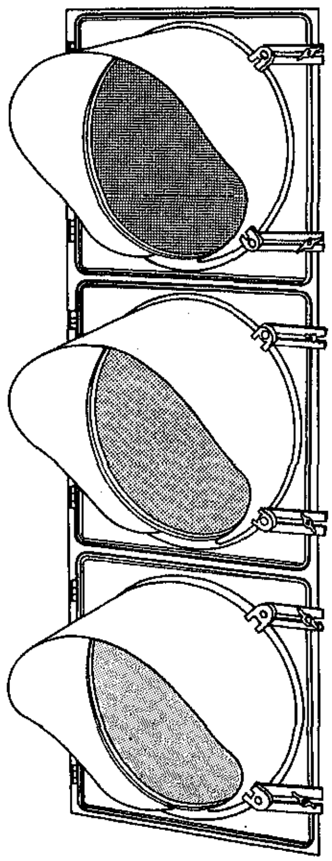
Implementation Package FHWA-IP-80-12
November 1980

User Guide

U.S. Department
of Transportation

**Federal Highway
Administration**

For Removal of Not Needed Traffic Signals



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User Guide

For Removal of Not Needed Traffic Signals

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CHAPTER I

INTRODUCTION

This users guide discusses the criteria that may be applied to determine if an existing traffic signal should be removed. The material and techniques presented are relatively straightforward and, when applied, will provide a strong factual basis for reaching, supporting, and defending a signal removal decision. The signal removal criteria apply only to signals on regular red, yellow, green color operation that alternately assign right-of-way, and not to flashing signals or beacons.

The users guide is a supplement to the technical report prepared as part of the FHWA sponsored research. The final report describes in detail the conduct of the study, the methods used to analyze the signal removal data base, the results of this analysis, the development of the signal removal criteria and removal procedural guidelines. This users guide includes the signal removal decision process and the procedural guidelines that may be used to carry out the actual removal of the signal.

SIGNAL REMOVAL CRITERIA AND DECISION PROCESS

The Need

Traffic control devices are used at intersections to regulate the flow of conflicting traffic streams. Since the traffic signal provides the strongest form of at-grade intersection control, the general public has erroneously assumed traffic signals are a panacea for intersection operations and safety problems. Thus, in many communities, due to lack of transportation engineering expertise, or public and political pressure or both, traffic control signals have been installed at intersections where they are not warranted. Additionally, at other intersections changing traffic patterns have caused signals that were originally warranted to no longer be warranted. The result has been an increase in the traffic accident frequency. Additionally, it is noted that existence of unjustified control devices breeds disrespect for the device in general.

While the relationship between new traffic signals, intersection accidents and operations has been widely studied, very little was known about the impacts when traffic signals were removed. The signal removal study was initiated by the Federal Highway ADministration (FHWA) to identify what conditions and criteria have been used throughout the United States for the removal of traffic signals and to develop criteria that may be adopted as warrants for the removal of existing traffic signals.

Criteria Development

The development of the signal removal criteria was based largely on the actual impacts resulting from traffic signal removals across the United States. Those cases where positive impacts were realized by removing signals served to identify the conditions under which other signals should be removed. Likewise, cases involving negative impacts or unsuccessful removal attempts were reviewed to identify those conditions where signal removal should not be pursued. The research compiled impact data from traffic signal removal experiences at over 200 intersections in 31 political entities throughout the United States, and summarized and analyzed this information to provide an objective base for the development of signal removal criteria.

The Decision Process

Traffic signals enjoy a high status among many segments of the public, elected officials, and public administrators. The popular belief, though often unsupported by evidence, is that signals somehow enhance traffic safety and improve traffic flow conditions. Given this popular bias, the practical reality is that signals are considerably harder to remove than to install. Additionally, the removal of a traffic signal often involves political and institutional considerations as well as technical factors. In keeping with these practical realities, the proposed approach to signal removal justification is a sequential screening process in which a series of criteria must all be satisfied and the various impacts predicted before signal removal is recommended.

The initial step of the signal removal analysis is to identify those intersections that are candidate locations for signal removal. The signal removal decision process is then applied to these intersections. The decision process is organized into the following two stages.

- Stage I - Preliminary Screening. This part of the process can be completed fairly quickly once the basic inventory data on intersection conditions have been collected. The purpose of this quick screening is to determine if additional analysis of the intersection is justified.

- Stage II - Detailed Analysis. This is a more time consuming process which is pursued only if the candidate intersection survives the screening process. The analysis includes predicting the change in accidents, computing traffic flow related impacts of signal removal, support or canvassing the general strength of signal removal opposition, and finally making the decision whether or not to remove the signal.

Knowing the probable impacts on intersection safety, traffic operations (e.g., delay, stops, and fuel consumption) and costs, the traffic engineer can then make a sound technical decision on the question of signal removal. Because the removal of a traffic signal often involves institutional and/or political constraints, the technical element must be tempered with professional judgment when making the final decision. The decision process allows for including these institutional and political considerations.

Signal Removal Procedural Guidelines

Once the decision has been made to remove an existing traffic signal, the actual removal of the signal hardware must be implemented in such a way to minimize the hazards associated with a change in a traffic control device. The users guide contains removal procedural guidelines and addresses such issues as interim control measures and advance public notification.

APPLYING THE USERS GUIDE

The user is reminded that the signal removal criteria and impact prediction methods apply only to signals in urban areas. The size of the signal removal data base for rural intersections was inadequate to draw any general conclusions.

The intersection data required to perform the signal removal analysis are basic -- specifically: side street sight distance; the traffic volumes entering the intersection in each hour from each approach during a representative day, and the prior accident experience at the intersection (total number of accidents) for at least one year, and preferably for several preceding years.

The techniques and suggestions contained herein should be interpreted as general guidelines. The user must also exercise judgement and knowledge of unique site specific conditions in the decision process. It is emphasized that the final decision concerning signal removal is a blend of analytical procedures coupled with professional judgement. In many cases, a number of institutional and political constraints must also be considered.

The purpose of the signal removal criteria and decision process is to provide the traffic engineer with a tool for identifying signalized locations where signal removals are likely to result in positive impacts and to provide a strong technical and factual basis for reaching, supporting, and defending final decisions.

CHAPTER II

SUMMARY OF STUDY RESULTS

IMPACTS STUDIED

Three major impacts of signal removal were of greatest concern: safety impacts, traffic flow impacts, and cost impacts.

The effects on accident frequency and severity are very important because of the common argument of signal removal opponents that accidents and injuries will increase if a signal is removed. The development of signal removal criteria obviously must include a good understanding of the actual accident impacts.

The impacts on stops and delays, and the corresponding changes in fuel consumption, are important concerns, especially during these times of high gas prices and uncertain supply.

The cost savings accruing to the traffic engineering agency as a result of replacing signals with stop control is also a major factor motivating decisions to remove signals. To jurisdictions operating with austere budgets this factor can be of paramount importance.

ACCIDENT IMPACTS

The size of the rural intersection data base was too small to be considered representative. Therefore, the analysis focused on the impacts of signal removals in urban areas.

Conversion to Multi-Way Stop Control

For the group of 26 intersections converted to multi-way stop control, there was a decrease in the average annual accident frequency of more than one accident per year. Annual accident frequency was reduced 60 percent from 1.70 to 0.68 accidents per year, a statistically significant change. Annual injury accident frequency per intersection was also reduced significantly from 0.50 to 0.19.

It must be emphasized that all the intersections in this group had characteristics favorable to multi-way stop control: i.e., low traffic volumes and evenly balanced main road and side road flows. These results should not be interpreted to mean that multi-way stop control should always be used when signals are removed. Indeed, in a majority of cases, side road volumes are much lower than main road volumes at candidate locations, and multi-way stop control is not an appropriate alternative.

Conversion to Two-Way Stop Control

Signals were replaced by two-way stops at 191 of the urban case study intersections. The average result was a small decrease in both total accidents (from 2.46 to 2.38 per year) and injury accidents (from 0.70 to 0.63). These changes were not statistically significant.

Right angle accidents increased 51 percent and rear-end accidents decreased 49 percent, as expected, following signal removal and replacement by two-way stop control. These changes are offsetting and did not result in any significant net change in either total collisions or injury accidents.

Factors Influencing Accident Impacts

There was a wide dispersion of accident impacts of signal removal at the individual intersections converted to two-way stop control. The study explored which intersection characteristics had a significant influence on whether accident frequency increased or decreased following signal removal.

Three variables were found to have a significant effect on the accident outcome of signal removal:

1. Adequacy of side street sight distance.

2. Traffic volume magnitude (i.e., as measured by the number of hours per day when traffic volumes satisfy at least 60 percent of the signal installation traffic volume warrant #1).

3. Average annual accident frequency at the intersection prior to signal removal.

Predicting Accident Impacts

Prediction models for estimating the accident impacts of replacing traffic signals with two-way stop control were developed from the case study data using two different methods -- cross-classification and multiple regression. Both methods used the same two independent (predictor) variables: (1) intersection volume magnitude as measured by the number of hours meeting 60 percent of signal installation volume warrant #1 and (2) the "before" annual accident frequency. The multiple regression approach proved to be a somewhat better prediction method than the cross-classification approach.

Both prediction methods indicate that higher volume intersectons are associated with increased accidents following signal removal, and vice versa. Intersections with low accident frequencies prior to signal removal tend to have increased accident frequency after removal, and vice versa. Intersections that are good candidates for signal removal are ones with relatively low traffic volumes and annual accidents of at least 2 or more per year.

Impact of Inadequate Side-Street Sight Distance

Signal removal experience at intersections with inadequate side-street sight distance was separately considered. The case study data set contained only 15 such intersections. For these, the average annual accident frequency following signal removal rose dramatically from 2.03. to 4.85 per year. Annual average injury accidents doubled from 0.60 to 1.21 per intersection. These increases can be fully attributed to the increased risk of right angle collisions.

IMPACTS ON DELAYS, STOPS, AND FUEL CONSUMPTION

Traffic signal removal results in substantial impacts on intersection delays, stops, and the resulting excess fuel consumption. Empirical data on intersection stops, delays, and fuel consumption were not available from the case study data base; consequently, analytical estimates of these impact variables were made for a range of intersection types and traffic volumes.

Conversion to Two-Way Stop Control

Replacing unjustified signals with 2-way stop control has an especially beneficial effect in reducing intersection delays, stops, and fuel consumption. The range of impacts per vehicle is relatively consistent for a wide range of intersection conditions.

When signals at 4-way intersections are replaced by 2-way stop signs, the following approximate impacts occur:

- Total delay per vehicle is reduced by about 10 seconds
- Idling delay per vehicle is reduced by about 5 to 6 seconds

- Stops are reduced from about 50 percent of total intersection traffic to about 20 to 25 percent or even less if side road volumes are low in relation to total intersection volume

- Excess fuel consumption due to intersection stops and delays is reduced by about 0.002 gallons per vehicle

In the case of similar volumes at a T-intersection, the reductions in delays, stops, and fuel consumption would be slightly greater.

The approximate order of magnitude of the daily impacts of signal removal and replacement by 2-way stop control can be estimated by multiplying the preceding "per-vehicle" impacts by total 24-hour traffic volumes. This would normally be computed for typical weekday volumes. Annual impacts can be approximated by multiplying the total weekday impact estimates by 320.

For example, with respect to excess fuel consumption, at an intersection with typical weekday traffic volume of 10,000 per day, traffic signal removal and replacement by 2-way stop control would save approximately 20 gallons per weekday which is equivalent to 6,400 gallons per year.

Conversion to Multi-Way Stop Control

When an unjustified traffic signal is replaced by multi-way stop control at a four-way intersection with moderate traffic volumes and fairly evenly balanced main road and side road flows, the following approximate impacts occur.

- Total delay per vehicle does not change by much

- Idling delay per vehicle is reduced by about 5 seconds

- Stops always equal 100 percent of total traffic, approximately double that experienced under signal control

- Excess fuel consumption is increased by about 0.0015 gallons per vehicle

At an intersection converted to multi-way stop control and serving 10,000 vehicles per day on an average weekday, the daily increases in fuel consumption would total roughly 15 gallons per weekday which is equivalent to 4,800 gallons per year.

Nomographs and Worksheets

A set of nomographs are included in the Users Guide for estimating intersection delays, stops, and excess fuel consumption for a wide range of combinations of main road and side road hourly volumes. The nomographs permit estimates of the impact variables under traffic signal control and two-way stop control for 6 different common intersection design types.

A standard worksheet is also included for systematic calculations of the daily impacts of signal removal from the nomograph estimates of hourly impacts.

COST SAVINGS OF SIGNAL REMOVAL

Traffic signal removal is one of those rare activities that saves the money of the traffic engineering agency. For a typical uncomplicated pre-timed existing signalized intersection, the comparative annual costs of continued signal operation versus signal removal and replacement with 2-way stop control are estimated as follows:

Annual Costs of Continued Signal Operation

Electrical costs	=	$ 250
Maintenance	=	1,100
Traffic signal timing	=	50
Total		$1,400

Annual Costs of Signal Removal

(Equivalent annual costs for 15 year period @ 12 percent interest)

Remove signal	=	$295
Install stop signs	=	25
Sign maintenance	=	20
Total		$340

The annual savings in agency costs resulting from signal removal for this typical case is $1,060 per year. It is emphasized that costs of signal removal and of continued signal operation are highly dependent on local conditions and on the unique features of a given signalized intersection.

CHAPTER III

TRAFFIC SIGNAL REMOVAL DECISION PROCESS

The following sections explain in detail the procedures that are utilized during each of the various stages that comprise the signal removal decision process. Forms for summarizing the results of the signal removal analysis are presented in Appendix A.

IDENTIFICATION OF CANDIDATE LOCATIONS

In most of the jurisdictions visited during this project, the identification of candidate locations for signal removal was an intuitive process. The local traffic engineer and staff determined which signals should be considered for removal based on their familiarity with the signal network, professional experience and judgment

The process of identifying candidate locations can be strengthened and systemized by listing those signalized intersections that fall into one or more of the following categories:

- Signals where the installation warrants are not met. At this stage, hourly volume counts are not necessary. The average daily traffic (ADT) of the major and minor streets can be used to estimate warrant satisfaction. The approximate ADT's needed to produce the 8 hour minimum volumes required by MUTCD Warrants #1 and #2 are shown in Table 1.

- Signals where neither intersecting street is a principal arterial. Those signalized locations which involve the intersection of a minor/minor, minor/collector, etc. are often candidates for signal removal

- Signals in close proximity (e.g. 6 blocks) to major or special traffic generators (e.g. large commercial establishments, schools, recreation and entertainment facilities) which are to be or have recently been closed. The reason for the signal being installed in the first place may have been the presence of the generator.

- Signals located in the vicinity of recent freeway construction or major urban redevelopment. These types of projects generally cause a modification in the street network (e.g. streets closed or continuity disrupted) which in turn significantly change the traffic flow patterns. Traffic conditions at signalized intersections may also be affected by a change in street operation (e.g. two-way converted to one-way)

Table 1. Approximate ADT's Required for Signal Installation Warrant Satisfaction

LANES/APPROACH		WARRANT #1 (Minimun Volume)		WARRANT #2 (Interruption)	
Major	Minor	Major St. ADT	Minor St. ADT	Major St. ADT	Minor St. ADT
1	1	8,300	4,600	12,500	2,300
2+	1	10,000	4,600	15,000	2,300
2+	2+	10,000	6,000	15,000	3,100
1	2+	8,300	6,000	12,500	3,100

- Major Street ADT is two-way volume level needed to produce minimum volumes during 8 peak hours.

- Minor Street ADT is two-way volume level needed to produce high direction minimum volumes during 8 peak hours.

- Signals requiring upgrading or major maintenance. There are undoubtedly signal installations in every jurisdiction where modernization and/or recurring major maintenance is necessary, due to substandard design, old and unreliable hardware, or repeated vandalism. While these conditions do not affect the determination of whether or not a signal is required, the removal of the signal may be a feasible and less expensive alternative to modernization/upgrading.

After the lists have been compiled for each of the above categories, they can be merged into a single list. As a last step, a priority listing of candidate locations for signal removal may be prepared based on preliminary field reconnaisance and engineering judgment.

STAGE I - PRELIMINARY SCREENING

Figure 1 illustrates the structure of the preliminary screening process. The first step of the process is to prepare an inventory of current conditions at the intersection. The specific data required to perform the signal removal analysis are the following:

- Intersection geometrics (e.g., number of lanes/approach)

- Side-street sight distance

- The hourly traffic volumes on each intersection approach during a representative day

- Accident experience at the intersection (total number of accidents). It is recommended that several years of accident data be obtained and converted into an average annual accident frequency. If this is not possible, as a minimum accident experience for at least one year should be used.

Depending on site-specific conditions, additional data, such as major street speeds, heavy turning movements, pedestrian counts, etc. may also be necessary.

