	385	64	68	14	1	0
26	109	2	1	2	2	2	1	2031	120	174	84	45	23	1	1
27	109	3	1	2	2	2	1	1412	434	459	76	157	22	3	1
28	109	4	1	2	2	2	1	1529	123	164	78	64	31	1	0
29	110	1	1	4	2	2	0	3488	19	43	100	16	48	0	0
30	110	2	1	4	2	2	0	4102	26	62	100	24	55	0	0
31	110	3	1	4	2	2	0	4499	290	958	100	211	44	4	1
32	110	4	1	4	2	2	0	5182	57	230	100	62	65	1	0
33	111	1	1	2	2	3	1	1537	267	289	83	55	12	1	0
34	111	2	1	2	2	3	1	1686	675	838	77	337	30	6	1
35	111	3	1	2	2	3	1	1707	740	897	85	436	35	8	1
36	111	4	1	2	2	3	1	1865	218	316	89	57	16	1	1
37	112	1	1	1	2	4	1	990	185	134	82	41	13	1	0
38	112	2	1	1	2	4	1	1013	938	700	93	481	31	9	1
39	112	3	1	1	2	4	1	1226	291	277	88	75	16	1	1
40	112	4	1	1	2	4	1	1267	142	142	90	48	20	1	1
41	113	1	2	1	2	2	0	1334	300	291	100	220	44	4	1
42	113	2	2	1	2	2	0	1539	473	519	100	647	82	12	1
43	113	3	2	1	2	2	0	1089	156	115	100	43	16	1	1
44	113	4	2	1	2	2	0	856	99	53	100	18	11	0	0
45	114	1	1	1	2	2	0	536	297	134	100	52	11	1	0
46	114	2	1	1	2	2	0	552	516	227	100	141	16	3	0
47	114	3	1	1	2	2	0	537	299	130	100	62	13	1	0
48	114	4	1	1	2	2	0	392	194	58	100	13	25	1	0
49	116	1	2	2	2	2	0	1344	248	240	100	71	17	1	0

Figure B-1. Database

12/24/81 FINAL REPORT PAGE 2

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
50	116	2	2	2	2	2	0	1591	418	523	100	87	13	2	0
51	116	3	2	2	2	2	0	1596	502	649	100	255	31	5	1
52	116	4	2	2	2	2	0	1368	221	238	100	43	12	1	0
53	117	1	2	2	2	2	0	1282	159	188	100	75	28	1	0
54	117	2	2	2	2	2	0	1503	271	361	100	208	46	4.	1
55	117	3	2	2	2	2	0	1395	331	389	100	122	22	2	0
56	117	4	2	2	2	2	0	1397	212	259	100	62	18	1	0
57	118	1	2	2	2	2	0	1794	245	312	100	38	9	1	0
58	118	2	2	2	2	2	0	1677	331	413	100	285	52	5	0
59	118	3	2	2	2	2	0	1684	261	349	100	75	17	1	0
60	118	4	2	2	2	2	0	1476	231	289	100	75	19	1	0
61	122	1	2	2	1	2	0	759	87	52	100	13	9	0	0
62	122	2	2	2	1	2	0	1138	207	184	100	86	25	2	0
63	122	3	2	2	1	2	0	1549	154	166	100	45	18	1	0
64	122	4	2	2	1	2	0	1459	38	34	100	9	15	0	0
65	123	1	2	1	3	1	0	818	213	85	100	29	8	1	0
66	123	2	2	1	3	1	0	905	209	116	100	32	9	1	0
67	123	3	2	1	3	1	0	1106	259	156	100	50	12	1	0
68	123	4	2	1	3	1	0	655	206	69	100	34	10	1	0
69	124	1	[illegible]	2	3	1	1	1521	422	506	60	65	9	1	1
70	124	2	[illegible]	2	3	1	1	1696	872	1133	66	189	13	3	1
71	124	3	1	2	3	1	1	1752	1075	1025	73	306	17	6	1
72	124	4	1	2	3	1	1	1772	1097	1510	70	253	14	5	1
73	126	1	2	2	2	3	0	972	360	307	100	86	14	2	0
74	126	2	2	2	2	3	0	1087	1133	1065	100	458	24	8	1
75	126	3	2	2	2	3	0	1205	1255	1317	100	259	12	5	1
76	126	4	2	2	2	3	0	1409	915	1116	100	847	56	15	1
77	128	1	2	1	2	2	0	363	312	100	100	48	9	1	0
78	128	2	2	1	2	2	0	432	357	144	100	60	10	1	0
79	128	3	2	1	2	2	0	434	408	158	100	91	13	2	0
80	128	4	2	1	2	2	0	550	204	102	100	39	11	1	0
81	130	1	1	1	1	2	0	719	350	48	100	14	3	0	0
82	130	2	1	1	1	2	0	986	607	135	100	43	4	1	0
83	130	3	1	1	1	2	0	1220	760	147	100	509	40	9	1
84	130	4	1	1	1	2	0	1346	446	105	100	43	6	1	0
85	131	1	2	2	3	2	0	432	646	139	100	45	4	1	0
86	131	2	2	2	3	2	0	384	903	188	100	46	3	1	0
87	131	3	2	2	3	2	0	489	1001	279	100	195	12	4	1
88	131	4	2	2	3	2	0	396	545	131	100	77	9	1	0
89	132	1	2	2	2	4	1	1078	79	79	76	22	17	0	0
90	132	2	2	2	2	4	1	1308	166	205	81	52	19	1	0
91	132	3	2	2	2	4	1	1697	288	465	77	88	18	2	1
92	132	4	2	2	2	4	1	1438	199	271	83	73	22	1	0
93	133	1	1	2	2	2	0	536	434	208	100	8	1	0	0
94	133	2	1	2	2	2	0	527	466	224	100	11	1	0	0
95	133	3	1	2	2	2	0	981	665	502	100	61	6	1	0
96	133	4	1	2	2	2	0	1115	768	684	100	61	6	1	0
97	135	1	2	3	2	2	0	2411	36	69	100	15	25	0	0
98	135	2	2	3	2	2	0	2704	242	491	100	136	34	3	0
99	135	3	2	3	2	2	0	2794	199	419	100	269	81	5	1

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 3

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
100	135	4	2	3	2	2	0	2794	158	323	100	40	15	1	0
101	136	1	1	3	1	2	1	2787	165	322	96	75	27	1	1
102	136	2	1	3	1	2	1	3012	213	478	92	208	59	4	1
103	136	3	1	3	1	2	1	3036	122	278	98	92	45	2	1
104	136	4	.	3	1	2	1	2493	70	123	90	43	37	1	1
105	137	1	1	2	2	2	1	1572	223	255	88	85	23	2	1
106	137	2	1	2	2	2	1	1833	307	415	73	103	20	2	1
107	137	3	1	2	2	2	1	1723	365	520	80	112	18	2	1
108	137	4	1	2	2	2	1	1459	247	268	86	48	12	1	1
109	141	1	1	2	2	3	1	1800	7	6	100	24	205	0	0
110	141	2	1	2	3	3	1	2851	1217	2994	93	*20	35	31	1
111	141	3	1	2	3	3	1	1824	501	638	94	136	16	3	1
112	141	4	1	2	3	3	1	1937	459	534	94	160	21	3	0
113	142	1	1	2	3	3	1	1783	1332	1602	78	697	31	13	1
114	142	2	1	2	4	3	1	2673	1942	3456	100	*30	44	26	1
115	142	3	1	2	4	3	1	2402	1006	1925	100	600	36	11	1
116	142	4	1	2	4	3	1	2608	974	1999	100	543	33	10	1
117	143	1	2	2	2	3	1	1906	555	583	92	494	53	9	1
118	143	2	2	2	2	3	1	2369	861	1264	97	*24	1.3	29	1
119	143	3	2	2	2	3	1	2045	542	742	83	208	23	4	1
120	143	4	2	2	2	3	1	2204	722	967	84	378	31	7	1
121	146	1	2	2	2	2	1	1202	403	311	71	77	.1	1	0
122	146	2	2	2	2	2	1	962	497	293	77	107	.3	2	1
123	146	3	2	2	2	2	1	1270	619	490	80	180	.7	3	1
124	146	4	2	2	2	2	1	1454	168	180	84	55	20	1	0
125	147	1	2	2	1	2	1	1258	172	138	97	68	24	1	0
126	147	2	2	2	1	2	1	1314	219	201	87	92	25	2	1
127	147	3	2	2	1	2	1	1538	279	296	84	105	23	2	1
128	147	4	2	2	1	2	1	1515	79	88	94	29	22	1	0
129	155	1	1	2	2	4	1	2323	404	825	64	75	.1	1	1
130	155	2	1	2	2	4	1	2561	593	1254	88	220	22	4	1
131	155	3	1	2	2	4	1	2383	511	1050	74	153	.8	3	1
132	155	4	1	2	2	4	1	2892	750	1847	63	241	.9	4	1
133	156	1	2	1	1	2	0	663	137	79	100	32	.4	1	0
134	156	2	2	1	1	2	0	941	230	111	100	23	6	0	0
135	156	3	2	1	1	2	0	844	201	90	100	29	9	1	0
136	156	4	2	1	1	2	0	724	168	64	100	34	.2	.	0
137	158	1	1	1	1	1	0	86	226	8	100	19	5	0	0
138	158	2	1	1	1	1	0	129	508	34	100	218	26	4	0
139	158	3	1	1	1	1	0	99	264	15	100	49	.1	1	0
140	158	4	1	1	1	1	0	99	98	6	100	16	9	0	0
141	159	1	1	2	2	2	0	1106	55	38	100	9	.0	0	0
142	159	2	1	2	2	2	0	1123	94	61	100	18	.1	0	0
143	159	3	1	2	2	2	0	1377	413	257	100	72	.1	1	0
144	159	4	1	2	2	2	0	1461	60	45	100	15	.5	0	0
145	160	1	2	2	2	2	0	694	68	41	100	11	9	0	0
146	160	2	2	2	2	2	0	798	139	101	100	8	3	0	0
147	160	3	2	2	2	2	0	905	194	154	100	20	6	0	0
148	160	4	2	2	2	2	0	844	149	108	100	10	4	0	0
149	161	1	2	2	1	3	0	1922	22	38	100	9	25	0	.

Figure B-1. Database (Cont'd)

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON-FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
150	161	2	2	2	1	3	0	2232	677	783	100	233	20	4	1
151	161	3	2	2	1	3	0	2292	7	14	100	5	41	0	0
152	162	1	1	1	2	2	1	641	535	205	50	76	9	1	0
153	162	2	1	1	2	2	1	810	723	370	66	211	18	4	1
154	162	3	1	1	2	2	1	1160	1024	824	65	390	23	7	1
155	162	4	1	1	2	2	1	1476	792	762	68	216	16	4	1
156	163	1	1	2	2	3	0	1339	79	75	100	29	22	1	0
157	163	2	1	2	2	3	0	1520	1087	1432	100	362	20	7	1
158	163	3	1	2	2	3	0	1649	108	152	100	29	16	1	0
159	163	4	1	2	2	3	0	1937	4	8	100	1	14	0	0
160	164	1	2	3	1	2	0	2961	62	145	100	22	21	0	0
161	164	2	2	3	1	2	0	2861	223	443	100	60	16	1	0
162	164	3	2	3	1	2	0	2947	168	339	100	55	20	1	0
163	164	4	2	3	1	2	0	2949	238	484	100	93	24	2	0
164	201	1	1	1	1	3	0	1253	165	146	100	59	21	1	0
165	201	2	1	1	1	3	0	1507	124	140	100	97	47	2	0
166	201	3	1	1	1	3	0	1682	173	203	100	126	42	2	1
167	201	4	1	1	.	3	0	2132	204	307	100	398	117	7	1
168	201	5	1	1	1	3	0	2208	199	303	100	570	172	10	1
.69	201	6	1	1	1	3	0	.600	192	217	100	215	67	4	1
170	201	7	1	1	1	3	0	1284	104	101	100	42	24	1	0
171	202	1	2	1	2	3	0	681	384	198	100	361	56	7	1
172	202	2	2	1	2	3	0	842	245	143	100	76	19	1	0
173	202	3	2	1	2	3	0	926	165	99	100	60	22	1	0
174	204	1	1	2	2	2	0	840	407	158	100	54	8	1	0
175	204	2	1	2	2	2	0	945	598	270	100	420	42	8	1
.76	204	3	1	2	2	2	0	894	657	268	100	400	37	7	1
177	204	4	1	2	2	2	0	915	355	161	100	80	13	1	0
178	205	1	2	2	1	1	0	2851	233	320	100	100	26	2	0
179	205	2	2	2	1	1	0	3089	223	344	100	68	18	1	0
180	205	3	2	2	1	.	0	3091	249	364	100	285	71	5	1
181	205	4	2	2	1	1	0	3078	138	212	100	46	20	1	0
182	208	1	2	1	1	2	0	1373	276	170	100	69	15	1	0
183	208	2	2	1	1	2	0	1380	309	233	100	187	36	3	0
184	208	3	2	1	1	2	0	909	148	95	100	22	9	0	0
185	209	1	2	1	1	2	0	1404	58	67	100	27	28	1	0
186	209	2	2	1	1	2	0	1308	122	134	100	70	34	1	0
187	210	1	2	2	2	2	0	515	151	53	100	9	4	0	0
188	210	2	2	2	2	2	0	696	196	88	100	8	3	0	0
189	211	1	1	2	2	3	1	1690	538	794	70	120	13	2	1
190	211	2	1	2	2	3	1	1661	764	1074	65	155	12	3	1
191	211	3	1	2	2	3	1	1441	298	380	75	72	15	1	1
192	211	4	1	2	2	3	1	1012	206	168	84	48	14	1	0
193	214	1	1	3	3	2	1	2369	687	1343	84	490	43	9	1
194	214	2	1	3	3	2	1	2728	766	1683	82	594	47	11	1
195	214	3	1	3	3	2	1	1799	305	541	79	151	27	3	1
196	218	1	2	2	2	2	1	238	300	57	66	60	12	1	0
197	218	2	2	2	2	2	1	255	511	101	62	109	13	2	1
198	218	3	2	2	2	2	1	150	318	38	60	42	8	1	0
199	220	1	1	2	2	2	0	898	279	166	100	17	4	0	0

Figure B-1. Database (Cont'd)

