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STOP, YIELD, AND NO CONTROL AT INTERSECTIONS

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DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
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Washington, D.C. 20590

FOREWORD

The objective of this study was to determine the operating characteristics and relative hazard associated with, and to establish criteria for, the application of two-way stop, yield, and no control at low volume intersections. The report will be of interest to traffic engineers involved in controlling traffic by signing.

Observations and measurements were made at 140 low volume intersections located in Texas, Florida, and New York. Control type, location (urban/rural), geometry (3-leg/4-leg), major roadway volume, and sight distances were examined to determine their individual and interactive effects on driver behavior, accident experience, and travel time through the intersection. Findings show that restrictive control (STOP) did not produce lower accident experience. Yield control resulted in the lowest travel time of the three control types considered.

Sufficient copies of the research report are being distributed to provide two copies to each regional office, one copy to each division office, and two copies to each State highway agency. Direct distribution is being made to each division office.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

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16. Abstract

Observations and measurements were made at 140 low volume intersections in three regions of the United States. Control type, region, location (urban/rural), geometry (3-leg/4-leg), major roadway volume and sight distance are examined to determine their individual and interactive effects on driver behavior, accident experience, and travel time.

Region, location and geometry have an essentially negligible effect on safety and operations at low volume intersections. Increasingly restrictive control did not result in reductions in accident experience. STOP control produced the highest travel times and thus the highest total road user costs; YIELD control resulted in the lowest road user costs of the three control types considered.

Less than 20% of the drivers observed voluntarily stopped, regardless of control type (STOP = 19%, YIELD = 8%, No Control = 9%). Accident rates were very low (0.13 accidents/intersection/year). A significant increase in accidents was observed at major road volumes above 2000 vehicles per day (vpd). Travel times were about two seconds higher at locations with major road volumes above 2000 vpd. Sight distance had no discernible effect on either safety or operations.

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CHAPTER 1: EXECUTIVE SUMMARY

Specific warrants for installation of STOP and YIELD signs at low volume intersections are not included in the current Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) (1) or other national policy manuals. In fact, the term "low volume" intersection is not specifically defined, although general practice has been to classify all intersections of minor roadways with less than 500 vehicles per day (vpd) with any other roadway as low volume intersections.

The MUTCD warrants for usage of STOP signs, although not specifically delineating intersection volume constraints, generally have been applied by practicing engineers at those intersections exhibiting high accident histories, or where the rule of right-of-way is unduly hazardous. The MUTCD however, specifies that a STOP sign may be used at the intersection of a street with a through highway or of two streets (volume unstated). Warrants for use of YIELD signs are equally non-specific with respect to traffic volume conditions.

In essence, there exist no specific guidelines by which the practicing engineer can objectively assess the need for installation of a STOP sign or a YIELD sign, as opposed to installing no sign control at a low volume intersection. Yet engineers are faced with this dilemma for more than an estimated half million "low volume" intersections (2) throughout the nation.

Several factors influence the need for objective criteria and warrants for regulatory signing (including "no-sign"). The economic constraints within which agencies must operate dictate that costly signs must be installed only where necessary for safety and efficient traffic operation. Sign installation costs represent only one economic factor; traffic control devices regulating operations affect road user costs, fuel consumption and exhaust emissions. The atmosphere with respect to tort liability is rapidly becoming a highly influential factor in the decisions to install traffic control devices. However, extravagant usage of unneeded traffic control breeds driver disrespect for the devices in general, which can lead to increased noncompliance and increased accident occurrence. These factors must be evaluated against the safety aspect of right-of-way control so that objective guidelines for signing of low volume intersections can be developed.

PURPOSE OF STUDY

This research study determined the operating characteristics and the relative hazard associated with, and establish definitive criteria for, the application of two-way STOP, YIELD and No Control at low volume intersections. The resulting criteria were based on the premise of using the minimum amount of control necessary to maintain a reasonable level of safety.

The types of intersections considered excluded those controlled by signals or multi-way STOP signs. They had at least one roadway with an ADT of 500 vehicles per day (vpd) or less and did not meet the MUTCD volume warrants for signals. The intersections studied were representative of urban and rural areas, the most common geometric layouts (3-leg and 4-leg), and a range of regional (Texas, Florida, and New York) differences. Major roadway volumes up to 10,000 vpd were included.

LITERATURE SURVEY

The bulk of the previous research has centered on one aspect or another of intersection operation and safety without adequate consideration of all possible variables.

Only four studies have specifically addressed low volume intersections.

Three of the four low volume intersection studies were based heavily on theoretical relationships, or on simulation, with some empirical data. All four studies demonstrated the feasibility of establishing minimum definitive warrants for STOP, YIELD and No Control at low volume intersections.

Other research, not necessarily restricted to low volume situations, identified other potentially important relationships. Several studies showed that both major and minor roadway volumes had a significant impact on accident rate. However, little change in accident rate was experienced when STOP signs were replaced with YIELD signs. Accident severity was found to increase with speed differential; accident cost increased with severity. Operating costs increased significantly with increasing major roadway volume. Compliance with STOP control has deteriorated consistently over the last 50 years to the extent that less than 20% of the drivers voluntarily stop. Researchers investigating compliance cited overuse of STOP signs as a primary reason for high violation rates.

DEVELOPMENT OF PRELIMINARY CRITERIA

Significant findings from the literature survey were examined in more detail for the purpose of developing the best possible set of criteria. Criteria employed by other agencies were also examined. A set of variables requiring validation was developed (Table 1). In most cases the variables had not been sufficiently validated to permit quantification of preliminary criteria without further extensive validation.

FIELD VALIDATION

Field validation was accomplished in two phases: 1) studies to screen for breakpoints in accident and operating characteristics, and 2) on-site field studies.

Screening Studies

Significant difficulties were encountered in conducting the screening studies as designed. Detailed intersection and/or control device inventories were found to be extremely rare in all parts of the country and across all jurisdictions. The use of YIELD and No Control is very limited, especially in rural areas. Traffic volumes at low volume intersectons are rarely counted, and almost never on a routine basis. For these reasons, the screening study was limited to Texas, where accident records were manually searched, control type was identified by on-site inspection, and traffic volumes were estimated from one-hour counts.

On-Site Field Studies

Field investigations were conducted in Texas, Florida and New York. Crews of two persons were dispatched to a total of 140 intersections (60 in Texas, 40 each in Florida and New York). In each region, a representative sample of STOP, YIELD and No Control in both urban and rural areas was examined.

Operational data collected included major roadway approach speeds and the following data on each minor roadway vehicle: approach speed, turning movement, total travel time [from 150 feet (45 m) in advance of the intersection to 150 feet (45 m) beyond], entry speed and conflicts. Physical characteristics included approach sight distance to the control device, and available sight distance on each quadrant, compared to the sight distance recommended by AASHTO. A three-year accident history was obtained for each intersection.

Intersections sampled in rural Florida proved to be somewhat anomalistic in that

Table I. Candidate Variables Studied

Dependent Variables	Independent Variables
Driver Behavior	Control Type
Forced Stops	Intersection Type
Voluntary Stops	Region
Slow Entries	Location
Fast Entries	Major Road Volume
Conflicts	Minor Road Volume
	Approach Speed
	Sight Distance
Accident Experience	
Accidents Per Intersection	
Intersections with Accidents	
Severity	
Travel Time	
3-Leg Intersections	
4-Leg Intersections	
Turning Movements	

there were no rural YIELD or No Control intersections, and that the volumes at rural STOP intersections were extremely low. These artifacts were adequately accounted for in the analysis.

DATA ANALYSIS AND RESULTS

Driver behavior, accident experience and travel time were analyzed for each independent variable: region, location, control, geometry and major volume.

A summary of the results by control type is shown in Table 2.

It was concluded that control type has no appreciable effect on accident experience at low volume intersections. Travel time is significantly affected by signing, with STOP control producing the longest travel time, and YIELD control the shortest.

Only minor operational differences were detected between regions. It was concluded that any signing criteria would have equal applicability in all regions.

Small differences in travel time were observed between urban and rural locations. These differences are primarily a function of major roadway volume.

Geometry (3-leg and 4-leg) does not play a major role in either the safety or operation of low volume intersections.

Major roadway volume significantly affects both the accident potential and operating characteristics of low volume intersections. The percentage of intersections experiencing accidents increases significantly at 2000 vpd and again at 4000 vpd (irrespective of control type). Travel time increases significantly at 2000 vpd, primarily due to increased forced stop rate.

Sight distance has no discernible effect on either safety or operations at low volume intersections.

EXPECTED BENEFITS AND COSTS

Costs resulting from a change in control type are those incurred by the highway agency in labor and materials required to effect the change. Benefits are the savings in vehicle operating costs and road user time costs resulting from the change. If a change is made from a more efficient to a less efficient control type, negative benefits to the road user are incurred.

Vehicle operating costs and road user time costs were computed for each device from the data collected in the field studies. Costs were computed separately for major roadway volumes below and above 2000 vpd, as that volume was the point of significance for most variables.

The average annual costs and benefits were computed assuming a seven-year service life of control devices, a five-percent discount rate and an annual growth of three percent in minor roadway traffic. A summary of these values is shown in Table 3. In no case was conversion to STOP control cost-effective. Conversions to YIELD control were always cost-effective.

A comparison of expected accident costs and road user savings showed that YIELD control is preferable for locations with up to 2 accidents in 3 years. If the minor road volume is greater than 300 vehicles per day, YIELD control is cost-effective with up to 3 accidents in 3 years. Higher accident frequencies justify STOP control, consistent with the "conventional wisdom" that STOP control will reduce the potential for accidents.

CONCLUSIONS

Based on the results of this study, the following criteria should govern the application of traffic control at low volume

TABLE 2. Summary of Significant Data

	Control Type			Statistical Significance
	STOP	YIELD	No Control	
Number of Intersections	48	48	44	-
Average Volume (vpd)				
Major Roadway	2530	2380	3800	-
Minor Roadway	200	190	120	-
Accident Experience (3 Years)	19 Acc.	20 Acc.	14 Acc.	-
Mean Acc./Intersection	.44	.42	.32	Not Sig.
Intersection W/No Acc.				
All Intersections	69%	83%	95%	Sig., p<.05
Major Volumes ≤ 2000	71%	91%	100%	-
Major Volumes > 2000	67%	62%	87%	-
Driver Behavior				
Voluntary Stops	19%	8%	9%	Not Sig.
Slow Entries (≤ 5 mph)	65%	79%	80%	Not Sig.
Fast Entries (> 5 mph)	16%	13%	11%	Not Sig.
Travel Time				
3-Leg Intersections (secs)	15.9	12.6	14.3	Sig., p<.05
4-Leg Intersections (secs)	15.8	13.1	16.8	Not Sig.
Turning Movements (secs)	15.8	12.7	14.6	Sig., p<.05

TABLE 3. Average Annual Highway Agency Costs and Road User Savings

Control Type Change		Highway Agency Cost[1/]		Expected Average Annual Savings				
				Minor Roadway Volume				
From Existing	To Proposed	3-Leg	4-Leg	100	200	300	400	500
Major Volume ≤ 2000 vpd								
STOP	YIELD	$ 7	$ 11	$ 240	$ 480	$ 720	$ 960	$1,200
STOP	No Control	5	5	44	88	132	176	220
No Control	YIELD	14	23	196	392	588	784	980
Major Volume > 2000 vpd								
STOP	YIELD	$ 7	$ 11	$ 244	$ 488	$ 732	$ 976	$1,220
STOP	No Control	5	5	155	310	465	620	775
No Control	YIELD	14	23	88	176	264	352	440

1/ From Table 48.

intersections.

1. STOP signs(s) should be installed on the minor approach(es) of intersections where one or more of the following conditions exist:

   a. Sight distance on any quadrant produces a safe approach speed on the minor approach of less than 10 mph (16 km/h)(per MUTCD).

   b. Accidents involving minor roadway vehicles have occurred with either of the following frequencies:
      - Four or more within the last three years, or
      - Three or more within the last three years, provided that minor roadway volumes are less than 300 vehicles per day.

2. YIELD sign(s) should be installed on the minor approach(es) of intersections where available sight distance exists on all quadrants to permit a safe approach speed of at least 10 mph (16 km/h) and one or more of the following conditions exist:

   a. No more than two accidents involving minor roadway vehicles have occurred within the last three years, or

   b. At intersections with minor roadway volumes greater than 300 vehicles per day, no more than three such accidents have occurred within the last three years.

3. No Control may be used at intersections where the sight distance specified for YIELD signs is afforded, and there have been no accidents in the last three years, and the major roadway volume is less than 2000 vehicles per day.

Table 4 summarizes the conditions under which each control type should be applied.

TABLE 4. Summary of Suggested Control Criteria.

<table>
<tr><th rowspan="2">Sight Distance</th><th rowspan="2">Accident History</th><th colspan="2">Major Roadway Volume</th></tr>
<tr><th>≤ 2000 vpd</th><th>> 2000 vpd</th></tr>
<tr><td rowspan="4">Adequate</td><td>0</td><td>No Control</td><td></td></tr>
<tr><td>≤2</td><td colspan="2">YIELD</td></tr>
<tr><td>3</td><td colspan="2">STOP*</td></tr>
<tr><td>4+</td><td colspan="2" rowspan="2">STOP</td></tr>
<tr><td>Not Adequate</td><td></td></tr>
</table>

*If minor roadway is greater than 300 vpd, YIELD control is appropriate for intersections with less than 4 accidents in 3 years.

The purpose of this task was to 1) review the pertinent literature, 2) identify, as closely as possible, the best set of criteria from the several sets available and, 3) determine the actual field data collection requirements. With these requirements in mind it was then possible to prepare an experimental plan that concentrated on the key variables and omitted or minimized study of extraneous variables.

LITERATURE REVIEW

The literature was categorized and will be discussed independently as follows:

(1) Current criteria, warrants, and practice,
(2) Low volume intersection research investigations, and
(3) Related research of merit.

Current Criteria, Warrants and Practice

Specific warrants for the installation of STOP and YIELD signs at low volume intersections are not included in the current Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) (1) or other national policy manuals. In fact, the term "low volume" intersection is not specifically defined, although general practice has been to classify intersections with at least one roadway of 500 vehicles per day (vpd) or less as "low volume" intersections -- analogous to the accepted "low volume" roadway definition.

Two-Way STOP Control

The MUTCD warrants for STOP signs, although not specifically delineating intersection volume constraints, generally have been applied by practicing engineers at those intersections exhibiting high accident histories, or where the rule of right-of-way is unduly hazardous. The MUTCD, however, specifies that a STOP sign may be used at the intersection of a street with a through highway, or of two streets (volume unstated). The warrants contained in the MUTCD for two-way STOP control are given below:

"Because the STOP sign causes a substantial inconvenience to motorists, it should be used only where warranted. A STOP sign may be warranted at an intersection where one or more of the following conditions exist:

1. Intersection of a less important road with a main road where application of normal right-of-way rule is unduly hazardous.
2. Street entering a through highway or street.
3. Unsignalized intersection in a signalized area.
4. Other intersections where a combination of high speed, restricted view, and serious accident record indicates a need for control by the STOP sign."

These warrants are broad, perhaps because at this time objective criteria are not available to state specifically those conditions under which two-way STOP control is warranted. The warrants refer to "undue hazard" and "serious accident record;" however, unlike signal warrants, guidelines to quantify these variables are not presented. Although warrant #3 above is unlikely to pertain to a low volume intersection condition, any of the four warranting conditions could exist at the low volume intersection. The problem is one of interpretation or definition of "need" for a sign based on comparative analysis of safety (once defined) and the economic effect of the device on operations.

Multi-Way STOP Control

The MUTCD warrants for multi-way STOP signs are more clearly defined with respect to measurable characteristics, such as approach traffic volumes, accident occurrence and vehicle/pedestrian conflict. The multi-way STOP warrants are presented as follows:

"Any of the following conditions may warrant a multi-way STOP sign installation:

(1) Where traffic signals are warranted and urgently needed, the multi-way stop is an interim measure that can be installed quickly to control traffic while arrangements are being made for the signal installation.

(2) An accident problem, as indicated by five or more reported accidents of a type susceptible to correction by multi-way stop installations in a 12-month period. Such accidents include right- and left-turn collisions as well as right-angle collisions.

Minimum traffic volumes:

(a) The total vehicular volume entering the intersection from all approaches must average at least 500 vehicles per hour for any 8 hours of an average day, and

(b) The combined vehicular and pedestrian volume from the minor street or highway must average at least 200 units per hour for the same 8 hours, with an average delay to minor street vehicular traffic of at least 30 seconds per vehicle during the maximum hour, but

(c) When the 85-percentile approach speed of the major street traffic exceeds 40 miles per hour, the minimum vehicular volume warrant is 70 percent of the above requirements."

Warrant #2 represents probably the only warrant applicable to low volume intersections.

Wenger (3), in a study of 38 intersections that were changed from two-way to four-way STOP control, concluded that four-way stops were warranted at relatively balanced volumes in the range immediately below that for signal warrants. This hypothesis was confirmed by Hammer in a study of six California intersections (4). Syrek (5) showed, however, that if the volumes were unbalanced, conversion from two-way to four-way STOP can cause an increase in accident rate. Dale (6) concluded in 1966 that there was "almost no economic justification for '4-way stop' control" except for unusual situations above medium volume conditions.

YIELD Control

Warrants for use of YIELD signs are equally non-specific with respect to traffic volume conditions. In essence, there exist no specific guidelines by which the practicing engineer can objectively assess the need for installation of a STOP sign or a YIELD sign,as opposed to installing no sign control at a low volume intersection. The YIELD sign represents a compromise device between rule-of-the-road control of right-of-way assignment and two-way STOP control, in that vehicles controlled by it must stop only when necessary to avoid interference with other traffic that is given the right-of-way.

"The YIELD sign may be warranted:

(1) On a minor road at the entrance to an intersection where it is necessary to assign right-of-way to the major road, but where a STOP is not necessary at

all times, and where the safe approach speed on the minor roads exceeds 10 miles per hour.

(2) At any intersection where a special problem exists and where an engineering study indicates the problem to be susceptible to correction by use of the YIELD sign."

It can be assumed that if neither STOP nor YIELD control is warranted, it is appropriate to leave the intersection uncontrolled. AASHTO (7) recommends certain sight triangle minimums, in the absence of control, based on vehicle operating speeds and assumed distances in which either or both conflicting drivers may execute evasive maneuvers to avoid conflict. Although the AASHTO recommended sight distances may be provided in a rural environment, it may be economically prohibitive to obtain them in an urban/suburban environment.

Previous research conducted in 1963 surveyed intersection signing control policies and practice on a national scope (8). Many of these guidelines are still being adhered to by states and municipalities and applied at low volume intersections. During the literature review conducted for the current project, more than thirty states were contacted regarding their current warrants and criteria for signing control at low volume intersections. A tabular synopsis of this reported data is presented in Tables 5 and 6.

Many different warranting systems exist, with most conforming to MUTCD standards. However, a better definition of both "warranted" and "unwarranted" is needed to guide the application of signing control at low volume intersections.

Low Volume Intersection Research

The literature review revealed that four research studies have been conducted that pertain specifically to the development of criteria and warrants for low volume intersection control. The studies include research by Walton, et. al. (9), Bandyopadhyay (10), Hall (11), and Glennon (2). In addition to the above, Leisch (8) investigated intersection operations for a variety of parameters, one of which was approach volume.