After the intersection data is obtained a series of criteria are considered, each of which must be satisfied in order for the intersection to survive the screening. Namely:

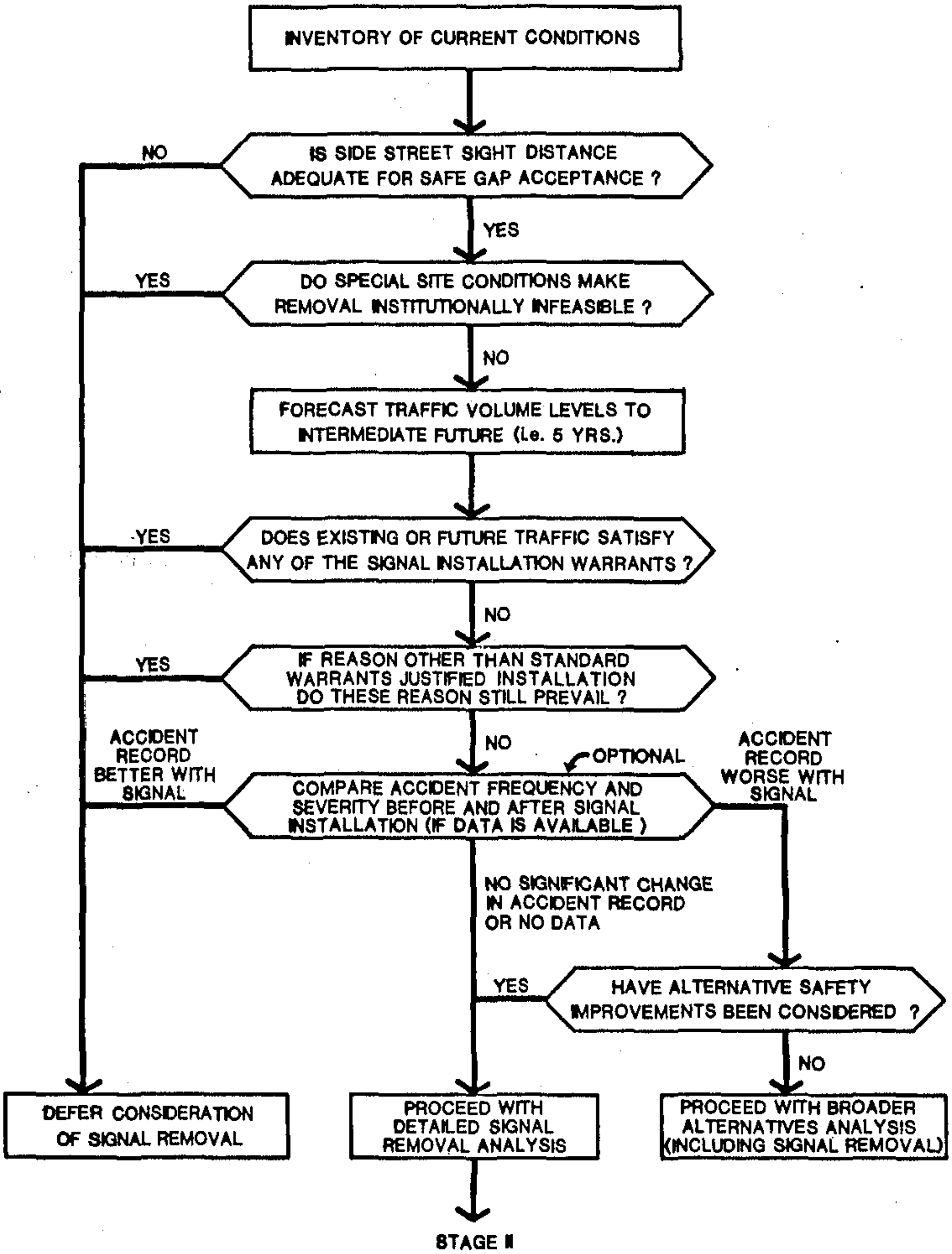


Figure 1. Signal Removal Decision Process
Stage I - Preliminary Screening

1. Sight Distance Adequacy?

Is the sight distance for side street drivers adequate for observation of acceptable gaps in the main road traffic stream in the event the signal is replaced by stop sign control? If the sight distance is less than the minimum values recommended in the Transportation and Traffic Engineering Handbook, the signal should be retained. (See Table 2). (Note - Intersections with inadequate sight distance experienced an average increase in accident frequency of + 2.82 accidents/year per intersection following signal removal.)

If limited sight distance is caused by an easily removed obstruction (e.g., overgrown foliage), or a multi-way stop control is planned after signal removal, consider this criterion satisfied and proceed to next step in the screening process.

2. Special Site Conditions?

Do special site conditions make a signal removal institutionally infeasible?[1] Two major types of recurring conditions are of special concern:

- Signals located at major traffic generators (especially employment sites) where sharp peaks occur during commuting periods and problems in crossing or entering the main road are perceived for these short periods.

- Signals located near special generators which generate either substantial or special categories of pedestrian traffic as perceived by those opposing removal (e.g., schools, libraries, homes for the elderly, hospitals, etc,)

At these locations it may be best to first discuss the proposed removal with representatives of the affected employment site, school or neighborhood association prior to making any in-depth studies.

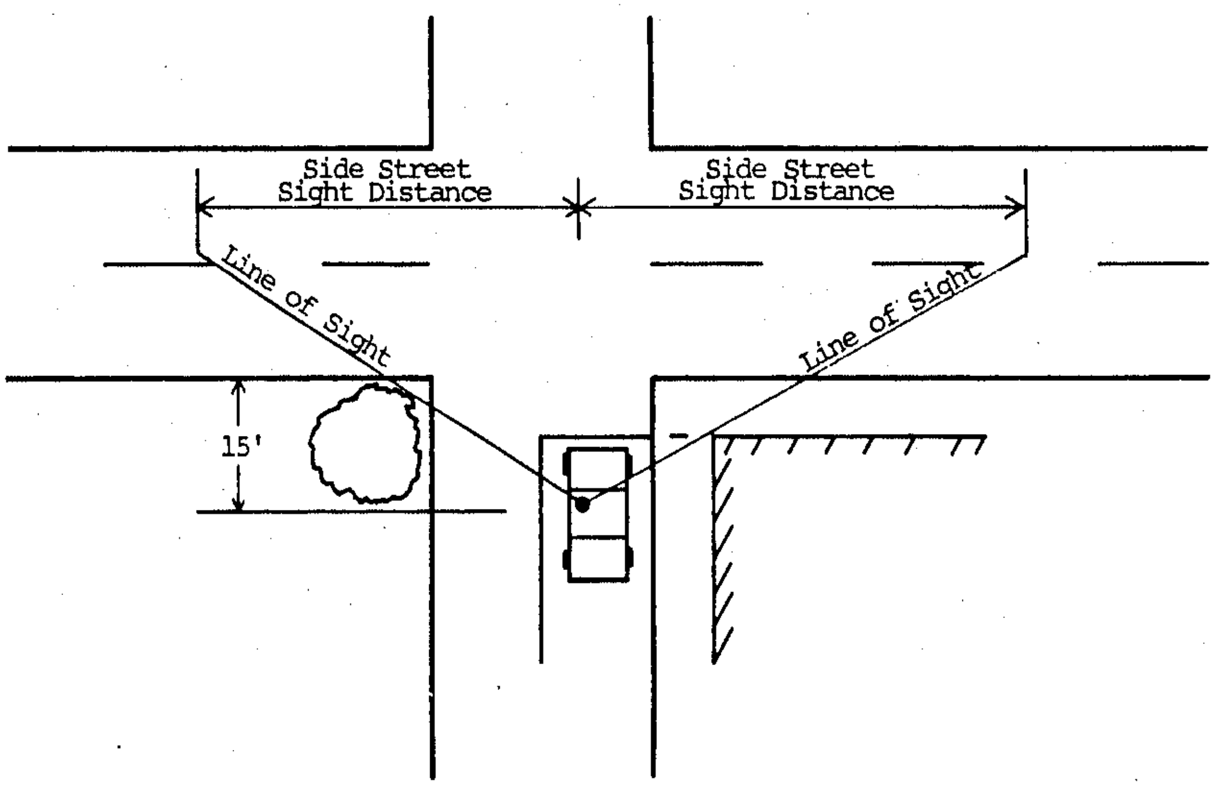
While the special pedestrian situations are the most common type generating intense, emotional opposition, it is very possible that the safety of general pedestrian traffic may also be an issue that is brought up by signal removal opponents. Regardless of the number of pedestrians that actually cross the major stteet, signal removal opponents will often argue that pedestrian safety is compromised with the removal of a signal. The results of the analysis of the signal removal data, however, do not substantiate this belief. At those intersections converted to two-way stop control,

Table 2. Suggested Corner Sight Distance at Intersections.

Design Speed	-	MPH	20	30	40
		(kmh)	(32)	(48)	(64)
Minimum Corner Intersection Sight Distance	-	ft	200	300	400
		(m)	(61)	(91)	(122)

*Corner sight distance measured from a point on the minor road at least 15 feet (4.6m) from the edge of the major road pavement and measured from a height of eye of 3.75 ft. (1.1 m) on the minor road to a height of object of 4.5 ft. (1.4 m) on the major road.

Source: Baerwald, J. E. (ed.), Transportation and Traffic Engineering Handbook, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, pg. 613. 1976.



the average annual pedestrian accident frequency was reduced after signal removal from .41/intersection to .083/intersection. This decrease was not statistically significant. It must be emphasized, however, that the level of pedestrian activity at the intersections in the data base was relatively low - an average of 14.1 pedestrians crossing the major street during the peak hour. While this technical information may prove useful, discussions with signal removal opponents on the subject of pedestrian safety will still require a very careful and tactful approach.

3. Signal Installation Warrants Met?

Are any of the MUTCD signal installation warrants satisfied by either current or future traffic volumes?

4. Special Justifications?

If reasons other than the standard warrants were used to justify the signal installation, do these reasons still prevail? There are undoutedly cases where unwarranted signals have been installed as a result of pressure from a small special interest group based on reasons which either are no longer perceived as problems or can be shown to be invalid.

5. Accident Changes After Signal Installation? (Optional Criterion)

Were accident frequency and severity levels significantly worse, or unchanged after signals were installed than before? This is an optional criterion which should only be used when the signal installation is relatively recent (e.g., five to ten years old), where adequate accident data were available, and where traffic volumes have not changed substantially during the life of the signal.

6. Alternative Improvements Considered?

If accident problems were significantly worse after signal installation than before, have alternative safety improvements been fully considered? Examples of alternative actions to consider in lieu of signal removal include:

- signal display upgrading
- signal clearance interval lengthening (using all red periods) if right angle collision frequency is high
- signal offset improvements to achieve smoother flow and reduction of stops

- double cycling of signal timing to reduce the number of side street greens per hour

- semi-actuation or full-actuation

- shortening of average side street green intervals through pedestrian actuation

- installation of advance warning devices

- improving pavement friction

- turn prohibitions

- parking prohibitions

- improved geometric design features

If such alternatives have not been considered, then their potential and relative costs should be investigated as possible alternatives to signal removal.

STAGE II - DETAILED ANALYSIS

This is a more time consuming analysis process which is pursued only if the candidate intersection survives the preliminary screening process. At this time a preliminary decision should be made concerning the type of sign control that is to be installed after the signal is removed--namely, either two-way stop or multi-way stop. This decision is a local matter and should be based on a number of factors including the traffic volumes entering the intersection, the ratio of the major street volume/side street volume, the current multi-way stop sign warrant contained in the MUTCD, the type of stop control used at adjacent intersections, the local policy and procedures for signing intersections, and engineering judgment. In the event the traffic engineer is unsure of the "best" type of sign control to install, the signal removal impacts should be calculated for both the two-way and multi-way cases. A final decision can be made based on these predicted impacts.

Figure 2 presents the framework for the more detailed stage of the traffic signal removal decision process. The steps contained in the detailed analysis are designed to allow the traffic engineer to predict the impacts that will result from the removal of the traffic signal at a particular intersection. Knowledge of these impacts forms the technical basis for the final decision to remove or not remove the signal. The steps in the detailed analysis are as follows:

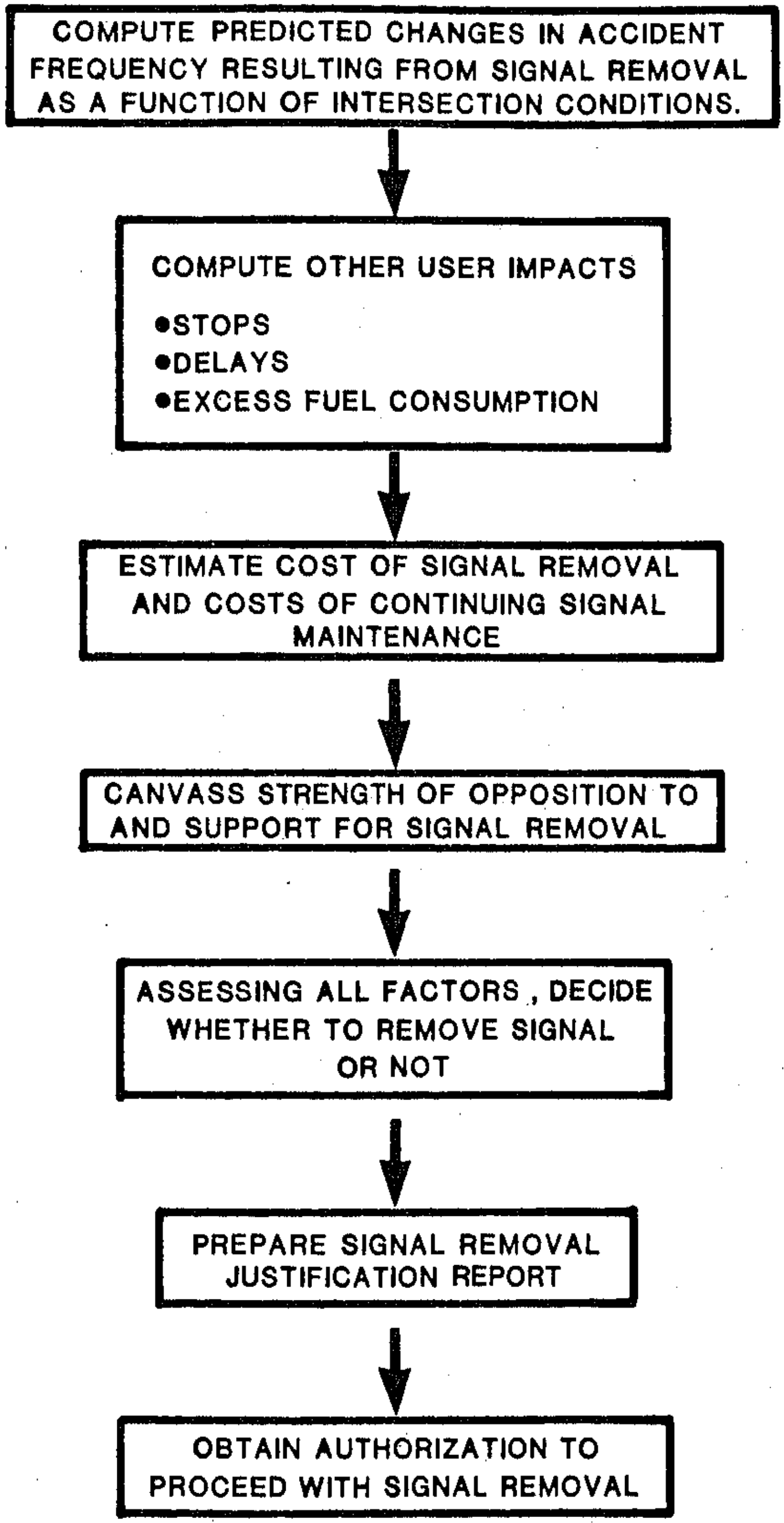


Figure 2. Signal Removal Decision Process
Stage II - Detailed Analysis

1. Accident Impacts

The predicted change in the annual accident frequency resulting from signal removal is calculated. If the signal is to be replaced with two-way stop control, the following equation is used:

$$Y = 1.01 + .139\ X_1 - .605\ X_2$$

where: Y = estimate of change in average annual accident frequency resulting from the removal of a signal and installation of two-way stop control

X_1 = Volume magnitude as measured by the number of hours per day when traffic volumes satisfy at least 60 percent of the signal installation volume warrant-MUTCD Warrant #1. (See Table 3 page 23).

X_2 = Average annual accident frequency at the intersection under signal control.

A nomograph of predicted changes in annual accident frequency for various combinations of X, and X_2 is shown in Figure 3. The nomograph was developed using the above equation and may be used for estimating the accident impacts resulting from signal removal.

If multi-way stop control is planned after removal of the signal, a decrease in accidents can generally be expected. (Note - for the intersections converted to multi-way stop control, there was a statistically significant decrease in average annual accident frequency of -1.02 accidents per intersection following signal removal.) It must be emphasized that this predicted decrease is valid only if the intersection possesses the following characteristics:

- low volumes (less than 800 entering vehicles during peak hour)
- relatively balanced flows (ratio of major street volume/side street volume < 3:1)

2. Traffic Flow Related Impacts

Compute estimate of other impacts of signal removal which are related to improved traffic flow efficiency, i.e., intersection stops and delays and derivative impacts on excess fuel consumption. Methods for doing this are discussed and presented in Appendix B.

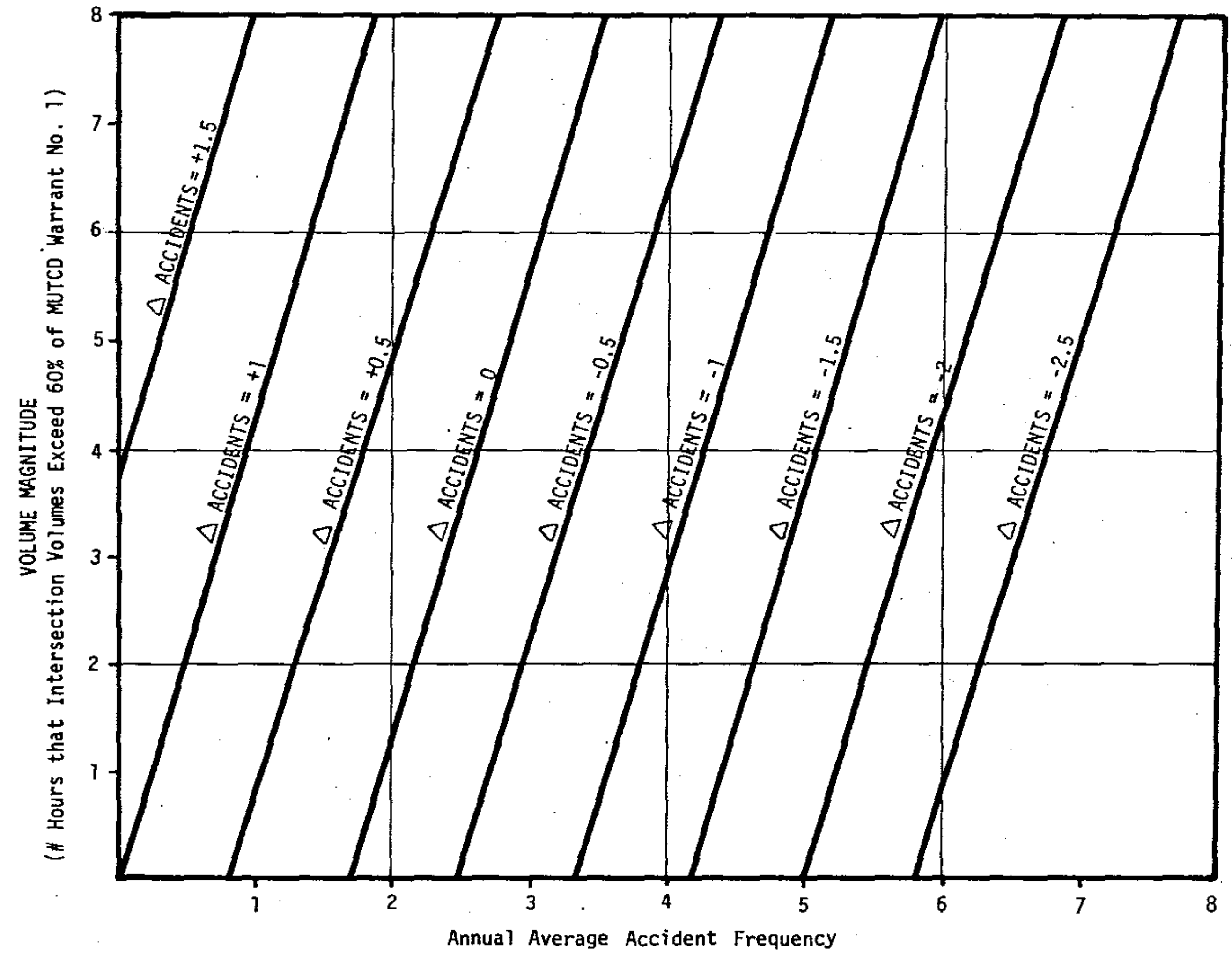


Figure 3. Predicted Changes in Average Annual Accident Frequency Following Signal Removal (Conversion to Two-Way Stop Control)

3. Jurisdiction-Related Costs

Estimate the costs of continued signal operation as compared to the costs of signal removal. The costs of a continued signal operation include the annual costs of maintenance, electricity, and other operational costs such as signal timing. Additionally, the annualized cost of upgrading the signal display may also be included if it is below design standards. The costs of signal removal include the one-time costs of removing the signal hardware and installing stop-signs; and the annual cost of maintaining the signs.