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON-FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
200	220	2	1	2	2	2	0	919	324	186	100	22	4	0	0
201	220	3	1	2	2	2	0	1013	273	162	100	53	12	1	0
202	221	1	2	2	1	2	0	703	98	40	100	5	3	0	0
203	221	2	2	2	1	2	0	572	76	25	100	6	5	0	0
204	222	1	2	2	2	3	1	1207	357	317	64	158	27	3	1
205	222	2	2	2	2	3	1	1317	751	878	85	*55	92	21	1
206	222	3	2	2	2	3	1	1420	651	539	61	239	22	4	1
207	223	1	2	2	2	3	0	631	273	105	100	79	17	1	0
208	223	2	2	2	2	3	0	586	523	212	100	214	25	4	1
209	223	3	2	2	2	3	0	795	532	288	100	231	26	4	1
210	223	4	2	2	2	3	0	814	595	308	100	264	27	5	1
211	223	5	2	2	2	3	0	776	506	258	100	246	29	5	1
212	223	6	2	2	2	3	0	334	156	64	100	58	16	1	0
213	225	1	1	2	1	2	1	2717	67	130	82	14	12	0	0
214	229	1	1	1	2	2	1	1293	418	475	89	252	36	5	1
215	229	2	1	1	2	2	1	1293	374	394	81	213	34	4	1
216	229	3	1	1	2	2	1	1386	378	430	80	228	36	4	1
217	230	1	1	2	1	2	0	924	168	125	100	271	97	5	0
218	230	2	1	2	1	2	0	922	175	112	100	72	25	1	0
219	230	3	1	2	1	2	0	652	108	49	100	50	24	1	0
220	233	1	1	3	2	3	1	3957	209	588	78	134	39	2	1
221	233	2	1	3	2	3	1	4515	357	1229	79	326	55	6	1
222	233	3	1	3	2	3	1	4504	214	721	82	154	43	3	1
223	234	1	1	3	2	3	1	4104	355	1260	89	410	69	7	1
224	234	2	1	3	2	3	1	4053	204	681	82	160	47	3	1
225	234	3	1	3	2	3	1	3658	130	381	89	84	39	2	1
226	236	1	1	2	3	2	1	2003	180	223	100	67	22	1	0
227	236	2	1	2	3	2	1	2361	183	280	96	80	26	2	0
228	236	3	1	2	3	2	1	2332	236	392	94	136	35	3	1
229	236	4	1	2	3	2	1	2235	204	341	93	96	28	2	1
230	242	1	2	2	3	3	1	2864	595	1163	88	492	50	9	1
231	242	2	2	2	3	3	1	2888	1332	2446	70	798	36	15	1
232	242	3	2	2	3	3	1	3074	641	1271	74	247	24	5	1
233	242	4	2	2	3	3	1	2844	686	1159	79	327	29	6	1
234	242	5	2	2	3	3	1	2402	367	598	66	151	25	3	1
235	242	6	2	2	3	3	1	2324	112	190	79	76	41	1	0
236	245	1	2	2	2	3	0	1411	14	18	100	3	14	0	0
237	245	2	2	2	2	3	0	1634	31	34	100	11	21	0	0
238	245	3	2	2	2	3	0	1667	211	246	100	197	56	4	1
239	246	1	1	2	3	3	1	1264	384	373	76	163	25	3	1
240	246	2	1	2	3	3	1	1248	537	519	73	304	34	6	1
241	246	3	1	2	3	3	1	1476	597	659	82	381	38	7	1
242	246	4	1	2	3	3	1	1541	991	1165	85	*66	65	19	1
243	246	5	1	2	3	3	1	.409	292	331	88	178	36	3	1
244	246	6	1	2	3	3	1	1059	165	149	91	97	37	2	1
245	247	1	2	2	2	3	0	1384	115	110	100	43	22	1	0
246	247	2	2	2	2	3	0	1677	223	250	100	92	25	2	0
247	247	3	2	2	2	3	0	1939	495	743	100	738	90	13	1
248	247	4	2	2	2	3	0	1498	230	238	100	80	21	1	0
249	247	5	2	2	2	3	0	972	72	59	100	19	16	0	0

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 6

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
250	251	1	1	3	3	3	1	2458	401	512	78	131	20	2	1
251	251	2	1	3	3	3	1	2872	528	838	81	292	33	5	1
252	251	3	[illegible]	3	3	3	1	2948	481	949	86	689	86	13	1
253	251	4	1	3	3	3	1	3553	465	995	81	261	34	5	1
254	251	5	1	3	3	3	1	4284	417	1144	83	380	55	7	1
255	251	6	1	3	3	3	1	3519	318	612	82	159	30	3	1
256	254	1	1	3	2	2	1	2463	216	360	84	121	34	2	1
257	254	2	1	3	2	2	1	2762	168	288	89	87	31	2	0
258	254	3	1	3	2	2	1	3146	252	583	89	216	51	4	1
259	302	1	2	1	1	3	0	1003	60	33	100	9	6	[illegible]	0
260	302	2	2	1	1	3	0	1144	96	51	100	17	17	0	0
261	302	3	2	1	1	3	0	1278	243	161	100	67	17	1	1
262	302	4	2	1	1	3	0	1493	281	189	100	75	16	1	0
263	302	5	2	1	1	3	0	1350	96	56	100	22	14	0	0
264	303	1	2	1	2	3	1	423	185	75	77	46	15	1	0
265	303	2	2	[illegible]	2	3	1	450	391	157	87	128	20	2	0
266	303	3	2	1	2	3	1	472	583	252	84	277	29	5	1
267	303	4	2	1	2	3	[illegible]	720	492	331	84	163	20	3	1
268	303	5	2	1	2	3	1	482	280	324	74	74	16	1	0
269	307	1	2	1	1	1	0	760	65	29	100	10	9	0	0
270	307	2	2	1	1	1	0	873	108	52	100	13	7	0	0
271	307	3	2	1	1	1	0	964	135	88	100	39	17	1	0
272	307	4	2	1	1	1	0	888	67	33	100	8	7	0	0
273	308	1	1	2	2	1	1	773	216	143	76	67	19	1	0
274	308	2	1	2	2	1	1	974	285	200	78	89	19	2	0
275	308	3	1	2	2	1	1	1005	420	229	97	351	50	6	1
276	308	4	1	2	2	1	1	907	315	160	89	455	87	8	1
277	308	5	1	2	2	1	1	861	317	155	85	150	28	3	1
278	308	6	1	2	2	1	1	588	209	65	72	52	15	1	0
279	310	1	1	2	1	2	0	296	34	9	100	9	16	0	0
280	310	2	1	2	1	2	0	434	237	87	100	38	10	1	0
281	310	3	1	2	1	2	0	754	194	123	100	50	15	1	0
282	310	4	1	2	1	2	0	602	78	38	100	14	11	0	0
283	311	1	2	2	1	1	1	836	249	156	94	70	17	1	1
284	311	2	2	2	1	1	1	892	286	193	92	96	20	2	1
285	311	3	2	2	1	1	1	968	268	194	93	92	21	2	1
286	311	4	2	2	1	1	1	976	447	301	96	186	25	3	1
287	311	5	2	2	1	1	1	931	348	270	97	131	23	2	1
288	311	6	2	2	1	1	1	802	178	105	81	40	13	1	0
289	312	1	2	1	1	1	0	537	161	59	100	38	14	1	0
290	312	2	2	1	1	1	0	485	98	38	100	29	18	1	0
291	312	3	2	1	1	1	0	627	111	50	100	40	22	1	0
292	312	4	2	1	1	1	0	584	125	60	100	38	18	1	0
293	314	1	2	3	2	2	1	1044	230	185	81	64	16	1	0
294	314	2	2	3	2	2	1	1073	305	259	71	89	18	2	1
295	314	3	2	3	2	2	1	1176	317	296	82	[illegible]	22	2	1
296	314	4	2	3	2	2	1	1404	415	498	77	163	24	3	1
297	314	5	2	3	2	2	1	1133	320	310	79	99	19	2	1
298	314	6	2	3	2	2	1	857	219	152	71	68	19	1	0
299	315	1	1	1	2	2	1	278	290	67	49	20	4	0	0

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 7

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
300	315	2	1	1	2	2	1	504	239	102	57	23	6	0	0
301	315	3	1	1	2	2	1	480	295	128	51	28	6	1	0
302	315	4	1	1	2	2	1	501	341	156	50	31	6	1	0
303	315	5	1	1	2	2	1	319	295	71	57	21	4	0	0
304	316	1	2	2	1	2	0	135	93	7	100	8	5	0	0
305	316	2	2	2	1	2	2	166	199	26	43	8	2	0	0
306	318	1	2	2	2	2	1	697	379	102	76	74	12	1	0
307	318	2	2	2	2	2	1	833	524	185	94	169	19	3	1
308	318	3	2	2	2	2	1	818	528	191	90	182	21	3	1
309	318	4	2	2	2	2	1	708	304	98	96	67	13	1	0
310	319	1	2	2	1	2	0	1150	245	198	100	64	16	1	0
311	319	2	2	2	1	2	0	1145	242	205	100	107	26	2	0
312	319	3	2	2	1	2	0	1054	247	250	100	184	45	3	1
313	319	4	2	2	1	2	0	1123	207	224	100	82	24	2	0
314	321	1	2	1	1	1	0	964	163	146	100	44	16	1	0
315	321	2	2	1	1	1	0	1138	175	171	100	64	22	1	0
316	321	3	2	1	1	1	0	950	91	80	100	32	21	1	0
317	321	4	2	1	1	1	0	975	82	76	100	15	11	0	0
318	322	1	2	2	1	2	1	1287	75	80	58	25	21	1	0
319	322	2	2	2	1	2	1	1317	55	62	48	18	20	0	0
320	322	3	2	2	1	2	1	910	137	124	58	57	25	1	0
321	322	4	2	2	1	2	1	921	132	122	33	27	12	1	0
322	323	1	1	2	1	2	1	894	134	90	82	66	29	1	0
323	323	2	1	2	1	2	1	960	200	138	80	101	30	2	1
324	323	3	1	2	1	2	1	1200	252	244	97	209	50	4	1
325	323	4	1	2	1	2	1	1384	281	322	93	196	42	4	1
326	323	5	1	2	1	2	1	1164	151	111	76	71	28	1	1
327	324	1	1	1	2	1	1	733	168	86	74	50	18	1	0
328	324	2	1	1	2	[illegible]	1	940	247	167	77	77	19	1	0
329	324	3	1	2	2	1	1	816	242	157	78	67	17	1	0
330	324	4	1	2	2	1	1	875	300	207	71	74	15	1	0
331	324	5	1	2	2	1	1	715	224	120	68	44	12	1	0
332	326	1	1	2	2	2	1	662	343	167	85	191	33	4	1
333	326	2	1	2	2	2	1	856	412	250	91	280	41	5	1
334	326	3	1	2	2	2	1	1156	326	259	94	197	36	4	1
335	326	4	1	2	2	2	1	1090	60	47	85	22	22	0	0
336	327	1	2	2	1	3	0	489	55	20	100	7	8	0	0
337	327	2	2	2	1	3	0	993	201	132	100	38	11	1	0
338	327	3	2	2	1	3	0	739	245	143	100	75	18	1	0
339	327	4	2	2	1	3	1	983	245	213	56	76	19	1	0
340	328	1	2	2	1	2	1	484	4	1	100	1	14	0	0
341	328	2	2	2	1	2	1	856	36	22	100	11	18	0	0
342	328	3	2	2	1	2	1	836	123	71	98	66	32	1	0
343	328	4	2	2	1	2	1	907	281	197	97	183	39	3	0
344	330	1	2	3	1	1	0	501	149	75	100	36	15	1	0
345	330	2	2	3	1	1	0	480	118	57	100	22	11	0	0
346	330	3	2	3	1	1	0	588	110	65	100	27	14	1	0
347	330	4	2	3	1	1	0	665	132	88	100	39	18	1	0
348	330	5	2	3	1	1	0	480	130	62	100	31	14	1	0
349	335	1	2	2	1	1	1	823	196	122	95	99	30	2	1

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 8

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
350	335	2	2	2	1	1	1	967	221	151	87	131	36	2	1
351	335	3	2	2	1	1	1	1022	240	207	93	163	41	3	1
352	335	4	2	2	1	1	1	929	209	141	90	67	19	1	0
353	338	1	2	1	2	3	0	211	110	22	100	13	7	0	0
354	338	2	2	1	2	3	0	504	195	96	100	24	8	0	0
355	338	3	2	1	2	3	0	429	247	103	100	28	7	1	0
356	338	4	2	1	2	3	0	237	156	36	100	15	6	0	0
357	338	5	2	1	2	3	0	161	87	13	100	7	5	0	0
358	340	1	2	2	2	3	1	801	65	42	100	13	12	0	0
359	340	2	2	2	2	3	1	1073	420	395	83	178	25	3	0
360	340	3	2	2	2	3	1	1248	391	414	63	112	17	2	1
361	340	4	2	2	2	3	1	1356	166	181	87	49	18	1	0
362	340	5	2	2	2	3	1	1209	134	140	89	59	26	1	0
363	341	1	2	2	1	2	1	1030	290	204	94	84	17	2	0
364	341	2	2	2	1	2	1	1146	185	138	95	86	28	2	0
365	341	3	2	2	1	2	1	1365	89	81	92	17	11	0	0
366	342	1	2	2	1	3	0	802	48	31	100	6	7	0	0
367	342	2	2	2	1	3	0	1027	187	161	100	79	25	1	0
368	342	3	2	2	1	3	0	952	63	49	100	10	9	0	0
369	344	1	2	2	2	3	1	759	118	56	73	20	10	0	0
370	344	2	2	2	2	3	1	936	571	332	64	122	13	2	1
371	344	3	2	2	2	3	1	850	384	184	68	57	9	1	0
372	344	4	2	2	2	3	1	1024	173	103	85	25	9	1	0
373	345	1	2	1	2	3	1	901	202	123	73	51	15	1	0
374	345	2	2	1	2	3	1	960	806	507	74	259	19	5	1
375	345	3	2	1	2	3	1	1277	188	118	81	37	12	1	0
376	347	1	1	1	1	3	1	796	62	27	81	7	7	0	0
377	347	2	1	1	1	3	1	1264	60	70	92	4	4	0	0
378	347	3	1	1	1	3	1	1526	26	13	91	4	10	0	0
379	347	4	1	1	1	3	1	1929	34	26	100	8	14	0	0
380	348	1	2	1	1	3	0	439	139	51	100	26	11	1	0
381	348	2	2	1	1	3	0	483	232	91	100	70	18	1	0
382	348	3	2	1	1	3	0	655	45	23	100	7	9	0	0
383	349	1	2	1	1	3	0	410	88	34	100	24	16	0	0
384	349	2	2	1	1	3	0	458	65	24	100	8	7	0	0
385	349	3	2	1	1	3	0	508	62	31	100	12	12	0	0
386	350	1	2	1	1	2	0	723	76	37	100	24	19	0	0
387	350	2	2	1	1	2	2	598	722	387	94	317	26	6	1
388	350	3	2	1	1	2	0	682	132	76	100	31	14	1	0
389	350	4	2	1	1	2	2	777	588	403	78	96	10	2	1
390	351	1	1	2	2	2	1	1398	355	353	98	365	62	7	1
391	351	2	1	2	2	2	1	1179	919	782	100	735	48	13	1
392	351	3	1	2	2	2	1	1103	392	362	100	197	30	4	1
393	351	4	1	2	2	2	1	1538	717	953	100	446	37	8	1
394	351	5	1	2	2	2	1	890	555	413	100	296	32	5	1
395	354	1	2	1	2	2	0	777	64	21	100	11	10	0	0
396	354	2	2	1	2	2	2	528	687	303	59	273	24	5	1
397	354	3	2	1	2	2	0	595	153	78	100	14	6	0	0
398	354	4	2	1	2	2	2	645	864	317	52	242	17	4	1
399	356	1	1	2	1	3	1	516	16	6	71	3	12	0	0