One of the first research efforts directed specifically to low volume intersection signing needs was conducted in 1974 as part of a study to identify signing needs on low volume roads (9). Walton, et al., developed a set of signing criteria based on a theoretical relationship between operating costs and accident costs derived from a "probability of conflict" analysis.

A deficiency in Walton's study, from an application viewpoint, was that it lacked field validation. Some of the assumptions that were necessary in the theoretical analysis, such as the length of a "conflict interval," the actual ratio of accidents per conflict and the absence of sight distance considerations, require further evaluation to incorporate portions of the study results into the development of criteria.

Bandyopadhyay conducted a study of 53 low volume intersections in Indiana, comparing safety to operating costs at rural and suburban intersections under three control types — two-way STOP, YIELD, and no control (10). Although his study identified parameters that merit further consideration for inclusion in criteria development, he formulated no specific conclusions regarding signing criteria for low volume intersections.

Hall expanded the results of previous research through a study completed in 1977 (11). Using computer simulation to perform systems trade-offs among safety, fuel con-

TABLE 5. STOP Control Application Criteria Other Than Or In Addition to MUTCD Criteria

	VOLUME	ACCIDENTS	SIGHT DISTANCE CRITERIA	OTHER (School, Ped., etc.)
State of Delaware		Two accidents correctable by STOP within 12 months.	Safe approach speed less than 24 mph.	Minor approaches at school crossings. May on major if more than 2500ft from previous STOP or YIELD. May if minor approach serves 15 or more homes.
State of New York			Critical approach speed less than 8 mph.	
State of North Dakota	Major approach ADT greater than 150 or total ADT greater than 250.		Less than AASHTO Case II.	
City of Baltimore, MD	Major volume exceeds 100vph		Safe approach speed less than 5 mph.	
		2 in 5 years, AND	Safe approach speed 5-10 mph.	
		2 in 1 year, or 3 in 5 years, AND	Safe approach speed greater than 10 mph.	
City of Concord, CA	Major volume exceeds 1000 vpd (or 100vph) and minor volume exceeds 500vpd (or 50vph).	4 in 1 year	Critical approach speed of 10 mph or less.	
	Major volume exceeds 500vpd (or 50vph) and minor volume exceeds 250vpd (or 25vph), AND/OR	2 or more within 1 year, AND/OR	Critical approach speed less than 15 mph.	Two or more criteria must be met.
Montgomery County, Maryland			Sight distance along major from 35ft back on minor is less than 125ft	

TABLE 6. YIELD Control Application Criteria Other Than Or In Addition to MUTCD Criteria

	VOLUME	ACCIDENTS	SIGHT DISTANCE CRITERIA	OTHER (School, Ped., etc.)
State of Delaware				Minor approach serves 5 or more homes.
State of New York			Critical approach speed greater than 8 mph.	
State of North Dakota	Less than 150vpd on major approach AND		Greater than AASHTO Case II modified for rural and urban separately, AND	Rural-gravel roads only. Urban-city streets only.
City of Baltimore, MD				At intersections where STOP is not warranted.
City of Concord, CA	Major street 500vpd or (50 vph) peak and minor street 250vpd (or 25vph) peak.	Two or more of correctable type in 12 months (if only STOP warrant met).	Critical approach speed between 15 and 20 mph.	
Montgomery County, MD			Sight distance along major from 35ft back on minor is greater than 125ft.	Some control dictated by geometrics, accidents, or volumes.

sumption, exhaust emissions, noise and delay for various control levels, he identified the most efficient control type for a given set of intersection conditions. From his simulations, Hall computed vehicle operating costs, delay, exhaust emissions and noise for the three control types. He used broad estimates for the safety effects of STOP and YIELD signs (though he found no evidence of difference) and modified Walton's expected accident rates to generate annual accident costs. Hall concluded that YIELD sign control was the most efficient control for volumes greater than 200 vehicles per day, and that no control was most efficient below 200 ADT. As with previous studies, Hall did not include the actual effects of sight distance on control requirements. He assumed that the absence of recommended sight distance necessitated STOP control.

Tables 7 and 8 present the dependent and independent variables considered by Walton, Bandyopadhyay, Hall, and Leisch and significant results reported.

Related Research of Merit

Although the volume of research on low volume intersections is limited, there has been considerable research on related topics. In many cases, information determined from a particular set of conditions may be readily applicable to another set. The following topics will each be discussed relative to the pertinent literature regarding the potential effect on safety and economy at low volume intersections.

Control Type

In a 1958 study, Kell (12) found that the installation of YIELD signs at uncontrolled, low volume urban intersections reduced accidents 44 percent at 13 intersections in Berkeley, and 52 percent at 30 Seattle intersections. He also found that when YIELD control was used on the cross-street approaches of nine intersections of a through street, the accidents decreased 46 percent, while ADT increased 23 percent. Inwood, et al. (13) observed that there was little change in accident experience when STOP signs were replaced with YIELD signs.

Accident Severity and Cost

Several sources have shown that severity of accidents is closely tied to speed (14, 15). Solomon (14) also points out that speed differential is a most prominent factor. Since the primary type of low volume intersection accident that will be influenced by type of control will be the right angle accident, the speed differential will be very nearly the approach speed of the major roadway. It is possible then that severity of accidents at low volume intersections may be substantially higher than that of low volume roadways in general.

Burke (16) showed that accident costs were directly related to severity. He reported that the highest accident rates occurred at ADT levels above 400 for all types of accidents (fatal, injury, property damage). Among the most accepted estimates of accident costs are those recommended by the National Safety Council (17): fatal - $113,500, injury - $6,200, and property damage only - $570.

Driver Behavior

Driver behavior relative to intersection type and the effect of various signing techniques have been investigated by several researchers. Numerous studies of driver compliance with STOP control have been conducted since 1931. A summary of the results of these studies is presented in Table 9. Since not all researchers used the same methodology in comparing forced stops and voluntary stops, the two have been lumped together. The voluntary stop rate must always be equal to or lower than the total

Table 7. Dependent Variables Considered in Previous Research

Dependent Variable	Research Study			
	Walton (9)	Bandyopadhyay (10)	Hall (11)	Leisch (8)
Accident Frequency	Theoretical estimates	Statistical transformation	Theoretical estimates	Accidents per MEV
Accident Severity	Theoretical estimates	Primary PDO; not considered further	Theoretical estimates	--
Conflicts	Used "probability of conflict" to estimate accidents	--	Used "probability of conflicts" to estimate accidents	--
Delay	--	--	Compared actual and theoretical travel time	Did not account for natural slowing
Travel Time	--	Primary dependent variable compared for different control types	Used to estimate delay	Used to estimate delay
Fuel Consumption	--	--	Only operating cost considered	--
Exhaust Emissions	--	--	Found no significant impacts	--
Sign Cost	Considered in economic analysis	--	--	--
Violations	--	Showed effect on travel time	--	--
Total Operating Cost	Vehicle only; no delay	--	--	--

Table 8. Independent Variables Considered in Previous Research

Independent Variable	Research Study			
	Walton (9)	Bandyopadhyay (10)	Hall (11)	Leisch (8)
ADT	Up to 400 vpd each roadway	--	In guidelines only	Not restricted to low volume
ADT ratio	Ratio of 1:1 produces highest theoretical conflict	--	--	No significant relaships
Hourly Volume	--	Controlled variable	Simulated for major volume up to 50 vph	Significant effect on delay
Approach Speed	Used to estimate accident severity	Controlled variable	Unstated	Significant effect on delay and accidents
Turning Movements	--	Significant effect on travel time	--	Significant effect of left turn on delay
Geometry	--	Mostly 4-leg; 3-leg for No Control	--	Only 4-leg studied
Sight Distance	--	--	--	Used safe approach speed
Region	--	--	--	Significant effect on delay and accidents
Location	Ostensibly rural	--	--	Urban only
Control Type	STOP/No Control	STOP/YIELD/No Control	STOP/YIELD/No Control	STOP/YIELD

TABLE 9. Summary of Previous Research on Driver Behavior at STOP Signs

Category	Morrison (1931)	Fisher (1935)	Eliot (1935)	Hanson (1960)	Leisch (1963)	Beaubien (1976)	Dyar (1977)
Full Stops	47%	45%	38%	20%	17%	22%	12%
Partial Violation (Rolling Stop)	42%	34%	42%	69%	69%	48%	60%
Full Violation (No Stop)	11%	21%	20%	11%	14%	30%	28%

Source: Ref. (23)

rate shown in the table. Therefore, the apparent steady decline in voluntary stop rate indicates that the liberal use of STOP signs has produced increasingly significant disrespect.

Traffic Characteristics

Walton (9), Hall (11), and Glennon (2), all based signing criteria in part on combined ADT. The usefulness of a measure such as combined ADT is cast somewhat into doubt by a California study (18) that showed no direct relation between accident rates and the sum of entering volume. That study showed that accident rates were much more sensitive to minor road volume changes than to major road volumes. It should be pointed out that the conclusions of the California study may not be valid for low volume intersections because the volumes considered were very high and the locations were on divided highways.

Intersection Geometry

In a California study of 660 intersections, Marks (19) reported that uncontrolled four-leg intersections exhibited 14 times the accident frequency of uncontrolled three-legs in limited access subdivisions and 41 times that of 3-legs in gridiron subdivisions. A Minnesota study (20) showed that the geometric advantage of the 3-leg intersection with respect to accident rate was more pronounced at high volume locations.

Four-leg intersections were found to experience four times the accident frequency of T- and Y-types in a study on Indiana county roads (21). A detailed study of two-lane rural roads by Raff (22) showed that 3-leg intersections had lower accident rates than 4-leg.

PRELIMINARY CRITERIA

The criteria development process identified all the variables that should be considered for inclusion in the criteria. These variables included not only those specifically studied in previous research but also any variable that may have shown some tendency to affect intersection operation. Table 10 shows the variables that formed the preliminary criteria.

Dependent Variables

The candidate dependent variables studied are grouped according to the assessment that can be made from constituent variables. Driver behavior variables can provide an indication of the operating characteristics associated with a given set of independent variables. Accident experience indicates the effect of the independent variables on the relative level of hazard. Travel time variables form the primary means of assessing delay costs.

Forced stops are primarily related to major volume, in that they include only those stops resulting from inadequate gaps in the major roadway stream. Voluntary stops, slow entries and fast entries together provide an indication of the drivers' perception of the appropriate maneuver as well as their respect for the control device (primarily STOP signs). High conflict rates may give an indication of potential hazard.

Accidents per intersection is the most common form of expressing accident experience. Since total accidents are likely to be low, and therefore, accident rate potentially inconclusive, percent of intersections experiencing accidents may be more meaningful. The latter variable permits the pooling of all intersections with similar characteristics to provide a larger and more stable accident sample size for evaluations.

Table 10. Candidate Variables Studied

Dependent Variables	Independent Variables
Driver Behavior	Control Type
Forced Stops	Intersection Type
Voluntary Stops	Region
Slow Entries	Location
Fast Entries	Major Road Volume
Conflicts	Minor Road Volume
	Approach Speed
	Sight Distance
Accident Experience	
Accidents Per Intersection	
Intersections with Accidents	
Severity	
Travel Time	
3-Leg Intersections	
4-Leg Intersections	
Turning Movements	

Differences in travel time between control types provides a basis for estimating relative operating costs. Travel time for 3-leg and 4-leg intersections are separated because the latter includes a through movement. The effects of geometry on travel time can be analyzed by comparing the turning movement travel time for both 3-leg and 4-leg intersections.

Independent Variables

Virtually all variables identified in previous research are included.

The controlled variables include:

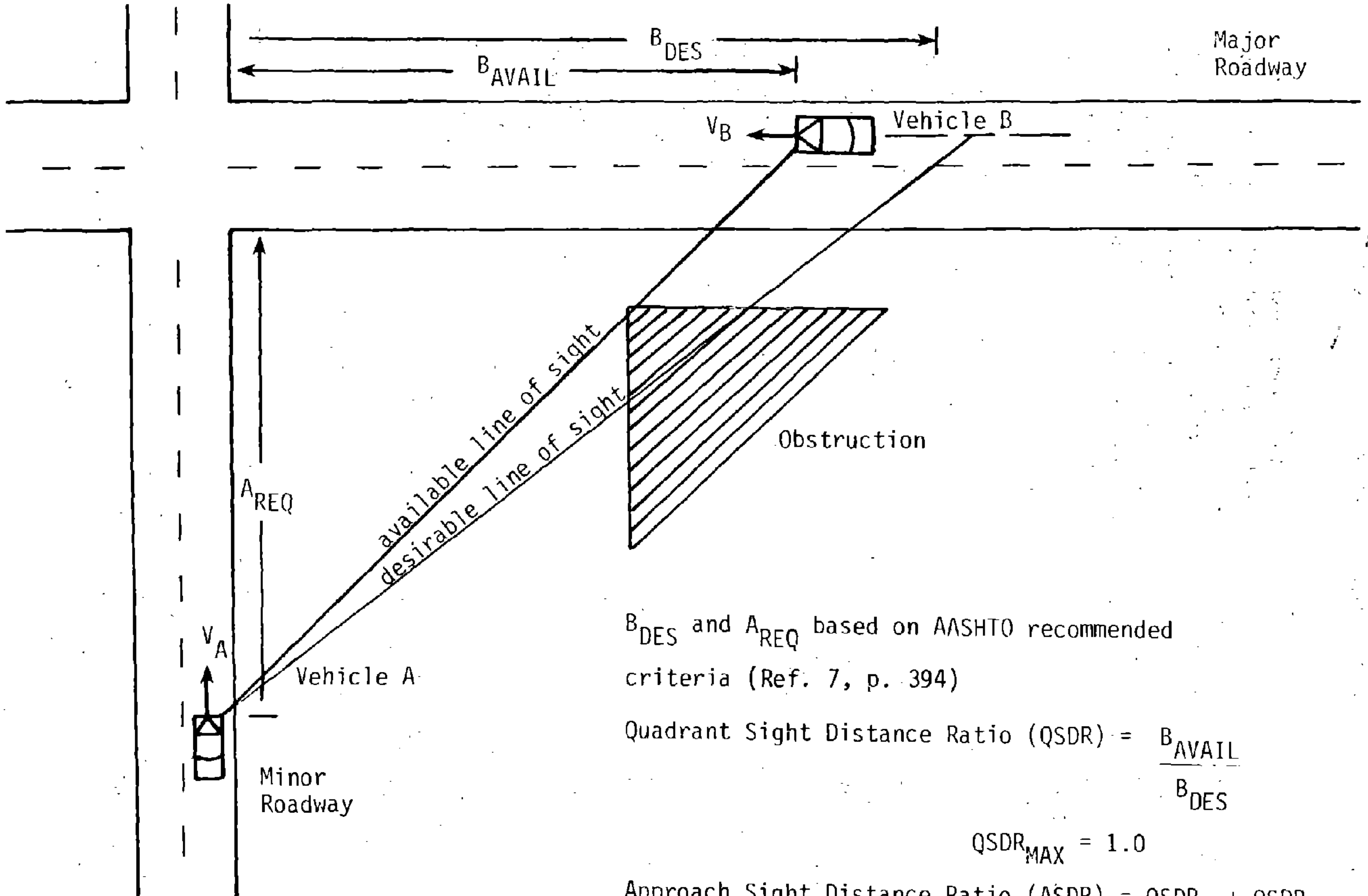
- Control type (STOP, YIELD, No Control,)
- Intersection type (3-leg, 4-leg),
- Region (Northeast, South, West), and
- Location (Urban/Rural).

The remaining variables are measured on site. Due to the many possible combinations of sight distance and approach speed, a single measure of this complex interaction is used. A quadrant sight distance ratio patterned closely after that of Lavette, et al. (24), is used as the composite variable. Though used originally for assessing the need for control at grade crossings, the quadrant sight distance ratio is a valid concept for low volume intersections. This value is the ratio of the quadrant sight distance available over the quadrant sight distance desirable based upon AASHTO sight triangle criteria for intersections. This ratio produces a dimensionless indicator of the relative sight distance afforded at an intersection (Figure 1). The combination of the quadrant sight distance ratio of both quadrants on each approach produces an approach sight distance ratio.

NEEDED QUANTIFICATION OF VARIABLES

The following describes those variables that require further quantification. All validations were made within the appropriate framework of control type, intersection type, region and location.

- Major Roadway Volume - Representative volumes were sought without upper bounds. The bulk of the major volumes are below 4,000 vpd, with the remainder (about 20%) extending up to 13,000 vehicles per day.
- Minor Roadway Volume - Volumes up to 500 vpd were analyzed.
- Approach Speed - Approach speeds from 20 to 60 mph (32 to 96 km/h) were considered, as preliminary speed sampling had shown to be typical.
- Sight Distance - All levels of sight distance were considered.



B_{DES} and A_{REQ} based on AASHTO recommended criteria (Ref. 7, p. 394)

Quadrant Sight Distance Ratio (QSDR) = $\frac{B_{AVAIL}}{B_{DES}}$

$$QSDR_{MAX} = 1.0$$

Approach Sight Distance Ratio (ASDR) = $QSDR_1 + QSDR_2$

$$ASDR_{MAX} = 1.0 + 1.0 = 2.0$$

Figure 1. Description of Quadrant Sight Distance Ratio.

CHAPTER 3: FIELD VALIDATION

EXPERIMENTAL PLAN

There were two phases involved in the experimental plan for validation of the traffic parameters used to establish the level of control for low volume intersections. The first phase (screening study) utilized historical records to investigate several different levels of control type, major road volume (vpd) and minor road volume (vpd).

SCREENING STUDIES

Accident experience at low volume intersections was examined and the data cast into a 5 x 5 matrix of major volume and minor volume ranges by control type. A row-by-row and column-by-column analysis was made to determine where there were significant differences in accident rate. These changes or "breakpoints" identified those conditions under which a change in control type could potentially be made. The final determination of whether such conditions permit a reduction in level of control was dependent on whether there was a significant difference in accident rate between the two control types.

Initially, the study was to proceed by accumulating accident data from the intersections located in Texas. While this effort was underway, two other states were to be located that could provide similar information. After several months it became apparent that the type of information needed was difficult to obtain.

Problems Encountered

Two primary difficulties arose in collecting the screening study data--lack of adequate control type and volume records for low volume intersections, and scarcity of YIELD and No Control sites. Few agencies routinely maintain traffic volume records for low volume intersections. Therefore, local traffic engineers' guidance was normally used for selecting sites that were almost assuredly low volume. Control device inventories were more readily available, but often somewhat inaccurate and without information on No Control locations. On-site inspection of the suspected low volume intersections was performed to identify control type.

In addition to the lack of usable record systems there was an evident reluctance to use a lower form of control. On most state systems the preferred control was the STOP sign, regardless of volume. YIELD control appeared to be reserved for use on ramps and some turning roadways.

YIELD and No Control were more common in urban areas. It appeared that, with the high concentration of STOP signs in urban areas, traffic engineers were seeking some alternative when a stop was not always necessary.

YIELD and No Control intersections occur primarily in about five cells in the 25-cell matrix. No Control was found at the intersections of local streets. In urban areas, traffic engineers were seeking some alternative when a stop was not always necessary.

YIELD and No Control intersections occur primarily in about five cells in the 25-cell matrix. No Control was found at the intersections of local streets. In urban areas YIELD control was found most often at the intersections of a local street and a collector street.