These costs vary widely between individual intersections and between jurisdictions. When these various costs are properly accounted for and adequate records are kept, the jurisdiction should use their own cost data to calculate the cost savings of signal removal. If local "actual" costs are not available, Tables 4 and 5 provide ranges of these costs which can be used to estimate the cost impacts.

As an example, using a "typical" intersection where signal removal may be considered (e.g. pre-timed control, standard design), the various costs are as follows:

Cost of Continued Signal Operation

Annual Electrical Costs	=	$250
Annual Maintenance Costs	=	$1100
Annual Timing Costs	=	$50
TOTAL	=	$1400

Cost of Signal Removal (Equivalent Annual Costs)

Remove Signal	=	$295
Install 2 Stop Signs	=	$25
Sign Maintenance	=	$20
TOTAL	=	$340

Cost Savings of Signal Removal = $1060/year (equivalent annual costs)

TABLE 3. VOLUME MAGNITUDE

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

TABLE 4. ANNUAL COST PER INTERSECTION OF CONTINUED SIGNAL OPERATION

COST COMPONENTS	TYPE OF SIGNAL CONTROL		
	PRETIMED	SEMI-ACTUATED	FULLY ACTUATED
ELECTRICAL	$50-$550	$50-$550	$50-$550
MAINTENANCE	$600-$1600	$750-$3000	$750-$3500
SIGNAL TIMING	$ 48	$ 24	$ 24
ANNUAL TOTAL COST	$700-$2200	$800-$3570	$800-$4075

TABLE 5. COST IMPACTS OF SIGNAL REMOVAL

ITEM	IMPLEMENTATION COST	EQUIVALENT UNIFORM ANNUAL COST*
REMOVE SIGNAL HARDWARE	$1,000- $3,000	$142 - $441
INSTALL STOP SIGNAL	$50 - $120	$ 7 - $18
SIGN MAINTENANCE	-	$5 - $15

*NOTE - ANALYSIS PERIOD IS 15 YEARS AND AN INTEREST RATE OF 12%

CAPITAL RECOVERY FACTOR = 0.142

4. Canvass Public Opposition

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

5. Signal Removal Decision

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

All of the findings of the decision process would be summarized by the traffic engineer in a signal removal justification report for use in gaining necessary authorizations to proceed.

DISCUSSION

The two stages that comprise the traffic signal removal decision process are very distinct and different. The first stage, or preliminary screening, is made up of a set of criteria with each individual criterion involving a go/no-go decision concerning signal removal. If the signalized intersection survives this preliminary screening, then the second stage, or detailed analysis, is pursued.

The detailed analysis does not involve actual criteria, but is instead a process for estimating the major technical and institutional impacts of removing a traffic signal--namely accidents, fuel consumption, jurisdiction-related costs, and public opposition. No decision should be made concerning traffic signal removal until all the impacts have been estimated and weighed by the traffic engineer.

Under normal circumstances, it is assumed that a traffic engineer will not remove a signal if an increase in accidents and/or a large amount of strong opposition is predicted. However, in the event of a jurisdiction undergoing a budgetary crisis or a severe fuel shortage, the reductions in jurisdiction costs and excess fuel consumption may be weighed more heavily. It is once again emphasized that the final decision concerning signal removal is a blend of analytical procedures and institutional/political considerations coupled with professional judgment.

CHAPTER IV

SIGNAL REMOVAL PROCEDURAL GUIDELINES

Once it has been determined that a traffic signal installation should be removed, orderly procedures are necessary to carry out the actual implementation of the removal of the signal hardware. The primary objectives of the removal procedures are as follows:

- To reduce the hazards associated with lack of driver awareness of the change in intersection control during the initial transition period; e.g., to reduce the surprise element.
- To convey to the public (including potential opponents) that the signal removal decision was carefully assessed and is likely to result in safety, energy conservation and traffic operations benefits.

The issues involved in these guidelines include advance public information needs, transition or interim control methods, and follow-up information needs. Each issue is discussed separately.

PUBLIC NOTIFICATION

In most communities, signal removal has been handled as a low-key process with little or no public notification. This may have been due, in part, to the fact that traffic engineers lacked reliable information on the impacts of signal removal. However, now with the signal removal criteria, local traffic engineers have the necessary information with which to counter the arguments of signal removal opponents. Thus, jurisdictions may want to re-evaluate their policy on public notification.

It is recognized that the issue of public notification is very much a local matter and is subject to a number of considerations including the local political atmosphere and the existing policies and procedures for notifying and responding to the public. Thus, the following recommendations concerning public notification are general in nature and may require modification to meet specific local needs.

Three methods of advance public notification have been used by various jurisdictions. Each one is discussed below:

- <u>News Release</u> - Distribution of a news release to local newspapers, radio, and television stations can potentially provide the widest coverage. When City Council approval is required for signal removal, press coverage of the Council meeting will often have the same value as a news release. However, a news release prior to the council meeting is more likely to present the matter in a positive light whereas news coverage of the matter in city council may give more emphasis to any controversy or colorful statements of the opposition. The major drawback to the release is that there is no guarantee that those residents, commercial establishments and drivers most affected by the signal removal will receive information. The release should include information such as the intersection location, the date and time that the signal is to go into the interim control mode, general reasons that the signal is being removed (e.g., change in traffic flow patterns, closing of nearby generator) and a description of the benefits that will be derived by its removal (reduction in delay, fuel consumption and accidents).

- <u>Letter</u> - A letter containing the same information as the press release can be sent directly to the residents and commercial establishments within the immediate vicinity, say two or three blocks, of the candidate signalized intersection. This ensures that these particular citizens will be notified of the proposed signal removal. The major drawbacks of this method are the time and cost involved in preparing and mailing/delivering the letters. An alternative might be to send the letter only to the appropriate citizens/neighborhood/business associations and post the letter in public places (e.g. banks, libraries) located in the vicinity of the candidate signal. Although this method does target those businesses and residents affected by the proposed signal removal, there is no way of ensuring that drivers who use the intersection will receive the information.

- <u>Sign</u> - Posting a sign on the intersection approaches is a very effective way of providing notification to both the surrounding residents/commercial establishments and the drivers who use the intersection. If used, a sign should be installed at the same time that the signal is placed in the interim control mode. A suggested sign for signal removal is shown in Figure 4.

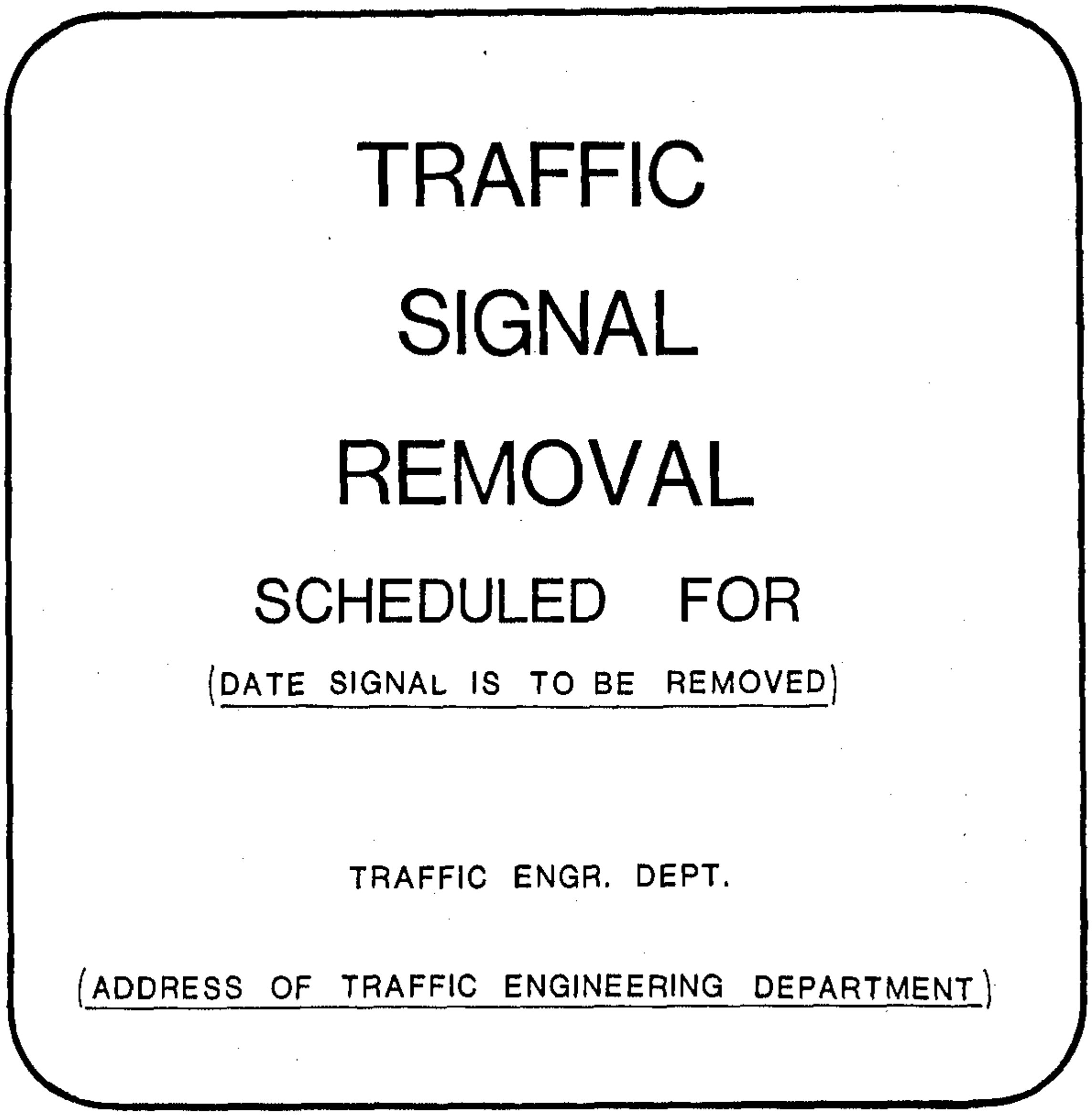


Figure 4. Suggested Signal Removal Sign

INTERIM CONTROL METHODS

All but two of the jurisdictions surveyed in this study either bagged the signal heads or placed the signals on flashing operation as an interim control measure prior to permanently removing the signal hardware. Accident experience during a one month interim control period was compared with the remainder of the "after" period following signal removal.

When the signals were flashed or bagged there was very little difference in the accident experience during the first month compared with the subsequent period. This indicates that both of these interim control measures provide for a smooth transition. On the other hand with no transition control, the accident experience was 43 percent higher during the first critical month than subsequently. Although this difference is not statistically significant, it indicates the possibility that a driver adjustment problem does exist and that some sort of interim control measure is required. It is suggested that signals be flashed or bagged for a minimum of 30 days prior to removal.

There were insufficient data to analyze transition methods at locations converted to multi-way stop control. Nevertheless, for the sake of consistancy, it might be advisable to use flashing or bagging as an interim control at these locations as well.

Although not used by any of the study jurisdictions, the "Stop Ahead" warning sign may be installed on the stop-controlled approaches to supplement the interim control at the intersection. After the 30 day interim control period when the signal has been removed, it may be advantageous to keep the "Stop Ahead" sign for a few months to emphasize the change in intersection control.

FOLLOW-UP ACCIDENT INFORMATION NEEDS

Clearly, because prediction of accidents at individual intersections is not completely accurate, it is important to closely monitor accidents throughout the interim control period. Thus, if not already in existance, a close liason needs to be developed between the traffic engineering department and the accident records division of the jurisdiction's police department.

An increase in the accident rate during the first critical month (e.g. 2 or more accidents during the first month, particularly if right angle or involving injuries) is not a sufficient reason to abandon the plans for removing the signal. Although if an increase does occur, the signal should remain in the transition control mode for a few more months. If the accident rate is still higher after a few months, an in-depth accident analysis should be performed and retention of the signal should be seriously considered.

Accurate accident information should be maintained on all the intersections in the jurisdiction where signals have been removed from several years following signal removal. Assuming that there will be a decrease in accidents at most of these intersections, this kind of "positive" information which is based on intersections within the jurisdiction itself not only lends credibility to the local signal removal program, but also sets a valuable precedent for additional signal removals.

REMOVAL OF SIGNAL HARDWARE

When it has been determined that the signal hardware can be removed, it may be advisable to remove the signal heads only, and monitor accidents and intersection operations for up to a year prior to removing the remaining hardware (e.g. poles, mast arms, controller, cabinets, etc.) In this way, if the signal needs to be reinstalled due to technical or political reasons, it will not be an expensive endeavor.

In most large jurisdictions, there are separate crews for sign work and signal work. Thus when this situation exists, one crew will be responsible for installing the stop signs and another crew for turning the signal off and removing the signal heads and related hardware. While it may seem very obvious, it is most imperative that the work of these separate crews be coordinated in such a manner to ensure that the stop signs are installed <u>before</u> the signal is turned off <u>and</u> that the signal is turned off shortly after the stop signs are installed. Leaving a once-signalized intersection with no traffic control devices for any period of time--even a few minutes--could cause serious accidents, jeopardize the jurisdiction's entire signal removal effort, and possibly lead to legal ramifications.

SUMMARY

The following signal removal procedural guidelines are suggested:

- Some form of public notification is suggested prior to the removal of the signal. The most effective method in terms of targeting the affected citizens is the use of a signal removal sign at the intersection.

- Signals should be flashed or bagged for a minimum of 30 days prior to the signal hardware being removed. The mode of flashing operation must obviously conform to the mode of stop control, i.e., flashing red-yellow for two-way stop control and flashing red-red for multi-way stop control.
- Accidents at the intersection should be monitored very closely during the interim control period. If there is an increase in accidents during this period, (e.g. 2 during the first month) the signal should remain in the transition control mode a few more months during which time the signal removal decision should be reassessed.

CHAPTER V

SPECIAL FACTORS INFLUENCING SIGNAL REMOVAL

The removal of a traffic signal often ivolves political and institutional considerations as much as it is a technical decision. There are certain strategies which have been shown to be very useful in increasing the chances of a signal removal attempt or even an entire signal removal program being successful. Several strategies were identified during the data collection phase and are discussed in the following paragraphs. Whether or not a particular strategy is applicable to a jurisdiction depends, of course, on local conditions.

STARTING SIGNAL REMOVAL PROGRAM

If a signal removal is a new undertaking for the traffic engineering department, it may be advantageous to first attempt removal at "easy" signalized intersections - those intersections where opposition is expected to be low or non-existent and success of the removal attempt is highly probable. In this way, the precedent of signal removal is established within the jurisdiction, and the signal removal program can build and grow on these successes.

OPPORTUNITY

Take advantage of special opportunities when they arise. For example, it may be possible to remove a signal that has been disabled due to vandalism or a traffic accident instead of repairing or replacing it. As another example, some jurisdictions plan the removal of a signal, whenever possible, while one of the intersecting streets is closed for repair or construction. After the completion of the construction, however, the signal is not reinstalled. These opportunities should only be pursued where the signal removal criteria and decision process indicates that signal removal will have beneficial impacts.

TIMING

It is best to avoid signal removal during politically sensitive times of the year. For example, in several cities, the traffic engineer does not bring signal removal proposals before the City Council during the members' campaign for re-election. With the removal of a signal being such a visible item and often politically sensitive, the chances of having the proposed signal removal approved by the council are at their lowest just prior to election time.

It is also best to avoid removal during periods of inclement winter weather. The transition period may involve more risk than usual at such times.

FACING THE OPPOSITION

Opposition to a proposed signal removal is often a very emotional situation. If opposition is obviously present, don't try to bypass it. It is best to face it squarely with the facts (e.g. predicted impacts) and try to work constructively to resolve differences. It may be advantageous for the traffic engineer or one of his assistants to meet with representatives of the opposition at the intersection during the peak hour to observe traffic when the intersection is being operated in the interim control mode.

There undoubtedly will be instances when opposition to a signal removal attempt is much stronger than expected, and technical and logical explanations will be fruitless. Under these circumstances, it is best to avoid unnecessary confrontations. If the traffic engineer believes in his judgment, that continuing a particular removal attempt in the face of strong opposition would jeopardize the entire signal removal program, the signal should be returned to normal operation.

RELOCATION

In this strategy the unwarranted signal is "relocated" to another, near-by intersection where the need for signal control is greater. By placing the unwarranted signal in the interim control mode at the same time the new near-by signal installation is turned on, a signal can be removed under conditions (such as public opposition and politics) that otherwise might make removal impossible.

The use if this strategy is dependent on there being an unsignalized intersection in the immediate area (two or three blocks at most) that is more suitable for signalization than the one planned for signal removal.

It is emphasized that the strategy of "relocation" does not decrease the number of signalized intersections and is thus not suggested as a general practice. It often involves the lesser of two evils and should be used only as a last resort. However, under the right circumstances and when severe political constraints exist, it is a worthwhile strategy to consider.

MOTIVATION

A strong underlying motivation for pursuing signal removal within the jurisdiction should be developed and then emphasized to all those involved and affected by the signal removal decision process. In todays circumstances, it may be especially effective to emphasize:

- Energy Conservation
- Budget Consciousness (taxpayer savings)

as the two principal reasons for pursuing signal removal opportunities. It can then be further demonstrated that improvements will also occur in:

- Safety
- Traffic Flow Efficiency

Which particular benefits are emphasized is a local decision and is dependent on the political and institutional atmosphere within the jurisdiction. Whatever the priorities, the above-mentioned benefits of removing signals are significant and an aggressive program of signal removal should be undertaken to achieve them.