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 9

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
400	356	2	1	2	1	3	1	533	605	260	88	383	38	7	1
401	356	3	1	2	1	3	1	577	19	10	50	3	9	0	0
402	356	4	1	2	1	3	1	789	610	430	94	390	38	7	1
403	363	1	1	2	1	3	0	427	69	20	100	10	9	0	0
404	363	2	1	2	1	3	0	609	113	57	100	14	7	0	0
405	363	3	1	2	2	3	0	665	117	72	100	19	10	0	0
406	363	4	1	2	2	3	0	489	36	17	100	3	6	0	0
407	365	1	1	1	1	2	1	239	125	19	92	33	16	1	0
408	365	2	1	1	1	2	1	362	108	27	100	20	11	0	
409	365	3	1	1	1	2	1	312	75	15	97	14	12	0	0
410	365	4	1	1	1	2	1	424	24	6	100	3	7	0	0
411	401	1	1	2	2	3	1	2015	446	620	69	185	25	3	1
412	401	2	1	2	2	3	1	1888	245	290	76	45	11	1	0
413	401	3	1	2	2	3	1	2350	632	1016	69	269	26	5	1
414	401	4	1	2	2	3	1	1666	192	168	76	33	10	1	0
415	404	1	1	2	2	2	1	1144	168	123	79	44	16	1	0
416	404	2	1	2	2	2	1	1290	490	387	82	242	30	4	1
417	404	3	1	2	2	2	1	1221	360	276	83	61	10	1	0
418	404	4	1	2	2	2	1	1290	372	363	88	85	14	2	1
419	404	5	1	2	2	2	1	1188	582	484	83	72	8	1	1
420	405	1	1	2	1	2	0	2328	327	411	100	202	37	4	1
421	405	2	1	2	1	2	0	2201	247	276	100	97	23	2	1
422	405	3	1	2	1	2	0	2268	317	367	100	86	16	2	1
423	405	4	1	2	1	2	0	2227	429	426	100	422	59	8	1
424	405	5	1	2	1	2	0	1562	96	81	100	39	25	1	0
425	406	1	1	3	2	2	1	2427	370	753	75	103	17	2	1
426	406	2	1	3	2	2	1	2371	218	450	84	60	16	1	1
427	406	3	1	3	2	2	1	2461	255	509	92	84	22	2	1
428	406	4	1	3	2	2	1	2238	84	169	89	39	28	1	0
429	414	1	1	1	2	2	1	1652	454	658	67	457	60	8	1
430	414	2	1	1	2	2	1	1577	446	635	76	215	29	4	1
431	414	3	1	1	2	2	1	1514	343	464	81	167	29	3	1
432	414	4	1	1	2	2	1	1504	243	350	88	94	23	2	1
433	415	1	1	2	3	3	0	1909	77	100	100	30	24	1	0
434	415	2	1	2	3	3	0	1987	175	246	100	51	18	1	0
435	415	3	1	2	3	3	0	1707	122	141	100	33	16	1	0
436	415	4	1	2	3	3	0	1739	77	101	100	28	22	1	0
437	417	1	2	3	1	3	0	2618	17	28	100	14	51	0	0
438	417	2	2	3	1	3	0	2138	16	15	100	11	39	0	0
439	417	3	2	3	1	3	0	2472	19	25	100	18	55	0	0
440	417	4	2	3	1	3	0	2716	26	36	100	14	33	0	0
441	417	5	2	3	1	3	0	2839	9	23	100	7	45	0	0
442	418	1	1	3	1	3	0	1469	79	67	100	22	16	0	0
443	418	2	1	3	1	3	0	1578	51	51	100	21	24	0	0
444	418	3	1	3	1	3	0	1785	190	185	100	54	17	1	0
445	418	4	1	3	1	3	0	1682	160	123	100	67	25	1	0
446	420	1	1	2	2	3	1	851	129	61	96	28	13	1	0
447	420	2	1	2	2	3	1	1346	1161	1343	80	615	32	11	1
448	420	3	1	2	2	3	1	535	221	104	87	47	13	1	0
449	420	4	1	2	2	3	1	415	69	25	90	19	16	0	0

Figure B-1. Database (Cont'd)

12/24/81	FINAL REPORT	PAGE 10

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
450	421	1	1	2	2	3	1	845	667	459	72	245	22	4	1
451	421	2	1	2	2	3	1	488	640	278	64	291	27	5	1
452	421	3	1	2	2	3	.	289	283	70	56	38	8	1	0
453	421	4	1	2	2	3	1	203	188	34	65	42	13	1	0
454	422	1	2	2	1	3	0	696	413	233	100	215	31	4	1
455	422	2	2	2	1	3	0	425	355	130	100	330	56	6	1
456	422	3	2	2	1	3	0	331	146	37	100	63	26	1	0
457	422	4	2	2	1	3	0	293	99	22	100	36	22	1	0
458	423	1	2	2	2	3	0	638	108	50	100	671	373	12	1
459	423	2	2	2	2	3	0	190	794	121	100	151	12	3	0
460	423	3	2	2	2	3	0	209	110	20	100	38	21	1	0
461	423	4	2	2	2	3	0	163	50	. 6	100	27	32	1	0
462	425	1	2	3	2	3	1	2093	96	141	93	36	23	1	0
463	425	2	2	3	2	3	1	2573	528	1003	68	118	13	2	1
464	425	3	2	3	2	3	1	2493	705	1366	73	153	13	3	1
465	425	4	2	3	2	3	1	3023	555	1249	82	186	20	3	1
466	426	1	2	3	2	3	1	2146	103	173	84	28	16	1	0
467	426	2	2	3	2	3	1	2405	415	742	75	163	24	3	1
468	426	3	2	3	2	3	1	2283	377	645	81	108	17	2	1
469	426	4	2	3	2	3	1	2345	535	985	72	174	20	3	1
470	426	5	2	3	2	3	1	2315	171	295	85	33	12	1	0
471	428	1	2	2	2	2	1	629	249	76	92	40	9	1	0
472	428	2	2	2	2	2	1	793	436	170	90	37	5	1	0
473	428	3	2	2	2	2	1	1416	446	303	88	55	7	1	1
474	428	4	2	2	2	2	1	1615	235	150	79	28	7	1	0
475	428	5	2	2	2	2	1	1003	242	118	72	12	3	0	0
476	429	1	2	1	2	3	1	1312	441	417	76	84	11	2	1
477	429	2	2	1	2	3	1	1306	514	492	88	251	29	5	1
478	429	3	2	1	2	3	1	1306	398	402	90	148	22	3	1
479	429	4	2	1	2	3	1	1260	324	310	76	60	11	1	0
480	432	1	1	2	1	3	0	-1978	70	67	100	34	30	1	0
481	432	2	1	2	1	3	0	2378	60	58	100	44	44	1	0
482	432	3	1	2	1	3	0	1387	65	44	100	13	17	0	.
.83	433	1	2	2	2	3	1	2288	470	969	82	206	26	4	1
484	433	2	2	2	2	3	1	2304	199	434	94	82	25	2	0
485	433	3	2	2	2	3	1	2256	120	249	86	48	24	1	0
486	433	4	2	2	2	3	1	2200	24	44	100	13	32	0	0
487	434	1	2	2	2	3	1	965	633	428	86	126	12	2	1
488	434	2	2	2	2	3	1	832	410	281	88	71	10	1	0
489	434	3	2	2	2	3	1	1079	591	535	83	107	11	2	1
490	434	4	2	2	2	3	1	792	293	195	91	64	13	1	0
491	435	1	2	2	2	3	1	u41	112	51	62	11	6	0	0
492	435	2	2	2	2	3	1	899	862	578	64	73	5	1	1
493	435	3	2	2	2	3	1	625	408	211	64	46	7	1	0
494	435	4	2	2	2	3	1	787	432	299	74	56	8	1	0
495	435	5	2	2	2	3	1	691	147	75	74	22	9	0	0
496	436	1	2	1	2	3	0	766	62	23	100	8	7	0	0
497	436	2	2	1	2	3	0	818	365	192	100	99	16	2	0
498	436	3	2	1	2	3	0	660	158	69	100	14	5	0	0
499	436	4	2	1	2	3	0	717	276	137	100	34	7	1	0

Figure B-1. Database (Cont'd)

12/24/81	FINAL REPORT	PAGE 11

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
500	436	5	2	1	2	3	0	686	81	35	100	3	2	0	0
501	439	1	1	2	1	3	0	1842	140	202	100	97	42	2	0
502	439	2	1	2	1	3	0	1793	123	168	100	70	34	1	0
503	439	3	1	2	1	3	0	1999	147	219	100	70	29	1	0
504	439	4	1	2	1	3	0	1918	245	359	100	152	37	3	1
505	439	5	1	2	1	3	0	2083	192	328	100	69	22	1	0
506	442	1	1	2	3	3	0	733	40	20	100	18	26	0	0
507	442	2	1	2	3	3	0	918	115	49	100	41	22	1	0
508	442	3	1	2	3	3	0	932	972	455	100	473	146	1	1
509	442	4	1	2	3	3	0	917	195	123	100	43	3	9	0
510	445	1	1	2	1	2	0	972	69	48	100	60	52	1	0
511	445	2	1	2	1	2	0	1245	100	99	100	57	33	1	0
512	445	3	1	2	1	2	0	1310	83	79	100	40	28	1	0
513	445	4	1	2	1	2	0	1101	62	45	100	39	38	1	0
514	446	1	1	3	3	3	1	1853	759	1068	87	577	46	11	1
515	446	2	1	3	3	3	1	1574	364	398	80	166	27	3	1
516	446	3	1	3	3	3	1	1823	434	556	86	83	11	2	0
517	446	4	1	3	3	3	1	1510	259	156	79	65	15	1	0
518	448	1	1	2	3	3	1	1336	94	105	59	5	3	0	0
519	448	2	1	2	3	3	1	1331	507	572	80	264	31	5	1
520	448	3	1	2	3	3	1	1725	543	733	71	56	6	1	0
521	448	4	1	2	3	3	1	1824	158	236	58	20	8	0	0
522	450	1	2	2	3	3	1	1971	178	271	89	43	15	1	0
523	450	2	2	2	3	3	1	2107	936	1504	94	199	13	4	1
524	450	3	2	2	3	3	1	2143	852	1444	81	152	11	3	1
525	450	4	2	2	3	3	1	2127	230	393	86	33	9	1	0
526	454	1	2	2	2	2	1	2086	660	885	67	109	10	2	1
527	454	2	2	2	2	2	1	2221	778	1129	65	129	10	2	1
528	454	3	2	2	2	2	1	2465	761	.346	57	193	15	4	1
529	454	4	2	2	2	2	1	2324	696	1138	67	138	12	3	1
530	455	1	2	1	2	3	0	382	240	75	100	53	13	1	0
531	455	2	2	1	2	3	0	300	218	59	100	47	13	1	0
532	455	3	2	1	2	3	0	367	290	92	100	206	43	4	1
533	411	1	1	3	1	3	0	2936	134	215	100	68	31	1	0
534	411	2	1	3	1	3	0	2696	187	268	100	139	44	3	1
535	411	3	1	3	1	3	0	3022	137	221	100	65	28	1	0
536	411	4	1	3	1	3	0	3017	77	132	100	19	15	0	0
537	505	1	1	2	2	2	1	1320	192	209	92	125	38	2	1
538	505	2	1	2	2	2	1	1623	249	336	88	94	23	2	1
539	505	3	1	2	2	2	1	1138	190	182	94	91	29	2	1
540	507	1	2	2	2	3	1	1082	357	239	72	114	19	2	1
541	507	2	2	2	2	3	1	1051	295	189	82	92	19	2	1
542	507	3	2	2	2	3	1	1182	309	221	75	70	14	1	1
543	507	4	2	2	2	3	1	1504	502	479	66	112	13	2	1
544	509	1	1	3	2	3	1	2490	234	381	100	81	21	1	1
545	509	2	1	3	2	3	1	2472	201	239	93	111	33	2	0
546	509	3	1	3	2	3	1	2344	159	261	95	93	35	2	1
547	509	4	1	3	2	3	1	2363	154	262	98	104	41	2	1
548	510	1	1	3	2	2	0	2574	225	420	100	93	25	2	0
549	510	2	1	3	2	2	0	2469	153	241	100	48	16	1	0

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 12

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON-FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
550	510	3	1	3	2	2	0	2364	146	223	100	80	33	1	0
551	511	1	1	2	2	3	1	1432	480	576	90	230	29	4	1
552	511	2	1	2	2	3	1	1058	150	136	89	62	25	1	0
553	512	1	1	3	2	3	1	1993	595	793	83	213	21	4	1
554	512	2	1	3	2	3	1	2022	213	348	89	101	28	2	1
555	514	1	2	1	1	3	0	98	9	0	100	2	10	0	0
556	514	2	2	1	1	3	0	144	42	3	100	7	10	0	0
557	519	1	1	3	2	2	1	2001	232	411	87	107	28	2	1
558	519	2	1	3	2	2	1	1854	291	470	87	192	40	4	1
559	519	3	1	3	2	2	1	1518	120	153	80	18	9	0	0
560	521	1	1	3	1	2	0	1890	132	180	100	28	13	1	0
561	521	2	1	3	1	2	0	2044	149	200	100	43	17	1	0
562	528	1	3	2	3	2	0	305	698	213	100	244	21	4	1
563	528	2	3	2	3	2	0	329	782	257	100	293	23	5	1
564	528	3	3	2	3	2	0	352	985	347	100	503	31	9	1
565	528	4	3	2	3	2	0	275	602	.66	100	131	13	2	1
566	529	1	1	1	2	3	0	500	226	84	100	168	44	3	1
567	529	2	1	1	2	3	0	870	219	153	100	150	42	3	1
568	529	3	1	1	2	3	0	656	243	126	100	100	25	2	0
569	530	1	1	2	1	2	0	693	221	118	100	54	15	1	0
570	530	2	1	2	1	2	0	720	144	85	100	51	21	1	0
571	531	1	2	2	2	2	0	1990	452	409	100	105	16	2	0
572	531	2	2	2	2	2	0	2409	435	475	100	92	13	2	0
573	531	3	2	2	2	2	0	1941	417	374	100	76	11	1	0
574	532	1	2	3	3	2	1	2685	448	885	97	295	39	5	1
575	532	2	2	3	3	2	1	2589	249	510	97	161	39	3	1
576	534	1	1	2	2	2	0	.609	143	201	100	40	14	1	0
577	534	2	1	2	2	2	0	1472	160	199	100	85	32	2	0
578	534	3	1	2	2	2	0	1782	66	105	100	11	10	0	0
579	535	1	1	2	3	2	1	1595	608	769	62	188	19	3	1
580	535	2	1	2	3	2	1	1797	803	1167	67	344	26	6	1
581	535	3	1	2	3	2	1	1322	761	818	77	356	28	6	1
582	535	4	1	2	3	2	1	1392	439	496	74	140	19	3	1
583	536	1	1	2	3	2	1	1915	391	622	69	125	19	2	1
584	536	2	1	2	3	2	1	2078	496	912	76	176	21	3	1
585	537	1	.	2	2	2	1	2368	128	187	81	33	16	1	0
586	537	2	1	2	2	2	1	2358	401	550	88	265	40	5	1
587	538	1	1	3	3	3	1	2931	233	400	74	53	14	1	0
588	538	2	1	3	3	3	1	3514	214	450	71	50	14	1	0
589	538	3	1	3	3	3	1	3316	127	257	74	36	17	1	0
590	540	1	1	2	2	2	1	1735	324	531	68	96	18	2	0
591	540	2	1	2	2	2	1	1823	479	815	85	151	19	3	1
592	540	3	1	2	2	2	1	1308	126	160	43	26	13	1	0
593	541	1	1	2	2	2	1	686	184	96	86	71	23	1	0
594	541	2	1	2	2	2	1	921	209	159	30	71	21	1	0
595	541	3	1	2	2	2	1	976	205	165	19	71	21	1	0
596	541	4	1	2	2	2	1	678	120	26	25	42	21	1	0
597	542	1	1	3	1	2	0	1630	89	98	100	21	14	0	0
598	542	2	1	3	1	2	0	1823	132	172	100	39	18	1	0
599	542	3	1	3	1	2	0	2020	132	200	100	41	18	1	0