Screening Study Findings

As a result of the difficulties encountered in obtaining information, it was mutually agreed (by FHWA and TTI) to modify the screening study approach. The majority of the effort was concentrated on collecting appropriate data from intersections in Texas. This effort included a manual search of accident files, visual inspection of intersections to ascertain control type and, in some cases, measuring daily traffic volumes. In this manner data from more than two thousand intersections were collected and analyzed. The findings based on Texas data suggested that, when analyzed by control type, accident experience appeared to be independent of major road volume. When minor road volume was considered, accident experience across control types appeared to be similar. There was an increase in accident experience around 300 vpd that continued to 500 vpd.

Additional analyses indicated that the lowest accident experience occurred in minor road volume cells below 250 vpd. The accident figures were still further reduced by restricting the major road volume to 1500 vpd (Table 11).

Although these findings were of interest, they had to be tempered with several considerations. The problem of identifying urban YIELD-controlled intersections in higher volume ranges and finding rural uncontrolled and YIELD intersections constrained the analyses and restricted the conclusions. There was also a question of accuracy of volume measurements, particularly on the minor road counts. The third consideration is the possibility of an undocumented change of control type which could present a distorted accident picture.

Because of these data limitations, no definite volume criterion was imposed for the on-site field studies. The minor road upper bound remained at 500 vpd, with no restrictions placed on the major road.

The low accident experience observed overall in the Texas data suggested that the economics of safety factors would not constitute a driving function in signing warrant criteria. Consequently, the on-site field studies concentrated on other aspects of traffic behavior.

ON-SITE FIELD STUDIES

Field investigations were conducted in Texas, Florida, and New York. These states were chosen because they are geographically representative of the western, southeastern and northeastern sections of the country. Further, the traffic, roadway and accident records maintained by these states are among the most complete of all the states surveyed. A list of the counties and cities in which studies were conducted is given in Table 12.

The field study of the nine counties and two urban areas in Texas was conducted in November 1979. Ten intersections in each of the six location/control categories were surveyed.

The Florida studies (one county and two cities) were conducted in January 1980. No rural YIELD or rural No Control were found in the locations surveyed. The number of intersections studied in each remaining group were: urban STOP - 8, urban YIELD - 16, urban No Control - 8, and rural STOP - 8. The only other significant problem encountered was the extremely low volumes observed at the rural STOP locations. These small sample sizes tended to magnify the problems of data interpretation.

The New York studies were conducted in May 1980. Forty intersections (eight each at rural STOP, rural YIELD, rural No Control, and urban No Control, and four each at urban STOP and urban YIELD) were examined in three counties and one city.

Field Site Selection

As mentioned previously, individual inter-

TABLE 11. Accident Experience by Control Type and Major and Minor Road Volumes for Texas Intersections.

Rural STOP

Minor Volume

Major Volume	0 - 225		226 - 500			
	104		138		242	
0 - 1500	7	6.73	33	23.91	40	16.53
	7	.0673	50	.3623	57	.2355
	233		273		506	
1501 -	26	11.16	64	23.44	90	17.79
4500	29	.1245	111	.4066	140	.2768
	337		411		748	
	33	9.79	97	23.60	130	17.38
	36	.1068	161	.3917	197	.2634

Rural No Control

Minor Volume

Major Volume	0 - 225		226 - 500			
	140		6		146	
0 - 1500	5	3.57	0	0	5	3.42
	5	.0357	0	0	5	.0342
	5		-		5	
1501 -	0	0	-		0	0
4500	0	0	-		0	0
	145		6		151	
	5	3.45	0	0	5	3.31
	5	.0345	0	0	5	.0331

LEGEND:

00	
11	12
21	22

00 - Number of intersections

11 - Number of intersections having at least one accident in 3 years.

21 - Number of accidents in 3 yrs.

12 - Percent (%) of intersections having accidents in three years.

22 - Average accidents per intersection.

TABLE 11. (Continued)

Accident Experience by Control Type and Major and Minor Road Volumes for Texas Intersections

Urban STOP
Minor Volume

Major Volume	0 - 225		226 - 500			
0 - 1500	88		63		151	
	12	13.64	16	25.39	28	18.54
	16	.1818	25	.3968	41	.2715
1501 - 4500	122		128		250	
	28	22.95	44	34.38	72	28.80
	40	.3279	90	.7031	130	.520
	210		191		401	
	40	19.05	60	31.41	100	24.94
	56	.2667	115	.6021	171	.4264

Urban YIELD
Minor Volume

Major Volume	0 - 225		226 - 500			
0 - 1500	111		126		237	
	18	16.22	26	20.63	44	18.56
	22	.1982	32	.2539	54	.2278
1501 - 4500	7		29		36	
	0	0	3	10.34	3	17.79
	0	0	3	.1034	3	.0833
	118		155		273	
	18	15.25	29	18.71	47	17.22
	22	.1864	35	.2258	57	.2088

Urban No Control
Minor Volume

Major Volume	0 - 225		226 - 500			
0 - 1500	308		55		363	
	10	3.25	7	12.73	17	4.68
	10	.0325	9	.1636	19	.0523
1501 - 4500	69		15		84	
	12	17.39	3	20.0	15	17.86
	19	.2754	6	0.40	25	.2976
	377		70		447	
	22	5.84	10	14.28	32	7.16
	29	.0769	15	.2143	44	.0984

LEGEND:

00	
11	12
21	22

00 - Number of Intersections

11 - Number of Intersections having at least one accident in 3 years.

21 - Number of accidents in 3 yrs.

12 - Percent (%) of intersections having accidents in three years.

22 - Average accidents per intersection.

Table 12. Field Study Sites

	Urban (Cities)	Rural (Counties)
Texas	Bryan/College Station San Antonio	Bell Brazos Burleson Leon McLennon Madison Milam Montgomery Walker
Florida	Orlando Tampa	Hillsborough
New York	Albany	Albany Rensselear Schenectady

section selection was based on minor road volume and control type. Prior to the dispensing of a crew to collect intersection data, a senior project staff member investigated each of the proposed sites to evaluate its suitability. Individual field crew supervisors had the authority to reject any previously approved intersection if for some reason it no longer met the necessary criteria (e.g., recent change in control type, volume on minor road too low to obtain a reasonable sample, etc.).

Data Collection Procedure

Field data collection began with the measurement of the sight distance available along each approach and quadrant according to current AASHTO sight distance criteria. Next, approach speeds were recorded at the limit of the radar equipment pulse range for all approaches. These speeds were used to calculate the desirable sight distances for each quadrant. The ratio between the two sight distances then served as the comparative measure.

Operational cost for an intersection of designated volume and control type was verified by the measurement of travel times. This travel time measurement was the time required to travel from 150 feet (45 m) upstream of the intersection on the entering minor leg to 150 feet (45 m) beyond the intersection on a departing leg (major or minor). Intersection geometry (affecting proportion of turns), as well as control type, could influence delay. Therefore, turning movements were noted.

Based upon the number of sites and volume ranges to be studied, a maximum of four hours study time, or one hundred vehicles on the low volume approach, was established for field study guidelines. Radar equipment was used only to measure approach speed at the maximum range of the radar. Therefore, no vehicle operator would see the equipment, thereby biasing the results.

Field Study Analysis Variables

Following is a description of the pertinent variables considered in the field validation.

Dependent Variables

1. Driver Behavior
   a) Forced Stop (FS) - vehicle on minor approach forced to stop because of vehicle approaching on major roadway.
   b) Voluntary Stop (VS)* - vehicle on minor approach stops in absence of oncoming traffic.
   c) Slow Entry (SE)* - slowing or "rolling stop," speed less than 5 mph (8 km/h) for vehicle on minor approach leg.
   d) Fast Entry (FE)* - vehicle on minor approach leg enters the intersection at speed greater than 5 mph (8 km/h).
   e) Conflict (CF) - vehicle entering the intersection from minor approach causes vehicle on major approach to decelerate, apply brakes or swerve.

*Note that b, c, and d are measures taken in the absence of oncoming major road traffic.

2. Accident Experience
   a) Average number of accidents per intersection in a three year period.
   b) Intersections with accidents in a three year period.

3. Travel Time
   a) Mean travel time for 3-leg intersections.
   b) Mean travel time for 4-leg intersections.
   c) Mean travel time for turning movements (3- and 4-leg intersectons).

Independent Variables

1. Region - Texas, Florida or New York

2. Location - Rural or Urban
3. Geometry - 3- or 4-leg
4. Signing - STOP, YIELD or No Control.
5. Major Roadway Volume - grouped in 1000 vpd increments. This variable was not used in the analysis of Voluntary Stop, Slow Entry and Fast Entry because these measures are independent of volume.

Where necessary for clarification of differences found, the following variable was used:

6. Sight Distance - The ratio of sight distance available to that required (AASHTO).

CHAPTER 4: FIELD DATA ANALYSIS

INTRODUCTION

The data collection constraints and the low accident experience prompted representatives of FHWA and TTI to revise the experimental plan. Instead of using accidents to define volume "breakpoints" and to identify specific intersections for subsequent detailed study, intersections were selected with a single volume criterion, i.e., less than 500 vpd on the minor approach. This volume is analogous to the low volume roadway definition generally accepted by the traffic engineering profession. Accident experience then was used as another dependent measure rather than as a screening variable.

The overall objectives of the project remained the same: to develop and validate criteria for the use of two-way STOP signs, YIELD signs, or No Control at low volume intersections. In order to satisfy these objectives, data were collected to answer the following questions:

Primary

1. Are there significant differences in operational behavior among STOP, YIELD and No Control low volume intersections?

Ancillary

2. Are there operational differences at low volume intersections located in different geographic regions?

3. Are there operational differences between urban and rural low volume intersections?

4. Are there operational differences between intersections of different geometrics (3-leg/4-leg)?

5. Are there operational differences that can be explained by consideration of major road volume?

Addressing these questions would allow determination of the operational characteristics of low volume intersections which, in turn, would allow decisions to be made about criteria for signing these intersections.

Procedures

The primary method of analysis was analysis of variance (ANOVA), which was taken from the Statistical Analysis System, Version 79.3 (SAS793) produced by SAS Institute, Inc. The procedure employed was a general linear model (GLM), which is a multiple regression approach to ANOVA. This approach is used because it can handle the case of unequal cell frequencies without violating the ANOVA assumption of independence of variables. This is accomplished by adjusting the proportion of variance attributed to a factor for the correlation of the factor with all other factors in the design. However, this approach does introduce a problem with this data. Higher order interactions (three-way and above) require the manipulation of cells that may not have had data collected for them. For this reason, all of these interactions have been lumped together and tested as Higher Interactions. In general, this does not affect the tests of the main effects or the two-way interactions. However, two difficulties were encountered. First, for the independent variable of major road volume, the use of six levels (increments of 1000 vpd per level) caused a breakdown of the GLM procedure because of the large number of missing cells. To overcome this difficulty, two levels of major road volume were used ($\leq$ 2000 vpd and > 2000 vpd). These volume ranges were chosen based on experience with Texas accident data and with analysis attempts using the original six levels. Where major road volume was a primary factor, additional information is presented for the original volume levels.

The second problem encountered was the absence of conflicts. Although scheduled as a dependent variable, so few were actually observed that it was deleted from the analysis section. Conflict rates are presented for general information in Tables 24, 25, and 26.

The following three sections are organized around the three broad categories of dependent variables (Driver Behavior, Accident Experience and Travel Time). Each section describes the specific dependent variable, the analysis procedure, the results, the findings and presents comments on the data.

DRIVER BEHAVIOR

General Comments

The hypothesis tested was that the driving behavior at low volume intersections remains the same regardless of the type of traffic control device, location, geometry, region or major road volume. Since the primary method of comparison was analysis of variance, frequencies of vehicles in each dependent variable category were converted to rates. The basis for the computation of rates for each variable is given in its respective section.

For those intersections where five or fewer vehicles were observed, the rates computed were probably spurious and nonrepresentative. In most analyses these rates were averaged with enough intersections to minimize their impact. However, in certain cases, these spurious rates presented a somewhat distorted picture when the analysis of variance was performed.

Forced Stop Rate

1. Specific Dependent Variable

Forced Stop Rate (FSR) - Number of vehicles forced to stop divided by the total number of vehicles (N) observed on the minor approaches.

$$FSR = \frac{FS}{N}$$

2. Analysis Procedures

Analysis of Variance
Correlation/Regression

3. Results

The results of the analysis indicate significant differences among Regions and between Major Volume ranges when considering the dependent variable of Forced Stop Rate (Table 13). There was also a significant interaction between Region and Location. The mean rates for each level of these variables are presented in Table 14.

4. Comments

These findings are not unexpected. The number of vehicles forced to stop at an intersection is dependent on the volume on the major approach. This is supported by the correlation of 0.51 that was observed between actual major road volume and FSR for all intersections (Table 15). Although only two volume ranges could be used in the analysis, examination of major road volume by 1000 vpd groups provides additional evidence that as major road volume increases, Forced Stop Rate increases (Figure 2).

Table 13. ANOVA Using The Dependent Variable of Forced Stop Rate (FSR).

Source	DF	Sum of Squares	F-Value	PR>F
Region	2	.1266	3.23	.0431
Location	1	.0055	.28	.59
Control	2	.1118	2.86	.06
Geometry	1	.0078	0.40	.53
Major Volume	1	.5152	26.31	.0001
Reg x Loc	2	.1841	4.70	.0109
Reg x Cont	4	.1723	2.20	.07
Reg x Geo	2	.0117	0.30	.74
Reg x MVol	2	.0569	1.45	.24
Loc x Cont	2	.0023	0.06	.94
Loc x Geo	1	.0001	0.01	.93
Loc x MVol	1	.0006	0.03	.86
Cont x Geo	2	.0074	0.19	.83
Cont x MVol	2	.1046	2.67	.07
Geo x MVol	1	.0143	0.73	.39
Model	26	1.3212	2.587	
Error	113	2.2196		
R^2 = 0.3731				
C.V. = 75.5828				

Table 14. Significant Main Effects and Interactions: Mean Forced Stop Rate (FSR)

Region		Mean FSR
New York		.322 (40)*
Texas		.138 (60)
Florida		.117 (40)
Major Volume		
≤ 2000 (vpd)		.079 (91)
> 2000 (vpd)		.382 (49)
Location	**Region**	**Mean FSR**
Urban	New York	.419 (16)
	Texas	.157 (30)
	Florida	.058 (32)
Rural	New York	.257 (24)
	Texas	.120 (30)
	Florida	.352 (8)

*Number of intersections observed

Table 15. Distributon of All Intersections By Major Approach Volume and Control Type.

Major Approach Volume (vpd)	Predicted FSR*	Frequency of Control Type		
		STOP	YIELD	No Control
1,000	.146	22	31	25
2,000	.167	5	4	4
3,000	.188	7	5	2
4,000	.209	5	1	1
5,000	.230	3	1	1
6,000	.251	1		3
7,000	.272	1	1	1
8,000	.293		1	
9,000	.314	2	1	
10,000	.335			
>10,000		2	3	7

*Based on a regression FSR = 0.000021 (ADT) + .1249 with an r = 0.51

Regional differences observed in FSR can also be attributed to major road volume. The average major road volume at intersections studied in New York was 7500 vehicles per day (vpd), for Texas 1427 vpd, and 492 vpd for Florida.

Urban intersections tend to have higher major road volumes than rural (3245 vpd vs. 2455 vpd) which, when combined with regional variations, contributes to the different rates found in the significant interaction.

Voluntary Stop Rate

1. Specific Dependent Variable

   Voluntary Stop Rate (VSR) - Number of vehicles which voluntarily stop divided by the difference between the total number of vehicles (N) and those forced to stop by oncoming traffic (FS).

$$VSR = \frac{VS}{N-FS}$$

2. Analysis Procedure

   Analysis of Variance
   Correlation/Regression

3. Results

   The results of the analysis of variance indicate a significant difference among Region and Location (urban/rural), using VSR as a dependent measure. These were also significant interactions between Region and Location and Region and Geometry (Table 16). The mean rates for these findings are presented in Table 17.

4. Comments

   Examination of these means suggests a very low VSR for the New York region, particularly in the urban area. It should also be noted that there is an unexpectedly high rate in rural Florida. This rate was in all likelihood caused by a sampling artifact. The raw data presented in Appendix A shows that, at these intersections, a low number of vehicles were observed, causing the rates to be high and probably nonrepresentative. This sampling and conversion artifact occurs throughout the analyses. In cases other than rural Florida data, its effect was reduced by observing more intersections.

   Aside from these anomalies, the rate of vehicles voluntarily stopping at intersections is low, usually less than 17%. Although significant difference was found among regions and locations, there were no differences among the two other major independent variables. However, there are still fluctuations in the voluntary stopping rates. For example, the stopping rates for STOP-controlled intersections were found to be about 10% higher than YIELD or No Control intersections. This difference could be attributable to the sign, to sampling artifacts, or it could be due in part to sight distance restrictions.

   It would be expected that intersections with restricted sight distances would have greater voluntary stopping. Further it could be expected that intersections with sight distance restrictions would be more likely to be STOP-controlled.

   The examination of the effects of sight distance as an independent variable required the computation of sight distance (SD) ratios (measured SD available/SD required by AASHTO) for each approach. Each quadrant was limited to

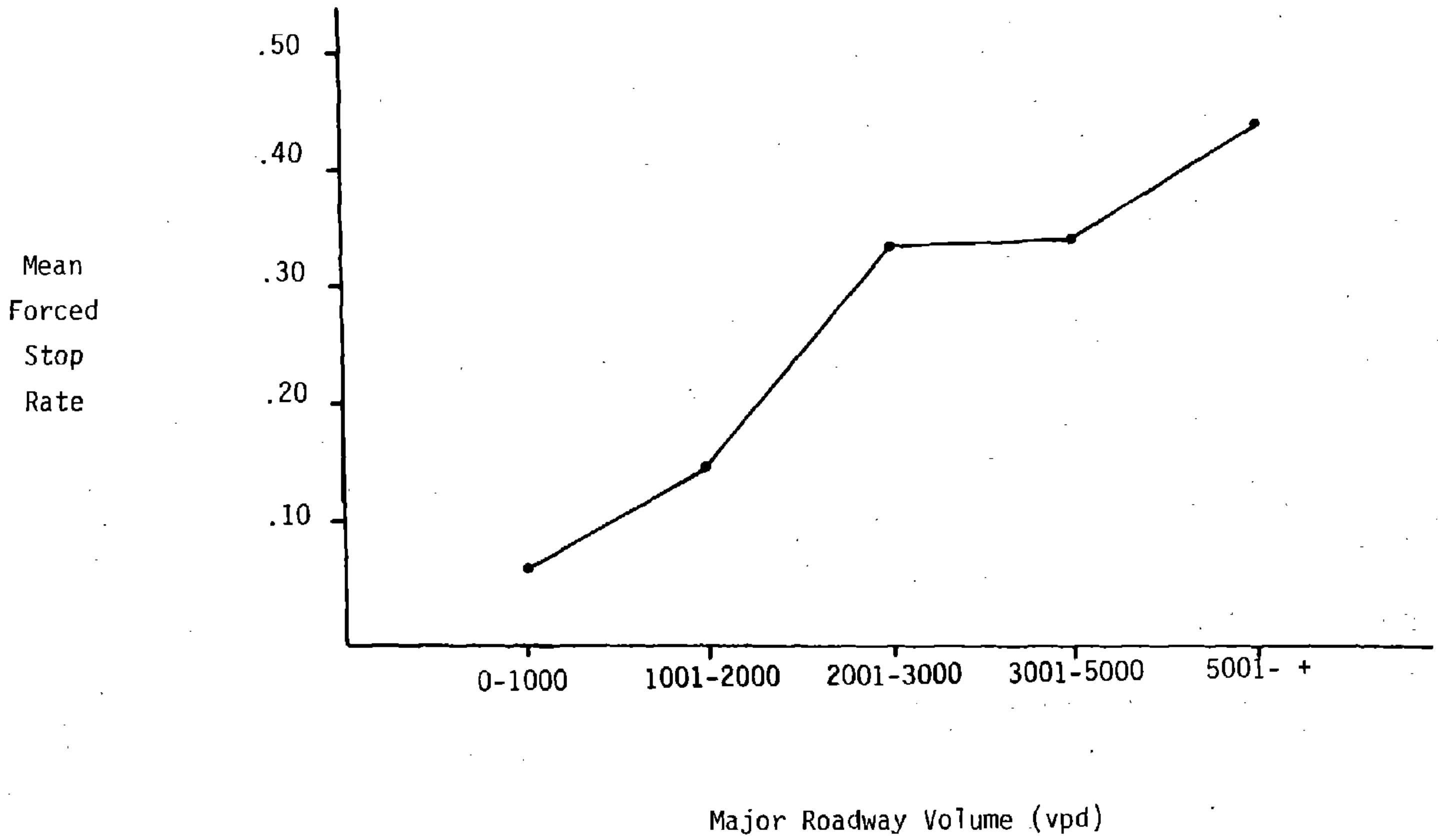


Figure 2. Forced Stop Rate by Major Roadway Volume

TABLE 16. ANOVA Using The Dependent Variable of Voluntary Stop Rate (VSR).