EFFECTS OF ADJACENT SIGNALS

All of the analysis of delays, stops and fuel consumption is based on the assumption that the signal being considered for removal is "isolated" from adjacent signalized intersections. Separation is assumed to be great enough to result in random arrivals rather than cyclical platooned arrivals at the candidate signal.

The existance of the two adjacent signals will have two types of effects when the middle signal is removed, compared with the isolated signal removal case:

1. Delays and stops on the main road approaches to the candidate signal will vary when there are adjacent signals that cause "platooned" arrivals. Usually, with platooned flow, it will be possible to set signal offsets so that traffic performance is better than with random arrivals at an isolated signal -- thus, the signal removal benefits to main road traffic would be less than the isolated case. Sometimes, however, the candidate signal may be located at "just the wrong place", making good signal offsets in both directions impossible, and possibly resulting in greater main road approach delays at the candidate signal than in the isolated signal case.

2. Delays and stops on the main road approaches to the adjacent signals from the direction of the candidate intersection may change when the candidate signal is removed. In the case of isolated signals (i.e., spacing long enough so that arrivals at adjacent signals are random), removing the middle signal has no effect on traffic arrivals or stops and delays at the other signals. However, when adjacent signals are close enough to result in cyclical platooned arrivals, removing the middle signal may permit better signal offsets between the two remaining outer signals, thereby providing additional signal removal benefits. On the other hand, removing the middle signal may "spread out" the platoons' arrivals at the outer signal due to longer platoon dispersion distances and, if the previous signal offsets (with the candidate signal not removed) were fairly good, delays may actually increase some after signal removal.

The above discussions indicate that it is not certain, a priori, that signal removal benefits will be greater or less when adjacent signal effects are accounted for. It will depend on the specific traffic flow, signal timing, and spacing conditions.

All of the analyses has assumed that if the candidate signal is not removed, it will be operated with near optimal signal timing. This assumption means that estimates of signal removal benefits are conservatively low -- i.e., signal delays are likely to be somewhat higher than estimated -- possibly by as much as 15 to 20 percent. This underestimation of benefits that may result from not taking adjacent signal effects into account when developing the signal removal impact nomographs.

In the final analysis, unless one knows the specific unique site characteristics of a signal removal candidate intersection and is willing and able to use a simulation tool like the TRANSYT model, the impact nomographs in Appendix B (which were computed assumming no adjacent signal effects) should be reasonably valid for making order of magnitude estimates of signal removal benefits.

APPENDIX A

INSTRUCTIONS FOR SIGNAL REMOVAL ANALYSIS WORKSHEET

I. INTERSECTION INVENTORY

Fill out the appropriate information as required.

- Indicate which street is the major street and which one is the side street.
- The ADT required is the two-way average daily traffic volume
- Side-street sight distance should be measured for all side-street approaches as shown in Table 2, p.16).

II. PRELIMINARY SCREENING

This is a quick screening to determine if additional analysis of the intersection is justified. It is made up of the following 4 separate criterion, each involving a go/no-go decision concerning signal removal:

1. Sight distance adequacy
2. Special site conditions - signals located at major traffic generators such as employment sites where sharp peaks occur during commuting periods; and signals located near pedestrian generators such as schools are often institutionally infeasible to remove.
3. Existing signal warrants met. - This can be estimated by comparing the actual ADT's with the approximate ADT's required for warrant satisfication (Table 1, p.12).
4. Special justifications

If any of the above criterion are answered "yes", signal removal should be deferred. Otherwise, proceed with the detailed analysis.

III. DETAILED ANALYSIS

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

Accident Impacts

a. From Table 3, (p.23) list the minimum required volume for determing the Volume Magnitude. The minimum volume is dependent on the number of lanes per approach.

b. List the major street volume (two-way) and higher side-street volume (one approach only) for the 8 peak hours. The major-street and side-street volumes are listed for the same hour. Although, during the 8 hours, the higher volume on the side-street may be one approach during some hours and on the opposite approach during the other hours.

c. If both the major street and side-street volumes exceed the minimum values, put a check in the box to the right. The number of boxes checked is the volume magnitude.

d. Record the number of intersection accidents and the period (month/year) during which they occurred. A period of 12 months must be used as a minimum.

e. The average annual accident frequency is calculated as follows:

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

where: AF = average annual accident frequency

t = number of months in the period covered

N = number of intersections during the period.

f. Using the accident nomograph in Figure 3 (p.21) entering the volume magnitude (left, vertical axis) and the average annual accident frequency (bottom, horizontal axis), the predicted change in annual accident frequency can be estimated. For greater accuracy, the equation on page 20 can be used.

If multi-way stop control is planned, the magnitude of the change in accident frequency cannot be predicted. Although under certain volume conditions (e.g. low volumes and balanced flows) a decrease in accidents can generally be expected. (see page 20).

Traffic Flow Related Impacts

Enter the daily estimated changes in idling delay, total delay, total stops, and excess fuel from the impacts worksheet (See Appendix B). Multiplying these values by 320 will provide the annual change.

Jurisdiction-Related Costs

a. Total the annual costs of continued signal operation.

b. Estimate the one time costs of signal removal and stop-sign installation and convert these to equivalent annual costs by multiplying these figures by 0.149. Total the annualized costs of signal removal.

c. The difference between the annual costs of operation and the annual removal costs is the annual cost savings from signal removal.

Anticipated Strength of Opposition/Support

The local politicians, business leaders and police can be contacted for their opinions. This initial canvassing provides a general idea of the opposition or support that may be encountered later on.

Final Decision

Weighing all the findings of the detailed analysis, make a decision whether the signal should be removed or not.

SIGNAL REMOVAL ANALYSIS WORKSHEET

I. INTERSECTION INVENTORY

Intersection: ______________________________ City: ________________

Major St.: ______________________ Lanes/Approach: _____ ADT: _____

Side St.: ______________________ Lanes/Approach: _____ ADT: _____

Major Street Speed: ________________

Side-Street Sight Distance: ______________________________

____

II. PRELIMINARY SCREENING

	NO	YES
1. Minimum Required Sight Distance (from table 2,Page 16) ________________ Is Intersection Sight Distance Less Than Minimum?	✓__	__
2. Do Special Site Conditions Make Signal Removal Institutionally Infeasable? .... Comments: ______________________________ ______________________________ ______________________________	__	__
3. Does Existing (or future) Traffic Satisfy Signal Installation Warrants?	__	__
4. Did Any Special Reasons Justify Signal Installation? Are These Reasons Still Valid? .... Comments: ______________________________ ______________________________ ______________________________	__	__

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

SIGNAL REMOVAL ANALYSIS WORKSHEET

III. DETAILED ANALYSIS: TWO-WAY STOP CONTROL

1. ACCIDENT IMPACTS

		Total Major Street Volume	Higher Volume Side Street Approach	Check If Minimum Satisfied
Minimum Required (Table 3)				
Nth Highest Hour – Volume	1st			☐
	2nd			☐
	3rd			☐
	4th			☐
	5th			☐
	6th			☐
	7th			☐
	8th			☐

Volume Magnitude (No. Hours Meeting Requirement) = ☐

Accident Experience

Total Accidents ________

Period Covered: From ____ To ____

Average Annual Accident Frequency ☐

From Accident Nomograph (Figure 3)

Predicted Change In Annual Accident Frequency = ☐

2. TRAFFIC FLOW RELATED IMPACTS

Change Per Vehicle (From Delay Worksheet)	Daily Change (From Delay Worksheet)	x 320	=	Annual Change
________	________	Idling Delay	→	☐
________	________	Total Delay	→	☐
________	________	Total Stops	→	☐
________	________	Excess Fuel	→	☐

3. JURISDICTION – RELATED COST IMPACTS

Annual Signal Operation Costs		Costs Of Signal Removal x CRF* = Annual Costs			
Electrical	________	Remove Hardware	________	x 0.142	________
Maintenance	________	Install Stop Signs	________	x 0.142	________
Timing	________	Annual Stop Sign Maintenance			________
Total	☐			Total	☐

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

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

4. ANTICIPATED STRENGTH OF OPPOSITION/SUPPORT FOR SIGNAL REMOVAL:

Comments: ____

____

5. FINAL DECISION: Retain Signal ☐ Recommend Removal ☐

Comments: ____

____

APPENDIX B

INSTRUCTIONS FOR SIGNAL REMOVAL IMPACTS WORKSHEET AND NOMOGRAPHS

The following instructions explain how to use the nomographs and worksheet for predicting the daily impacts of signal removal and replacement by two-way stop control. An example worksheet for a 4-way intersection, 4-lane major and 4-lane minor street is presented as Table 6. See the Summary Chapter (page 8) for a discussion of impacts when converting a signal to multi-way stop control.

Step 1. Indicate the intersection type (4-way or T) and the number of lanes (2 or 4) on the main road and side road. The number of lanes is defined as the total number of lanes in both directions on a given road (e.g. 4 lanes means two lanes in each direction).

Step 2. Enter the traffic volumes for the average of the 2 peak hours of the day.

a. For the main road, enter the total volume for the 2 approaches averaged for the 2 peak hours. For example:

	Main Road		
	Approach 1	Approach 2	Total
Highest Hour	600	500	1100
2nd Highest Hour	500	400	900
			2 ⟌2000

Total main road volume per hour = 1000 vph

b. For the side road, enter the average volume per approach for the 2 approaches averaged for the 2 peak hours. For example:

	Side Road		
	Approach 1	Approach 2	Average
Highest Hour	140	120	130
2nd Highest Hour	120	120	120
			2 ⟌250

Average side road volume per hour per approach = 125 vph

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

			IDLING DELAY (VEH. HRS.)	TOTAL DELAY (VEH. HRS.)	TOTAL STOPS (VEH. STOPS)	EXCESS FUEL CONSUMPTION (GAL.)
① INTERSECTION TYPE: [X] 4-Way, [ ] T-Intersection; Main Road: [ ] 2 Lane, [X] 4 Lane; Side Road: [ ] 2 Lane, [X] 4 Lane						
AVERAGE OF THE 2 PEAK HOURS		③ a. Signal Control (From Nomographs)	2.3	5.2	680	4.4
		b. 2 Way Stop Control (From Nomographs)	0.5	1.5	280	1.6
② a. Total Main Road Vol. = 1000; b. Side Road Vol. / Approach = 125; c. Total Intersection Vol. = 1250		c. DIFFERENCE	1.8	3.7	400	2.8
④ TOTAL OF THE TWO PEAK HOURS	a. x 2 = 2500	b. x 2 = DIFFERENCE	x 2 3.6	x 2 7.4	x 2 800	x 2 5.6
AVERAGE OF THE REMAINING 22 HOURS		⑥ a. Signal Control (From Nomographs)	0.8	2.0	270	1.6
		b. 2 Way Stop Control (From Nomographs)	0.1	0.4	110	0.5
⑤ a. Total Main Road Vol. = 400; b. Side Road Vol./ Approach = 50; c. Total Intersection Vol. = 500		c. DIFFERENCE	0.7	1.6	160	1.1
⑦ TOTAL OF THE REMAINING 22 HOURS	a. x 22 = 11,000	b. x 22 = DIFFERENCE	x 22 15.4	x 22 35.2	x 22 3520	x 22 24.2
⑧ 24 HOUR TOTAL	2 Hrs.+22 Hrs. = a. 13,500	2 Hrs.+22 Hrs. = DIFFERENCE b.	2+22 19.0	2+22 42.6	2+22 4320	2+22 29.8
⑨ PER VEHICLE IMPACTS (Divide 24 Hour Differences By 24 Hour Volume)			.0014	.0032	0.32	.0022

TABLE 6. WORKSHEET FOR ESTIMATING DAILY IMPACTS OF SIGNAL REMOVAL AND REPLACEMENT BY TWO WAY STOPS

EXAMPLE

c. Enter the total intersection approach volume averaged for the 2 peak hours. For a 4-way intersection sum the total main road volume (entry 2a) and 2 times the side road volume per approach (2 X entry 2b). For example, from above:

Total main road volume	=	1000 vph
2 X Average side road vol./approach	=	2 X 125 vph
Total	=	1250 vph

(For a T-intersection, sum the total main road volume plus the only side road approach volume.)

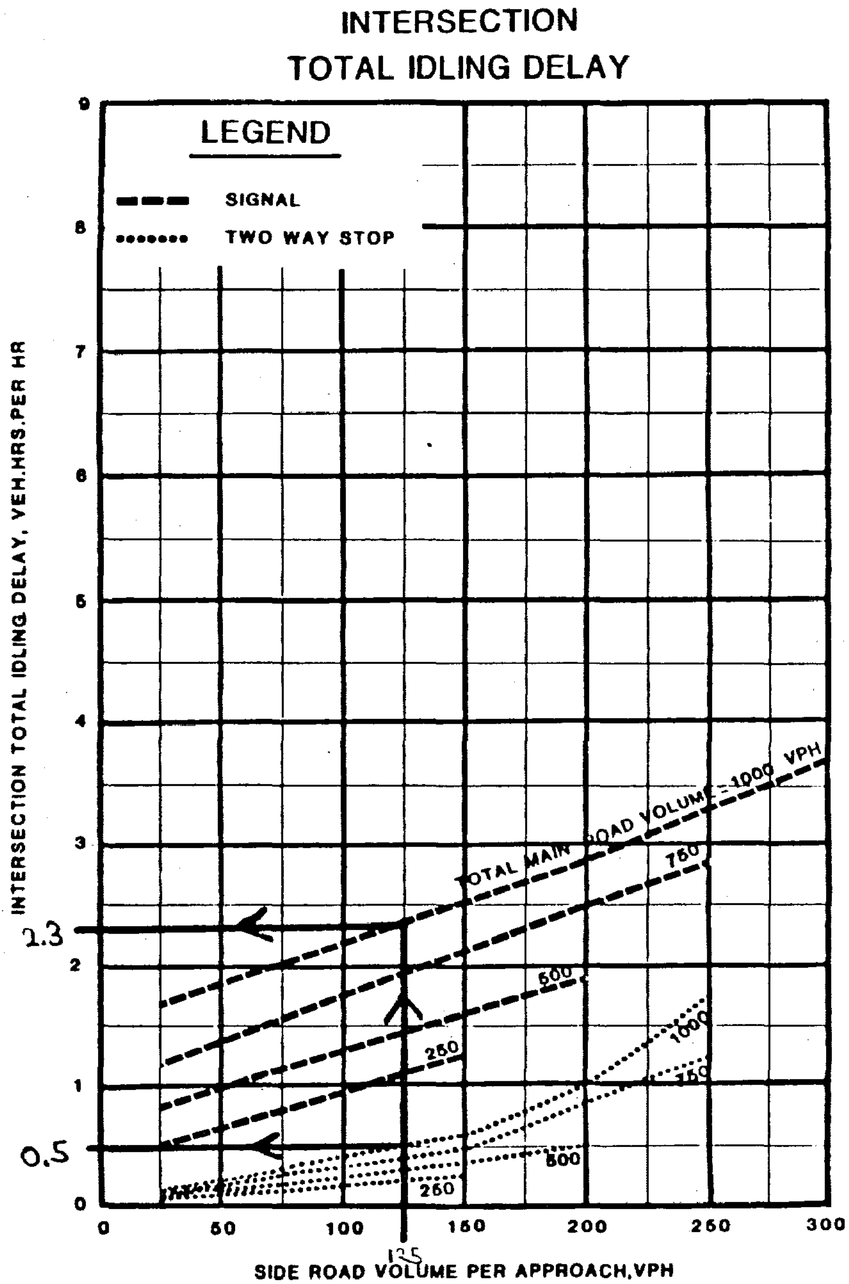
Step 3. For the average of the 2 peak hours, read from the nomographs the per hour estimates of the 4 impact variables: idling delay, total delay, total stops, and excess fuel consumption. (Figure B-3 is a list of nomographs by intersection type to guide you in the selection of the correct nomographs.)

a. Estimate the 4 impact variables for signal control.

On each nomograph:

- Enter side road volume per approach (from Step 2b.) on the bottom horizontal axis.
- Draw a vertical line and locate on it the point equal to total main road volume (from Step 2a.) on the family of lines representing signal control (the dashed lines).
- From this point, draw a horizontal line to the left vertical axis and read the estimated value of the impact variable. Enter this value on the worksheet on line 3a.

b. Estimate the 4 impact variables for 2-way stop control. Use the same nomographs in the same manner as in Step 3a, but for total main road volume use the family of lines representing 2-way stop control (the dotted lines). Enter the estimates on the Worksheet on line 3b. (Nomographs for the example worksheet are provided in Figure 5 and 6).