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 13

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON-FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
600	547	1	1	2	2	2	1	1680	121	190	70	32	16	1	0
601	547	2	1	2	2	2	1	1752	168	273	80	65	23	1	0
602	547	3	1	2	2	2	1	1954	108	305	80	79	43	1	0
603	553	1	1	2	3	3	1	1644	297	339	44	60	12	1	0
604	553	2	1	2	3	3	1	1581	348	425	60	72	12	1	0
605	553	3	1	2	3	3	1	1790	284	383	50	45	10	1	0
606	553	4	1	2	3	3	1	1103	137	138	56	28	12	1	0
607	557	1	1	1	2	3	0	1325	412	338	100	735	107	13	1
608	557	2	1	1	2	3	0	1252	389	298	100	497	77	9	1
609	558	1	1	1	1	2	0	2427	414	301	100	152	22	3	1
610	558	2	1	1	1	2	0	1416	360	135	100	102	17	2	0
611	559	1	1	1	2	2	1	680	480	259	63	137	17	3	1
612	559	2	1	1	2	2	1	809	509	306	66	112	13	2	1
613	559	3	1	1	2	2	1	741	439	256	67	119	16	2	1
614	561	1	2	1	1	3	0	1239	141	113	100	84	36	2	0
615	561	2	2	1	1	3	0	967	240	175	.00	114	28	2	0
616	561	3	2	1	1	3	0	1058	189	155	100	92	29	2	0
617	561	4	2	1	1	3	0	432	64	22	100	18	16	0	0
618	566	1	1	3	1	2	1	2166	308	605	71	107	21	2	1
619	566	2	1	3	1	2	1	2656	420	1011	81	375	54	7	1
620	566	3	1	3	1	2	1	1769	161	238	89	75	27	1	0
621	567	1	1	2	2	2	1	1749	170	267	83	47	17	1	0
622	567	2	1	2	2	2	1	1737	182	279	54	34	11	1	0
623	567	3	1	2	2	2	1	2093	218	408	84	104	29	2	1
624	567	4	1	2	2	2	1	1938	243	406	83	138	34	3	1
625	601	1	1	2	2	4	0	2074	264	430	100	578	131	11	1
626	601	2	1	2	2	4	0	2354	324	587	100	*95	351	34	1
627	601	3	1	2	2	4	0	1872	348	514	100	*72	305	32	1
628	601	4	1	2	2	4	0	1949	350	525	100	*93	461	49	1
629	602	1	2	3	2	2	1	860	188	162	72	26	8	1	0
630	602	2	2	3	2	2	1	806	202	163	88	56	17	1	0
631	602	3	2	3	2	2	1	886	566	501	76	178	19	3	1
632	602	4	2	3	2	2	1	917	182	167	86	30	10	1	0
633	604	1	2	2	1	2	0	1201	245	260	100	91	22	2	0
634	604	2	2	2	1	2	0	1429	254	336	100	234	55	4	1
635	604	3	2	2	1	2	0	1459	247	318	100	143	35	3	0
636	604	4	2	2	1	2	0	1346	264	314	100	136	31	3	0
637	608	1	2	1	2	4	0	427	300	115	100	50	10	1	0
638	608	2	2	1	2	4	0	562	444	206	100	94	13	2	0
639	608	3	2	1	2	4	0	757	422	245	100	162	23	3	0
640	608	4	2	1	2	4	0	766	459	258	100	141	18	3	0
641	611	1	1	2	2	3	1	2682	350	788	82	156	27	3	1
642	611	2	1	2	2	3	1	2370	281	543	78	133	28	2	1
643	611	3	1	2	2	3	1	4662	237	897	76	121	31	2	1
644	625	1	1	2	2	1	1	1337	139	148	93	86	37	2	0
645	625	2	1	2	2	1	1	1817	163	247	88	86	32	2	0
646	625	3	1	2	2	1	1	1925	290	476	97	265	55	5	1
647	625	4	1	2	2	1	1	1820	136	212	85	63	28	1	0
648	626	1	1	2	2	2	1	843	406	322	77	111	16	2	0
649	626	2	1	2	2	2	1	1095	438	413	74	221	30	4	1

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 14

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
650	626	3	1	2	2	2	1	1114	1013	829	67	507	30	9	1
651	626	4	1	2	2	2	1	1076	497	492	75	150	18	3	1
652	627	1	2	2	2	2	0	887	314	253	100	56	11	1	0
653	627	2	2	2	2	2	0	1326	353	413	100	235	40	4	1
654	627	3	2	2	2	2	0	1281	360	395	100	167	28	3	0
655	627	4	2	2	2	2	0	1118	333	331	100	158	29	3	0
656	628	1	2	2	1	3	0	4606	166	444	100	70	25	1	0
657	628	2	2	2	1	3	0	4808	146	375	100	68	28	1	0
658	628	3	2	2	1	3	0	4886	211	560	100	484	137	9	1
659	630	1	1	2	3	3	1	857	349	245	78	51	9	1	0
660	630	2	1	2	3	3	1	895	1543	1107	62	681	27	12	1
661	630	3	1	2	3	3	1	1075	893	611	61	358	24	7	1
662	630	4	1	2	3	3	1	1029	426	389	85	125	18	2	0
663	631	1	1	2	2	2	1	3463	,68	510	93	86	31	2	1
664	631	2	1	2	2	2	1	2796	226	538	84	114	30	2	1
665	631	3	1	2	2	2	1	3281	283	786	82	113	24	2	1
666	631	4	1	2	2	2	1	2831	149	378	95	75	30	1	1
667	637	1	2	3	1	2	1	3074	662	1876	82	363	33	7	1
668	637	2	2	3	2	2	1	3884	600	2248	76	232	23	4	1
669	637	3	2	3	2	2	1	3929	989	3718	90	662	40	12	1
670	637	4	2	3	1	2	1	4157	1001	3907	89	594	36	11	1
671	641	1	1	2	2	3	1	2307	53	97	100	19	21	0	0
672	641	2	1	2	2	3	1	2633	89	167	97	24	16	0	0
673	641	3	1	2	2	3	1	3064	499	1184	91	320	38	6	1
674	643	1	1	3	1	3	1	1853	68	85	86	17	15	0	0
675	643	2	1	3	1	3	1	2177	676	1126	87	798	71	15	1
676	643	3	1	3	1	3	1	2659	208	422	84	87	25	2	1
677	645	1	1	3	2	2	0	3195	99	228	100	53	32	1	0
678	645	2	1	3	2	2	0	3710	101	285	100	146	87	3	1
679	645	3	1	3	2	2	0	3847	105	320	100	140	80	3	1
680	646	1	2	3	1	2	0	3593	497	1235	100	552	67	11	1
681	646	2	2	3	1	2	0	4608	468	1418	100	*59	161	23	1
682	646	3	2	3	1	2	0	5213	413	1340	100	553	80	10	1
683	646	4	2	3	1	2	0	2929	158	788	100	75	28	1	1
684	653	1	1	1	1	2	0	734	308	195	100	55	11	1	0
685	653	2	1	1	1	2	0	791	430	262	100	193	27	4	1
686	653	3	1	1	1	2	0	751	414	244	100	173	25	3	1
687	653	4	1	1	1	2	0	549	301	137	100	37	7	1	0
688	657	1	2	2	2	2	0	1993	370	517	100	176	29	3	1
689	657	2	2	2	2	2	0	1972	413	586	100	232	34	4	1
690	657	3	2	2	2	2	0	2186	588	787	100	443	45	8	1
691	657	4	2	2	2	2	0	1639	413	501	100	231	34	4	1
692	658	1	2	1	1	2	0	746	286	137	100	368	77	7	1
693	658	2	2	1	1	2	0	941	204	117	100	87	26	2	0
694	658	3	2	1	1	2	0	1080	165	103	100	96	35	2	0
695	658	4	2	1	1	2	0	1063	204	130	100	103	30	2	0
696	659	1	1	1	2	3	1	1150	293	239	82	109	22	2	1
697	659	2	1	1	2	3	1	1222	365	318	73	144	24	3	1
698	659	3	1	1	2	3	1	1510	180	158	76	76	25	1	0
699	659	4	1	1	2	3	1	1639	108	100	89	51	29	1	0

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 15

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON- FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
700	660	1	1	1	1	2	0	1065	204	111	100	76	22	1	0
701	660	2	1	1	1	2	0	1057	346	227	100	311	54	6	1
702	660	3	1	1	1	2	0	1070	338	231	100	197	35	4	1
703	660	4	1	1	1	2	0	1018	427	293	100	341	48	6	1
704	661	1	2	2	2	4	1	999	273	202	68	68	15	1	1
705	661	2	2	2	2	4	1	977	336	257	85	113	20	2	1
706	661	3	2	2	2	4	1	1111	327	289	79	104	19	2	1
707	661	4	2	2	2	4	1	1277	441	432	75	126	17	2	1
708	662	1	2	2	2	2	1	960	372	254	61	97	16	2	1
709	662	2	2	2	2	2	1	904	423	276	67	128	18	2	1
710	662	3	2	2	2	2	1	917	302	204	73	107	21	2	0
711	662	4	2	2	2	2	1	936	326	232	66	99	18	2	0
712	663	1	2	2	2	2	0	1017	543	324	100	240	27	4	1
713	663	2	2	2	2	2	0	1064	627	375	100	309	30	6	1
714	663	3	2	2	2	2	0	1123	677	436	100	351	31	6	1
715	663	4	2	2	2	2	0	1131	497	342	100	254	31	5	1
716	664	1	1	3	2	2	1	2684	202	450	80	105	31	2	1
717	664	2	1	3	2	2	1	2619	222	489	80	154	42	3	1
718	664	3	1	3	2	2	1	2507	204	443	87	124	36	2	1
719	664	4	1	3	2	2	1	2390	116	225	69	50	26	1	0
720	665	1	2	3	2	3	1	1773	199	253	89	130	39	2	1
721	665	2	2	3	2	3	1	1927	173	222	85	96	33	2	1
722	665	3	2	3	2	3	1	2031	192	266	85	110	35	2	1
723	665	4	2	3	2	3	1	1936	209	257	78	119	34	2	1
724	666	1	2	1	2	4	1	991	245	184	80	81	20	2	1
725	666	2	2	1	2	4	1	1224	427	461	85	255	36	5	1
726	666	3	2	1	2	4	1	1166	449	443	87	262	35	5	1
727	666	4	2	1	2	4	1	1349	432	479	87	231	32	4	1
728	668	1	2	1	1	3	0	977	132	113	100	94	43	2	0
729	668	2	2	1	1	3	0	1097	163	161	100	160	59	3	0
730	668	3	2	1	1	3	0	1241	123	139	100	175	86	3	0
731	668	4	2	1	1	3	0	1266	24	28	100	15	38	0	0
732	669	1	2	2	2	3	0	1151	406	269	100	135	20	3	1
733	669	2	2	2	2	3	0	876	701	507	100	765	66	14	1
734	669	3	2	2	2	3	0	1148	408	265	100	147	22	3	1
735	669	4	2	2	2	3	0	888	184	90	100	52	17	1	0
736	670	1	1	3	3	3	1	2463	1135	1808	49	221	12	4	1
737	670	2	1	3	3	3	1	2491	1433	2268	54	458	19	8	1
738	670	3	1	3	3	3	1	2222	888	1232	45	161	11	3	1
739	670	4	1	3	3	3	1	1836	571	620	34	71	8	1	1
740	671	1	1	2	2	2	1	1172	290	191	87	107	22	2	0
741	671	2	1	2	2	2	1	1474	355	322	87	130	22	2	1
742	671	3	1	2	2	2	1	1411	459	389	90	188	25	3	1
743	671	4	1	2	2	2	1	1300	329	251	85	112	20	2	0
744	672	1	2	2	2	3	0	2249	399	650	100	359	54	7	1
745	672	2	2	2	2	3	0	2570	331	586	100	263	48	5	1
746	672	3	2	2	2	3	0	2570	159	271	100	88	34	2	0
747	672	4	2	2	2	3	0	2598	90	154	100	43	29	0	0
748	673	1	1	2	1	3	-	1939	161	269	87	94	35	2	0
749	673	2	1	2	1	3	1	2468	391	821	88	456	70	8	1

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 16

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON-FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
750	673	3	1	2	1	3	1	2564	211	474	75	110	31	2	1
751	673	4	1	2	1	3	1	2451	115	255	79	76	40	1	0
752	674	1	1	2	2	3	1	1993	496	826	90	856	103	16	1
753	674	2	1	2	2	3	1	2632	487	1150	89	473	58	9	1
754	674	3	1	2	2	3	1	2693	567	1332	90	436	46	8	1
755	674	4	1	2	2	3	1	3013	431	1150	89	351	49	6	1
756	675	1	1	3	2	2	1	2257	385	790	90	272	43	5	1
757	675	2	1	3	2	2	1	2674	282	638	92	234	50	4	1
758	675	3	1	3	2	2	1	3084	523	1333	84	404	46	7	1
759	675	4	1	3	2	2	1	3265	311	846	86	247	44	5	1
760	676	1	1	3	2	2	1	2596	669	1271	73	329	30	6	1
761	676	2	1	3	2	2	1	2579	744	1406	64	309	25	6	1
762	676	3	1	3	2	2	1	2991	898	1880	70	409	28	7	1
763	676	4	1	3	2	2	1	1736	713	915	71	366	31	7	1
764	677	1	1	1	2	2	0	704	279	112	100	92	20	2	0
765	677	2	1	1	2	2	0	1127	312	218	100	181	35	3	1
766	677	3	1	1	2	2	0	1373	473	365	100	800	102	15	1
767	677	4	1	1	2	2	0	1140	338	253	100	261	47	5	1
768	678	1	2	2	2	2	0	780	216	132	100	93	26	2	0
769	678	2	2	2	2	2	0	816	266	153	100	154	35	3	1
770	678	3	2	2	2	2	0	1073	279	224	100	223	48	4	1
771	678	4	2	2	2	2	0	1046	331	250	100	235	43	4	1
772	679	1	2	2	2	2	1	927	377	215	70	124	20	2	0
773	679	2	2	2	2	2	1	948	369	199	82	170	28	3	1
774	679	3	2	2	2	2	1	1114	511	324	67	150	18	3	1
775	679	4	2	2	2	2	1	1116	559	363	74	157	17	3	1
776	680	1	2	1	1	3	0	1094	96	68	100	53	33	1	0
777	680	2	2	1	1	3	0	1219	194	166	100	128	40	2	0
778	680	3	2	1	1	3	0	1298	156	148	100	258	99	5	0
779	680	4	2	1	1	3	0	1132	22	18	100	17	47	0	0
780	601	0	1	2	2	4	0	2010	315	462	100	465	89	8	1
781	602	0	2	3	2	2	1	972	327	318	89	45	8	1	0
782	604	0	2	2	1	2	0	1431	246	325	100	240	59	4	1
783	606	0	2	1	1	1	0	1209	108	84	100	39	22	1	0
784	607	0	2	1	2	2	1	1386	318	368	79	129	24	2	1
785	609	0	1	3	1	1	0	2244	93	207	100	41	27	1	0
786	611	0	1	2	2	3	1	2840	318	757	86	213	40	4	1
787	612	0	2	2	2	2	0	760	926	551	100	*40	66	19	1
788	613	0	2	1	1	1	0	369	300	111	100	545	109	10	1
789	617	0	2	2	1	2	1	2127	192	258	86	41	13	1	0
790	618	0	1	2	1	2	1	2145	189	239	94	130	41	2	1
791	620	0	1	2	2	2	0	1269	453	361	100	203	27	4	1
792	622	0	1	2	3	2	1	948	333	243	62	101	18	2	1
793	623	0	2	1	2	2	0	669	555	225	100	118	13	2	0
794	625	0	1	2	2	1	1	1776	298	413	94	187	38	3	1
795	626	0	1	2	2	2	1	1075	591	591	86	294	30	5	1
796	627	0	2	2	2	2	0	1308	396	471	100	240	36	4	1
797	628	0	2	2	1	3	0	4812	213	573	100	284	80	5	1
798	629	0	1	3	2	3	1	4266	333	1353	95	309	56	6	1
799	630	0	1	2	3	3	1	793	1068	713	76	*65	66	21	1

Figure B-1. Database (Cont'd)

12/24/81 FINAL REPORT PAGE 17

REC NUM	I/S NUM	OBS NUM	TYPE	LANES MAIN	LANES CROSS	SPEED LIMIT	CONTROL DEVICE	VOLUME MAIN	VOLUME CROSS	CON-FLICT	PCT STOP	TOTAL DELAY	AVE DELAY	AVE QUEUE	JUDG
800	631	0	1	2	2	2	1	3150	387	1024	84	275	43	5	1
801	633	0	1	2	2	3	1	1173	693	657	83	502	43	9	1
802	634	0	2	3	3	2	1	2289	351	600	52	98	17	2	0
803	636	0	1	2	2	3	1	1476	168	197	93	121	43	2	0
804	637	0	2	3	2	2	1	3900	816	3083	88	747	55	14	1
805	641	0	1	2	2	3	1	2838	495	1041	96	980	119	18	1
806	643	0	1	3	1	3	1	1887	525	753	94	558	64	1	1
807	645	0	1	3	2	2	0	3255	174	430	100	445	154	8	1
808	646	0	2	3	1	2	0	4116	477	1387	100	*29	226	33	1
809	647	0	2	1	1	2	0	960	243	166	100	99	24	2	0
810	649	0	2	2	2	2	0	622	459	216	100	129	17	2	0
811	650	0	1	1	1	2	0	900	85	152	100	90	19	2	0
812	651	0	1	1	1	2	0	1083	117	92	100	54	28	1	0
813	652	0	2	1	2	2	0	1044	232	175	100	98	26	2	0
814	653	0	1	1	1	2	0	849	417	280	100	219	32	4	1
815	654	0	2	1	1	2	0	960	184	130	100	69	23	1	0
816	655	0	2	1	2	2	0	1365	201	185	100	51	15	1	0
817	656	0	2	2	2	3	0	2892	212	507	100	103	29	2	0

Figure B-1. Database (Cont'd)

APPENDIX C

DATA COLLECTION PROCEDURES

As part of Task 1, a careful study of the data definitions of the two warrants was used to develop a final set of descriptive characteristics which were necessary for the evaluation of the warrants. The set of characteristics and the method of obtaining them is defined below:

1. Total side street delay--obtained from a delay study;
2. Average side street delay--obtained from a delay study;
3. Average queue--obtained from a delay study;
4. Traffic volumes--obtained from a turning movement and percent stopping count;
5. Number of right-turning vehicles--obtained from a turning movement count;
6. Number of trucks--obtained from a classification count;
7. Number of lanes per approach--obtained from a field sketch;
8. Intersection geometry--obtained from a field sketch;
9. Pavement markings--obtained from a field sketch;
10. Traffic signal equipment--obtained from a field inventory;
11. Approach speed--obtained from a field inventory;
12. Encompassing community size--obtained from interviews of local officials;
13. Adjacent land use, driveways, curb usage--obtained from photographs; and
14. Traffic generators--obtained from field observations and interviews of local officials.