Source	DF	Sum of Squares	F-Value	PR>F
Region	2	.5972	16.81	.0001
Location	1	.3105	17.48	.0001
Control	2	.0028	.08	.92
Geometry	1	.0163	.92	.33
Reg x Loc	2	.9152	25.76	.0001
Reg x Cont	4	.0939	1.32	.26
Reg x Geo	2	.1429	4.02	.0204
Loc x Cont	2	.0066	0.19	.82
Loc x Geo	1	.0180	1.02	.31
Cont x Geo	2	.0728	2.05	.13
Model	19	2.1762	6.44	
Error	120	2.1315		
R^2 = .505				
C.V. = 115.9371				

Table 17. Significant Main Effects and Interactions: Mean Voluntary Stop Rate (VSR)

Region		Mean VSR
New York		.026 (40)*
Texas		.115 (60)
Florida		.202 (40)
Location		
Urban		.100 (78)
Rural		.132 (62)
Location	**Region**	**Mean VSR**
Urban	New York	.003 (16)
	Texas	.158 (30)
	Florida	.094 (32)
Rural	New York	.041 (24)
	Texas	.072 (30)
	Florida	.634 (8)
Geometry	**Region**	
3-Leg	New York	.024 (34)
	Texas	.076 (43)
	Florida	.217 (24)
4-Leg	New York	.035 (6)
	Texas	.214 (17)
	Florida	.180 (16)

*Number of intersections observed

a maximum ratio of 1.00 (i.e., sight distance available ≥ sight distance required). The ratios for the two quadrants on each minor approach were combined to produce the approach SD ratios and 3-leg intersections would have only one. The dependent variable of voluntary stop rate was used in a regression analysis to determine if the relationship was in the expected direction, and to determine the strength of the relationship. The results indicated very poor relationship between the two variables ($r = -.126$).

Further, a chi-squared test performed on the distributions of intersections by control type and sight distance did not support the supposition that STOP signs are placed where available sight distance was poor (Table 18).

Apparently, the fluctuation in VSR for signing is due to the effects of the control type and, to some extent, sampling error.

Slow Entry Rate

1. Specific Dependent Variable

Slow Entry Rate (SER) - Vehicles entering the intersection at less than 5 mph (8 km/h) divided by the difference between the total number of vehicles (N) and those forced to stop by oncoming traffic (FS).

$$SER = \frac{SE}{N-FS}$$

2. Analysis Procedure

Analysis of Variance

3. Results

The results of the analysis indicate a significant main effect for Location and a significant interaction between Region and Location (Table 19). The mean rates are presented in Table 20.

4. Comments

These results are, to some extent, a consequence of the sampling artifact previously discussed and of the somewhat subjective nature of discriminating between slow and fast entering vehicles.

Fast Entry Rate

1. Specific Dependent Variable

Fast Entry Rate (FER) - Vehicles entering the intersection at greater than 5 mph (8 km/h) divided by the difference between the total number of vehicles (N) and those forced to stop by oncoming traffic (FS).

$$FER = \frac{FE}{N-FS}$$

2. Analysis Procedure

Analysis of Variance

3. Results

The analysis using this dependent measure indicated a significant difference among Regions and a significant interaction between Region and Location (Table 21). The mean rates for these variables are given in Table 22.

4. Comments

Fast entry rates are based on the remainder of vehicles that did not volun-

TABLE 18. Chi-Squared Test of Frequency of Approaches by Control Type and Sight Distance for AASHTO Case II Sight Distance.

Control Type	0 - .5	.51 - 1.0	1.01 - 1.5	1.51+		
STOP	18	26	16	9	69	χ^2_{obs} = 6.902
YIELD	7	27	17	11	62	$\chi^2_{.95}$ = 12.59
No Control	11	14	16	7	48	
	36	67	49	27	179	

TABLE 19. ANOVA Using The Dependent Variable of Slow Entry Rate (SER).

Source	DF	Sum of Squares	F-Value	PR>F
Region	2	.1370	1.84	.16
Location	1	.1581	4.24	.0415
Control	2	.0389	0.52	.59
Geometry	1	.0646	1.74	.19
Reg x Loc	2	.2319	3.11	.0480
Reg x Cont	4	.1752	1.18	.32
Reg x Geo	2	.0164	0.22	.80
Loc x Cont	2	.0771	1.04	.35
Loc x Geo	1	.0008	0.02	.87
Cont x Geo	2	.0644	0.86	.42
Model	19	.9644	1.36	
Error	120	4.4745		
R^2 = .1773				
C.V. = 25.6692				

TABLE 20. Significant Main Effects and Interactions:
Mean Slow Entry Rate (SER)

Location		Mean SER
Urban		.776 (78)*
Rural		.720 (62)
Location	**Region**	**Mean SER**
	New York	.744 (16)
Urban	Texas	.786 (30)
	Florida	.784 (32)
	New York	.751 (24)
Rural	Texas	.759 (30)
	Florida	.482 (8)

*Number of intersections observed

TABLE 21. ANOVA Using The Dependent Variable of Fast Entry Rate (FER).

Source	DF	Sum of Squares	F-Value	PR>F
Region	2	.2641	5.59	.0048
Location	1	.0011	0.05	.82
Control	2	.0376	0.80	.45
Geometry	1	.0011	0.05	.82
Reg x Loc	2	.1937	4.10	.0189
Reg x Cont	4	.0624	0.66	.62
Reg x Geo	2	.0115	0.24	.78
Loc x Cont	2	.0648	1.37	.25
Loc x Geo	1	.0032	0.14	.71
Cont x Geo	2	.0017	0.04	.96
Model	19	.6412	1.428	
Error	120	2.8347		
R^2 = .1844				
C.V. = 106.1263				

Table 22. Significant Main Effects and Interactions: Mean Fast Entry Rate (FER)

Region		Mean FER
New York		.228 (40)*
Texas		.111 (60)
Florida		.111 (40)

Location	Region	Mean FER
	New York	.259 (16)
Urban	Texas	.054 (30)
	Florida	.121 (32)
	New York	.207 (24)
Rural	Texas	.168 (30)
	Florida	.070 (8)

*Number of intersections observed

tarily stop or enter slowly.

Rates from all three of these variables reflect regional and rural and urban influence. In general, fewer vehicles voluntarily stop in urban areas (such as New York) but slightly more enter intersections at slower speeds. However, a substantial portion of these vehicles not voluntarily stopping enter intersections at higher speeds.

Summary

In general, there are two characteristics of driver behavior at low volume intersections worthy of note. Those dependent measures that are subject to influence by volume of the major roadway are so influenced; the remaining measures (those not influenced by volume) vary regionally and by location.

The number of forced stops at intersections increase as the volume on the major road increases. Variations from this finding are probably a function of small cell sizes and/or a sampling or an analysis artifact.

There are regional differences in measures that are not directly influenced by volume. New York experiences a lower rate of voluntary stopping behavior, while in Florida, fewer drivers enter intersections at greater than 5 mph (8 km/h). Again, minor fluctuations or differences among dependent measures are best understood by considering sampling and data collection techniques. Sight distance apparently does not contribute to the differences observed.

The significant differences found among the independent variables are given in Table 23 for each dependent variable.

Summary rates for dependent variables are presented for major independent classifications in Tables 24 through 26.

ACCIDENT EXPERIENCE

General Comments

The constraints imposed on using accident information as a screening device for intersections did not negate its usefulness in the analysis of operational behavior. Although the overall accident experiences of low volume intersections in Texas were considered to be few, it was necessary to investigate accidents in other states, and by other independent variable classifications. In this manner, an intersection's accident history served as a dependent variable to aid in answering the research questions needed to satisfy the objectives of the project.

The primary method of analysis used was the previously described analysis of variance procedure. However, since a large number of intersections had no accident experience in three years, there was some question as to the normality of the data. Consequently, non-parametric tests were used to support the findings of the primary analysis. Most of the higher order interactions were deleted from the analysis to make the tests conservative and to reduce the probability of empty cells.

The analysis based on the two forms of this dependent variable are discussed in the following sections.

Accidents Per Intersection

1. Specific Dependent Variable

   Average Number of accidents per intersection in three years -- number of accidents in three years/number of intersections observed.

2. Analysis Procedure

   Analysis of Variance

TABLE 23. Summary of Significant Independent Variables for Driver Behavior.

Independent Variables	Dependent Variables			
	FSR	VSR	SER	FER
Region	X*	X		X
Location		X	X	
Control				
Geometry				
Major Road Volume	X	--**	--	--
Reg x Loc	X	X	X	X
Reg x Cont		X	X	X
Reg x Geo		X		
Reg x MVol		--	--	--
Loc x Cont				
Loc x Geo				
Loc x MVol		--	--	--
Cont x Geo				
Cont x MVol		--	--	--
Geo x MVol		--	--	--

* $p < .05$

** VSR, SER, FER not tested for effects of Major Volume, as indicated by "--".

Table 24. Dependent Variable Rates for STOP Control by Region and Location

	FSR	VSR	SER	FER	CFR*
New York	.286	.056	.747	.210	.028
Urban	.462	.024	.762	.262	.047
Rural	.195	.067	.742	.192	.013
Texas	.236	.210	.624	.166	.010
Urban	.261	.215	.632	.153	.020
Rural	.210	.205	.616	.178	.000
Florida	.342	.240	.654	.115	.006
Urban	.169	.061	.755	.184	.000
Rural	.514	.418	.552	.045	.013
Distribution of vehicles not forced to stop		.186	.647	.167	
Distribution of all vehicles	.263		.737		.012

*CFR = Conflict Rate

Table 25. Dependent Variable Rates for YIELD Control by Region and Location.

	FSR	VSR	SER	FER	CFR*
New York	.380	.018	.649	.333	.041
Urban	.464	.000	.700	.300	.020
Rural	.341	.025	.630	.346	.051
Texas	.022	.060	.831	.110	.004
Urban	.034	.119	.852	.029	.040
Rural	.009	.000	.810	.190	.000
Florida	.054	.142	.754	.104	.000
Urban	.054	.142	.754	.104	.000
Rural	----	----	----	----	----
Distributon of vehicles not forced to stop		.082	.790	.128	
Distribution of all Vehicles	.099		.901		.018

*CFR = Conflict Rate

Table 26. Dependent Variable Rate for No Control by Region and Location

	FSR	VSR	SER	FER	CFR*
New York	.311	.022	.770	.417	.039
Urban	.390	.000	.750	.250	.046
Rural	.231	.044	.789	.167	.031
Texas	.119	.124	.808	.069	.026
Urban	.187	.130	.845	.025	.016
Rural	.051	.117	.771	.112	.017
Florida	.000	.067	.800	.133	.000
Urban	.000	.067	.800	.133	.000
Rural	----	----	----	----	----
Distribution of vehicles not forced to stop		.091	.795	.114	
Distribution of all vehicles	.187		.813		.021

* CFR = Conflict Rate

3. Results

The ANOVA results indicate a significant main effect of Major Volume and a significant interaction between Major Volume and Region (Table 27).

The mean rates for these variables are given in Table 28.

4. Comments

The difference observed in average three-year accident rates between the two volume ranges can also be seen when finer volume ranges are considered. The graph in Figure 3 shows the breakdown of accident rates at various volume levels. Note that the 3-4000 and 4-5000 vpd levels have been combined because of the small number of intersections studied from each group.

The significant interaction was due in part to Texas intersections with major road volumes greater than 2000 vehicles per day. The accident rate in this category does not follow the pattern from the other two states.

Intersections With Accidents

1. Specific Dependent Variable

Number of intersections recording at least one accident in three years.

2. Analysis Procedure

Chi-Squared Test

3. Results

Chi-squared tests performed on the major independent variables indicate significant differences among Control types, and Geometry (Table 29) and among Major Volume levels (Table 30).

4. Comments

The number of STOP-controlled intersections having at least one accident in three years is proportionally higher than YIELD or Uncontrolled intersections. This difference could possibly be due to a change in signing status as a result of accident experience. However, none of the records available indicated such.

Intersections with four legs have operational characteristics that increase the probability of conflict and apparently the accident experience.

Significant differences in accident experiences were observed at the 2000 and 4000 vpd levels. Figure 4 displays the percentage of intersections experiencing accidents at various volume levels. Once again, the 3001-5000 vpd ranges are collapsed to compensate for small cell frequencies.

Summary

There is an indication of significantly different accident experience among sign types, volume levels and between 3- and 4-leg intersections. These differences were observed using non-parametric tests which may be more appropriate for this type of data. A summary of significant findings is presented in Table 31.

A note of particular interest is the increase in accident experience above 2000 vpd on the major road. This increase was significant using analysis of variance and Chi-Squared tests. This interesting trend may indeed be a "breakpoint". Using the classification of intersections with and without accidents and collapsing across different volume ranges, the tests indicate that intersections with major road volumes of 2000

TABLE 27. ANOVA Using The Dependent Variable of Average Number of Accidents Per Intersection In Three Years.

Source	DF	Sum of Squares	F Value	PR>F
Region	2	3.0024	1.08	.34
Location	1	2.4148	1.74	.18
Control	2	.1839	.07	.93
Geometry	1	.3485	.25	.61
Major Volume	1	12.3779	8.91	.0035
Reg x Loc	2	1.6552	.60	.55
Reg x Cont	4	.7252	.13	.97
Reg x Geo	2	.1104	.04	.96
Reg x MVol	2	9.1769	3.30	.0403
Loc x Cont	2	5.0316	1.81	.16
Loc x Geo	1	.7948	.57	.45
Loc x MVol	1	1.8512	1.33	.25
Cont x Geo	2	.4662	.17	.84
Cont x MVol	2	2.8805	1.04	.35
Geo x MVol	1	.1030	.07	.78
Model	26	41.1225	1.238	
Error	113	156.9812		
R^2 = .2075				
C.V. = 317.2522				

Table 28. Significant Main Effects and Interactions: Average Number of Accidents Per Intersection In Three Years

Major Volume		Accident Rate
≤ 2000 (vpd)		.142 (91)*
> 2000 (vpd)		.795 (49)
Major Volume	**Region**	**Accident Rate**
	New York	.100 (10)
≤ 2000 (vpd)	Texas	.136 (44)
	Florida	.162 (37)
	New York	1.00 (30)
> 2000 (vpd)	Texas	.125 (16)
	Florida	2.33 (3)

*Number of intersections observed

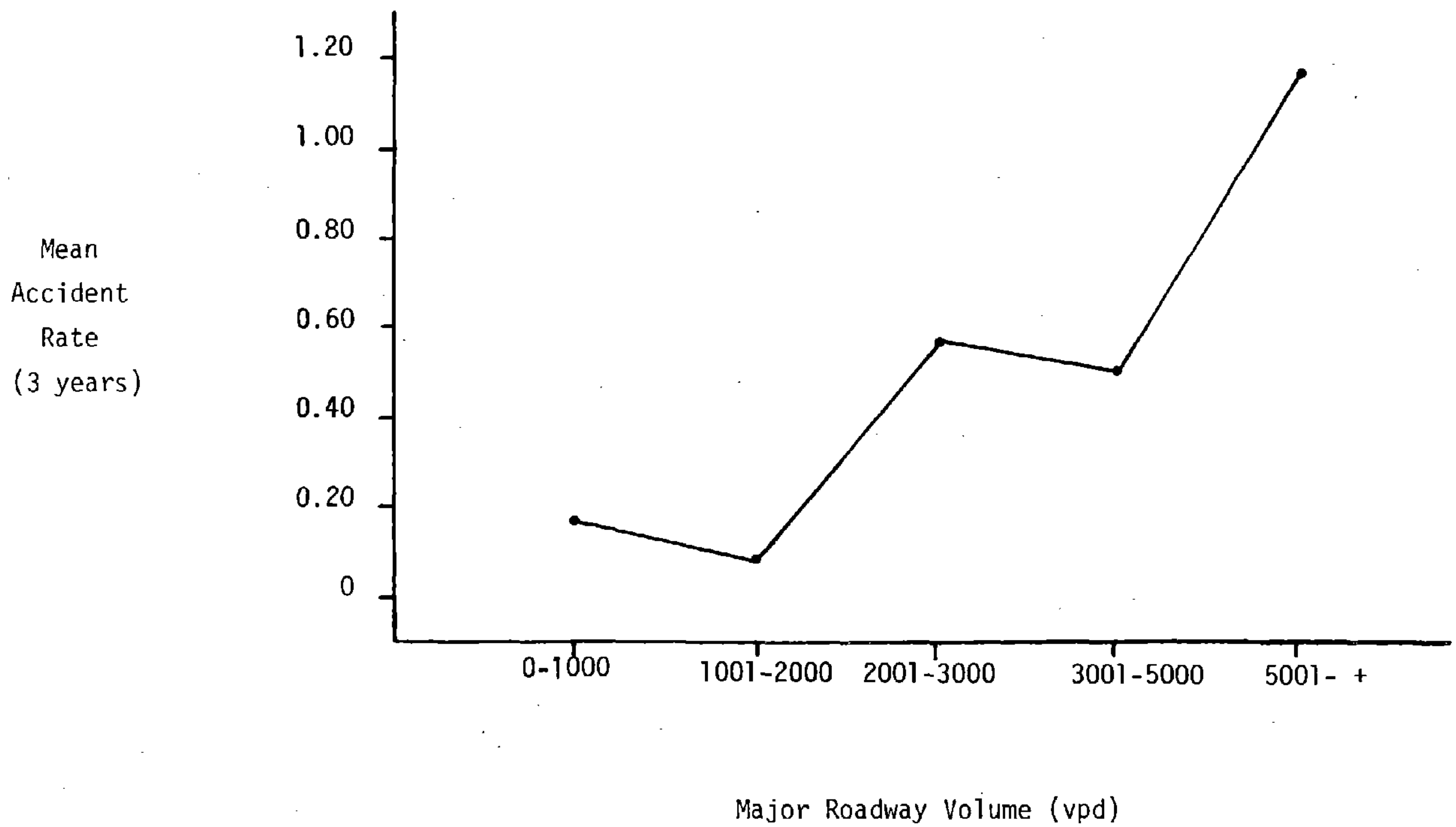


Figure 3. Mean Accident Rate by Major Roadway Volume

Table 29. Non-Parametric Analysis: Intersections With At Lease One Accident In Three Years.