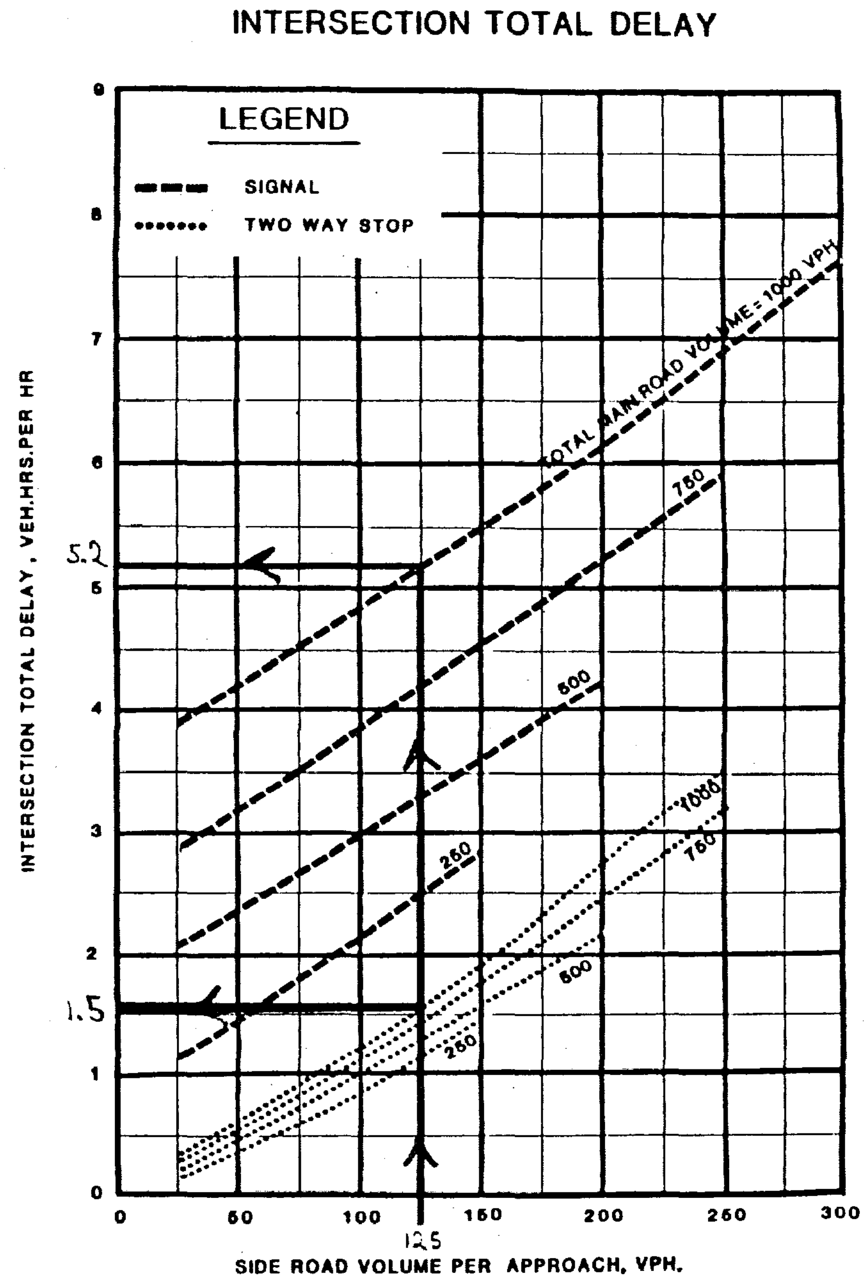
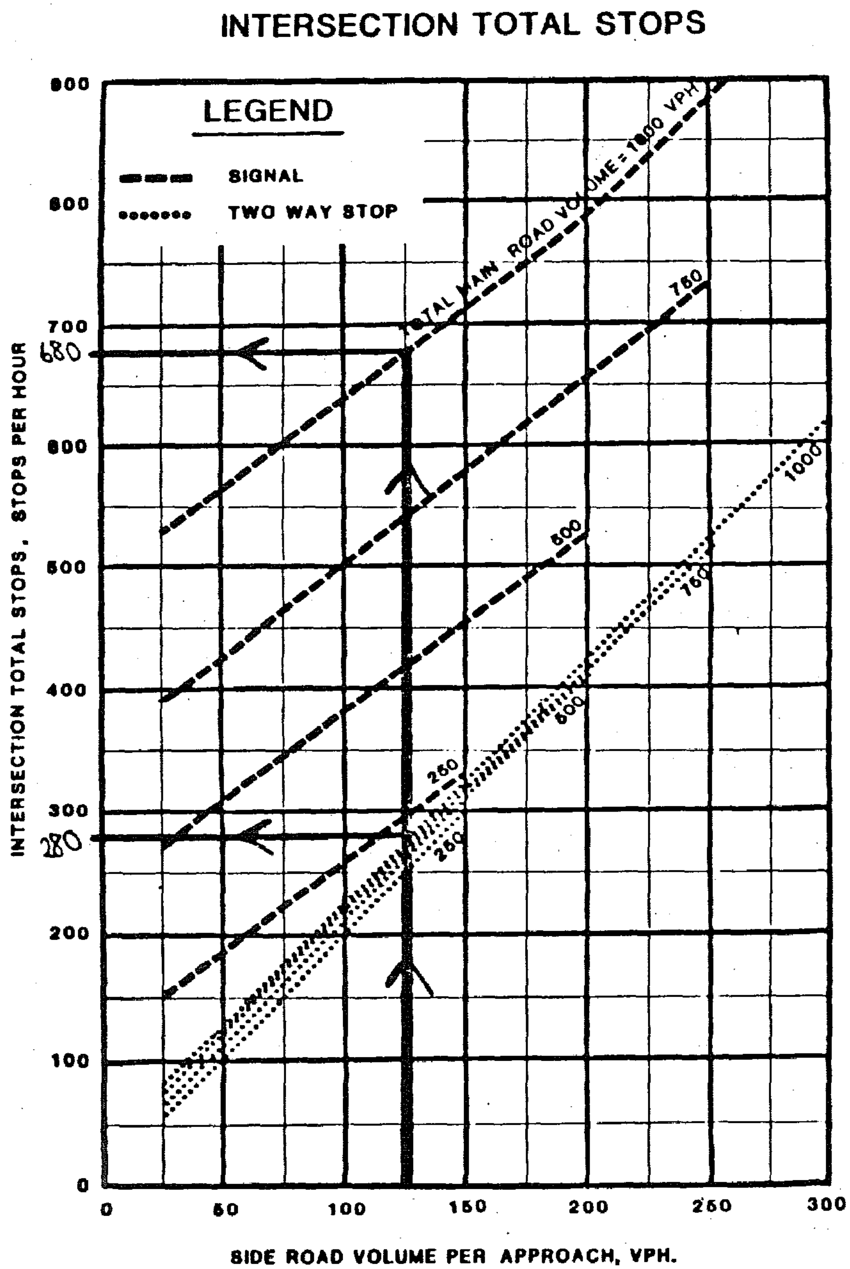


FIGURE 5. IDLING AND TOTAL DELAY - EXAMPLE
(FOUR WAY INTERSECTION: FOUR LANE MAJOR, FOUR LANE MINOR)



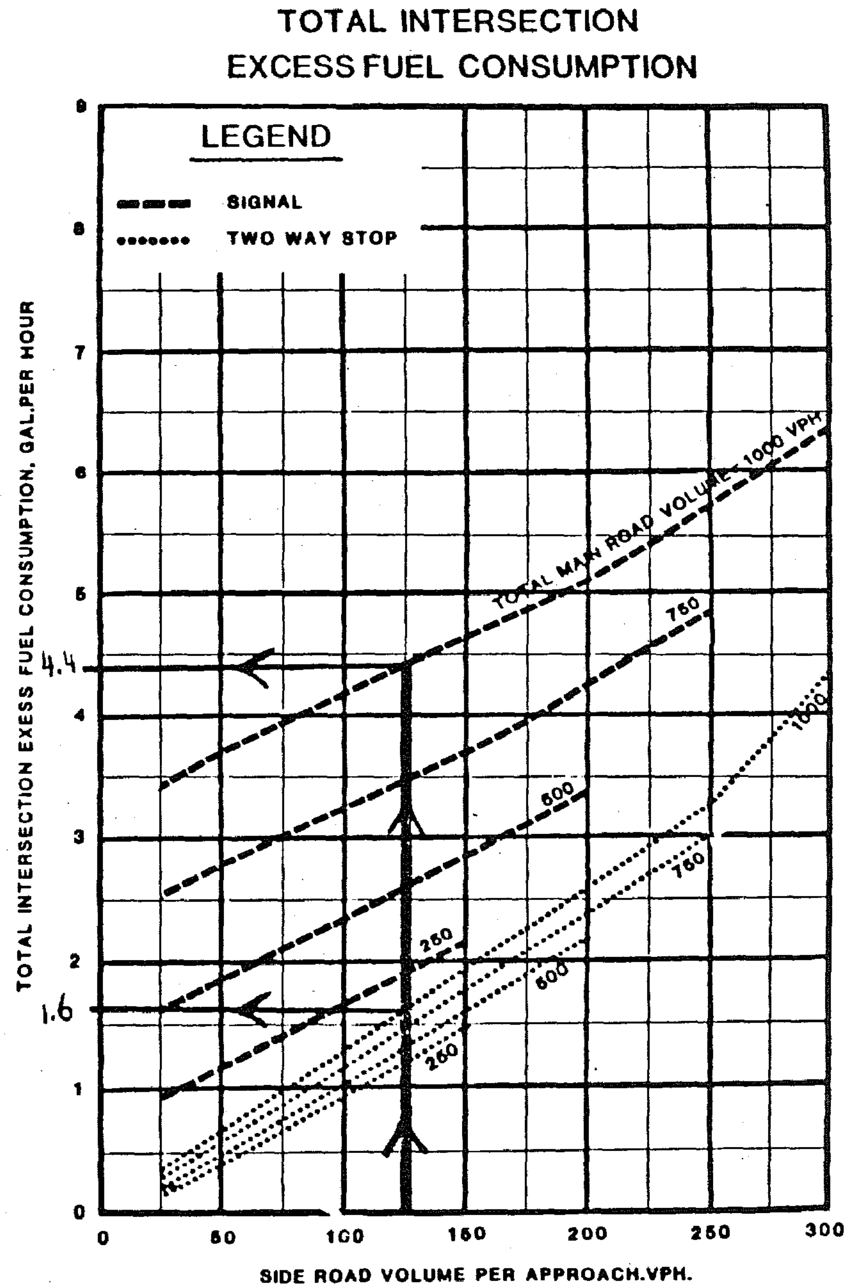


FIGURE 6 STOPS AND EXCESS FUEL CONSUMPTION - EXAMPLE
(FOUR WAY INTERSECTION: FOUR LANE MAJOR, FOUR LANE MINOR)

c. For each of the 4 impact variables, calculate the difference between the signal control and 2-way stop control estimates. (i.e. subtract the 3b entries from the 3a entries.)

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

Step 4. Calculate impacts for the total of the 2 peak hours.

a. Calculate total intersection approach volume for the total of the 2 peak hours (i.e., multiply the entry on line 2c by 2).

b. Calculate the signal removal impacts for the total of the 2 peak hours (i.e., multiply each of the 4 impact variables entered on line 3c by 2).

Step 5. Enter the traffic volumes for the average of the 22 remaining hours of the day.

a. For the main road, first sum the 2 approach directions for each of the remaining 22 hours and then calculate the average hourly total main road volume for these 22 hours.

b. For the side road, first calculate the average volume per approach for each of the 22 hours and then calculate the average hourly side road volume per approach for these 22 hours.

c. Calculate the total intersection approach volume, averaged for the 22 remaining hours.

(The above steps follow the same procedures as Steps 2 a, b, and c, except that volume data for the 22 remaining hours are used instead of the 2 peak hours.)

Step 6. For the average of the 22 remaining hours, read from the nomographs the per hour estimates of the 4 impact variables: idling delay, total delay, total stops, and excess fuel consumption.

(See Figure 7 to guide the selection of the correct nomographs.)

a. Estimate the 4 impact variables for signal control. (Use same procedure as in Step 3a.)

b. Estimate the 4 impact variables for 2-way stop control. (Use same procedure as in Step 3b.)

c. For each of the 4 impact variables, calculate the difference between signal control and 2-way stop control (i.e., subtract the 6b entries from the 6a entries.)

Step 7. Calculate impacts for the total of the 22 remaining hours.

a. Calculate total intersection approach volume for the total of the 22 hours (i.e., multiply the entry on line 5c by 22).

b. Calculate the signal removal impacts for the total of the 22 hours (i.e., multiply each of the 4 entries on line 6c by 22).

Step 8. Calculate 24 hour total impacts.

a. Calculate 24 hour total intersection approach volume (i.e., sum line 4a and line 7a).

b. Calculate the signal removal impacts for the total of 24 hours (i.e., sum the 4b entries and 7b entries for each of the 4 impact variables).

Step 9. Calculate per vehicle impacts. Divide the 24 hour total impacts on line 8b by the 24 hour total volume on line 8a. In the case of idling delay and total delay, if desired, convert per vehicle delays from hours to seconds by multiplying by 3600.

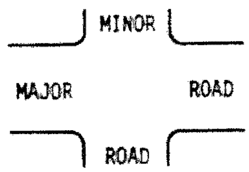
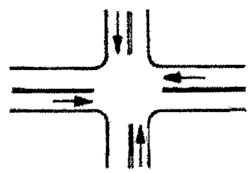
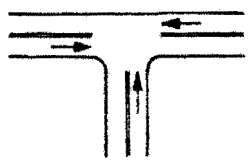
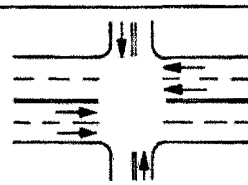
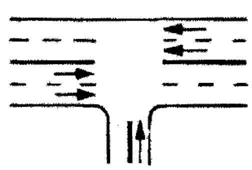
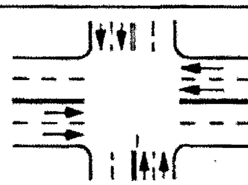
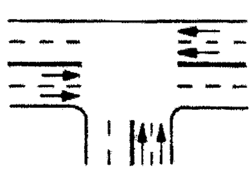
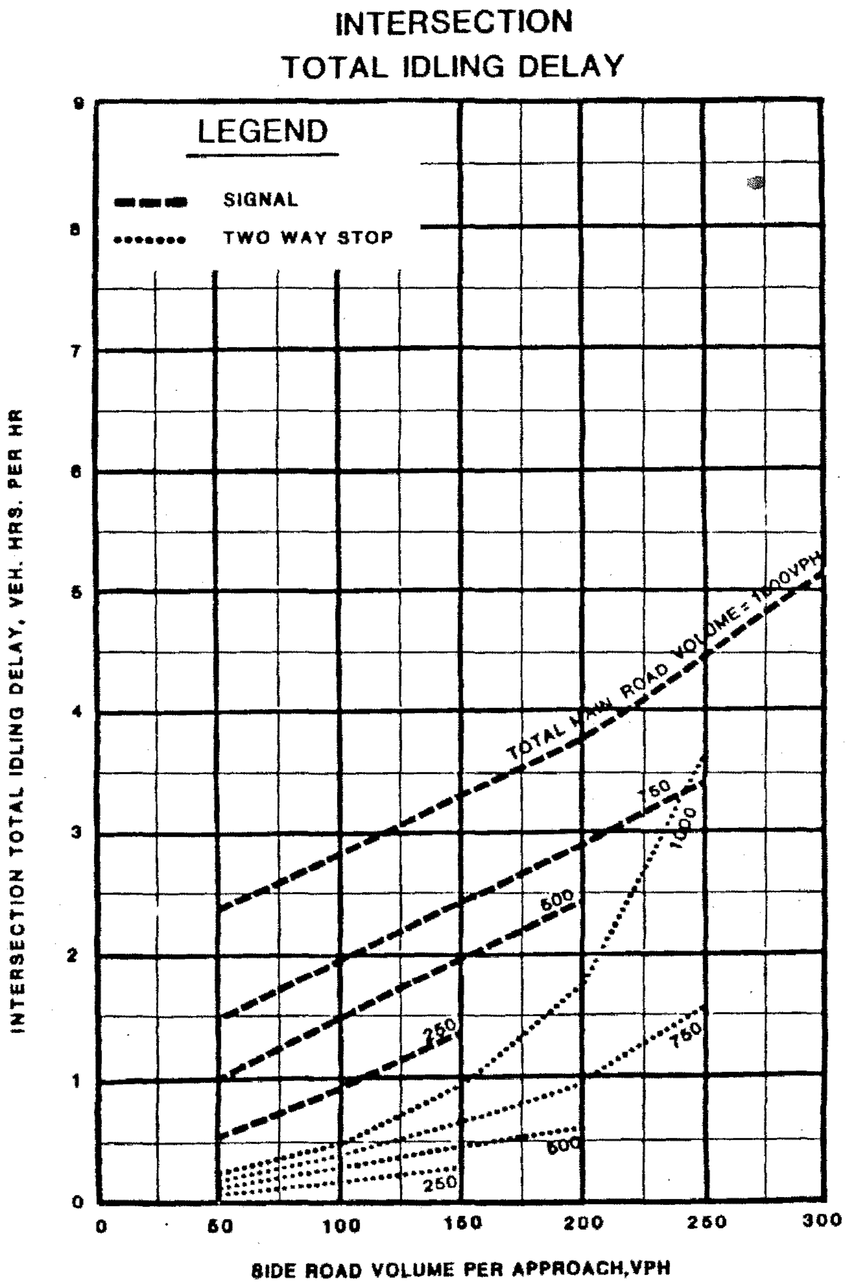
INTERSECTION TYPE	ILLUSTRATION 	NOMOGRAPH FIGURE NUMBERS	
		IDLING & TOTAL DELAY	STOPS & FUEL
4-WAY INTERSECTION, 2-LANE MAJOR ROAD, 2-LANE MINOR ROAD.		8	9
T-INTERSECTION, 2-LANE MAJOR ROAD, 2-LANE MINOR ROAD.		10	11
4-WAY INTERSECTION, 4-LANE MAJOR ROAD, 2-LANE MINOR ROAD.		12	13
T-INTERSECTION, 4-LANE MAJOR ROAD, 2-LANE MINOR ROAD.		14	15
4-WAY INTERSECTION, 4-LANE MAJOR ROAD, 4-LANE MINOR ROAD.		16	17
T-INTERSECTION, 4-LANE MAJOR ROAD, 4-LANE MINOR ROAD.		18	19

Figure 7. List of Nomographs By Intersection Type



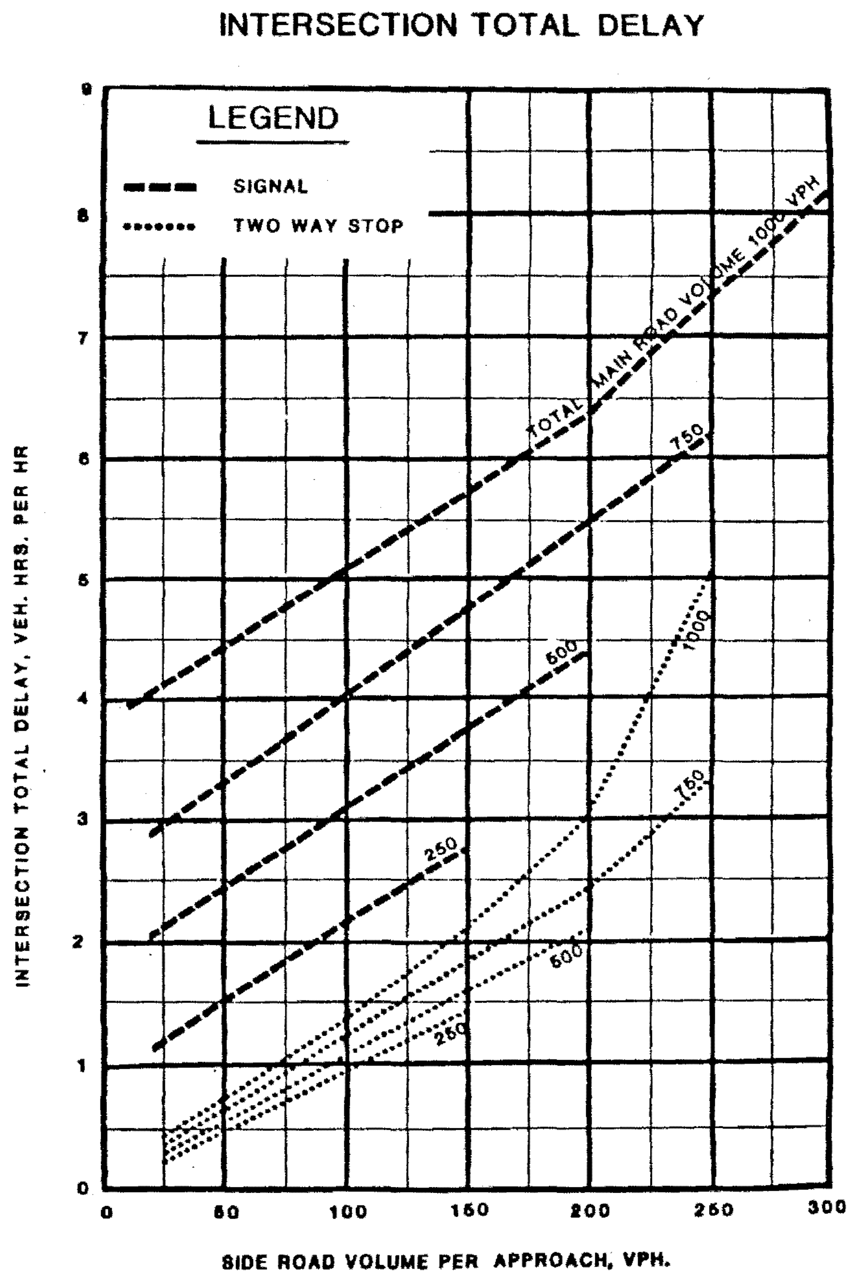


FIGURE 8. IDLING AND TOTAL DELAY

(FOUR WAY INTERSECTION: TWO LANE MAJOR, TWO LANE MINOR)