To gather this data, four types of studies were performed at approximately 200 signalized and non-signalized intersections in the United States. The studies included the following:

- Intersection delay studies;
- Percent stopping studies;
- Traffic volume counts; and
- Physical inventories.

Each of these studies is briefly described below:

Intersection Delay Study - The delay study followed the methodology for conducting an intersection delay study described by Reilly[1/]. The time period which was observed was selected so as to encompass the peak demand period.

Percent Stopping Study - This technique is also described by Reilly. This study was performed only at signalized intersections. It encompassed the same time intervals and locations as those used for the intersection delay study. It included as a by-product a volume count on each approach.

Volume Counts - As mentioned above, volume count observations were obtained for signalized intersections as part of the percent stopping study. For unsignalized intersections, separate volume counts were conducted as the basis for estimating delay per vehicle. Since an estimate of percent right turns is required for applying the NCHRP warrant, the volume counts included whether or not a vehicle turned right as well as classifying it as an automobile, truck, or motorcycle.

Physical Inventory - A physical inventory was conducted at each of the studied intersections. This inventory included all traffic control devices within 100 feet of the intersection; a sketch of the intersection; and photographs of the approaches. This inventory was conducted by a JHK professional and comments regarding any atypical features were recorded.

The techniques for conducting the studies were refined through a pilot test which was conducted at the Northwestern University Traffic Institute. Four sites in the Evanston area were studied using NUTI staff and Reilly's techniques. From these preliminary studies, the specific tasks that each member of the field crew would perform during the data collection effort were determined.

It was found that a four-person field crew could collect all the necessary data for all geometric configurations of intersections. In addition, a JHK professional would be on-site to supervise the data collection effort. The specific tasks that each person performed are described below.

The JHK professional:

1. Completed the Intersection Data Sheet, being sure to describe the traffic generator.
2. Took photographs of each intersection approach.
3. Supervised all counts.
4. Made an intuitive judgement of whether or not a signal was warranted. This was based on such factors as availability of gaps, perceived average delay of vehicles, and an "informal judgement" by the engineer as to whether or not the intersection does or would work better with a signal than without one.

Person No. 1:

1. Acted as the crew chief during the traffic counts. He insured that all persons knew which approaches they were to count, were located properly to conduct the count, knew how long the count was to be conducted, and gave the signals which began and ended the traffic counts.
2. Performed a delay study on the delay approach. This was done using the procedures described in A Technique for Measurement of Delay at Intersections, Volume 3, User's Manual.

Person No. 2 conducted the percent stopping-classification-turning movement count, or the classification-turning movement count depending on the method of intersection control as noted on Figures C-1 and C-2. The percent stopping-classification-turning movement count was conducted using the procedures described in A Technique for Measurement of Delay of Intersections, Volume 3, User's Manual. The only difference was that, in addition to determining whether or not a vehicle stopped, each vehicle was classified as an automobile, truck, or motorcycle and its movement at the intersection was noted.

Persons No. 3 and No. 4 conducted the classification-turning movement counts as noted on Figures C-1 and C-2.

Another by-product of the pilot test was the development of the data collection forms to be used. These forms are described below:

1. Intersection Data Sheet (Figure C-3)--Completed by the JHK representative. This form shows all general data for the intersection;
2. Intersection Delay Study Form (Figure C-4)--Completed by Person No. 1 while conducting a delay study;
3. Percent Stopping Study Form (Figure C-5)--Completed by Person No. 2 while conducting a percent stopping-classification-turning movement count; and

1/ Reilly, W. R., C. C. Gardner, and J. H. Kell, A Technique for Measurement of Delay at Intersections, San Francisco, CA, JHK & Associates, September 1976, (FHWA-RD-76-135), three Vols.

4. Turning Movement and Classification Count Form (Figure C-6)--Completed by Persons No. 1, No. 2, No. 3, or No. 4 while conducting a classification-turning movement count.

Data were collected in six cities across the United States. The cities were Atlanta, Denver, Hartford, Phoenix, Tucson, and Washington, D.C. The studies were started in Washington in the fall of 1980 and continued through the summer of 1981. Data were collected in Washington during the winter of 1980 whenever the weather permitted it. In the spring, the Co-Principal Investigator visited each of the other five cities to help organize the studies, to train the temporary personnel, to identify the study locations, and to brief the local JHK representative on the techniques of conducting the study.

Prior to traveling to a city, the local JHK office was contacted and the project was described to the office manager. The description included the project objective, the project methodology, and the type of intersections which were necessary for data collection. In addition, the Co-PI requested that local mapping be obtained and that a preliminary list of candidate intersections be prepared.

Also before visiting a city, the Co-PI contacted the local traffic engineer and the traffic division of the local police department. The project was described and an interview meeting was arranged with each of them.

When the Co-PI arrived at a city, he first went to the JHK office and discussed the project with the local staff member that was to be involved with the project. During this meeting, the list of candidate sites which the local office had developed was plotted on a map.

The next step of the process was to rent an airplane and fly over the city, looking for potential count sites. These were identified by locating exits from large parking lots, which were easily identified from the air. These locations were plotted on a map. After the flight, the rest of the day was spent driving around the city to check the locations which had been identified up to that point and to identify any new candidates.

When identifying intersections for study, it was determined that it was best to avoid locations which were near areas of construction, which were controlled by four-way stop signs, which had poor sight distance, or which were on steep grades. These conditions introduced extraneous variables that would require special control.

Day 2 began with interviews with the police department and the traffic engineer. A list of candidate sites was obtained from each of them and these locations were plotted on the map.

The rest of day 2 and the morning of day 3 was spent driving around the city to check the candidate sites and to find new sites. From all of these sources, a final list of sites was established by the end of day 3.

On day 4, the Co-PI visited the city offices and obtained any existing volume counts for the intersections to be studied. From these counts, the peak period was identified.

The Co-PI identified approximately 60 candidate locations in each city. Typically, counts were available for only ten of the 60 candidate locations. Originally, the peak periods at the other intersections were going to be determined by placing road tube counters on the side streets and collect count data. However, few of the cities had road tube counters available, so an alternative means of collecting data was developed. Instead of installing mechanical counters, the field crew conducted "short counts" at each intersection at which the peak period had not been previously identified from City counts or from the Co-PI's travels. During these short counts, a volume count was conducted on the study approach of an intersection for at least ten minutes of each half hour between 3:00 and 6:00 PM. Sites were selected so that one person could count two intersections, with a maximum of five minutes of travel time between the intersections. The person would count for ten minutes at Intersection 1; move to Intersection 2 and count ten minutes; move back to Intersection 1, and so on. This process was continued for two hours.

From these counts, the local JHK personnel were able to determine which intersections had strong peaking characteristics and when the peak occurred. The "short count" method was found to be a less expensive and quicker method of determining an intersection's peaking characteristics than installing road tubes. This process typically found that only 30 of the 60 candidate locations had suitable peaking characteristics for further study.

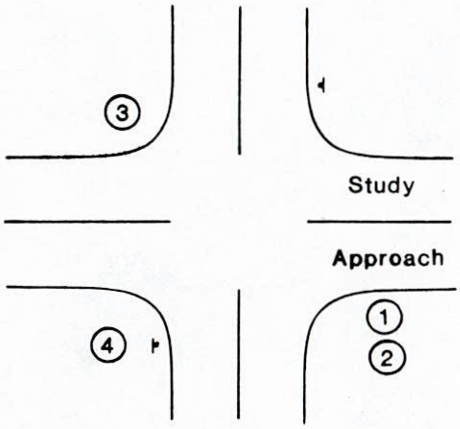
The rest of day 4 was spent training the people involved with the project. The Co-PI explained all the study procedures to the local JHK representative. The methodology of the counts was carefully explained, as was the use of the forms. After the JHK staff member was trained, the field crew, which had been hired by the local staff, was given training. Again, the Co-PI explained how to conduct all the counts. Assignments of duties were made at this time. Day 4 ended with the field crew conducting a delay study at an intersection near the office. This was strictly supervised by the Co-PI and the local JHK representative to ensure that the field crew totally understood how to conduct the studies. The field crew was encouraged to ask questions during this trial run. They were also evaluated by the JHK staff and, if it was felt that they were not able to perform the study, they were replaced.

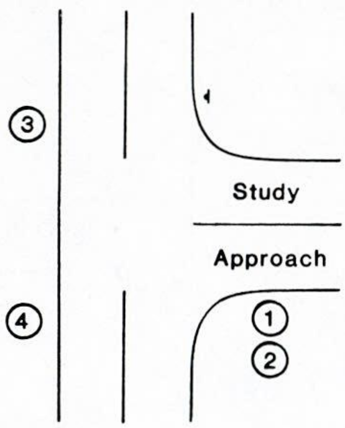
Day 5 was spent doing miscellaneous paper work and conducting a delay study at an intersection. Again, the studies were highly supervised.

The counts were performed for four 25-minute study periods over a two hour period. A five minute break was given between study periods. Counts were not conducted during inclement weather conditions. It took approximately six weeks to collect data in each of the cities.

TWO-WAY MAIN STREET

1. Delay - d.,g.
2. Classification, turn move-t.
3. Classification, turn move:main st, heavy-t.
4. Classification, turn move:main st, light; side street, light-t.

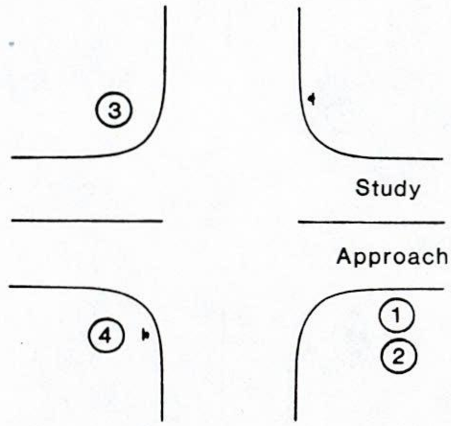


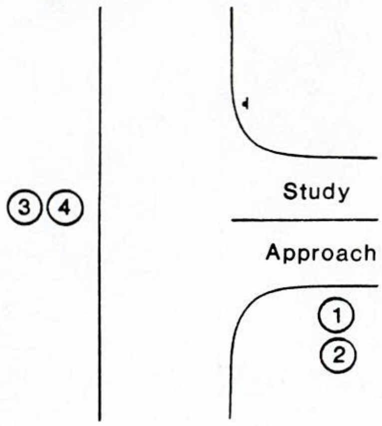


1. Delay - d.,g.
2. Classification, turn move-t.
3. Classification, turn move:main st, heavy-t.
4. Classification, turn move:main st, light-t.

ONE-WAY MAIN STREET

1. Delay - d.,g.
2. Classification, turn move-t.
3. Classification, turn move:main st.-t.
4. Classification, turn move:side st.-t.





1. Delay - d.,g.
2. Classification, turn move-t.
3. Classification, turn move:main st, left lane(s)-t.
4. Classification, turn move:main st, right lane(s)-t.

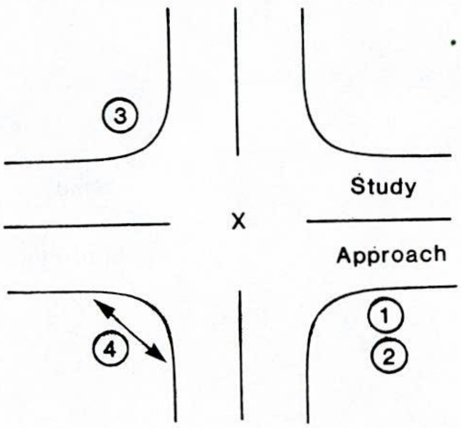
Legend

d = Intersection Delay Study form
g = Intersection Data Sheet
t = Turning Movement and Classification Count form

Figure C-1. Data Collection Assignments - Stop Sign Control

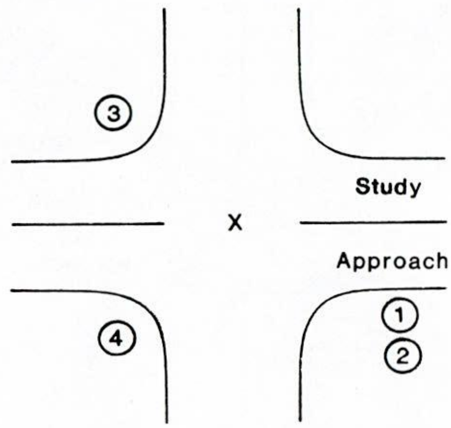
TWO WAY MAIN STREET

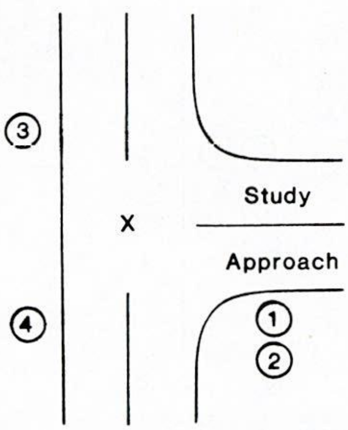
1. Delay - d.,g.
2. % stop, classification, turn move-%
3. Classification, turn move:main st-t.
4. Classification, turn move:main st, side st-t.



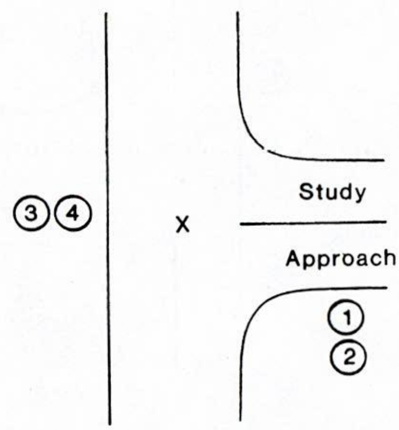
ONE-WAY MAIN STREET

1. Delay - d.,g.
2. % stop, classification, turn move-%
3. Classification, turn move:main st-t.
4. Classification, turn move:side st-t.





1. Delay - d.,g.
2. % stop, classification, turn move-%
3. Classification, turn move:main st-t.
4. Classification, turn move:main st-t.