1. Chi-Squared - Region x Accidents

	0	1+		
New York	29	11	40	
Florida	34	6	40	$\chi^2_{obs} = 3.59$
Texas	52	8	60	$\chi^2_{exp} = 5.99$
	115	25	140	

2. Chi-Squared - Location x Accidents

	0	1+		
Urban	65	13	78	$\chi^2_{obs} = .170$
Rural	50	12	62	$\chi^2_{exp} = 3.84$
	115	25	140	

3. Chi-Squared - Control x Accidents

	0	1+		
STOP	33	15	48	
YIELD	40	8	48	$\chi^2_{obs} = 11.23$*
No Control	42	2	44	$\chi^2_{exp} = 9.21$
	115	25	140	

4. Chi-Squared - Geometry x Accidents

	0	1+		
3 - Leg	88	13	101	$\chi^2_{obs} = 4.98$**
4 - Leg	27	12	39	$\chi^2_{exp} = 3.84$
	115	25	140	

*significant ($p<.01$)
**significant ($p<.05$)

0-intersections without an accident in three years

TABLE 30. Non-Parametric Analysis: Intersections with Accidents by Major Road Volume.

Major Road Volume (VPD)	Intersection Without Accidents	Intersection With Accidents	
0 - 1000	68	10	78
1001 - 2000	12	1	13
2001 - 3000	9	4	13
3001 - 4000	7	1	8
4001 - 5000	2	3	5
5001 +	17	6	23
	115	25	140

$\chi^2_{obs} = 11.0147$

$\chi^2_{.95} = 11.07$

TABLE 30. Non-Parametric Analysis: Intersections with Accident by Major Road Volume (Continued)

Exact Partition of χ^2

	Major Road Volume	Intersection Without Accidents	Intersection With Accidents		
1.	0 - 1000	68	10	78	$\chi^2_{obs} = 0.199777$
	1001 - 2000	12	1	13	$\chi^2_{.95} = 3.841$
		80	11	91	
2.	0 - 2000	80	11	91	$\chi^2_{obs} = 2.706354$ $\chi^2_{.95} = 3.841$
	2001 - 3000	9	4	13	$\chi^2_{.90} = 2.706$
		89	15	104	
3.	0 - 3000	89	15	104	$\chi^2_{obs} = .018729$
	3001 - 4000	7	1	8	$\chi^2_{.95} = 3.841$
		96	16	112	
4.	0 - 4000	96	16	112	$\chi^2_{obs} = 6.819056$
	4001 - 5000	2	3	5	$\chi^2_{.95} = 3.841$
		98	19	117	
5.	0 - 5000	98	19	117	$\chi^2_{obs} = 1.270773$
	5001 +	17	6	23	$\chi^2_{.95} = 3.841$
		115	25	140	

Total $\chi^2_{obs} = 11.0147$

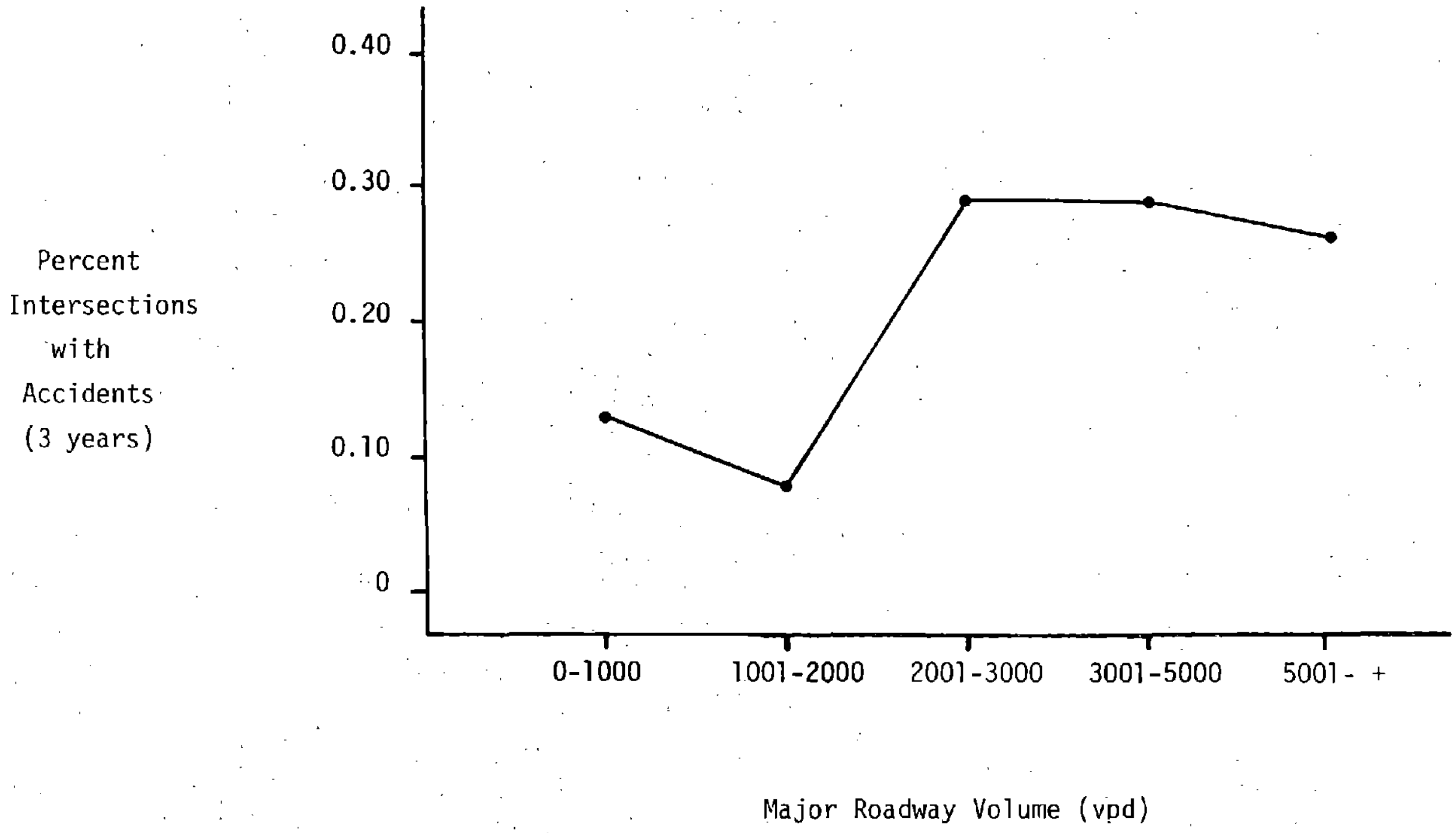


Figure 4. Percent Intersections with Accidents by Major Roadway Volume

Table 31. Summary of Significant Independent Variables for Accident Experience.

Independent Variables	Dependent Variables: Average Number of Accidonts Per Intersection (In 3 Years)	Dependent Variables: Intersectons With At Least One Accident (3 Years)
Region		
Location		
Control		X*
Geometry		X
Major Road Volume	X	X
Reg x Loc		--**
Reg x Cont		--
Reg x Geo		--
Reg x MVol	X	--
Loc x Cont		--
Loc x Geo		--
Loc x MVol		--
Cont x Geo		--
Cont x MVol		--
Geo x MVol		--

* $p < .05$

**Not tested with Chi-squared tests.

vpd or less had a lower proportion of intersections with accidents than those with major road volumes above 2000 vpd. A significant difference was also observed at the 4000 vpd level, which may be another point of interest, although it is restricted somewhat by sample size.

TRAVEL TIME

General Comments

Travel time as a dependent variable is a measure which can be used to assess operational differences among intersections of different control types, or other characteristics. It can also be used as a means of determining certain aspects of operational costs where differences are detected.

Travel times were collected for each type of movement (left turn, right turn or thru) for the minor approach leg of each intersection. Since 3-leg intersections have no thru movements, total travel time for each geometry were analyzed separately. For the purpose of assessing geometric differences, total travel time for turning movements only were analyzed with geometry as an independent variable.

The analysis procedure used was Analysis of Variance. Again higher order interactions were deleted to prevent the occurrence of empty cells and to make the tests somewhat more conservative.

Mean Travel Time: 3-Leg

1. Specific Dependent Variable

   Mean travel time for 3-leg intersections--combined travel time for left and right turn movements for each intersection.

2. Analysis Procedure

   Analysis of Variance

3. Results

   The analysis of variance indicates significant main effects due to Control and Major Volume. There were also significant interactions between Region and Location and Location and Control (Table 32). The mean travel times for these variables are presented in Table 33.

4. Comments

   YIELD-controlled intersections have shorter travel times than intersections observed with other control types. This reflects earlier indications of lower overall stopping rates (FSR plus VSR) of 17.3% for YIELD, 26.1% for No-Control and 40.0% for STOP-controlled intersections.

   As with the variable of forced stop, travel time increases as the volume on the major road increases. The majority of intersections observed in the field were 3-leg, allowing an adequate sample size to detect the trend.

   The travel time at intersections below 2000 vpd were significantly lower than those of higher volumes (Figure 5).

Mean Travel Time: 4-Leg

1. Specific Dependent Variable

   Mean travel time for 4-leg intersections--combined travel time for left turns, right turns and thru movements for each intersections.

2. Analysis Procedure

   Analysis of Variance

Table 32. ANOVA Using The Dependent Variable of Mean Travel Time for 3-Leg Intersections

Source	DF	Sum of Squares	F-Value	PR>F
Region	2	2.1947	.28	.75
Location	1	8.6311	2.19	.14
Control	2	75.4681	9.59	.0002
Major Volume	1	25.6849	6.53	.0125
Reg x Loc	2	41.3969	5.26	.0071
Reg x Cont	4	33.6407	2.14	.08
Reg x MVol	2	15.5737	1.98	.14
Loc x Cont	2	50.6433	6.43	.0026
Loc x MVol	1	.9215	.25	.62
Cont x MVol	2	3.2390	.41	.66
Model	19	257.3939	3.44	
Error	81	318.7130		
R^2 = .4467				
C.V. = 14.00				

Table 33. Significant Main Effects and Interactions: Mean Travel Time, 3-Leg Intersections

Control	Mean Travel Time
STOP	15.88 (27)
YIELD	12.59 (34)
No Control	14.34 (40)
Major Volume	
< 2000 (vpd)	13.26 (60)
> 2000 (vpd)	15.49 (41)

	Mean Travel Time	
Region	Urban	Rural
New York	14.46 (13)	15.15 (21)
Texas	14.85 (19)	12.81 (24)
Florida	13.23 (19)	16.72 (5)
Control		
STOP	14.73 (11)	16.68 (16)
YIELD	13.54 (16)	11.75 (18)
No Control	14.29 (24)	14.43 (16)

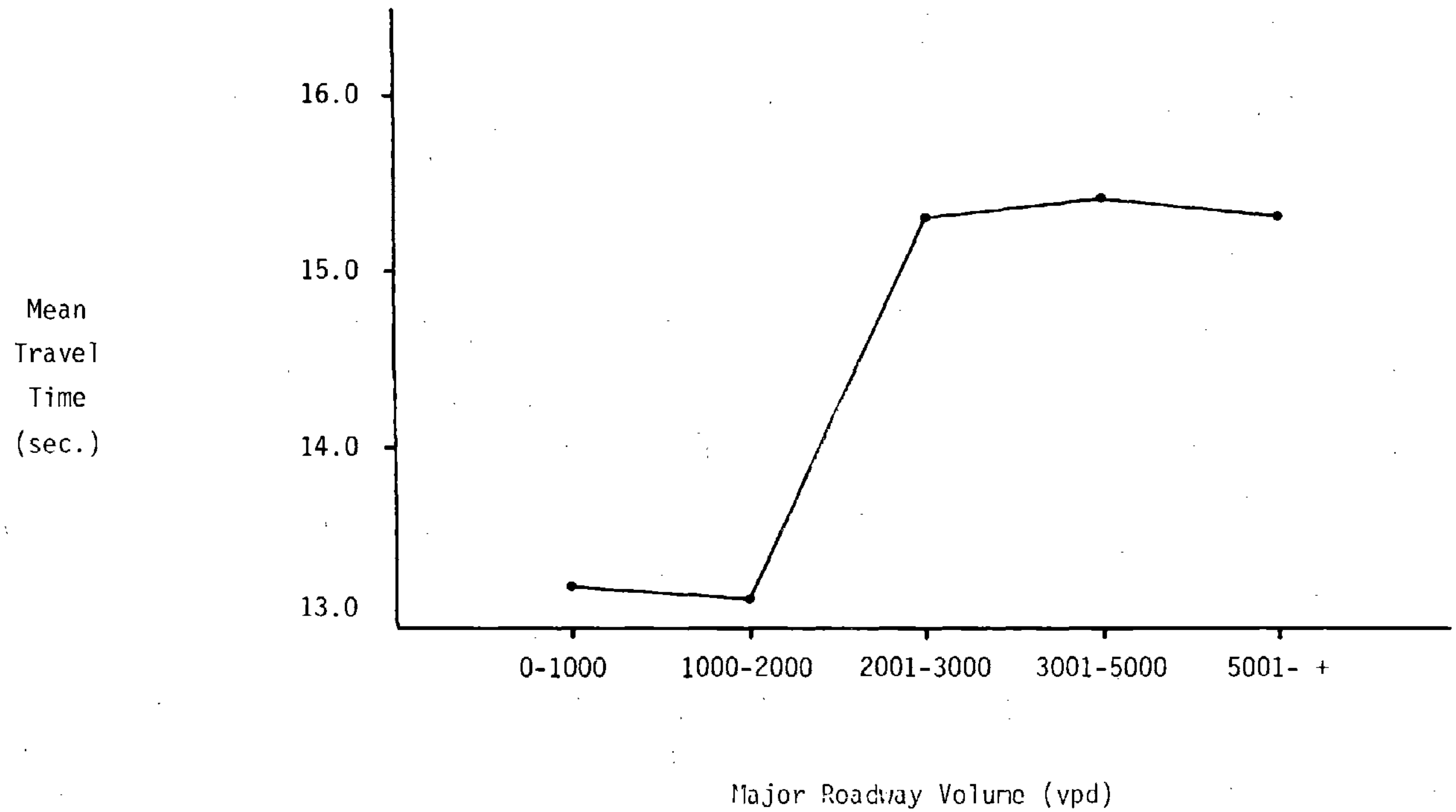


Figure 5. Travel Time for 3-Leg Intersections by Major Roadway Volume

3. Results

The analysis shows significant differences between locations and a significant interaction between region and location (Table 34). The means for these comparisons are given in Table 35.

4. Comments

Apparently the travel time at rural, 4-leg interections is greater than in urban areas. This difference occurs in every state although New York's rural and urban travel times are very close, which is understandable given that the volumes on the rural roads studied in New York are as great as those found in urban areas in other regions (Table 36).

The relationship of major road volume to travel time was not as strong as observed with other dependent variables, which is probably due to the low number of observations in the lower volume ranges. This sample size problem is responsible for the zero sums of squares in the ANOVA source table.

Mean Travel Time: Turning Movements

1. Specific Dependent Variable

Mean travel time for turning movements--combined travel time for left and right turns for 3- and 4-leg intersections.

2. Analysis Procedure

Analysis of Variance

3. Results

The analysis indicates significant differences among all variables but Geometry (Table 37). There were also significant interactions between Region and Location, and Location and Control. Mean rates for the main effects and interactions are shown in Table 38.

4. Comments

The combined data for 3- and 4-leg intersections suggest that at least with respect to turning movements, travel time is shorter for YIELD-controlled traffic, shorter in urban areas, and at lower major road volumes. A plot of the turning movement travel time by volume level is given in Figure 6.

Travel Time Summary

In general travel times are shorter for YIELD-controlled intersections and longer for rural areas. The summary of significant variables is presented in Table 39.

In addition to these findings, a significant effect of major road volume was detected. Travel times for these intersections with major road volumes less than 2000 vpd had significantly lower travel times by an average of about 2 seconds.

TABLE 34. ANOVA Using The Dependent Variable of Average Number of Mean Travel Time for 4-Leg Intersections.

Source	DF	Sum of Squares	F	PR>F
Region	2	17.4681	2.17	.13
Location	1	35.3555	8.79	.0067
Control	2	2.1441	.27	.76
Major Volume	1	.1416	.04	.85
Reg x Loc	1	32.0305	7.97	.0094
Reg x Cont	1	2.2312	.55	.46
Reg x MVol	2	7.2947	.91	.41
Loc x Cont	2	6.1891	1.54	.22
Loc x MVol	-	-	-	-
Cont x MVol	-	-	-	-
Model	11	102.8548	2.323	
Error	27	108.6925		

R^2 = .486

C.V. = 13.4536

TABLE 35. Main Effects and Significant Interactions; Mean Travel Time -- 4-Leg

		Mean Travel Time (4-Leg)
TOTAL	Urban	17.7 sec. (12)*
	Rural	13.6 sec. (27)
Florida	Urban	21.8 sec. (3)
	Rural	12.1 sec. (13)
New York	Urban	14.7 sec. (3)
	Rural	14.4 sec. (3)
Texas	Urban	17.2 sec. (16)
	Rural	15.1 sec. (11)

*Number of intersections observed.

Table 36. Average Major Roadway Volume by Region and Location

	Urban	Rural
New York	12,017	4,490
Florida	445	678
Texas	1,553	1,301

Table 37. ANOVA Using The Dependent Variable of Mean Turning Movement Travel Time (3-Leg & 4-Leg Intersections Combined)

Source	DF	Sum of Squares	F-Value	PR>F
Region	2	25.3813	3.14	.0472
Location	1	49.2889	12.18	.0007
Control	2	72.8320	9.00	.0002
Geometry	1	9.7971	2.42	.12
Major Volume	1	27.9866	6.92	.0097
Reg x Loc	2	82.7577	10.23	.0001
Reg x Cont	4	46.3915	2.87	.0264
Reg x Geo	2	.8316	.10	.90
Reg x MVol	2	16.8501	2.08	.12
Loc x Cont	2	58.3982	7.22	.0011
Loc x Geo	1	11.6453	2.88	.09
Loc x MVol	1	8.7771	2.17	.14
Cont x Geo	2	9.9464	1.23	.29
Cont x MVol	2	10.5958	1.31	.27
Geo x MVol	1	6.2299	1.54	.21
Model	26	437.7095	4.16	
Error	113	456.7017		
R^2 = .489				
C.V. = 13.99				

Table 38. Significant Main Effects and Interactions: Mean Turning Movement Travel Time

Region		Mean Travel Time
New York		14.84 (40)*
Texas		14.34 (60)
Florida		13.95 (40)
Location		
Rural		14.88 (62)
Urban		13.97 (78)
Control		
STOP		15.82 (48)
YIELD		12.73 (48)
No Control		14.57 (44)
Major Volume		
≤ 2000 vpd		13.71 (91)
> 2000 vpd		15.59 (49)
Location	**Region**	
	New York	14.45 (16)
Urban	Texas	14.97 (30)
	Florida	12.79 (32)
	New York	15.10 (24)
Rural	Texas	13.70 (30)
	Florida	18.62 (8)

	Control		
Region	STOP	YIELD	No Control
New York	15.31 (12)	14.93 (12)	14.43 (16)
Texas	16.06 (20)	12.02 (20)	14.93 (20)
Florida	15.92 (16)	11.99 (16)	13.95 (8)
Location			
Urban	14.41 (22)	13.33 (30)	14.33 (26)
Rural	17.02 (26)	11.75 (18)	14.91 (18)

*Number of intersections observed.