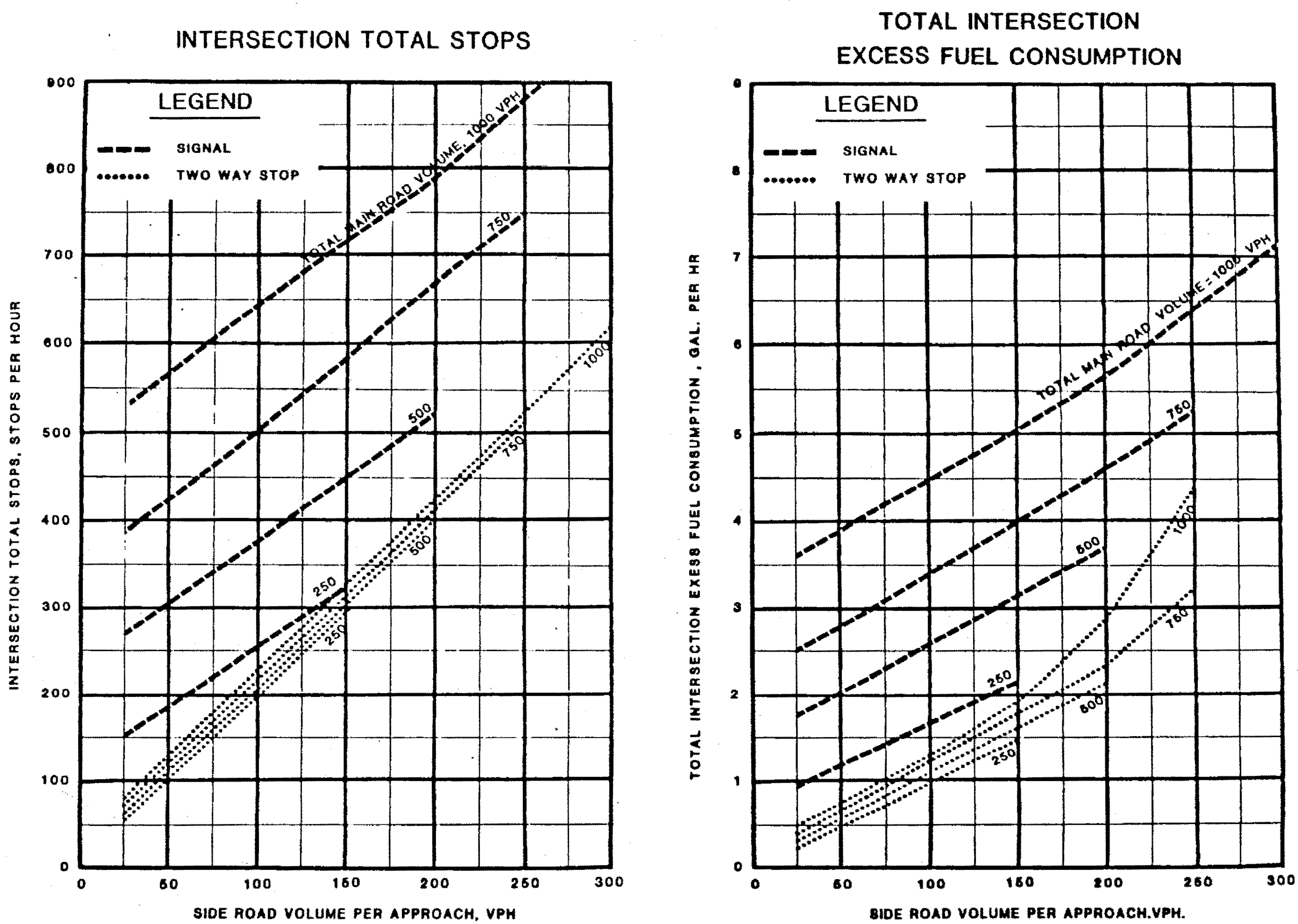


FIGURE 9. STOPS AND EXCESS FUEL CONSUMPTION

(FOUR WAY INTERSECTION: TWO LANE MAJOR, TWO LANE MINOR)

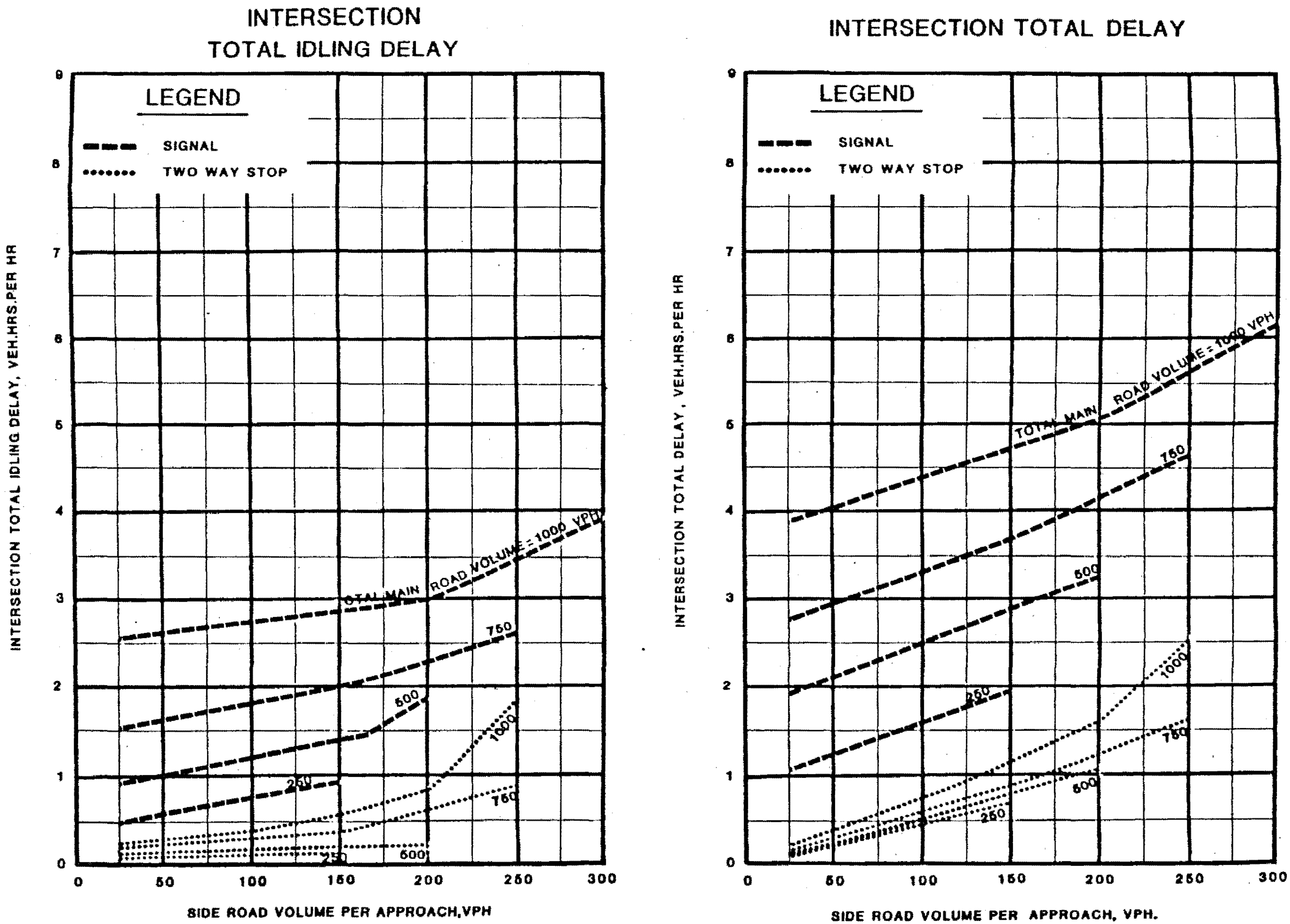


FIGURE 10. IDLING AND TOTAL DE Y
("T" INTERSECTION: TWO LANE MAJOR, TWO LANE MINOR)

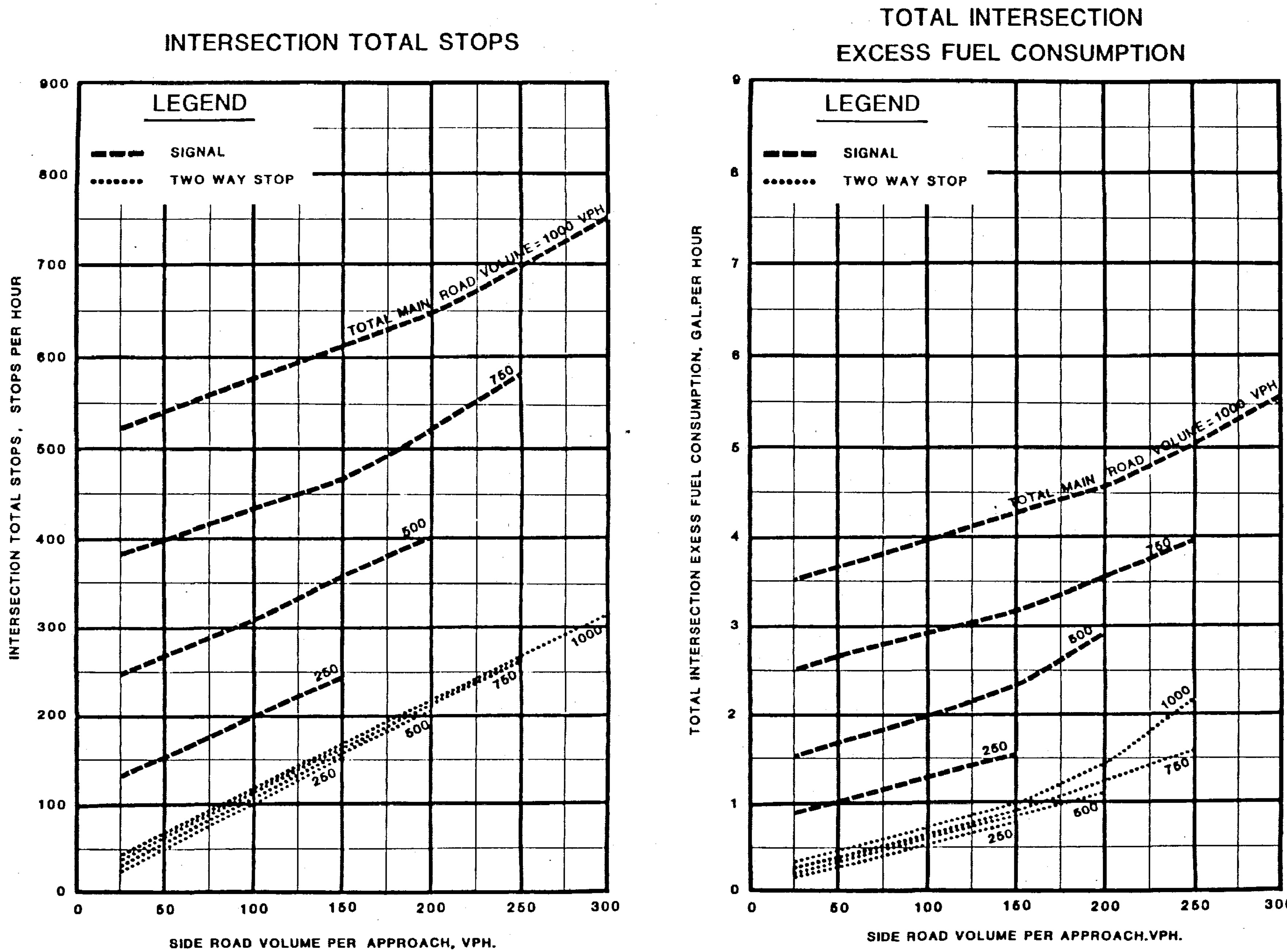


FIGURE 11. STOPS AND EXCESS FUEL CONSUMPTION
("T" INTERSECTION: TWO LANE MAJOR, TWO LANE MINOR)

INTERSECTION TOTAL IDLING DELAY

INTERSECTION TOTAL DELAY

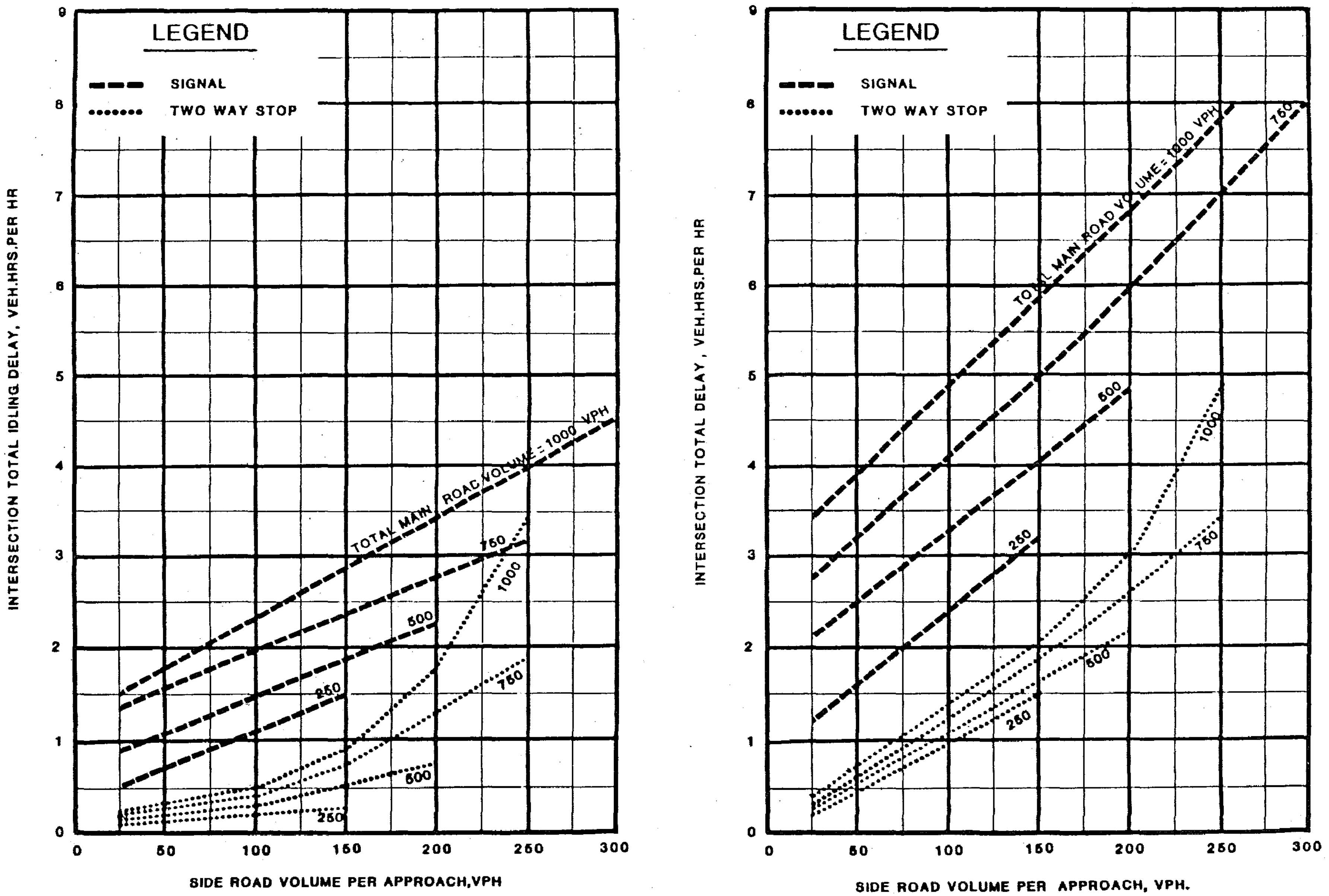


FIGURE 12. IDLING AND TOTAL DELAY
(FOUR WAY INTERSECTION: FOUR LANE MAJOR, TWO LANE MINOR)