1. Delay - d.,g.
2. % stop, classification, turn move-%
3. Classification, turn move:main st, left lane(s)-t
4. Classification, turn move:main st, right lane(s)-t

Legend

d = Intersection Delay Study form
g = Intersection Data Sheet
t = Turning Movement and Classification Count form
% = Percent Stopping Study form

Figure C- 2. Data Collection Assignments - Signal Control

INTERSECTION DATA SHEET

CITY ____________________

INTERSECTION OF ____________________ AND ____________________
Main Street / Cross Street

DATE OF COUNT ____________________ TIME OF COUNT ____________________

CONTROLLED BY

☐ STOP SIGN ☐ SIGNAL ☐ POLICE OFFICER

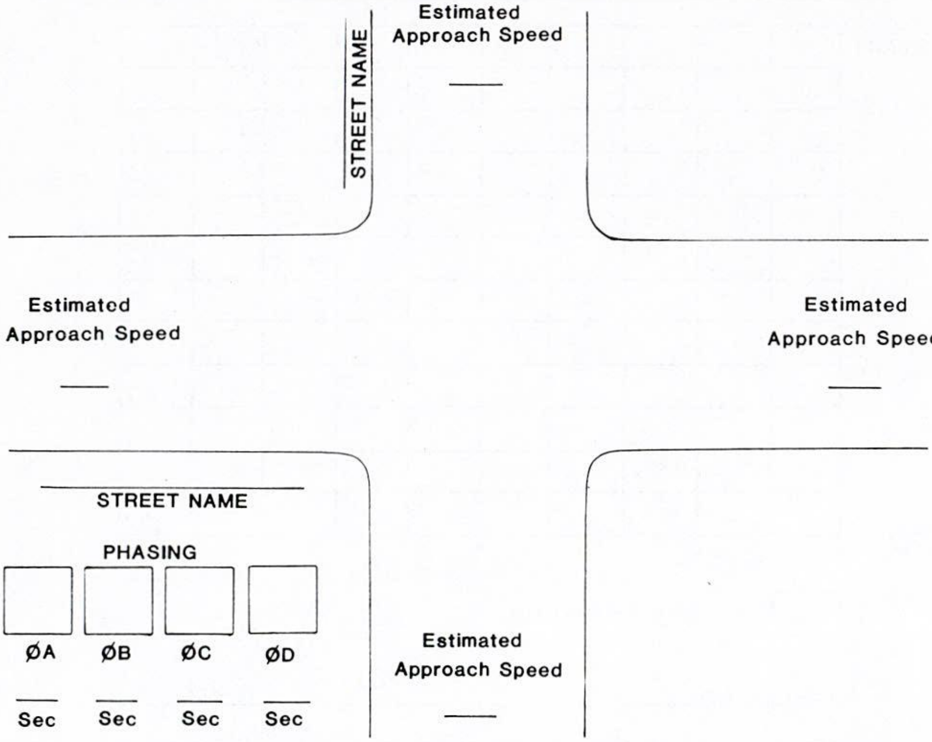
IF SIGNALIZED MODE OF OPERATION

☐ PRETIMED ☐ SEMI-ACTUATED ☐ FULLY ACTUATED

STUDY APPROACH

☐ NB ☐ SB ☐ EB ☐ WB

TRAFFIC GENERATOR ____________________



BASED ON PEAK PERIOD OBSERVATIONS ,
SHOULD THIS INTERSECTION BE SIGNALIZED ? ____________________

COMMENTS ____________________

Figure C- 3. Intersection Data Sheet

INTERSECTION DELAY STUDY

POINT SAMPLE, STOPPED DELAY METHOD

Intersection ____________________ Study Traffic On ____________________

City and State ____________________ Agency ____________________

Day, Date ______________ Study Period ______________ Observer ______________

Study Approach __________ Weather ____________________
NB, SB, EB, WB

If more than one person is studying same approach, explain division of responsibilities. ____________________

INTERVAL BETWEEN SAMPLES = ______ SECS.

START

									7:30 30
									15:00 60
									20:00
									90
									120

OBSERVED TOTAL, ALL SAMPLES ______

| 30 | DENOTES 30TH SAMPLE

COMMENTS: ____________________

Figure C-4. Intersection Delay Study Form

PERCENT STOPPING STUDY

Intersection ______________ Study Traffic On ______________

City and State ______________ Agency ______________

Day, Date ______________ Study Period ______________ Observer ______________

Study Approach ______________ (NB,SB,EB,WB) Weather ______________

If more than one person is studying same approach, explain division of responsibilities. ______________

STOPPING

	LEFT	THRU	RIGHT	TOTAL
A				
T				
M				

NOT STOPPING

	LEFT	THRU	RIGHT	TOTAL
A				
T				
M				

* IF TALLY MARK IS USED, ~~THIS~~ DENOTES A COUNT OF "5"

TOTAL STOPPING ___ TOTAL NOT STOPPING ___

COMMENTS: ______________

Figure C-5. Percent Stopping Study Form

TURNING MOVEMENT AND CLASSIFICATION COUNT

INTERSECTION ______________________ DATE ____________ jhk & associates

TIME OF COUNT	TYPE OF VEHICLE	NORTHBOUND				SOUTHBOUND				EASTBOUND				WESTBOUND				LENGTH OF COUNT (MIN)
		LEFT	THRU	RIGHT	TOTAL	LEFT	THRU	RIGHT	TOTAL	LEFT	THRU	RIGHT	TOTAL	LEFT	THRU	RIGHT	TOTAL	
	A																	
	T																	
	M																	
	A																	
	T																	
	M																	
	A																	
	T																	
	M																	
	A																	
	T																	
	M																	

Figure C-6. Turning Movement and Classification Count Form

APPENDIX D

USER ACCEPTABILITY OF PEAK-HOUR SIGNAL WARRANT CONCEPTS

This appendix outlines activities undertaken by the research team in order to assess the acceptability of potential peak-hour signal warrant concepts and analytical techniques to practicing traffic engineers. User needs and capabilities were considered, as they may affect the value and useability of such a warrant.

A questionnaire was prepared and distributed to participants in a special two-hour workshop session conducted at The Traffic Institute Training Center, Evanston, Illinois on November 17, 1981. The results of this questionnaire are not intended to be, and should not be interpreted as, representative of a national cross-section of potential warrant users. Nevertheless, this limited sampling of responses does yield an indication of warrant acceptability to the engineering community, and it was used as advisory input in the development and analysis of alternative peak-hour signal warrants.

METHODOLOGY

Members of two groups of practicing traffic engineers were invited to attend a special two-hour evening workshop session on peak-hour signal warrants. All members of the Illinois Section of the Institute of Transportation Engineers (approximately 220 individuals) were sent an introductory letter four weeks prior to the workshop. A second, follow-up letter was sent to 35 Illinois Section ITE members who indicated an interest in the workshop session. Copies of these letters are included as Figures D-1 and D-2 respectively.

Similar invitations were sent to 28 individuals registered for a one-week continuing education course entitled Traffic Signal Workshop conducted November 16-20, 1981 by the Traffic Institute.

Information provided to workshop participants prior to the session included:

1. Objectives of NCHRP Project 3-20A;
2. Objectives of the workship session;
3. Summary descriptions of the proposed "NCHRP" and "NAC" warrants; and
4. Summary of warrant data requirements.

Thus, workshop participants were somewhat knowledgeable about concept, application, and format of the two candidate peak-hour warrants prior to the workshop session.

The agenda for the workshop is included as Figure D-3. After a brief introduction to the project, participants were requested to complete questions 1 through 10 of the questionnaire shown in Figure D-4. This strategy was employed to avoid significantly biasing the participant responses related to the importance and acceptable limits of various characteristics related to peak-hour traffic operations.

At this point in the research project, the proposed NCHRP peak-hour signal warrant appeared to hold greater promise than did the proposed NAC warrant. Therefore, the analytical basis of the NCHRP warrant was briefly presented and its application techniques described. No attempt was made to thoroughly educate workshop participants in the use of this proposed warrant. Rather, participants were given the case study work project shown as Figure D-5 after the brief introduction, and were asked to apply the proposed warrant. This was intended to test the comprehensibility of the warrant instructions. Participants then completed questions 11 through 18 of the questionnaire, and the session was concluded with a discussion of the current status and future direction of the research project.

THE TRAFFIC INSTITUTE
NORTHWESTERN UNIVERSITY
555 CLARK ST. P.O. BOX 1409 EVANSTON, IL 60204

NOEL C. BUFE, Ph.D.
Director

October 21, 1981

Dear Illinois Section ITE Member:

We would like to invite you to participate in a special two-hour workshop session dealing with a proposed new warrant for traffic signal installation, based on peak hour conditions. This is your opportunity to help shape the content of a new signal warrant. This session will be held at The Traffic Institute Training Center, Evanston, Illinois on Tuesday evening, November 17, 1981.

The Traffic Institute and JHK and Associates are currently performing a study of alternative peak-hour warrants for the National Cooperative Highway Research Program. The need for a traffic signal warrant based on peak-hour conditions has been identified by traffic engineers. This warrant would be used to supplement the existing warrants in the Manual on Uniform Traffic Control Devices (MUTCD) by providing a basis for determining the need for a traffic signal due to the unique peak-hour conditions that are not fully considered by the other warrants.

Several peak-hour warrant elements have been proposed by various organizations, but have not been verified with regard to the acceptability of the underlying assumptions and the actual numerical values. These elements are being investigated and verified to determine which should be adopted for general use.

The purpose of this special workshop session is to present and test the proposed new warrant within the practicing traffic engineering community. We wish to obtain your input on the acceptability and applicability of the warrant. We will present the proposed warrant, direct a workshop session in applying the warrant to a series of example intersection conditions, and elicit your reactions through a discussion session and questionnaire.

This is your opportunity to become familiar with the proposed new signal warrant, as well as, providing input into the evaluation process that will shape the final format and contents of the warrant. If your organization is currently, or has recently considered the installation of a traffic signal at an intersection where heavy traffic volumes during the peak period indicate the desirability of signal control, but none of the conventional eight signal warrants are met, we would be interested in using this as a case study.

If you are interested in possibly participating in this workshop session, please complete and mail the attached response form prior to November 2, 1981. Approximately one week before the session, we will send additional information about the workshop schedule and the proposed warrant. Following the sessions, we invite you to join us for a reception with refreshments.

Very truly yours,

Robert K. Seyfried

Robert K. Seyfried
Senior Transportation Engineer
Transportation Engineering Division

PHONES (Area Code 312)

Director	492-5476	Engineering	492-5040	Legal	492-5280
Business Manager	492-5050	Field Services	492-5300	Motor Vehicle Adm.	492-5257
Library	492-5273	Research & Development	492-3270	Publications	492-3033
Registrar	492-7245	Training	492-5222	Book Order Dept.	492-5053

Figure D-1. Introductory Letter

RESPONSE FORM

PROPOSED PEAK-HOUR
TRAFFIC SIGNAL WARRANT
WORKSHOP SESSION

TUESDAY, NOVEMBER 17, 1981
TRAFFIC INSTITUTE TRAINING CENTER
EVANSTON, ILLINOIS

If you are interested in attending this session, please complete and return this form before November 2, 1981. Additional information will be forwarded about one week before the session.

YES, I AM INTERESTED IN ATTENDING /__/

NAME________________________________

TITLE________________________________

ORGANIZATION________________________________

MAILING ADDRESS________________________________

____

PHONE________________________________

Return to:

Robert K. Seyfried
The Traffic Institute
555 Clark Street
P.O. Box 1409
Evanston, Illinois 60204-1409

Figure D-1. Introductory Letter (Con't.)

THE TRAFFIC INSTITUTE
NORTHWESTERN UNIVERSITY
555 CLARK ST. P.O. BOX 1409 EVANSTON, IL 60204

NOEL C. BUFE, Ph.D.
Director

November 9, 1981

Dear Participants:

You have indicated an interest in attending our special workshop on the proposed Peak Hour Signal Warrant. This workshop will be held at 7:00 p.m., Tuesday, November 17, 1981 at The Traffic Institute Training Center, 555 Clark Street, Evanston, Illinois. A map of downtown Evanston is enclosed, indicating the location of The Traffic Institute. The session will last about 1½ hours and will be followed by a reception.

Two alternative proposed warrants have been under consideration in this study. These are referred to as the "NAC" Warrant and the "NCHRP" Warrant. The essential elements of these two proposed warrants are described on the accompanying pages. It is likely that the final warrant will be some modification of one of these. In the special workshop session, we will discuss the basis of the alternative warrants, data requirements, analysis procedures, and results of field testing. We will also solicit your comments and criticisms.

If you are familiar with an intersection where heavy peak hour traffic volumes indicate the desirability of signal control, but none of the conventional eight signal warrants are met, you may wish to bring to the meeting enough data to test the proposed warrant(s). The following data will be required for the peak hour (four consecutive 15-minute periods) on an average week day:

1. Total main street entering traffic (both directions)

2. Highest side street approach entering traffic (one direction)

3. 85th percentile speed (or speed limit) of main street

4. Intersection geometry (number of approach lanes)

5. (Optional) Average queue length on highest volume side street approach during peak hours (use measurement technique contained in <u>A Technique for Measurement of Delay at Intersections</u>, Federal Highway Administration Report No. RD-76-137, NTIS No. PB265 703, November 1976). This assumes current 2-way STOP control.

6. Your intuitive judgement as to whether a signal be appropriate at the intersection.

If you do not have such data available, we will provide sample data for use in testing the proposed warrant(s).

Very truly yours,

Robert K. Seyfried
Senior Transportation Engineer
Transportation Engineering Division

Enclosures

PHONES: (Area Code 312)

Director	492-5476	Engineering	492-5040	Legal	492-5280
Business Manager	492-5050	Field Services	492-5380	Motor Vehicle Adm.	492-5257
Library	492-5273	Research & Development	492-3270	Publications	492-3033
Registrar	492-7245	Training	492-5222	Book Order Dept.	492-5053

Figure D-2. Follow-Up Letter

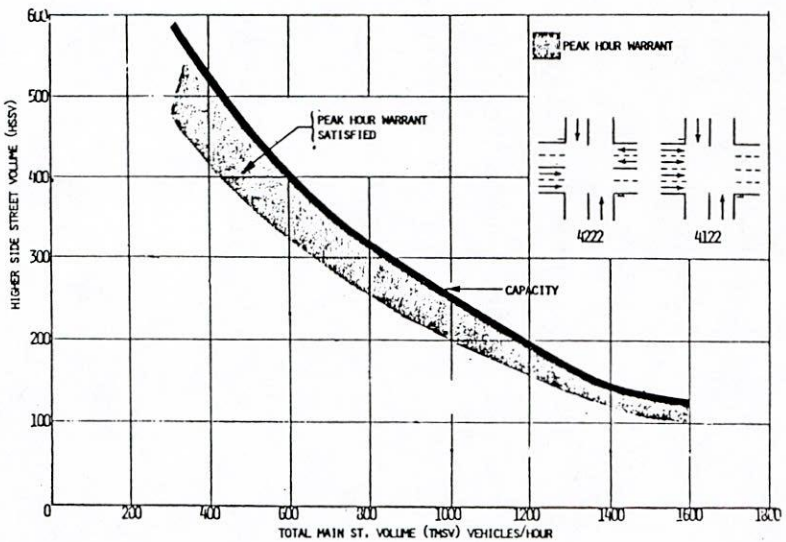
NCHRP PROPOSED PEAK HOUR WARRANT (SUMMARY)

The peak hour warrant is satisfied when for any four consecutive 15-minute periods during an average weekday:

1. The ratio of traffic demand to capacity on the highest volume side street approach exceeds 0.80. This "saturation ratio" implies an average queue length of about 4 vehicles on the side street for the hour. This translates to 4 vehicle-hours of delay and

2. Certain minimum volume requirements are met.

The peak hour warrant is satisfied when the plotted point representing vehicles per hour on the major street (total of both approaches) and the corresponding "equivalent" vehicles per hour on the higher volume side street approach (one direction only) falls within the shaded area in the figure below. Different warrent diagrams are used for different geometric intersection configurations. "Equivalent" side street volumes are computed by adjusting for percent of right turn traffic and commercial vehicles.



NAC PROPOSED PEAK HOUR WARRANT (SUMMARY)

The peak hour warrant is satisfied when for any four consecutive 15-minute periods of an average weekday:

1. The total delay experienced by the traffic on a side street 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. Certain minimum volume requirements are met.

The peak hour warrant is interpretted as being satisfied when the plotted point 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) falls above the appropriate curves in the figure below. The curves are modified for rural/high speed conditions.