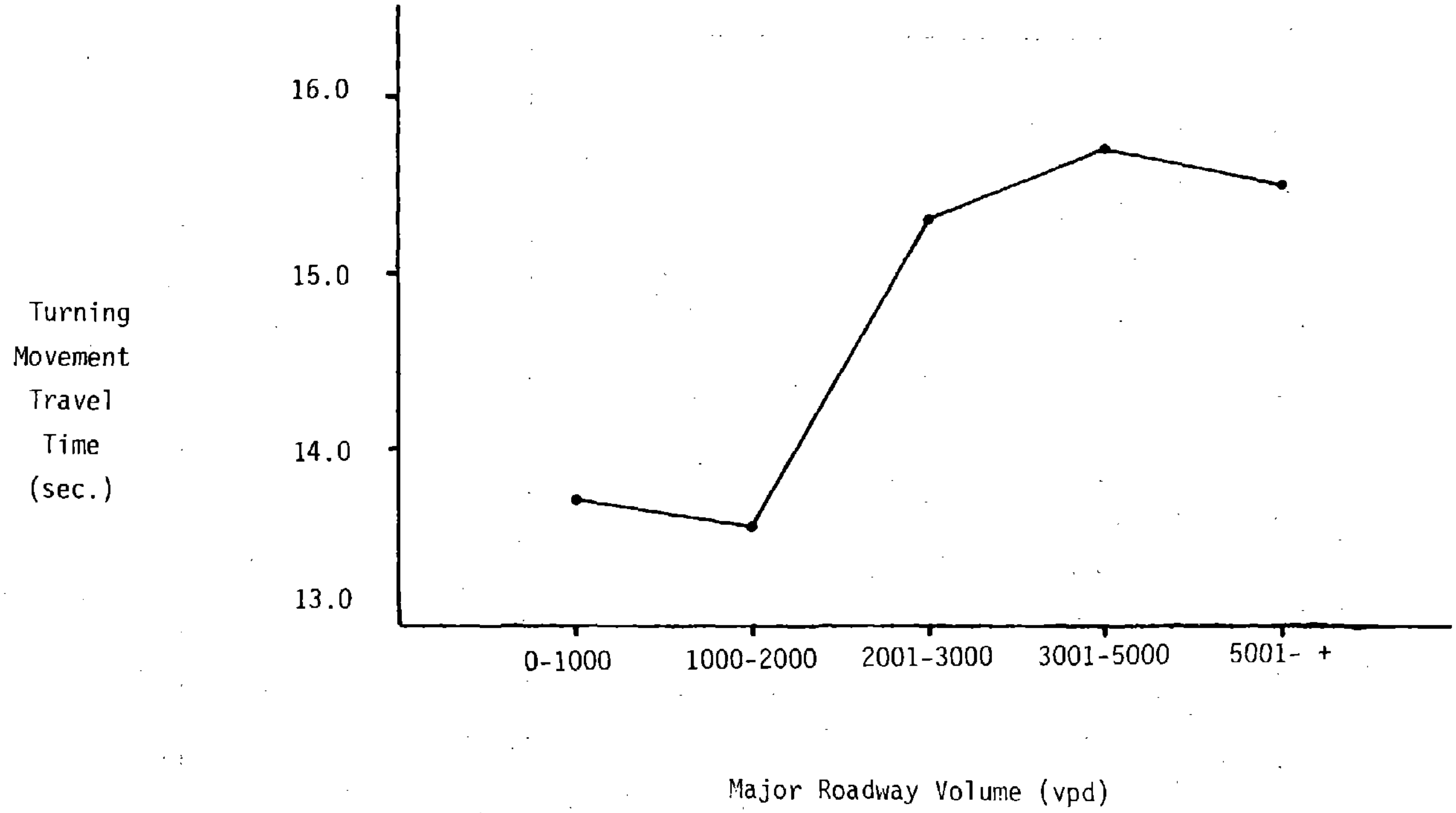


Figure 6. Turning Movement Travel Time by Major Roadway Volume

TABLE 39. Summary of Significant Independent Variables for Travel Time

Independent Variables	Dependent Variables: Mean Travel Time (4-Leg)	Mean Travel Time (3-Leg)	Mean Turning Movement Time (3- & 4-Leg)
Region			X
Location	X*		X
Control		X	X
Geometry	--**	--	
Major Volume		X	X
Reg x Loc	X	X	X
Reg x Sign			X
Reg x Geo	--	--	
Reg x MVol			X
Loc x Sign		X	
Loc x Geo	--	--	
Loc x MVol			
Sign x Geo	--	--	
Sign x MVol			
Geo x MVol	--	--	

* p < .05
** Not tested

INTRODUCTION

Several indirect measures of operation and safety were computed from the driver behavior, accident experience, and travel time data collected in the field studies. The purpose of the indirect measures was to convert operational measures into a common base for economic comparison where possible. The measures considered were: road user operating costs, accident costs, highway agency costs, and fuel consumption. The benefits computed are applicable to vehicles on the minor approaches only. No significant benefits or costs are expected to accrue for the major roadway, since no changes in driver behavior are expected.

ROAD USER OPERATING COSTS

The costs absorbed directly by the road user are vehicle operating costs and time costs.

Vehicle Operating Costs

Excess operating costs over continuing at a constant speed were computed from running cost tables developed by Winfrey (25) and updated to 1980 costs by Ritch and Buffington (26). To account for variations in driver behavior and initial approach speed, costs were computed on a component basis across these two variables (Tables 40 and 41).

Driving behavior included all three voluntary behaviors. Slow entry (SE) was assumed to require the driver to slow to 5 mph (8 km/h) instead of stopping. Similarly, fast entries (FE) were assumed to enter the intersection at 10 mph (16 km/h). As can be seen in the tables, the distribution of driving behavior rates varies for each type of control.

Initial approach speed has a significant effect on operating costs. All intersections observed had a minor roadway approach speed of 55 mph (88 km/h) or less. Speeds in the range of 25-45 mph (40-72 km/h) were most common.

Vehicle operating costs are subdivided into the two tables based on major roadway volume ranges, because the distribution of driving behavior rates changes significantly at 2000 vpd (Chapter 4). Table 40 gives operating cost in cents/vehicle/speed change cycle for major roadway volume ≤ 2000 vpd; Table 41 provides the same information for major volume > 2000 vehicles per day.

The composite values for each control type differ little from each other. For example, there is essentially no difference between YIELD and No Control in Table 40, and only .04 - .06 cents difference between STOP and YIELD (at low speeds the savings amount to more than 4%). At 55 mph (88 km/h) YIELD produces only a 1% savings in operating cost. Even this small savings, however, produces a substantial absolute amount over the service life of the device. Table 42 summarizes the average cost per speed change cycle for major roadway volumes below and above 2000 vpd for each control type.

Road User Time Costs

Delay costs were computed two different ways. The first way utilized Winfrey's excess hours consumed in speed change cycles, distributed across driver behavior rates and approach speeds in a manner similar to that used for vehicle operating costs. Tables 43 and 44 reflect the results of these computations. A time value of $6.31/hour was used, as recommended by Pinnell, et. al., (27). Average occupancy was assumed to be 1.3 persons per vehicle.

Table 40. Computation of Vehicle Operating Costs: Major Volume ≤ 2000 vpd

Control Type	Behavior Rates	Cost in ¢/veh/cycle 1/ — Initial Speed (mph) 2/: 20	25	30	35	40	45	50	55	Average
STOP	VS = .262	.38	.53	.72	.94	1.21	1.53	1.93	2.41	
	SE = .584	.65	.99	1.40	1.89	2.49	3.21	4.09	5.15	
	FE = .154	.12	.21	.31	.44	.60	.79	1.02	1.30	
		1.15	1.73	2.43	3.27	4.30	5.53	7.04	8.86	4.29
YIELD	VS = .089	.13	.18	.24	.32	.41	.52	.66	.82	
	SE = .777	.87	1.32	1.86	2.52	3.31	4.28	5.44	6.85	
	FE = .134	.10	.18	.27	.39	.52	.69	.89	1.13	
		1.10	1.68	2.37	3.73	4.24	5.49	6.99	8.80	4.24
No Control	VS = .082	.12	.17	.22	.29	.38	.48	.60	.76	
	SE = .820	.92	1.39	1.97	2.65	3.50	4.51	5.74	7.23	
	FE = .098	.08	.13	.20	.28	.38	.50	.65	.83	
		1.12	1.69	2.39	3.22	4.26	5.49	6.99	8.82	4.25

1/ Updated costs derived from report by Ritch and Buffington in Texas Transportation Institute Research Report 210-5, May 1980.

2/ To convert from miles per hour to kilometres per hour, multiply by 1.60934.

Table 41. Computation of Vehicle Operating Costs: Major Volume > 2000 vpd

Control Type	Behavior Rates	Cost in ¢/veh/cycle 1/ Initial Speed (mph) 2/								
		20	25	30	35	40	45	50	55	Average
STOP										
	VS = .096	.14	.20	.26	.34	.44	.56	.70	.88	
	SE = .737	.82	1.25	1.77	2.39	3.14	4.06	5.16	6.50	
	FE = .167	.13	.23	.34	.48	.65	.86	1.11	1.41	
		1.09	1.68	2.37	3.21	4.23	5.48	6.97	8.79	4.23
YIELD										
	VS = .029	.04	.06	.08	.10	.13	.17	.21	.27	
	SE = .776	.87	1.32	1.86	2.51	3.31	4.27	5.43	6.85	
	FE = .195	.15	.26	.40	.56	.76	1.00	1.29	1.64	
		1.06	1.64	2.34	3.17	4.20	5.44	6.93	8.76	4.19
No Control										
	VS = .044	.06	.09	.12	.16	.20	.26	.32	.41	
	SE = .809	.90	1.37	1.94	2.62	3.45	4.45	5.66	7.14	
	FE = .147	.11	.20	.30	.42	.57	.75	.97	1.24	
		1.07	1.66	2.36	3.20	4.22	5.46	6.95	8.79	4.21

1/ Updated costs derived from report by Ritch and Buffington in Texas Transportation Institute Research Report 210-5, May 1980.

2/ To convert from miles per hour to kilometres per hour, multiply by 1.60934.

TABLE 42. Average Vehicle Operating Costs

CONTROL TYPE	COST IN CENTS PER CYCLE	
	Major Roadway Volume	
	≤ 2000 vpd 1/	> 2000 vpd 2/
STOP	4.29	4.23
YIELD	4.24	4.19
No Control	4.25	4.21

1/ From Table 40

2/ From Table 41

Table 43. Computation of Road User Delay Costs (Winfrey): Major Volume ≤ 2000 vpd

Control Type	Behavior Rates	Cost in ¢/veh/cycle 1/ — Initial Speed (mph) 2/								
		20	25	30	35	40	45	50	55	Average
STOP										
	VS = .262	.54	.64	.74	.85	.95	1.05	1.15	1.26	
	SE = .584	.78	1.01	1.25	1.48	1.72	1.94	2.17	2.40	
	FE = .154	.12	.18	.24	.30	.35	.41	.47	.53	
		1.44	1.83	2.23	2.63	3.02	3.40	3.79	4.19	2.82
YIELD										
	VS = .089	.18	.22	.25	.29	.32	.36	.39	.43	
	SE = .777	1.03	1.34	1.66	1.97	2.28	2.59	2.89	3.20	
	FE = .134	.10	.15	.21	.26	.31	.36	.41	.46	
		1.31	1.71	2.12	2.52	2.91	3.31	3.69	4.09	2.71
No Control										
	VS = .082	.17	.20	.23	.27	.30	.33	.36	.39	
	SE = .820	1.09	1.42	1.75	2.08	2.41	2.73	3.05	3.38	
	FE = .098	.07	.11	.15	.19	.23	.26	.30	.34	
		1.33	1.73	2.13	2.54	2.94	3.32	3.71	4.11	2.73

1/ Delay time based on Robley Winfrey, Economic Analysis for Highways, International Textbook Co., Scranton, PA, 1969. Value of time based on Reference 27. Assumes 1.3 occupants/vehicle.

2/ To convert from miles per hour to kilometres per hour, multiply by 1.60934.

Table 44. Computation of Road User Delay Costs (Winfrey): Major Volume > 2000 vpd

Control Type	Behavior Rates	Cost in ¢/veh/cycle 1/ Initial Speed (mph) 2/								
		20	25	30	35	40	45	50	55	Average
STOP										
	VS = .096	.20	.23	.27	.31	.35	.39	.42	.46	
	SE = .737	.98	1.28	1.57	1.87	2.16	2.45	2.74	3.03	
	FE = .167	.13	.19	.26	.32	.38	.45	.51	.58	
		1.31	1.70	2.10	2.50	2.89	3.29	3.67	4.07	2.69
YIELD										
	VS = .029	.06	.07	.08	.09	.11	.12	.13	.14	
	SE = .776	1.03	1.34	1.66	1.97	2.28	2.58	2.89	3.20	
	FE = .195	.15	.22	.30	.37	.45	.52	.60	.67	
		1.24	1.63	2.04	2.43	2.84	3.22	3.62	4.01	2.63
No Control										
	VS = .044	.09	.11	.12	.14	.16	.18	.19	.21	
	SE = .809	1.08	1.40	1.73	2.05	2.38	2.69	3.01	3.33	
	FE = .147	.11	.17	.23	.28	.34	.40	.45	.51	
		1.28	1.68	2.08	2.47	2.88	3.27	3.65	4.05	2.67

1/ Updated costs derived from report by Ritch and Buffington in Texas Transportation Institute Research Report 210-5, May 1980.

2/ To convert from miles per hour to kilometres per hour, multiply by 1.60934.

Actual measured travel times from the field studies were used for the second method of delay computation. Table 45 shows average travel times and delay cost per cycle for the two volume ranges considered.

The actual costs computed for each control type in Table 45 cannot be compared directly with the costs in Tables 43 and 44. The costs, based on Winfrey's data (Tables 43 and 44), are excess costs over a constant speed; TTI's costs are total time costs from 150 feet (45m) upstream to 150 feet (45m) downstream of the intersection. However, the difference in cost between control types should be comparable.

Table 46 compares the differences in delay cost between control types for both methods of computation. The TTI figures are substantially higher, but probably more representative than the figures based on Winfrey's data. Winfrey's data (averaged over all initial speeds in Table 46) includes no time for looking or waiting. Both could normally be determined from idling time, but since this variable was not measured directly, such a computation was impossible. Therefore, the time costs based on the field studies in this project (shown as TTI costs) were used to compute total road user cost.

Composite Road User Operating Costs

Table 47 presents the total road user costs summarized in Tables 42 and 46. The increase in operating cost between the lower and higher volume ranges is approximately 5% for STOP, 5% for YIELD and 1% for No Control.

In both volume ranges, YIELD and No Control offer savings over STOP control. Below 2000 vpd YIELD control represents an 8% decrease and No Control, a 1% decrease. Above 2000 vpd YIELD is 8% lower than STOP and No Control, 5% lower.

ACCIDENT COSTS

Since accidents were independent of control type, it was not possible to ascribe superior benefits to either STOP or YIELD control. The "conventional wisdom" of the general public and of most agencies responsible for traffic control maintains that STOP is "safer" than YIELD. While there is no evidence to that effect at low volume intersections, an awareness of the public attitude dictates that STOP control should be implemented at locations with significant accident history.

A determination of significant accident history was made using the field data and analyses of this project. According to a Poisson distribution of accident frequency, an intersection will experience two or fewer accidents in three years ($p < .01$), regardless of control type. If the expected savings resulting from YIELD control exceed the average cost of an accident, then the warranting accident criteria would be adjusted to three accidents.

The weighted average cost of an accident is \$2300, based on the distribution and cost of injury and property damage accidents. Injury accidents (\$6200, Ref. 17) accounted for 31% of all accidents; the remaining 69% were property damage only at \$570 each.[1] The expected annual savings of YIELD over STOP per 100 minor road vehicles is about \$240 (Table 50). The expected three-year savings approximately equals the expected cost of one accident when the minor road volume exceeds 320 vehicles per day (3.20 vehicles x \$240/year x 3 years = \$2300). Therefore, at YIELD-controlled intersections, one additional accident every three years can be tolerated without adverse economic impact. More than three accidents would dictate a change to STOP control consistent with "conventional wisdom".

TABLE 45. Computation of Road User Delay Costs: Field Data.

	Major Roadway Volumes	
	≤ 2000 vpd	> 2000 vpd
STOP		
N	41	27
Avg TT (sec)	14.9	16.7
¢/cycle	3.40[1/]	3.81
YIELD		
N	45	14
Avg TT (sec)	12.5	14.2
¢/cycle	2.85	3.24
No Control		
N	32	16
Avg TT (Sec)	14.6	15.1
¢/cycle	3.33	3.44

1/ Assumes 1.3 occupants/vehicles and time values of $6.31/hour (Reference 26).

TABLE 46. Comparison of Delay Costs Between Winfrey and TTI Computations

CONTROL TYPE	COST IN CENTS PER CYCLE			
	Major Roadway Volume			
	≤ 2000 vpd		> 2000 vpd	
	Winfrey 1/	TTI 2/	Winfrey 3/	TTI 2/
STOP	2.82	3.40	2.69	3.81
YIELD	2.71	2.85	2.63	3.24
No Control	2.73	3.33	2.67	3.44

1/ From Table 43.
2/ From Table 45.
3/ From Table 44.

TABLE 47. Composite Road User Costs

CONTROL TYPE	COST IN CENTS PER CYCLE					
	Major Roadway Volume					
	≤ 2000 vpd			> 2000 vpd		
	Vehicle Costs 1/	Delay Costs 2/	TOTAL	Vehicle Costs 1/	Delay Costs 2/	TOTAL
STOP	4.29	3.40	7.69	4.23	3.81	8.04
YIELD	4.24	2.85	7.09	4.19	3.24	7.43
No Control	4.25	3.33	7.58	4.21	3.44	7.65

1/ From Table 42. 2/ From Table 46.

HIGHWAY AGENCY COSTS

The responsible highway agency will incur additional costs any time a sign is installed, removed or changed (e.g., from STOP to YIELD). These costs must be balanced against the expected benefits to be derived from the change.

Initial costs of installation or change were based on representative costs obtained from a district of the Texas State Department of Highways and Public Transportation for all items except the sign blanks. The Texas Department of Corrections supplied the costs for sign blanks, which are available to governmental agencies only and are substantially less than commercial costs. Both of these sources were assumed to be fairly representative of nationwide costs. However, the representativeness of these figures is not particularly important to this analysis, since the expected road user savings are significantly greater than sign change costs.

Sign blank costs were $14 each for 24-inch (60-cm) STOP signs and $12 each for 30-inch (75-cm) YIELD signs. Average cost to change an existing sign at a 3-leg intersection (from STOP to YIELD) was $32, including vehicle and labor costs. Installation of a sign at a 3-leg intersection where no sign existed before was estimated to cost $72, including post, installation material, vehicle and labor. Costs for these and other types of changes at 3- and 4-leg intersections are summarized in Table 48.

It is assumed that no maintenance is performed other than replacement as necessary. A service life of seven years is assumed.

EXPECTED FUEL CONSUMPTION

Excess fuel consumed in speed change cycles was computed from data by Winfrey (25), based on the distribution of driving actions [stops, slows to 5 mph (8 km/h), and slows to 10 mph (16 km/h)]. Excess fuel consumed for each control type is shown in Table 49 for both major volume ranges. These results show that fuel consumption is essentially insensitive to the minor variations in entry speed observed.