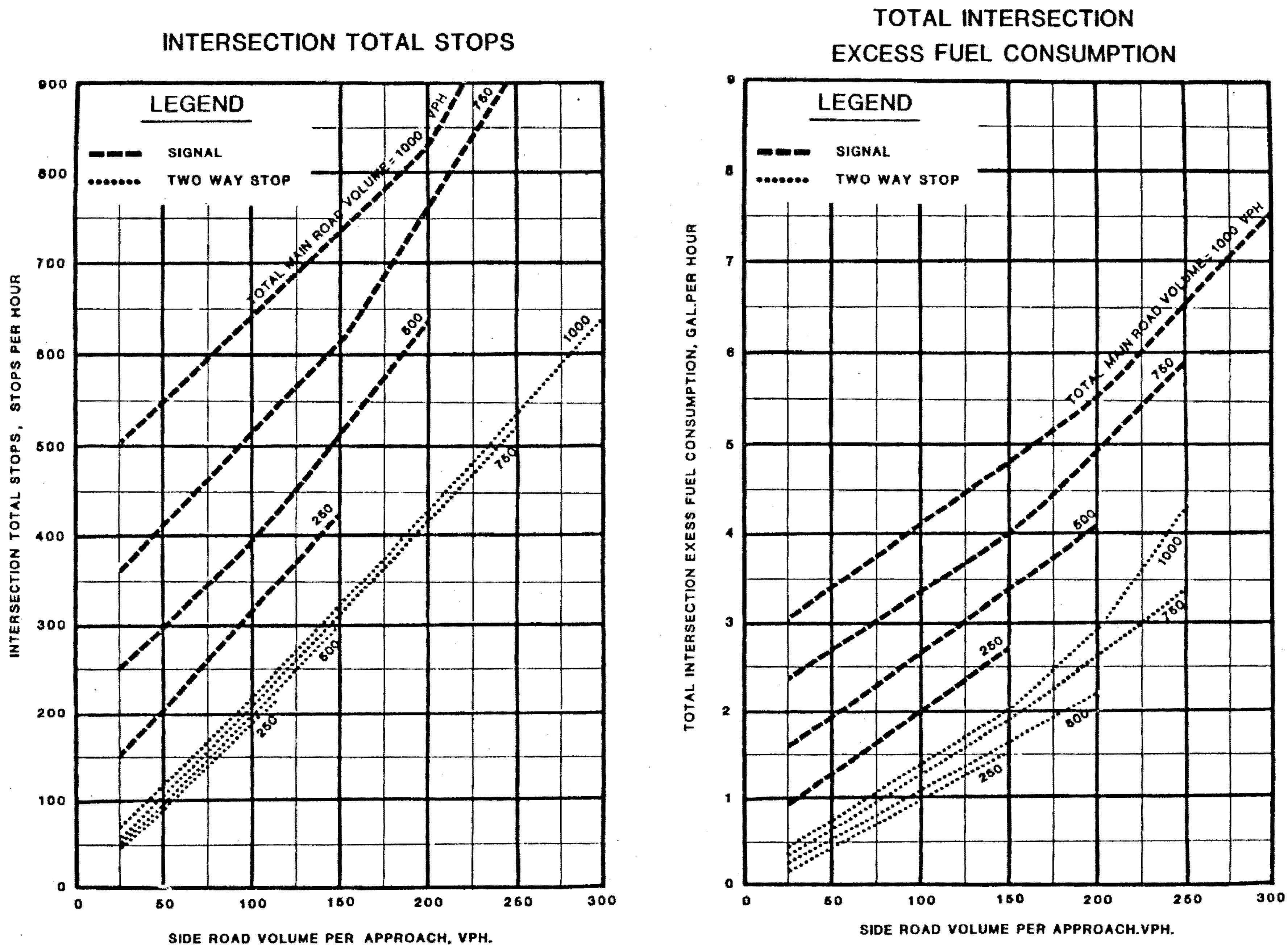
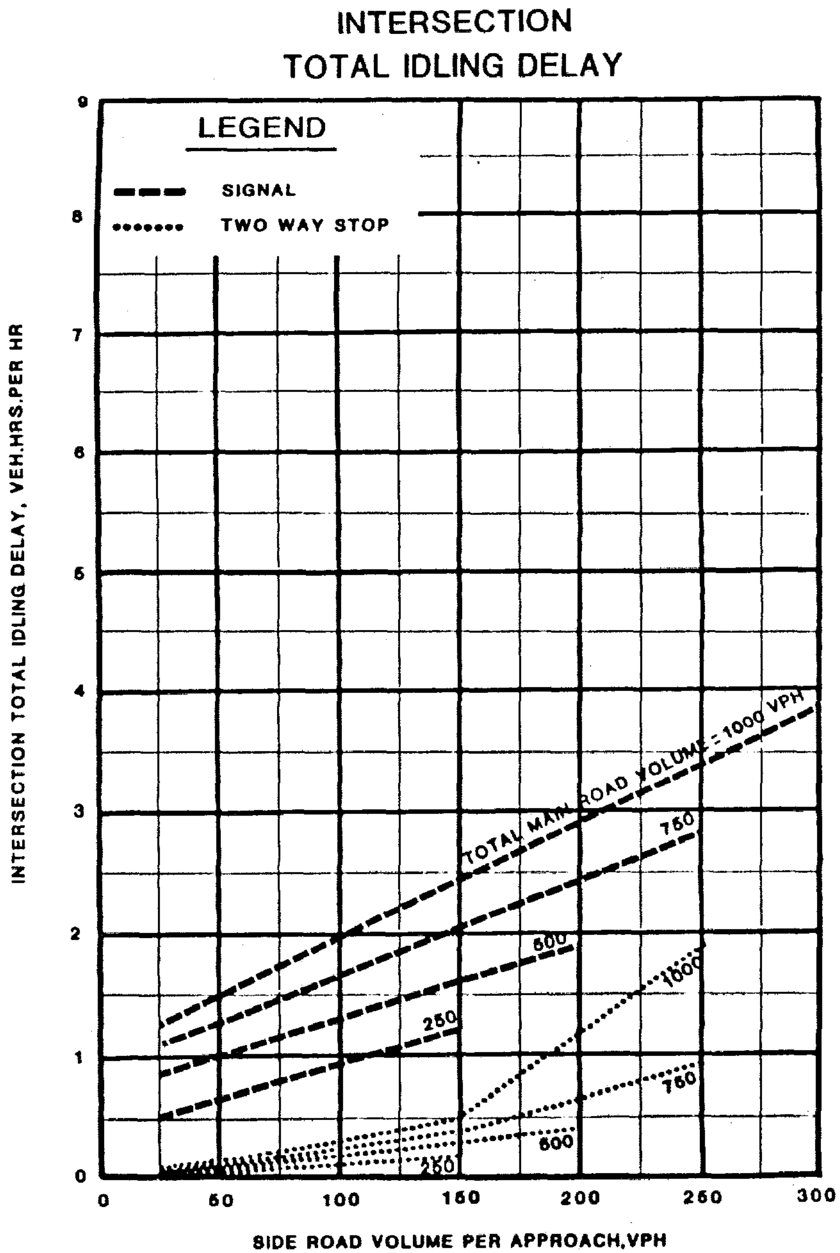


FIGURE 13. STOPS AND EXCESS FUEL CONSUMPTION
(FOUR WAY INTERSECTION: FOUR LANE MAJOR, TWO LANE MINOR)



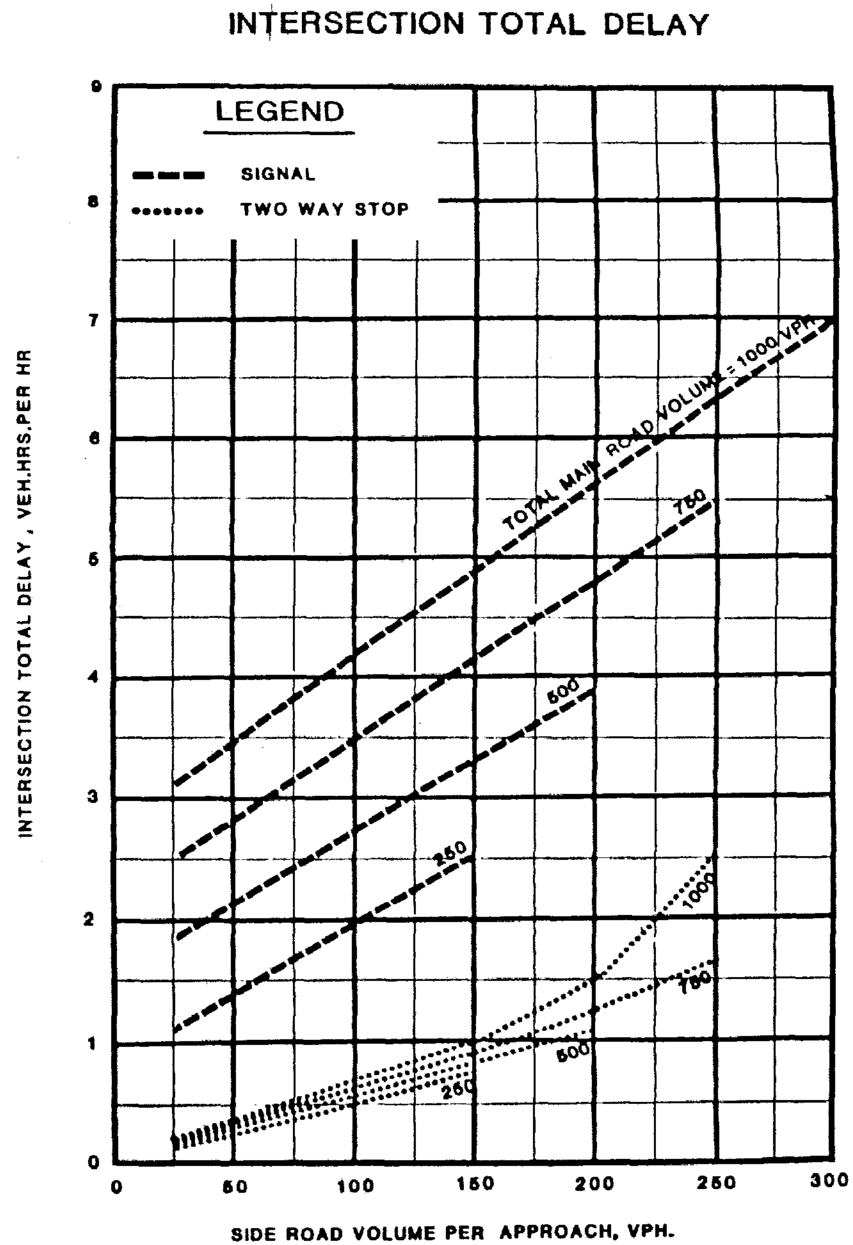


FIGURE 14. IDLING AND TOTAL DELAY
("T" INTERSECTION: FOUR LANE MAJOR, TWO LANE MINOR)

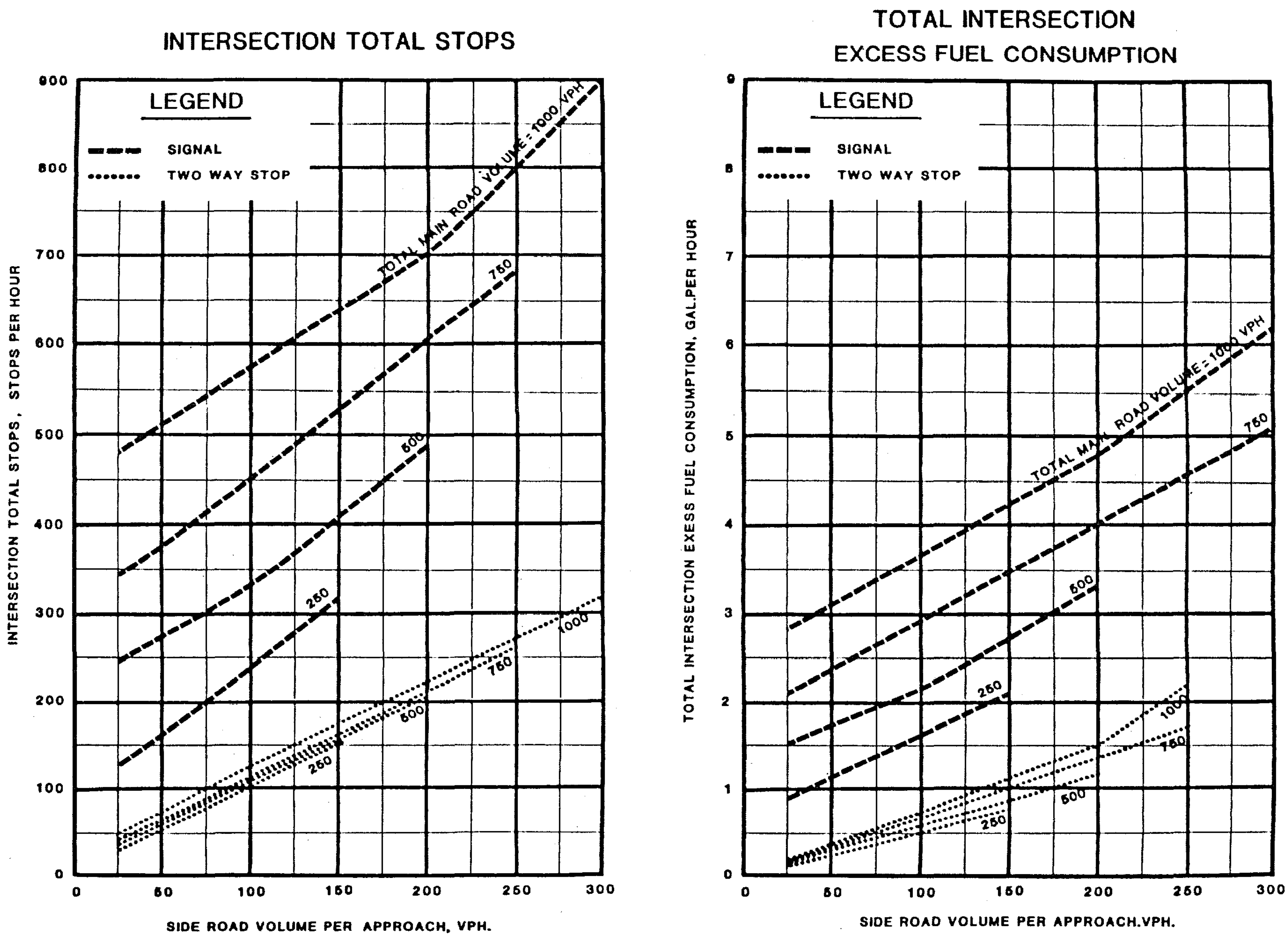
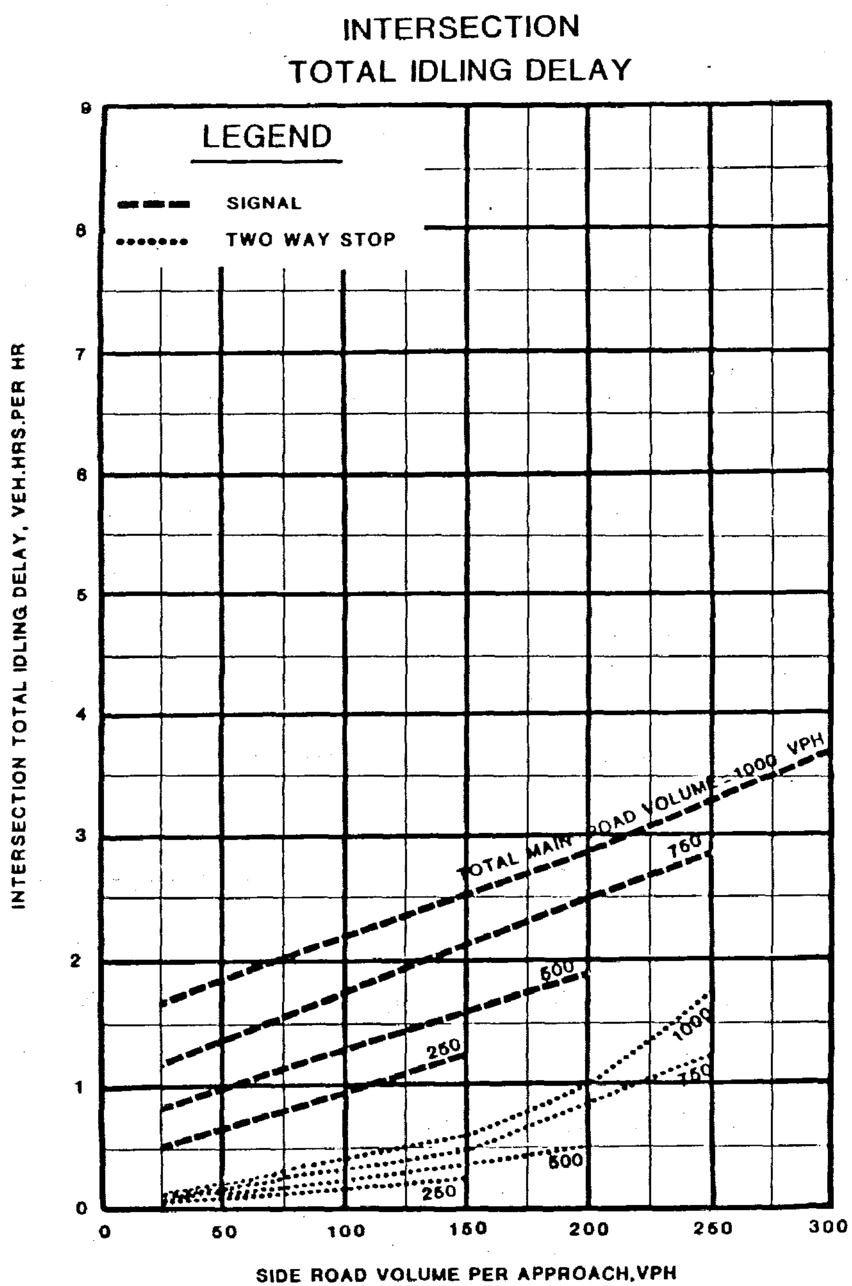


FIGURE 15. STOPS AND EXCESS FUEL CONSUMPTION
("T" INTERSECTION: FOUR LANE MAJOR, TWO LANE MINOR)