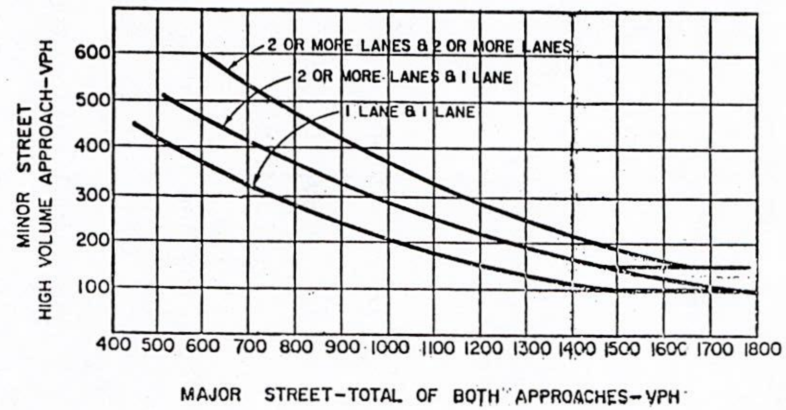


Figure D-2. Follow-Up Letter (Con't.)

I. Introduction

   A. Need for peak hour warrant

II. Questionnaire - Questions 1 - 10

III. Proposed Peak Hour Warrants

   A. Analytical basis

   B. Application techniques/data collection

IV. Case Study - Participant Work Project

   A. Presentation

   B. Review

V. Questionnaire - Questions 11 - 18.

VI. Project 3-20A

   A. History/status

   B. Theoretical basis of the peak hour warrants

   C. Potential future developments

Figure D-3. Peak Hour Signal Warrant Workshop Agenda

PEAK HOUR SIGNAL WARRANT
NCHRP 3-20A RESEARCH PROJECT

1. What type of agency do you work for? (Check one)

   ____Federal; ____State; ____Municipal; ____County; ____Consultant

   Other______________________________

2. Are you attending the NUTI Traffic Signal Workshop.

   ____Yes; ____No.

3. Do your responsibilities involve making recommendations or decisions regarding the installation of traffic signals? (Check one)

   ____Yes; ____No.

4. Does your organization use formal warrants (guidelines, criteria) for signal installation to supplement the eight warrants currently included in the U.S. MUTCD? (Check one)

   ____Yes; ____No.

   If yes, briefly describe the additional warrants:

   1. ______________________________
   ____
   ____

   2. ______________________________
   ____
   ____

Peak Hour Conditions

5. Do you believe that there is a need for an additional signal warrant in the MUTCD based on peak hour traffic conditions? (Please rate this need on a scale from 1 to 10 by circling the number which best reflects your opinion)

   Strong need for Peak Hour Warrant — Peak Hour Warrant not needed

   10 9 8 7 6 5 4 3 2 1

6. Have you had occasion to make recommendations or decisions regarding signal installation where signals were desired because of peak period congestion, but none of the eight MUTCD warrants were met? (Check one)

   ____Yes; ____No.

   If yes, briefly describe criteria or considerations used in arriving at your decision or recommendation?

   ____
   ____
   ____
   ____
   ____
   ____

7. Please rate the following factors in terms of their potential importance in considering the installation of signals where congestion is a problem one or two hours of the day (rate the importance on a scale of 1 to 10 by checking the number which best reflects your opinion)

Factors	Scale of importance: Very Important									Not Important
	10	9	8	7	6	5	4	3	2	1
1. Main street volumes (peak hour)	10	9	8	7	6	5	4	3	2	1
2. Side street volumes (peak hour)	10	9	8	7	6	5	4	3	2	1
3. Side street delay (peak hour)	10	9	8	7	6	5	4	3	2	1
4. Side street queue length (peak hour)	10	9	8	7	6	5	4	3	2	1
5. Distance to nearest signal	10	9	8	7	6	5	4	3	2	1
6. Main street speeds	10	9	8	7	6	5	4	3	2	1
7. Number of approach lanes	10	9	8	7	6	5	4	3	2	1
Others										
8.	10	9	8	7	6	5	4	3	2	1
9.	10	9	8	7	6	5	4	3	2	1
10.	10	9	8	7	6	5	4	3	2	1

Figure D-4. Questionnaire

8. Please rate the experience and capability of your organization in collecting the following types of traffic data (check the rating which best reflects your organization's present practices)

Data Collection	Frequently Do/ Fully Capable	Occasionally Do/ Possible But Difficult	Never Do Not Capable
1. Machine volume counts	______	______	______
2. Manual volume counts	______	______	______
3. Spot speeds	______	______	______
4. Average queue length	______	______	______
5. Average approach delay	______	______	______
6. Total approach delay	______	______	______

9. To the best of your ability, fill in values for the following table, indicating desirable maximum and absolute tolerable maximum conditions for <u>side street traffic in the peak hour</u> with stop sign control. Leave lines blank if you do not have a good "feel" for some values.

	Side Street Peak Hour Condition	
	Desirable Maximum	Maximum Tolerable
Average Delay/Vehicle (Seconds)	______	______
Maximum Delay/Vehicle (Seconds)	______	______
Total Approach Delay (Vehicle-Hours)	______	______
Average Queue Length (vehicles)	______	______
Maximum Queue Length (Vehicles)	______	______

10. Is there a minimum side street volume that should be present (one approach) in the peak hour before signal installation is considered, regardless of other factors.

__Yes; ___No.

If yes, what minimum volume should be required on:

1 lane approach ______________________

2 lane approach ______________________

3 or more lane approach ______________________

<u>Evaluation of Proposed NCHRP Warrant</u>

The following questions relate to the proposed peak hour signal warrant presented. Please indicate your opinions based upon your brief exposure to the method.

11. Ease of understanding concepts. (Please rate on scale from 1 to 10 by circling the number which best reflects your opinion)

Basis of warrant was easy to understand									Basis of warrant was difficult to understand
10	9	8	7	6	5	4	3	2	1

11a. What concepts were easily understood? ______________________

____

____

11b. What concepts were difficult to understand? ______________________

____

____

12. Ease of application of warrant.

Warrant would be easy to use									Warrant would be difficult to use
10	9	8	7	6	5	4	3	2	1

12a. Indicate what aspects were easy to use ______________________

____

____

12b. Indicate what aspects were difficult to use ______________________

____

____

12c. Do you prefer a graphical or tabular presentation of volume criteria for the warrant? (Check one)

Prefer graph ________

Prefer table ________

Figure D-4. Questionnaire (Con't.)

13. How well does the proposed warrant apply to your analysis needs?

Would handle many Signal installation decisions									Would not be used
10	9	8	7	6	5	4	3	2	1

14. Is the required data collection effort for this warrant acceptable with respect to your agency's man-power and technical capabilities?

Reasonable level of effort									Too much effort
10	9	8	7	6	5	4	3	2	1

14a. Please indicate changes in required data collection that you would suggest (if any)?

____

____

____

15. Is the required analysis effort for this warrant acceptable with respect to your agency's man-power and technical capabilities?

Reasonable level of effort for purpose of analysis									Too much effort for purpose of analysis
10	9	8	7	6	5	4	3	2	1

15a. Please indicate changes in analysis methods that you would suggest (if any)?

____

____

____

16. Does this warrant give results that are consistant with your engineering judgement as to the appropriateness of traffic signal control?

Method seems to be highly consistant with my judgement									Method seems to be highly inconsistant with my judgement
10	9	8	7	6	5	4	3	2	1

16a. Please describe inconsistancies (if any)?____________________

____

____

17. If there is anything else you like about the procedure, please not it here:

____

____

____

18. If there is anything else about the procedure you did not like, please note it here:

____

____

____

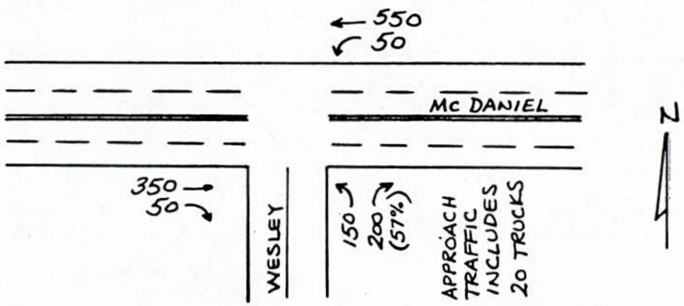
Figure D-4. Questionnaire (Con't.)

PEAK HOUR SIGNAL WARRANT
CASE STUDY

DATA

Given:

1. The T-intersection as shown, with peak hour approach volumes in VPH.



2. 85th percentile speed on Mc Daniel Avenue is 35 MPH.

3. Intersection delay field data collection during peak hour as shown on attached forms.

Find:

1. Apply the proposed peak hour warrant to this intersection to determine whether traffic signal installation is warranted.

2. Is the result "reasonable"?

NCHRP PEAK HOUR SIGNAL WARRANT

1. Select one of the (at least) eight hours of data collected to determine the value of Total Major Street Volume (TMSV), i.e., sum of both approaches if two-way traffic is serviced.

2. For each such hour note the total volume of traffic on each side street approach (SSV), the associated percentage of right-turn movements (P_R) and the volume of truck and bus traffic (Q_T).

3. For each side street approach, calculate the "equivalent" volume, $Q_{ss} = SSV + Q_T$, which states that one truck/bus is equivalent to two passenger cars.

4. For each side street approach, enter the appropriate table (A-2 through A-5) for the intersection configuration, with Q_{ss} and P_R to obtain the "Effective Side Street Volume," (ESSV).

5. Define HSSV as the higher value of ESSV, and LSSV as the lower value (for two side street approaches).

6. If TMSV + HSSV + LSSV > 800 for two side street approaches or TMSV + HSSV > 650 for one side street approach (T-intersection), proceed to Step 7. Otherwise, this condition does not satisfy the

Figure D-5. Case Study

warrant. Return to Step 1 if there is additional data; if not, proceed to Step 8.

7. Plot the point defined by the coordinates (TMSV, HSSV) on the appropriate Warrant Diagram (Figures A-1 through A-4) for this intersection configuration. When the value of TMSV exceeds 1600 vph, the point lies above the warrant curve if the value of HSSV exceeds 75 vph for a one-lane approach, 100 vph for a two-lane approach. Return to Step 1 if there is additional data; if not, proceed to Step 8.

8. ~~A traffic signal is warranted if any four plotted points lie above the signal warrant curve within the region labelled, "VOLUME WARRANT SATISFIED."~~

3.2 Peak-Hour Warrant

A traffic signal is warranted if one (or more) point(s) plotted on the Warrant Diagram lies within the shaded region labelled, "PEAK-HOUR WARRANT SATISFIED." When a value of TMSV exceeds 1600 vph, a traffic signal is warranted if the associated value of HSSV exceeds 100 vph for a one-lane side street approach, 150 vph for a two-lane approach.

A traffic signal installed under this warrant should be either semi- or full-traffic-actuated as determined by the responsible engineer.

Table A-3

Impact of Right-Turn Movements: Configuration 4222*

Equivalent Side Street Volume Q_{SS}	Effective Side-Street Volumes (ESSV) for Indicated Right-Turn Percentages (P_R)							
	10	20	30	40	50	60	70	80
100	90	80	70	-	-	-	-	-
140	130	120	110	90	80	-	-	-
180	170	150	140	120	100	80	-	-
220	200	180	160	140	120	100	80	-
260	250	230	210	190	160	130	80	-
300	290	270	250	230	200	180	150	100
340	330	320	310	290	250	220	200	170
380	370	360	350	330	300	270	250	220
420	410	400	390	370	340	320	290	270

(Rounded to multiples of 10)

* Also 4122, 4211, 4111

Figure D-5. Case Study (Con't.)

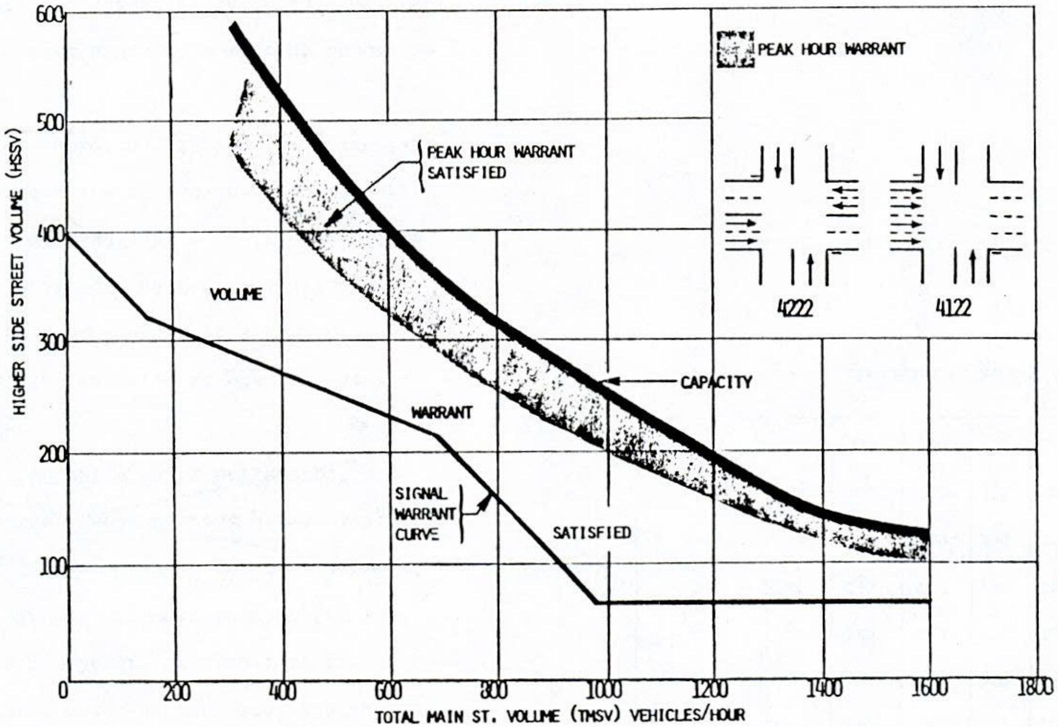


Figure A-4. Vehicular Volume and Peak-Hour Volume Warrant Diagram for the 4222, 4122, 4211 and 4111 Intersection Configurations

Figure D-5. Case Study (Con't.)

DISCUSSION OF RESPONSES

The following analysis of data obtained from the questionnaire addresses each question separately. All statistics are computed based on the number of responses to the given question. Overall, 35 individuals participated in the workshop session and 33 questionnaires were returned. Questionnaire responses are tabulated in Figure D-6.

Question 1

Most workshop participants (69 percent) resided in the State of Illinois. However, a total of 7 states and Puerto Rico were represented. About half (17 of 33) of responding participants were employed by private consulting firms. This distribution is important since consultants may act in an advisory role concerning signal installation, but tend to be somewhat farther removed from the final decision-making process than traffic engineers employed by public agencies.

Question 2

All workshop participants attended this session voluntarily, presumably because of an interest in and desire to learn more about the proposed warrants. This may have resulted in a greater receptiveness to new concepts and techniques than might ordinarily be found in the overall traffic engineering profession.

Question 3

Nearly all responders (85 percent) indicated some current responsibility related to installation of traffic signals.

Question 4

Twenty-two percent of responding participants indicated the use of criteria in addition to the 8 warrants currently contained in the U.S. MUTCD. Most of these responses appeared to be related to a state of Illinois warrant for signals at commercial or industrial driveways.

Question 5

Participants indicated a strong need for an additional MUTCD warrant based on peak-hour conditions. There was probably an inherent bias in this group since individuals with little interest in peak-hour warrants were unlikely to attend.

Question 6

Thirty-nine percent of responding participants had occasion to make signal installation judgements that may have been aided by a peak-hour signal warrant. Present and future traffic volumes and delay appeared to be important concerns in making such judgements.

Question 7

Main street and side street traffic volumes and side street delays are perceived as very important in making a determination on signals for peak-hour conditions. Significantly, side street queue is perceived as of only moderate importance. This appears to indicate that the responders did not perceive any correspondence between average queue and delay. The other listed factors were also perceived as being of moderate importance.