This finding is not unexpected, considering the small relative contribution of vehicle operating cost to composite road user costs (Table 47). Fuel consumption accounts for only a small portion of vehicle operating costs, with the remainder relating to tires, engine oil, maintenance and depreciation. Therefore, it is concluded that fuel consumption is not a significant factor in establishing control criteria.

ANNUAL COSTS AND BENEFITS

For comparison of all control alternatives on a common economic base, all costs and benefits were annualized. Costs expected are those ascribed to the highway agency (Table 48). As these are initial costs only, they were converted to equivalent annual costs ($i = 5\%$).

Benefits considered are the annual savings derived from the difference in per cycle costs shown in Table 47. For example, a change from STOP to YIELD, for a major volume less than 2000 vpd, would result in a 0.6¢ savings per cycle (7.69¢ - 7.09¢). Multiplied by the minor volume and by 365 days per year, this value would give the expected annual savings of the change. The expected average annual savings for all levels of minor volume are shown in Table 50 for three types of control change. These average annual savings represent the initial year savings compounded annually by three percent (to account for growth in traffic volumes) and averaged over seven years (expected service life).

The three types of control change shown in

TABLE 48. Initial Costs of Sign Change and Installation

Type of Action	3-Leg Intersection			4-Leg Intersecton		
	Sign Blank	Labor and Other Matls	TOTAL	Sign Blank	Labor and Other Matls	TOTAL
Install STOP	$14	$72	$86	$28	$112	$140
Install YIELD	12	72	84	24	112	136
Change YIELD to STOP	14	32	46	28	42	70
Change STOP to YIELD	12	32	44	24	42	66

TABLE 49. Approximate Excess Fuel Consumed Per Speed Change Cycle

CONTROL TYPE	Average Excess Fuel Consumed/Cycle 1/ (Gallons) 2/ — Major Roadway Volume	
	≤ 2000 vpd	> 2000 vpd
STOP	0.0106	0.0107
YIELD	0.0104	0.0106
No Control	0.0104	0.0107

1/ Based on Reference 25.
2/ To convert from gallons per cycle to liters per cycle, multiply by 3.7854.

TABLE 50. Average Annual Highway Agency Costs and Road User Savings

Control Type Change		Highway Agency Cost[1/]		Expected Average Annual Savings				
				Minor Roadway Volume				
From Existing	To Proposed	3-Leg	4-Leg	100	200	300	400	500
Major Volume ≤ 2000 vpd								
STOP	YIELD	$ 7	$ 11	$ 240	$ 480	$ 720	$ 960	$1,200
STOP	No Control	5	5	44	88	132	176	220
No Control	YIELD	14	23	196	392	588	784	980
Major Volume > 2000 vpd								
STOP	YIELD	$ 7	$ 11	$ 244	$ 488	$ 732	$ 976	$1,220
STOP	No Control	5	5	155	310	465	620	775
No Control	YIELD	14	23	88	176	264	352	440

1/ From Table 48.

Table 50 are those that produce positive benefits (i.e., the existing control type is more expensive than the proposed control type). A negative benefit would accrue if the control change were reversed.

All costs were converted to annual rates using a control device service life of seven years and a discount of five percent, as recommended by Buffington, et. al. (28). An annual growth rate in traffic of three percent was assumed.

In no instance is the annualized cost of the proposed change greater than the expected average annual savings. Net total benefit can be determined by subtracting the highway agency cost from the road user savings.

SUMMARY OF MAIN EFFECTS AND SIGNIFICANT INTERACTIONS

The main effects and significant interactions of the field data analysis are summarized in Table 51. For each condition in which the main effect was significant, the direction or the level of the independent variable at which significance occurred is shown on the matrix. Significant interactions are indicated only by an "X". A blank indicates non-significance; a "--" indicates that the independent variable was not tested.

Control Type

"Are there significant differences in operational behavior among STOP, YIELD, and No Control low volume intersections?"

Accident Experience

Control type appears to affect accidents in a manner opposite to that expected, as evidenced by the significant differences shown in the dependent variable intersections with accidents. There are three possible explanations for the trend shown. First, it cannot be unequivocally stated that the control type in place during the field studies was also in place during the accident analysis period (1975-77). In most cases, the operating agency could verify the control type, but in other cases the records were unclear. Second, there may be other intersection characteristics that were not identified that had a significant effect on historical accidents.

The most likely explanation is that major volume had a significant impact that shows up not only under the independent variable of major volume but also under control type. Figure 7 shows the distribution of minor roadway control type by each major volume category (also shown in tabular form in Table 14). As major volume increases, the porportion of STOP-controlled intersections studied also increases, with the exception of the 5000+ range. Since major volume was significant for the dependent variable intersections with accidents, it is probable that the trend shown for signing is not representative of what could be expected by a change in control type.

Travel Time and Driver Behavior

The significant difference in combined travel time is the result of the tendency for drivers to slow down more for STOP signs than for the other control types. This tendency is borne out by the differences shown for behavior rates. For example, the voluntary stop rate was approximately 10% higher for STOP control than for the others.

No control produced slower driver behavior than did YIELD control and consequently, a significantly longer travel time. This finding is most likely due to some misinterpretation of YIELD control coupled with extreme caution and/or uncertainity at No Control intersections.

Conclusions

It is concluded that the effect of control type on accident potential at low volume intersections is not appreciable. Control type does result in significantly different travel times, with STOP control requiring the longest travel time and YIELD control the shortest.

Regions

"Are there operational differences at low volume intersections located in different geographic regions?"

TABLE 51. Summary of Main Effects and Significant Interactions: All Dependent Variables.

Independent Variables	Dependent Variables								
	FSR	Acc. Int.	Int. w/Acc.*	TT 4-Leg	TT 3-Leg	TT Comb.	VSR	SER	FER
Region	NY>TX>FL					NY>TX/FL	FL>TX>NY		NY>TX/FL
Location				U > R		R > U	R > U	U > R	
Control			S>Y>NC		S>NC>Y	S>NC>Y			
Geometry			4>3	--***	--				
Major Volume**	HV > LV	HV > LV	2000/4000		HV > LV	HV > LV	--	--	--
Reg X Loc	X		--	X	X	X	X	X	X
Reg X Cont			--			X			
Reg X Geo			--				X		
Reg X M Vol		X	--			X	--	--	--
Loc X Cont			--		X				
Loc X Geo			--						
Loc X M Vol			--				--	--	--
Cont X Geo			--						
Cont X M Vol			--				--	--	--
Geo X M Vol			--				--	--	--

* Based on a chi-squared analysis.

** HV = Major Volume > 2000 vpd

LV = Major Volume ≤ 2000 vpd

*** "--" indicates variable not tested

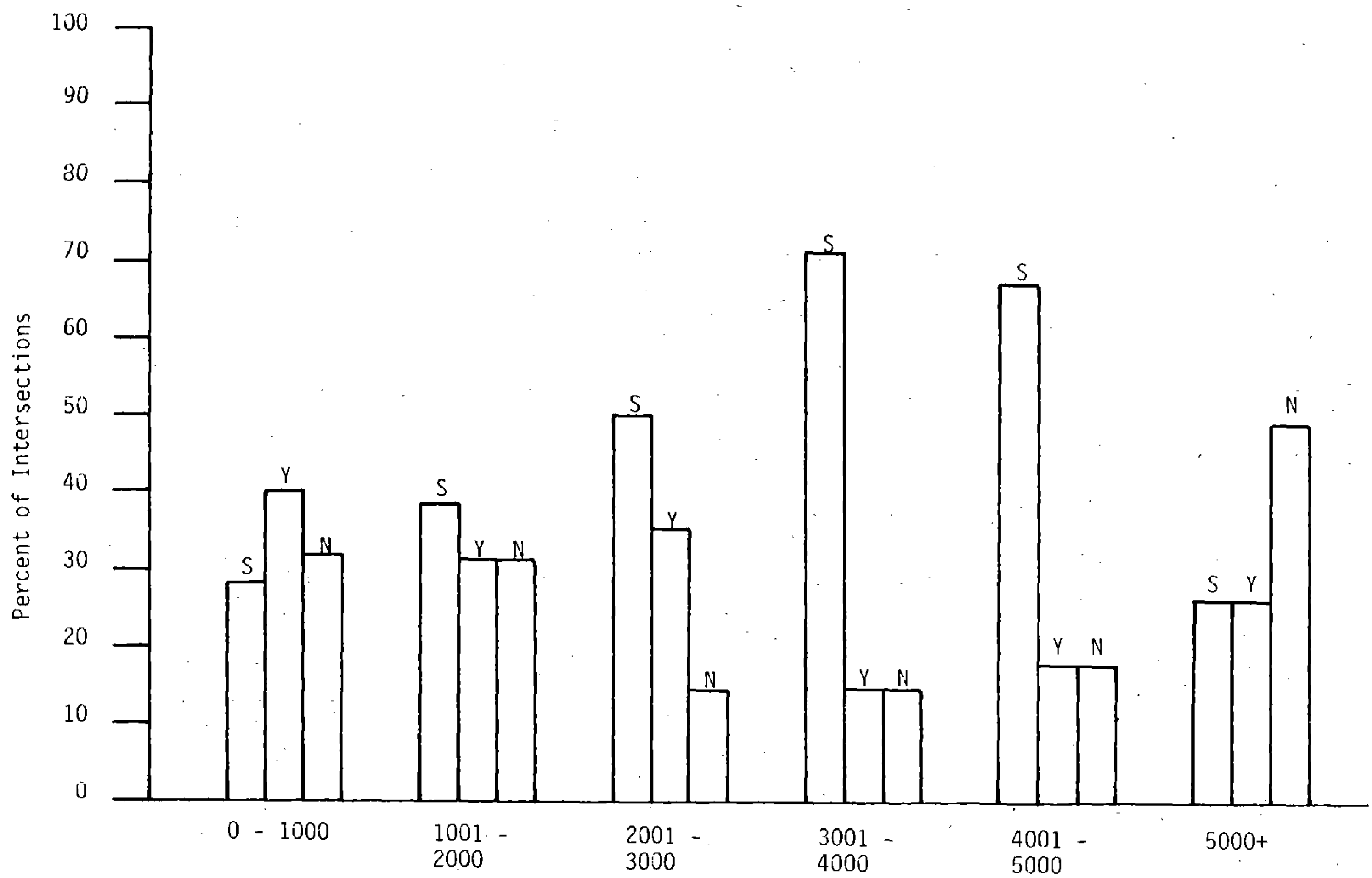


Figure 7. Distribution of Control Type by Major Roadway Volume

Driver Behavior

Analysis of the field data showed that driver behavior varied significantly among regions. Aside from contributory sampling artifacts experienced in Florida, the differences observed can be attributed to the influence of the volume characteristics of each region. For example, New York, which had the highest major roadway volumes, had higher forced stop and fast entry rates and lower voluntary stop rates.

Travel Time

The effect of major volume on higher forced stop rates in New York manifests itself in terms of increased turning movement travel times.

Conclusions

Although regional differences were observed, they appear to be a consequence of differences in major roadway volume. This being the case, volume, rather than regional differences, should be considered in the establishment of control criteria.

Location

"Are there operational differences between urban and rural low volume intersections?"

Driver Behavior

Voluntary stop rate was significantly higher for rural intersections than for urban. The opposite case was found for slow entry rate (urban higher than rural). It is possible that both findings are related to the drivers' expectation of the likelihood of being afforded an adequate gap in the major stream. In the urban areas, where major volumes are higher, drivers may be conditioned to accept a gap quickly, even if it means making a "rolling stop" (slow entry). Since the drivers in rural areas were more likely to have an acceptable gap available (due to lower major volumes), a voluntary stop would not produce significant delay.

Travel Time

Although the rural travel time at 4-leg intersections was approximately 4 seconds longer than the urban travel time, the bulk of the difference was the result of the sampling artifact encountered at rural 4-leg intersections in Florida (Table 35). This assumption is affirmed by the significant interaction of region and location. Combined travel times were less than one second longer for rural intersections, demonstrating the impact of the sampling artifact on 4-leg travel times.

Conclusions

Differences observed between urban and rural locations were probably a function of major roadway volume and/or sampling artifacts. These minor differences do not justify establishing different control criteria for urban and rural locations.

Geometry

"Are there operational differences between intersections of different geometrics?" That is, does the traffic at "T" intersections behave differently from the traffic at "+" intersections.

Accident Experience

There were no significant main effects in the ANOVA, but a chi-squared analysis showed that 4-leg intersections had significantly more accidents than did 3-leg intersections ($p<.05$). The most likely interpretation of this finding is that there is a greater opportunity for conflict, and consequently accidents, at 4-leg intersections.

Conclusions

It is concluded that intersection geometry does not play a major role in either safety or operational considerations, and therefore, should not be included in control criteria.

Major Volume

"Are there operational differences that can be explained by consideration of major volume?"

Driver Behavior

Major roadway volume appears to be the predominant variable in low volume intersection operation. Forced stop rate increases significantly at 2000 vehicles per day (vpd).

Accident Experience

The analysis showed significant relationships main effects for both accident-related variables. A chi-squared analysis indicated significant increases in intersections with accidents at 2000 vpd and again at 4000 vpd ($p<.05$). This finding indicates that major volume is the primary variable affecting accident experience. Support to this finding is added by the analysis of the Texas accident data, in which 1500 vpd surfaced as the point of significant change in accident experience.

Travel Time

Travel time for 3-leg intersections and turning movements increased significantly at 2000 vpd, probably as a result of the change in forced stop rate at the same volume level.

Conclusions

Major volume significantly impacts both accident potential and operation at low volume intersections. Above 2000 vpd, accident potential and operating cost increase significantly. It should be noted that although accidents increase at major volumes above 2000 vpd, there is little indication that intersections above that level are unsafe. Table 52 shows that although the annual accident rate from the field studies increases, it is extremely low compared to most accident standards.

Sight Distance

Though not included among the significant questions to be answered, the role of sight distance was considered to be potentially influential. The effects of sight distance would be most readily demonstrated by changes in the voluntary driver behavior rates. Voluntary stop and slow entry would be expected to increase, and fast entry decrease. These variables were tested for the effects of sight distance; it was found that sight distance had no discernable effect.

Conclusions

Sight distance at low volume intersections has no effect on safety or operations. However, in no case should a control type be recommended for a location at which the driver is not afforded sight distance adequate to perform the maneuver associated with that type of control. The results of this research suggest that the safe approach speed of 10 mph (16 km/h) recommended in the MUTCD may be overly conservative. More liberal values such as those used by several jurisdictions [5 and 8 mph (8 and 13 km/h)] may be adequate. Further research is needed to establish the minimum safe approach speed for YIELD and No Control operation. Since a less conservative value cannot be statistically justified, the 10 mph (16 km/h) value specified in the MUTCD should be adhered to.

TABLE 52. Average Annual Accidents Experienced At Field Study Intersections

Control Type	Annual Accident Rate		
	Major Roadway Volume		
	0 - 2000 vpd	2001-4000 vpd	4000 + vpd
STOP	.099 (27)*	.030 (11)	.333 (10)
YIELD	.048 (35)	.333 (6)	.429 (7)
No Control	0 (29)	0 (3)	.389 (12)
TOTAL	.051 (91)	.143 (20)	.381 (29)

* Number of intersections observed.

COST-EFFECTIVENESS OF CONTROL ALTERNATIVES

Chapter 5 explored in depth the factors bearing on the expected costs and benefits to be derived from changes in control type. It was clearly demonstrated that YIELD control produces significant savings to the road user. The level of the total savings is dependent on the number of vehicles on the minor roadway. Removal of STOP contol always produces greater savings than the cost of removal or change. Changes away from YIELD control produce significant disbenefit to the road user without any demonstrated increase in safety.

It is concluded that YIELD control is the most cost-effective control type for low volume intersections. STOP control is the least cost-effective alternative at any major roadway volume. Though there is no demonstrated effect of control type on accidents, conventional wisdom maintains that STOP control produces safer operation than YIELD. Even considering potential accident costs, YIELD control is demonstrably more cost-effective than STOP up to 2 accidents in 3 years. (If the minor road volume exceeds 300 vpd, up to 3 accidents in 3 years with YIELD control is cost-effective.) STOP control should be installed at locations with more than 3 accidents.

SUGGESTED CRITERIA

Based on the results of this study, the following criteria should govern the application of traffic control at low volume intersectons:

1. STOP sign(s) should be installed on the minor approach(es) of interesections where one or more of the following conditions exist:

   a. Sight distance on any quadrant produces a safe approach speed on the minor approach of less than 10 mph (16 km/h) (per <u>MUTCD</u>).

   b. Accidents involving minor roadway vehicles have occurred with either of the following frequencies:
      - o Four or more within any 12 month period during the last three years, or
      - o Three or more within the last three years, provided the minor roadway volumes are less than 300 vehicles per day.

2. YIELD sign(s) should be installed on the minor approach(es) of intersections where available sight distance exists on <u>all</u> quadrants, to permit a safe approach speed of at least 10 mph (16 km/h) <u>and</u> one or more of the following conditions exist:

   a. No more than two accidents involving minor roadway vehicles have occurred within the last three years, or

   b. At intersections with minor roadway volumes greater than 300 vehicles per day, no more than three such accidents have occurred within the last three years.

3. No Control may be used at intersections where the sight distance specified for YIELD signs is afforded, <u>and</u> there have been no accidents in the last three years, <u>and</u> the major roadway volume is less than 2000 vehicles per day.

Table 53 summarizes the conditions under which each control type should be applied.

TABLE 53. Summary of Suggested Control Criteria.

Sight Distance	Accident History	Major Roadway Volume	
		≤ 2000 vpd	> 2000 vpd
Adequate	0	No Control	
	≤2	YIELD	
	3	STOP*	
	4+	STOP	
Not Adequate			

*If minor roadway is greater than 300 vpd, YIELD control is appropriate for intersections with less than 4 accidents in 3 years.

Implementation of low volume intersection control criteria should be considered in a priority order for two categories: new intersections and existing intersections. This chapter details the order in which control changes should be considered and the analyses necessary to identify appropriate control for each location.

NEW INTERSECTIONS

New intersections are those created by the opening of new streets, either singly or in subdivisions. For new intersections of low volume streets entering collector streets, YIELD control should be installed in the close proximity, time-wise, of the opening of the street. The only analysis required will be an estimate of the adequacy of sight distance for proper YIELD operation. Details on this measurement are provided in the section on existing streets.

Intersections of new local/local streets in a subdivision should be left uncontrolled, provided there is adequate sight distance and no other circumstances requiring control.

EXISTING INTERSECTIONS

Control changes at locations where conditions are known to be within the recommended criteria should be implemented immediately. At all other locations, estimates of traffic volumes, sight distance and a determination of accident history must be made prior to the implementation of control changes. For situations where a city-wide or county-wide assessment of all intersections is impractical due to funding or personnel constraints, STOP-controlled intersections should be considered first, because the changeover from STOP to YIELD control produces the maximum benefit. The remaining intersections should be considered as time and funding permit. The following sections identify the procedures necessary in determining the feasibility of a control change.

Identification of Low Volume Intersections

A determination of which of the candidate intersections fit the low volume criterion should be made first. If traffic volumes are not known, a one-hour count should be conducted. In the absence of better local adjustment factors, counted volumes can be converted to vpd estimates using the conversion factors in Figure 8. Intersections that do not meet the minimum criteria for changing control (minor vpd < 500) should be discarded.