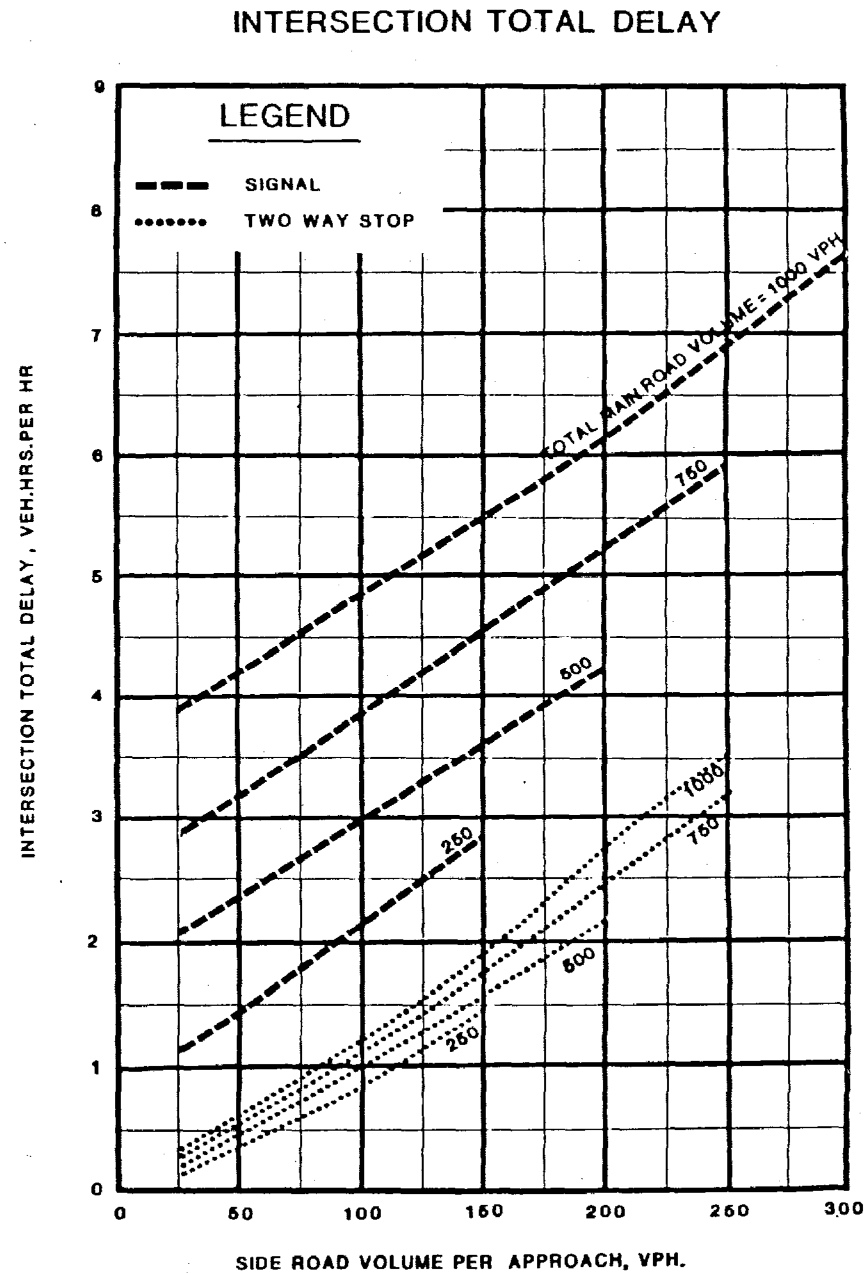


FIGURE 16. IDLING AND TOTAL DELAY
(FOUR WAY INTERSECTION: FOUR LANE MAJOR, FOUR LANE MINOR)

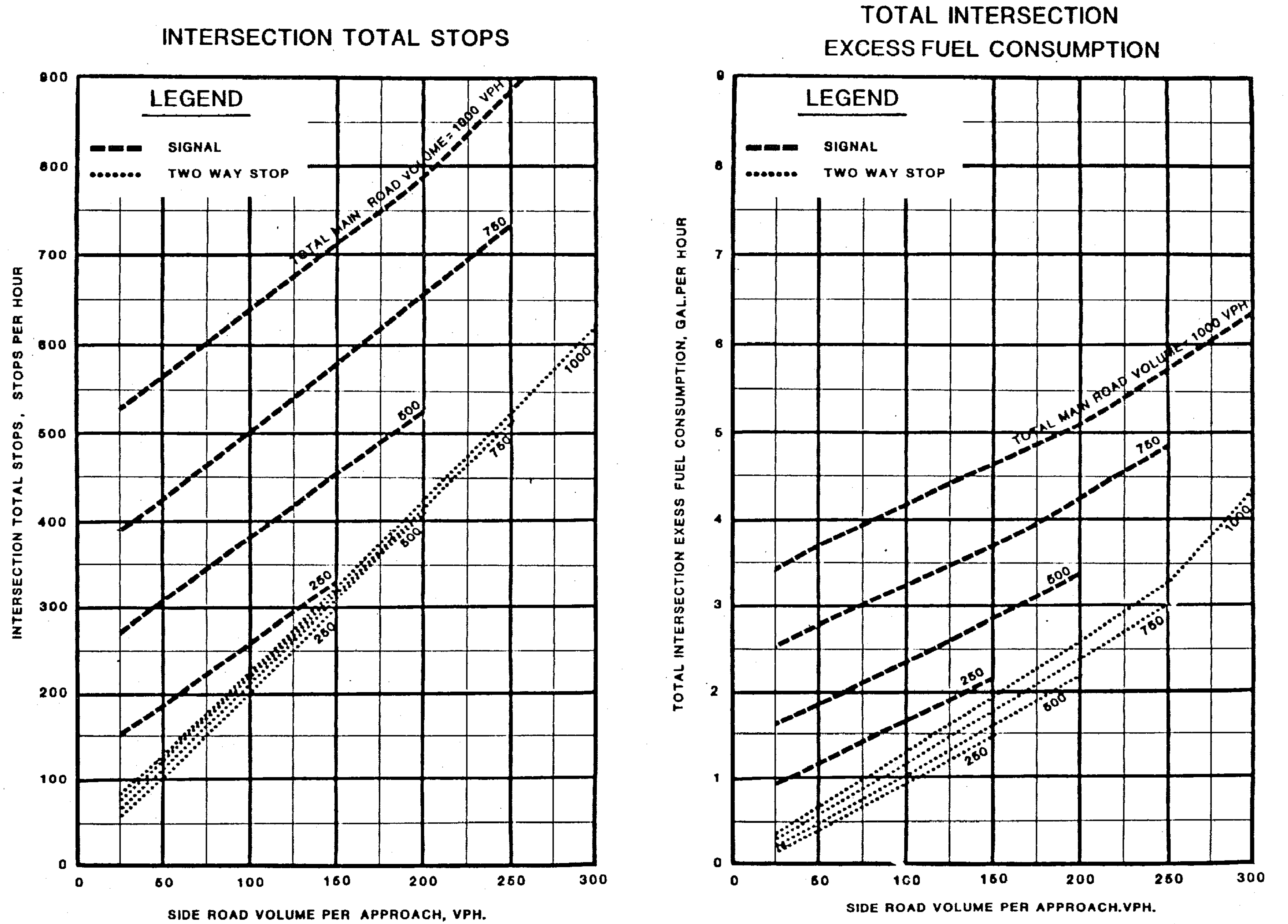


FIGURE 17. STOPS AND EXCESS FUEL CONSUMPTION
(FOUR WAY INTERSECTION: FOUR LANE MAJOR, FOUR LANE MINOR)

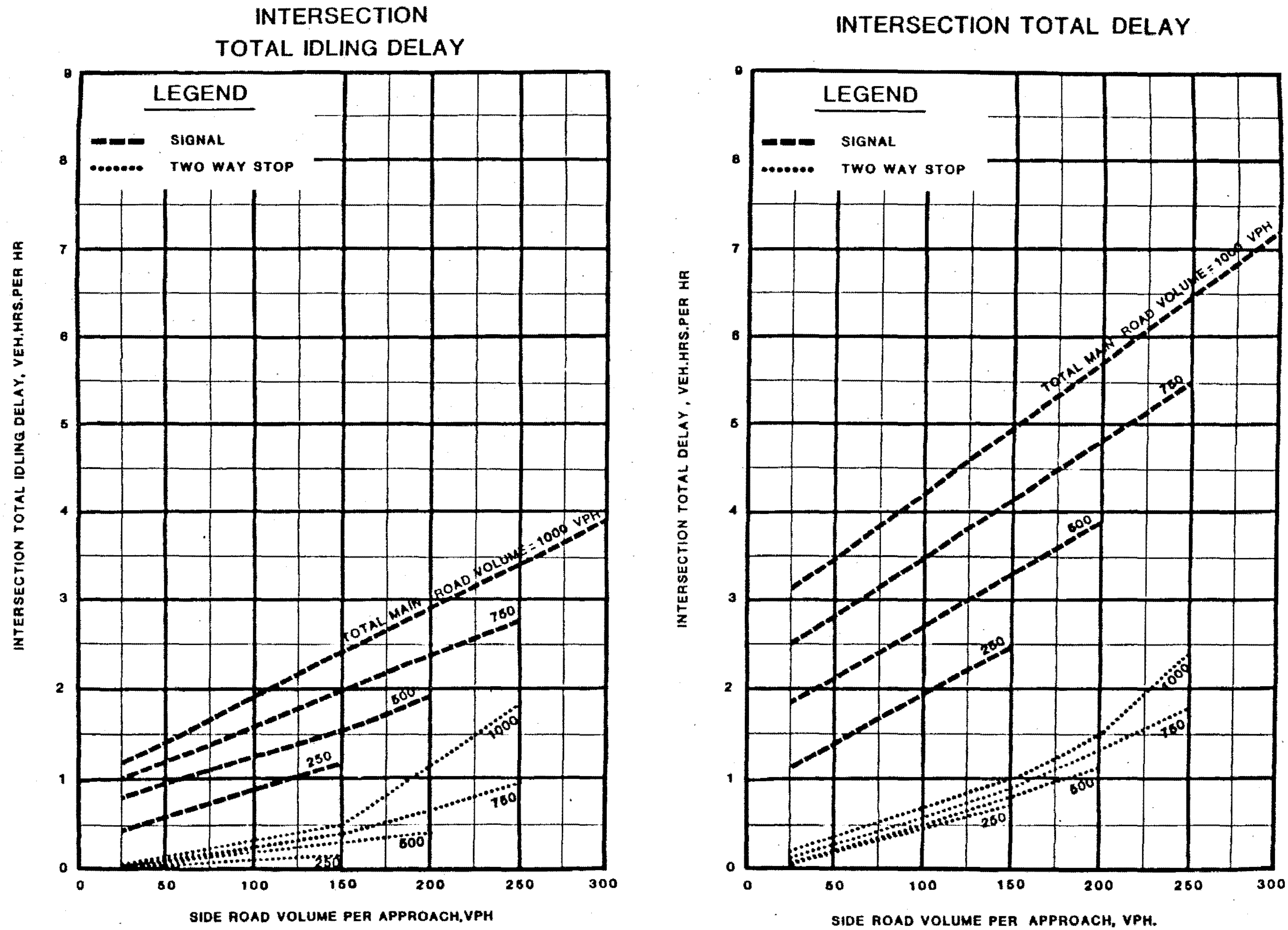
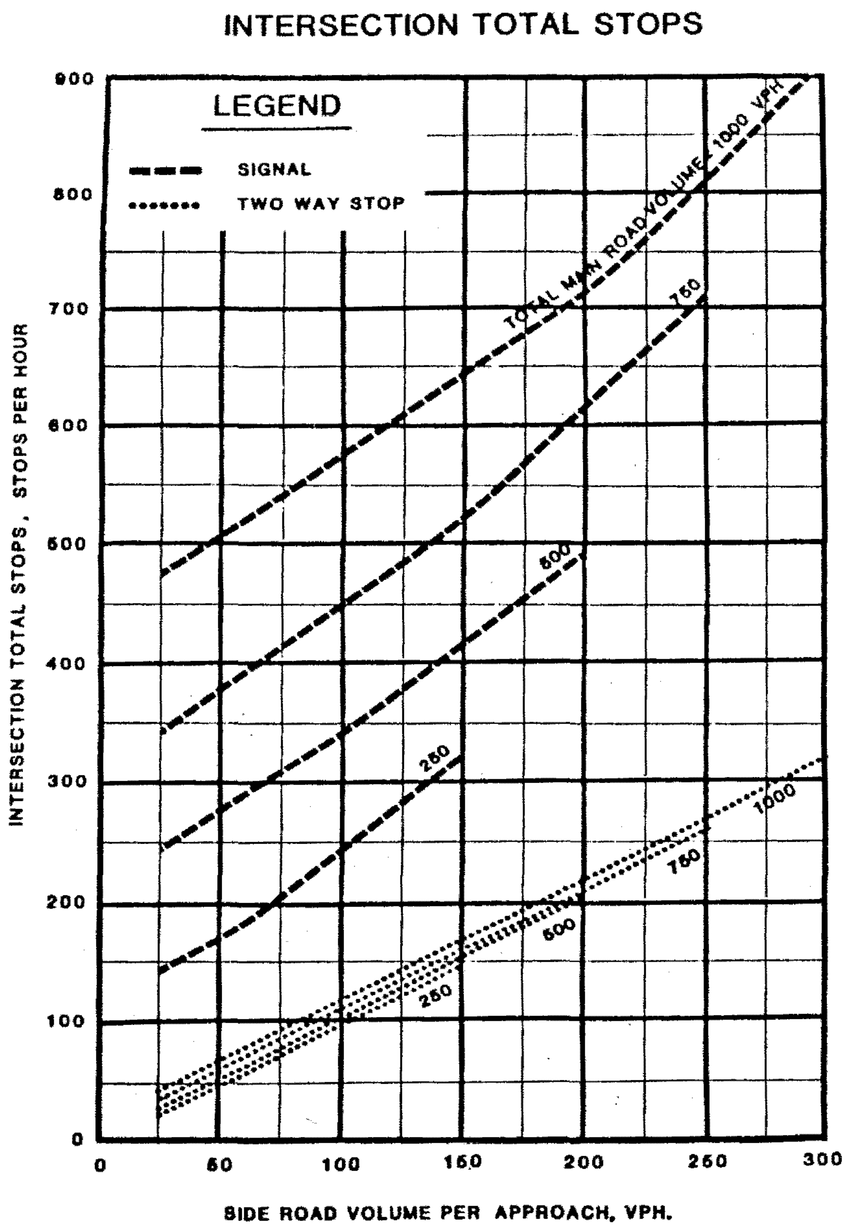


FIGURE 18. IDLING AND TOTAL DELAY
("T" INTERSECTION: FOUR LANE MAJOR, FOUR LANE MINOR)



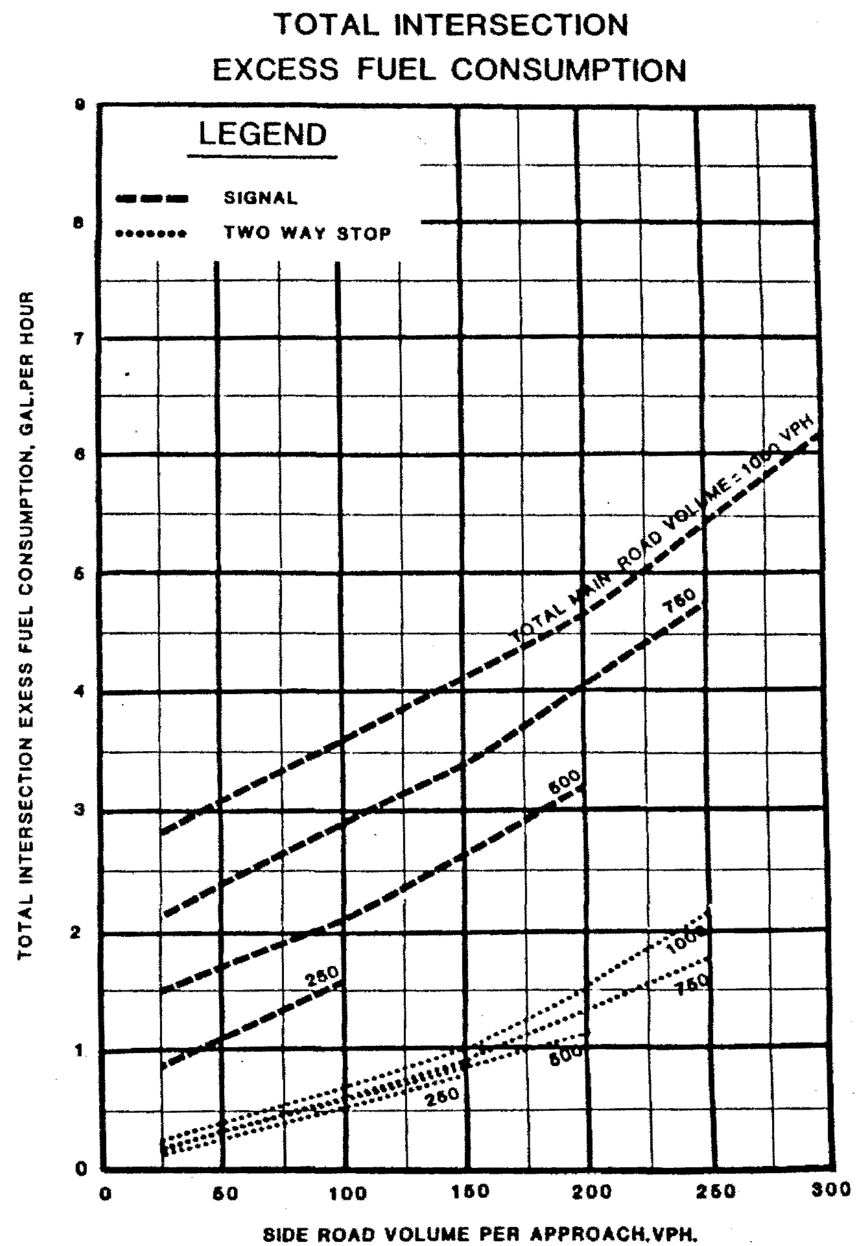


FIGURE 19. STOPS AND EXCESS FUEL CONSUMPTION
("T" INTERSECTION: FOUR LANE MAJOR, FOUR LANE MINOR)

Item		Idling Delay (Veh. Hrs.)	Total Delay (Veh. Hrs.)	Total Stops (Veh. Stops)	Excess Fuel Consumption (Gal.)
① Intersection Type ☐ 4-Way ☐ T-Intersection Main Road ☐ 2 Lane ☐ 4 Lane Side Road ☐ 2 Lane ☐ 4 Lane					
Average of the 2 Peak Hours	③ a. Signal Control (From Nomographs)				
	b. 2 Way Stop Control (From Nomographs)				
② a. Total Main Road Vol. = ____ b. Side Road Vol. / Approach = ____ c. Total Intersection Vol. = ____	c. Difference				
④ Total of the Two Peak Hours — a. x 2 =	b. x 2 = Difference	x 2 ☐	x 2 ☐	x 2 ☐	x 2 ☐
Average of the Remaining 22 Hours	⑥ a. Signal Control (From Nomographs)				
	b. 2 Way Stop Control (From Nomographs)				
⑤ a. Total Main Road Vol. = ____ b. Side Road Vol./ Approach = ____ c. Total Intersection Vol. = ____	c. Difference				
⑦ Total of the Remaining 22 Hours — a. x 22 =	b. x 22 = Difference	x 22 ☐	x 22 ☐	x 22 ☐	x 22 ☐
⑧ 24 Hour Total — a. 2 Hrs. + 22 Hrs. =	b. 2 Hrs. + 22 Hrs. = Difference	2 + 22 ☐	2 + 22 ☐	2 + 22 ☐	2 + 22 ☐
⑨ Per Vehicle Impacts (Divide 24 Hour Differences By 24 Hour Volume)					

WORKSHEET FOR ESTIMATING DAILY IMPACTS OF SIGNAL REMOVAL AND REPLACEMENT BY TWO WAY STOPS

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