Question 8

Manual and machine traffic volume counts were indicated as being familiar and fully within the organizational capabilities of nearly all responders. The remaining data collection techniques were rated as being only moderately familiar or within organizational capabilities. Generally less experience with the latter data collection processes is likely to explain these lower ratings.

Question 9

Responding participants were requested to estimate values for "desirable maximum" and "absolute tolerable maximum" conditions under STOP sign control. No great confidence in the reported statistics should be inferred. This was a relatively small sample, and responses varied over a considerable range.

Several items of interest may be noted, however. The sample average (64.4 seconds) and median (60 seconds) values for desirable maximum delay per vehicle is close to the value (56.9 seconds) for delay that should not be exceeded for any vehicle on a STOP approach as suggested by Lieberman.

Also, average (4.2 vehicle-hours) and median (4 vehicle-hours) maximum tolerable total approach delay values are similar to the basic criteria imbedded in the proposed NCHRP and NAC peak hour warrants. It should be noted, however, that the average and median values for average queue are not consistent with values for total delay. As discussed for Question 7, this may indicate that the responders did not associate the two characteristics.

Question 10

Seventy-one percent of responding participants indicated that there is some minimum side street volume threshold that should be exceeded before signals are considered, regardless of other factors. The median responses for one lane and two lane approaches (100 and 150 veicles per hour respectively) correspond exactly with volume thresholds in the proposed NCHRP and NAC peak hour signal warrants. Summaries of these proposed warrants were available to the participants prior to the workshop session.

Questions 11 through 18 were completed by participants after the proposed NCHRP peak hour signal warrant had been described and participants had applied it to an example intersection case study (included as Figure D-5). Responses to questions 11 and 18 relate specifically to the proposed NCHRP warrant.

Question 11

Responding participants indicated that the concepts underlying the NCHRP warrant were moderately well understood, although several indicated great difficulty with it. The concepts of volume adjustments and graphical presentation of the warrant appear well accepted. However, a number of commenters expressed difficulty with the terminology and abbreviations used in the warrant instructions. Also, specific conditions required for application of the warrant were not fully understood.

Question 12

Responding participants also indicated that the proposed NCHRP warrant would be relatively easy to apply to practical signal installation decision-making. The use of a graphical presentation was particularly well accepted. Terminology was confusing, and interpolation within the right turn adjustment table tended to be a problem in applying the technique. Sixty-seven percent of those responding indicated a preference for a graphical rather than a tabular presentation of warrant criteria.

Question 13

The proposed warrant was rated as having moderate applicability to the signal installation decision needs of participants. This is consistent with the level of interest in peak-hour signal warrants represented within the group.

Question 14

The level of data collection required for application of the warrant was rated as highly acceptable. The type of data required appears to be well within the capabilities and experience of most agencies. This result corresponds well with the responses to Question 8.

Question 15

The level of analysis was also judged as being highly reasonable with respect to man-power and technical capabilities of the agencies represented. There were indications again, however, that the warrant terminology and computational instructions require clarification.

Question 16

The results of the warrant appear to be moderately to highly consistent with the engineering judgement of nearly all of the responding participants. That is, the warrant yields credible results to technical personnel. Most comments on this question seem to relate to Question 11 and 12, concerning concepts and ease of application rather than consistency of results.

Question 17

This question elicited no new comments of interest.

Question 18

A number of comments and concerns about the proposed NCHRP warrant were expressed in response to this question. However, the comments are highly diverse and there do not appear to be any dominant reservations or concerns which are prevelant throughout the responding participant group.

QUESTIONNAIRE

PEAK HOUR SIGNAL WARRANT

NCHRP 3-20A RESEARCH PROJECT

TABULATION OF RESPONSES

1. What type of agency do you work for? (Check one)

   0 Federal; *6* State; *6* Municipal; *3* County; *17* Consultant

   Other *Transit: 1*

2. Are you attending the NUTI Traffic Signal Workshop.

   12 Yes; *21* No.

3. Do your responsibilities involve making recommendations or decisions regarding the installation of traffic signals? (Check one)

   28 Yes; *6* No.

4. Does your organization use formal warrants (guidelines, criteria) for signal installation to supplement the eight warrants currently included in the U.S. MUTCD? (Check one)

   7 Yes; *25* No.

   If yes, briefly describe the additional warrants:

   1. *Missouri 2-hour warrant*
   2. *2-hour peak at 4x Warrant #2*
   3. *Political*
   4. *ILL. Industrial Warrant*
   5. *Commercial-Industrial warrant (factor x Warrants 1 & 2)*

Peak Hour Conditions

5. Do you believe that there is a need for an additional signal warrant in the MUTCD based on peak hour traffic conditions? (Please rate this need on a scale from 1 to 10 by circling the number which best reflects your opinion)

Strong need for Peak Hour Warrant									Peak Hour Warrant not needed
10	9	8	7	6	5	4	3	2	1
10	*4*	*8*	*4*	*2*	*2*	*1*	*2*		

Average = 7.9, Median = 8, Mode = 10

6. Have you had occasion to make recommendations or decisions regarding signal installation where signals were desired because of peak period congestion, but none of the eight MUTCD warrants were met? (Check one)

   13 Yes; *20* No.

   If yes, briefly describe criteria or considerations used in arriving at your decision or recommendation?

   Delay; energy consumption; likely non-observance of stop sign; Illinois commercial-industrial warrant; Volumes; Gaps; Approach width; delay; accidents; Intuitive judgement; bus volume and scheduling; future growth of traffic; land use changes; politics; 2-hour peak at 4x Warrant #2

7. Please rate the following factors in terms of their potential importance in considering the installation of signals where congestion is a problem one or two hours of the day (rate the importance on a scale of 1 to 10 by checking the number which best reflects your opinion)

Factors	Scale of importance: Very Important 10	9	8	7	6	5	4	3	2	Not Important 1
1. Main street volumes (peak hour)	*14*	*4*	*4*	*3*	*2*	*1*	*2*	*1**		
2. Side street volumes (peak hour)	*12*	*4*	*4*	*2*	*4*	*1*	*4**			
3. Side street delay (peak hour)	*11*	*5*	*4*	*1*	*5*	*3*	*2**			
4. Side street queue length (peak hour)	*3*	*5*	*5*	*1*	*8*	*3*	*4*	*1*		*1**
5. Distance to nearest signal	*2*	*4*	*8*	*7*	*2*	*6*	*1*	*3**		
6. Main street speeds	*5*	*3*	*8*	*3*	*3*	*5*	*4*	*1**		
7. Number of approach lanes	*6*	*3*	*1*	*6*	*5*	*6*	*3*	*1**		

Others: *8. Total delay 9. No. stops 10. Accidents 11. Gaps in main street traffic 12. Modification of traffic demand 13. Frequency of peak conditions 14. Main street delay 15. Possible additional driveways 16. Politics 17. Left turn volumes 18. Progression 19. Bus volume/turns 20. Climatic conditions/grades 21. Geometrics*

**1. Average = 8.3, Median = 9, Mode = 10, 2. Average = 8.0, Median = 9, Mode = 10, 3. Average = 8.0, Median = 9, Mode = 10, 4. Average = 6.6, Median = 6, Mode = 6, 5. Average = 6.9, Median = 7, Mode = 8, 6. Average = 7.0, Median = 7, Mode = 8, 7. Average = 6.8, Median = 7, Mode = 7.*

Figure D-6. Tabulation of Questionnaire

8. Please rate the experience and capability of your organization in collecting the following types of traffic data (check the rating which best reflects your organization's present practices)

Data Collection	Frequently Do/ Fully Capable	Occasionally Do/ Possible But Difficult	Never Do Not Capable
1. Machine volume counts	*23*	*4*	*5*
2. Manual volume counts	*27*	*4*	*2*
3. Spot speeds	*14*	*12*	*6*
4. Average queue length	*11*	*14*	*8*
5. Average approach delay	*9*	*12*	*12*
6. Total approach delay	*9*	*11*	*12*

9. To the best of your ability, fill in values for the following table, indicating desirable maximum and absolute tolerable maximum conditions for side street traffic in the peak hour with stop sign control. Leave lines blank if you do not have a good "feel" for some values.

	Side Street Peak Hour Condition	
	Desirable Maximum	Maximum Tolerable
Average Delay/Vehicle (Seconds)	*Ave.=34.5 Med.=30*	*Ave.=59.4 Med.=40*
Maximum Delay/Vehicle (Seconds)	*Ave.=64.4 Med.=60*	*Ave.=75.9 Med.=60*
Total Approach Delay (Vehicle-Hours)*	*Ave. 3.2 Med.= 4*	*Ave.= 4.2 Med.= 4*
Average Queue Length (vehicles)	*Ave. 5.8 Med.= 5*	*Ave.=11.0 Med.= 8*
Maximum Queue Length (Vehicles)	*Ave. 9.5 Med.= 8*	*Ave.=13.3 Med.=10*

*(*6 responses)*

10. Is there a minimum side street volume that should be present (one apprcach) in the peak hour before signal installation is considered, regardless cf other factors.

22 Yes; *0* No.

If yes, what minimum volume should be required on:

1 lane approach *Ave. = 118.6 Med. = 100*

2 lane approach *Ave. = 188.9 Med. = 150*

3 or more lane approach *Ave. =222.9 Med. = 175*

Evaluation of Proposed NCHRP Warrant

The following questions relate to the proposed peak hour signal warrant presented. Please indicate your opinions based upon your brief exposure to the method.

11. Ease of understanding concepts. (Please rate on scale from 1 to 10 by circling the number which best reflects your opinion)

Basis of warrant was easy to understand									Basis of warrant was difficult to understand
10	9	8	7	6	5	4	3	2	1
2	*5*	*10*	*6*	*3*	*1*	*3*	*1*		*2*

Average = 6.9, Median = 8, Mode = 8.

11a. What concepts were easily understood? *TMSV; All; Comparative street volumes; Equivalent vehicles; Equivalent volume; ESSV; the curve; TMSV, SSV, Qss; Procedure simple; Volume basis; ESSV; Shaded region; Graph; Table; Calculations; ESSV; Qss and ESSV; Use of volumes; Volumes and adjustments; Peak hour volume; Adjustment factors; Data collection; ESSV and adjustments; Graph; Not counterintuitive; ESSV; TMSV, SSV,* F_p*; Major and minor street volumes; Volume relationships.*

11b. What concepts were difficult to understand? *HSSV, LSSV, TMSV, shaded region of graph; difficult to explain to layman; ESSV; None; Right turn adjustment; average and maximum delay; explanations are awful; what values are to be used and what are not; ESSV; what is major street approach; should right turns be counted if there is a right turn lane?; abbreviations; too simple to be confident in results; terminology confusing; procedure confusing; terminology; interpolation in chart; graph; None; HSSV; definition of peak hour; instructions; TMSV; do not account for unusual gap occurance; terminology; what is peak hour; right turns; right turn adjustment; capacity definition; HSSV/LSSV; HSSV; abbreviations.*

12. Ease of application of warrant.

Warrant would be easy to use									Warrant would be difficult to use
10	9	8	7	6	5	4	3	2	1
10	*5*	*6*	*4*	*4*	*1*	*2*	*2*		

Average = 7.7, Median = 8, Mode = 10.

12a. Indicate what aspects were easy to use *Plotting on graph; calculations of TMSV & SSV; graph and charts; whole warrant procedure clear; 1 hour of traffic count; geometrics; TMSV; all; data collection; chart; cook book easy to follow; Instructions easy to follow if terms defined; calculations; volumes easy to obtain; math is straight forward; table and graph; graph; overall sequence; graph; simple data collection; calculations; chart simplicity; table and graph; Warrant clear and simple; easily computed; calculations; data collection; graph simple calculations; .*

12b. Indicate what aspects were difficult to use *Equivalent/effective-terminology; difficult to explain to layment; simplify; no feel for it; none; when volumes higher than table; what data should be used; none; terminology; Table (interpolation); terminology; no exact answers; abbreviations; HSSV; TMSV; instruction poor; interpolation in table; none; data base not clear; meaning of peak hour; interpolation in table; arbitrary; right turns; terminology; interpolation in table; table.*

12c. Do you prefer a graphical or tabular presentation of volume criteria for the warrant? (Check one)

Prefer graph *22*

Prefer table *11*

Figure D-6. Tabulation of Questionnaire (Con't.)

13. How well does the proposed warrant apply to your analysis needs?

Would handle many Signal installation decisions — Would not be used

10	9	8	7	6	5	4	3	2	1
4	2	5	2	3	7	3	4	·	1

Average = 6.1, Median = 6, Mode = 5.

14. Is the required data collection effort for this warrant acceptable with respect to your agency's man-power and technical capabilities?

Reasonable level of effort — Too much effort

10	9	8	7	6	5	4	3	2	1
11	10	4			2	1	1		1

Average = 8.3, Median = 9, Mode = 10.

14a. Please indicate changes in required data collection that you would suggest (if any)?

Geometric considerations; pedestrians; right turn traffic from major to minor street; clarify definition of conflicting volumes; prefer 2 hour count; OK if volume data used, more effort if delay is used; require 15 minute counting periods; seems simple enough; each intersection much be evaluated on its own basis.

15 Is the required analysis effort for this warrant acceptable with respect to your agency's man-power and technical capabilities?

Reasonable level of effort for purpose of analysis — Too much effort for purpose of analysis

10	9	8	7	6	5	4	3	2	1
16	8	3	1	2		1			

Average = 9.0, Median = 10, Mode = 10.

15a. Please indicate changes in analysis methods that you would suggest (if any)?

No reason to collect 8 hours of data; interpolation awkward; gap acceptance; simplify calculations; analysis of gaps; adjust rruck factor to greater than 2 PCE; table; simplify HSSV and ESSV; instruction's hard to follow; interpolation; use mathematical equations to determine answers; terminology; better definition of peak hour and data collection needed; incorporate delay/queue length measures unless volume is good surrogate; clarify terminology and formulas.

16. Does this warrant give results that are consistant with your engineering judgement as to the appropriateness of traffic signal control?

Method seems to be highly consistant with my judgement — Method seems to be highly inconsistant with my judgement

10	9	8	7	6	5	4	3	2	1
4	4	5	4	6	2		1	1	

Average = 7.2, Median = 7, Mode = 6.

16a. Please describe inconsistancies (if any)? *Terminology; definitions; relationship to nearby signals not explicit; should consider delay more explicitly; engineering judgment needed; saturation ratio is very subjective; right turns from major onto minor street; treatment of non-conflicting right turns; effect of seasonal variations?; interpolation difficult; treatment of "T" and 4-leg intersection the same; Queues, delay, physical conditions.*

17. If there is anything else you like about the procedure, please not it here:

Like right turn adjustment concept, east of use; limited data needed; define trucks.

18. If there is anything else about the procedure you did not like, please note it here:

Basic approach reasonable; flash or tight actuated control imparative in off-peak; need higher truck equivalents; difficult to explain to laymen; interpolations complicated; what if plotted point is above "capacity"? too many calculations and charts; delay/queue length not included; main street right turns at "T" intersection; treatment of off-peak operation; warrant does not typify actual peak hour; what does "capacity" line represent? terminology confusing; too simplistic to be applied without judgment.

Figure D-6. Tabulation of Questionnaire (Con't.)

THE TRANSPORTATION RESEARCH BOARD is an agency of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 250 committees, task forces, and panels composed of more than 3100 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, and other organizations and individuals interested in the development of transportation.

The Transportation Research Board operates within the Commission on Sociotechnical Systems of the National Research Council. The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine.

The National Academy of Sciences was established in 1863 by Act of Congress as a private, nonprofit, self-governing membership corporation for the furtherance of science and technology, required to advise the Federal Government upon request within its fields of competence. Under its corporate charter the Academy established the National Research Council in 1916, the National Academy of Engineering in 1964, and the Institute of Medicine in 1970.

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 42970

000015M001
JAMES W HILL
RESEARCH SUPERVISOR

IDAHO TRANS DEPT DIV OF HWYS
P O BOX 7129 3311 W STATE ST
BOISE ID 83707