Identification of Control Type

This activity applies only to studies considering all low volume intersections, not those considering only STOP control. On-site inspection (during the counting activity) of each intersection is needed to insure the type of device in place. This seemingly unnecessary task is included because significant error was encountered in all control device records examined. Intersections with YIELD control can be eliminated from further study.

Determination of Accident History

The accident history should be determined for each of the remaining intersections. Only accidents involving minor roadway vehicles should be considered. Intersections with four or more accidents in the last three years should be STOP-controlled. Those with two or fewer accidents can be further considered for a control type change.

Determine Adequacy of Sight Distance

Before either YIELD or No Control can be implemented, sight distance adequate for a safe approach speed of 10 mph (16km/h) must be verified. Safe approach speed can be determined from the figure and chart shown in Appendix B. Speeds should be measured if possible; if speed measurement is not pos-

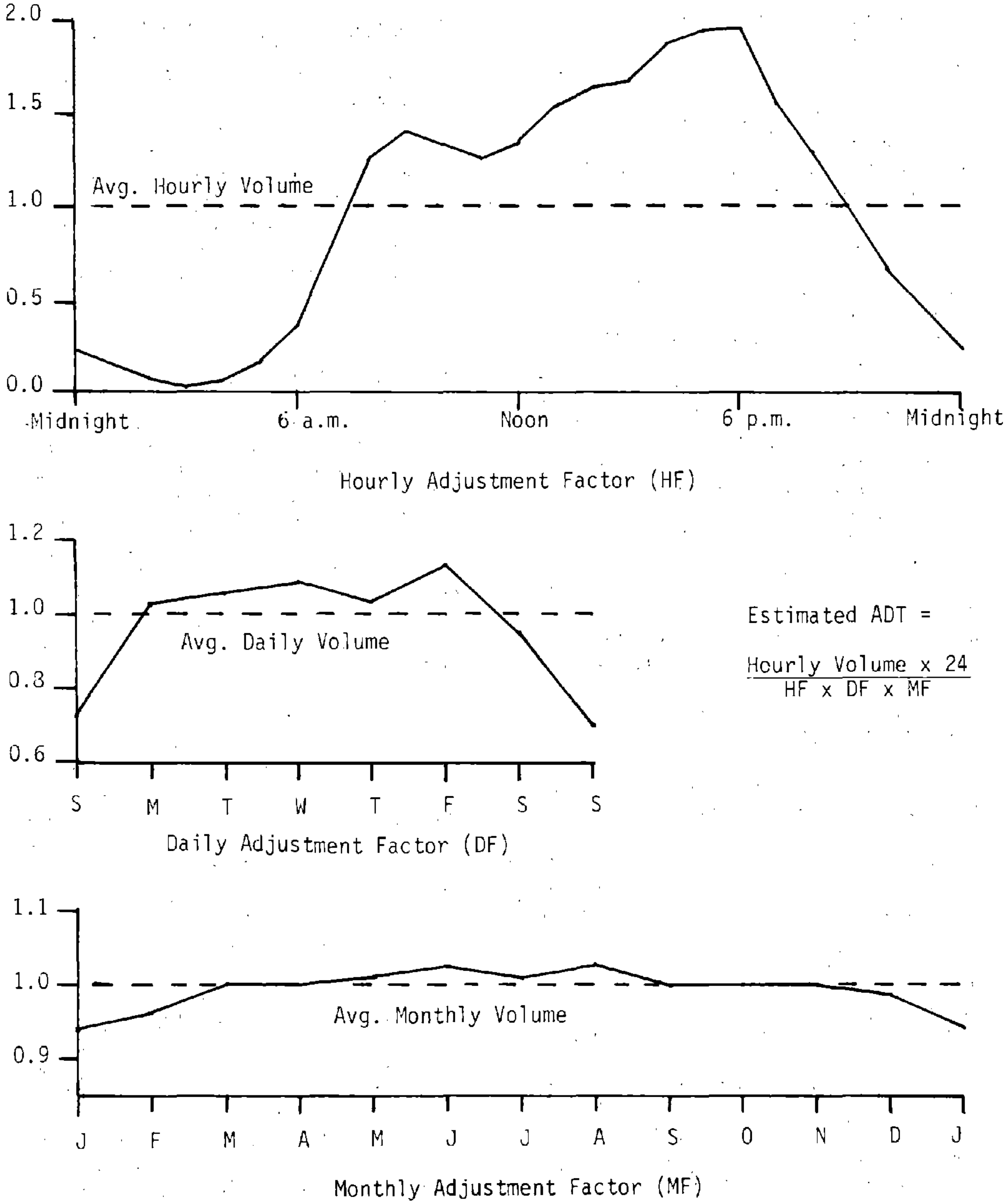


Figure 8. Factors for Converting Counted Volumes to ADTs.

sible, the posted speed limit for the approach should be used.

Priorities of Control Changes

First priority for change of all the intersections that meet the above criteria for YIELD should be those STOP-controlled intersections with major volumes less than 2000 vehicles per day. This is the category where the need for change can be most readily demonstrated. Implementation in this category will enhance future implementation at higher volume ranges. Implementation in this range should be undertaken immediately.

Next priority should be given to changing STOP-controlled intersections in the > 2000 vpd range to YIELD, followed by No Control to YIELD at local/local intersections as funding permits. Although YIELD produces lower operating costs than No Control, care should be exercised not to apply control at every local/local intersection, lest the effectiveness eventually be diminished through overuse.

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APPENDIX A
FIELD DATA

Texas Rural STOP

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	16	0	12	0	28	2	0
3-leg	16	0	4	4	24	4	0
3-leg	6	7	9	6	28	0	0
3-leg	2	3	15	3	23	0	1
3-leg	3	0	8	2	13	0	0
3-leg	8	0	14	0	22	2	1
4-leg	7	13	47	19	86	0	1
4-leg	15	1	17	8	41	0	0
4-leg	8	14	13	1	36	0	0
4-leg	29	47	116	31	223	1	1

Texas Urban STOP

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	13	2	13	1	29	1	0
3-leg	25	25	33	4	87	2	0
3-leg	21	7	54	17	99	5	0
3-leg	0	2	6	4	12	0	0
3-leg	29	1	7	1	38	4	0
4-leg	1	14	22	12	49	0	1
4-leg	9	4	29	5	47	2	0
4-leg	5	3	8	0	16	2	1
4-leg	8	7	21	3	39	0	0
4-leg	9	8	22	5	44	0	0

Texas Rural YIELD

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	0	0	16	0	16	0	1
3-leg	0	0	8	4	12	0	0
3-leg	2	0	18	6	26	0	0
3-leg	0	0	32	0	32	0	0
3-leg	0	0	28	0	28	0	0
3-leg	0	0	15	3	18	0	0
3-leg	0	0	28	6	34	0	0
3-leg	0	0	3	15	18	0	0
3-leg	0	0	8	2	10	0	0
3-leg	0	0	14	4	18	0	0

Texas Urban YIELD

Geo	FS	VS	SE	FE	TVEH	CR	ACC
3-leg	0	0	23	0	23	0	0
3-leg	0	4	20	0	24	0	0
3-leg	0	2	8	0	10	0	0
3-leg	1	0	11	0	12	0	0
3-leg	0	0	58	5	63	0	0
4-leg	0	0	36	0	36	0	0
4-leg	2	0	26	0	28	0	1
4-leg	6	3	25	0	34	3	0
4-leg	0	16	48	4	68	0	0
4-leg	2	12	10	0	24	0	0

Texas Rural No Control

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	0	0	31	1	32	0	0
3-leg	0	0	10	2	12	0	0
3-leg	0	0	8	0	8	0	0
3-leg	1	1	8	15	25	1	0
3-leg	0	1	7	0	8	0	0
3-leg	0	0	8	0	8	0	0
3-leg	6	0	6	0	12	1	0
3-leg	0	0	13	3	16	0	0
4-leg	0	16	16	0	32	0	0
4-leg	3	4	38	0	45	0	0

Texas Urban No Control

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	2	0	20	0	22	0	0
3-leg	8	4	16	0	28	0	0
3-leg	0	0	21	0	21	0	0
3-leg	0	0	4	0	4	0	0
3-leg	2	4	6	0	12	1	0
3-leg	12	3	6	0	21	1	0
3-leg	2	0	7	0	9	1	0
3-leg	11	4	19	0	34	5	0
3-leg	0	2	5	0	7	0	0
4-leg	0	4	32	4	40	1	0

Florida Rural STOP

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	3	0	1	0	4	0	0
3-leg	6	5	4	0	15	0	0
3-leg	0	2	0	1	2	0	0
3-leg	0	1	0	0	1	0	0
3-leg	0	2	1	0	3	0	0
4-leg	9	14	15	2	40	0	0
4-leg	22	2	9	0	33	1	1
4-leg	31	2	7	0	40	3	0

Florida Urban STOP

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	0	0	3	2	5	0	0
3-leg	5	0	5	0	10	0	3
3-leg	4	0	10	1	15	0	0
3-leg	1	2	14	3	20	0	0
4-leg	2	2	13	6	23	0	0
4-leg	0	1	14	3	18	0	0
4-leg	8	0	13	1	22	0	0
4-leg	0	1	2	2	5	0	1

Florida Urban YIELD

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	0	0	5	0	5	0	0
3-leg	0	1	13	0	14	0	0
3-leg	0	0	7	1	8	0	0
3-leg	1	0	11	1	13	0	0
3-leg	0	0	5	1	6	0	0
3-leg	0	1	7	0	8	0	0
3-leg	0	1	4	0	5	0	0
4-leg	1	6	10	1	18	0	0
4-leg	0	5	6	0	11	0	0
4-leg	4	3	12	0	19	0	4
4-leg	0	3	14	6	23	0	2
4-leg	1	3	14	2	20	0	0
4-leg	0	3	18	4	25	0	2
4-leg	5	2	15	2	24	0	0
4-leg	0	0	7	4	11	0	0
4-leg	0	2	11	0	13	0	0

Florida Urban No Control

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	0	0	2	0	2	0	0
3-leg	0	0	1	0	1	0	0
3-leg	0	0	3	0	3	0	0
3-leg	0	0	2	1	3	0	0
3-leg	0	0	1	0	1	0	0
3-leg	0	0	1	1	2	0	0
3-leg	0	1	1	0	2	0	0
3-leg	0	0	1	0	1	0	0

New York Rural STOP

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	7	0	5	1	13	0	1
3-leg	0	1	14	5	20	0	1
3-leg	6	1	6	0	13	0	0
3-leg	7	1	12	2	22	1	1
3-leg	1	1	8	1	11	0	0
4-leg	3	0	10	3	16	1	1
4-leg	0	3	18	6	27	0	0
4-leg	5	1	16	5	27	0	0

New York Urban STOP

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	7	0	7	3	17	1	1
3-leg	6	0	3	2	11	1	0
4-leg	15	0	8	2	25	1	0
4-leg	8	1	14	4	25	1	3

New York Rural YIELD

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	6	0	7	6	19	1	1
3-leg	9	0	6	4	19	0	0
3-leg	7	0	9	1	17	1	0
3-leg	0	0	3	11	14	0	0
3-leg	4	0	4	1	9	1	0
3-leg	2	0	4	1	7	1	0
3-leg	2	1	11	4	18	0	0
3-leg	12	1	7	0	20	1	0

New York Urban YIELD

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	6	0	6	0	12	1	1
3-leg	8	0	6	3	17	0	0
3-leg	10	0	6	4	20	0	8
3-leg	2	0	3	2	7	0	0

New York Rural No Control

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	3	1	9	5	18	1	0
3-leg	2	1	10	0	13	0	0
3-leg	8	0	6	0	14	1	0
3-leg	6	0	9	0	15	0	8
3-leg	5	2	10	3	20	0	0
3-leg	1	0	14	1	16	0	0
3-leg	0	0	5	3	8	1	0
3-leg	2	0	8	3	13	0	0

New York Urban No Control

Geo	FS	VS	SE	FE	TVEH	CF	ACC
3-leg	3	0	6	2	11	1	0
3-leg	3	0	5	1	9	0	0
3-leg	5	0	6	3	14	0	0
3-leg	6	0	5	1	12	1	0
3-leg	9	0	8	3	20	1	6
3-leg	3	0	4	1	8	0	0
3-leg	8	0	8	2	18	2	0
4-leg	9	0	12	5	26	1	0

REG	LOC	CONTROL	GEO	INT	FS	VS	SE	FE	TVEH	CF	ACC
TEXAS	RURAL	STOP	3-Leg	6	51	10	62	15	138	8	2
			4-Leg	4	59	75	193	59	386	1	2
		YIELD	3-Leg	10	2	0	170	40	212	0	1
			4-Leg	0	--	--	--	--	--	--	--
		No Control	3-Leg	8	7	2	91	21	121	2	0
			4-Leg	2	3	20	54	0	77	0	0
		TOTAL	--	30	122	107	570	135	934	11	5
	URBAN	STOP	3-Leg	5	88	37	113	27	265	12	0
			4-Leg	5	32	36	102	25	195	4	2
		YIELD	3-Leg	5	1	6	120	5	132	0	0
			4-Leg	5	10	31	145	4	190	3	1
		No Control	3-Leg	9	37	17	104	0	158	8	0
			4-Leg	1	0	4	32	4	40	1	0
		TOTAL	--	30	168	131	616	65	980	28	3
	TOTAL	--	--	60	290	238	1186	200	1914	39	8

REG	LOC	CONTROL	GEO	INT	FS	VS	SE	FE	TVEH	CF	ACC
FLORIDA	RURAL	STOP	3-Leg	5	9	10	6	1	25	0	0
			4-Leg	3	62	18	31	2	113	4	1
		YIELD	0	--	--	--	--	--	--	--	--
		No Control	0	--	--	--	--	--	--	--	--
		TOTAL	--	8	71	28	37	3	138	4	1
	URBAN	STOP	3-Leg	4	10	2	32	6	50	0	3
			4-Leg	4	10	4	42	12	68	0	1
		YIELD	3-Leg	7	1	3	52	3	59	0	0
			4-Leg	9	11	27	107	19	164	0	8
		No Control	3-Leg	8	0	1	12	2	15	0	0
			4-Leg	0	--	--	--	--	--	--	--
		TOTAL	--	32	32	37	245	42	356	0	12
	TOTAL	--	--	40	103	65	282	45	494	4	13

REG	LOC	CONTROL	GEO	INT	FS	VS	SE	FE	TVEH	CF	ACC
NEW YORK	RURAL	STOP	3-Leg	5	21	4	45	9	79	1	3
			4-Leg	3	8	4	44	14	70	1	1
		YIELD	3-Leg	8	42	2	51	28	123	5	1
			4-Leg	0	--	--	--	--	--	--	--
		No Control	3-Leg	8	27	4	71	15	117	3	8
			4-Leg	0	--	--	--	--	--	--	--
		TOTAL	--	24	98	14	211	66	389	10	13
	URBAN	STOP	3-Leg	2	13	0	10	5	28	2	1
			4-Leg	2	23	1	22	6	50	2	3
		YIELD	3-Leg	4	26	0	21	9	56	1	9
			4-Leg	0	--	--	--	--	--	--	--
		No Control	3-Leg	7	37	0	42	13	92	5	6
			4-Leg	1	9	0	12	5	26	1	0
		TOTAL	--	16	108	1	107	38	252	11	19
	TOTAL	--	--	40	206	15	318	104	641	21	32

APPENDIX B. DETERMINATION OF SAFE APPROACH SPEED

The following discussion of safe approach speed is taken from the Traffic Engieering Handbook, Institute of Traffic Engineers, 1965.

Safe approach speed studies are conducted to determine the maximum speed at which a vehicle can approach an intersection and still be able to stop in time to avoid a collision with a vehicle approaching on the intersecting street. The value of the safe approach speed can then be used to determine the appropriate vehicle right-of-way control at the intersection.

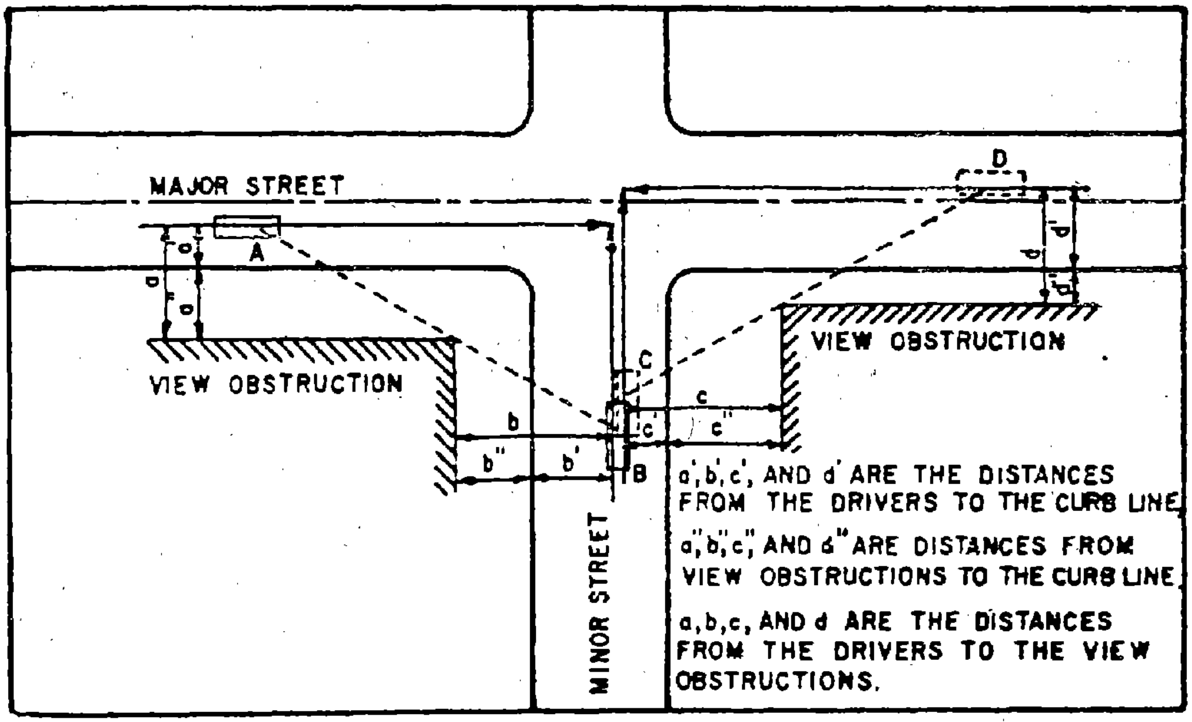
Figure 9 shows the typical situation. Two cases are illustrated: vehicle B on the minor street approach is in potential conflict with vehicle A approaching from the left on the major street; or, vehicle C on the minor street approach is in potential conflict with vehicle D approaching from the right on the major street.

The values of a' and c' are assumed to be either 12 ft. (3.6 m) (with curb parking), or 6 ft. (1.8 m) (without parking), for both two-way and one-way streets. For two-way streets, the values of b' and d' are either one-half the street width plus 3 ft. (.9 m), or the street width minus 12 ft. (3.6 m), whichever is smaller; for one-way streets the values for b' and d' are either 9 ft. (2.7 m) (with curb parking) or 3 ft. (.9 m) (without parking). Values for a', b', c', and d' are measured in the field. Values for a, b, c, and d can then be computed.

The approach speed of the major street vehicles used in this analysis must be at least the 85th percentile of the spot speeds observed on this street; use of a higher value than this will provide a safety factor.

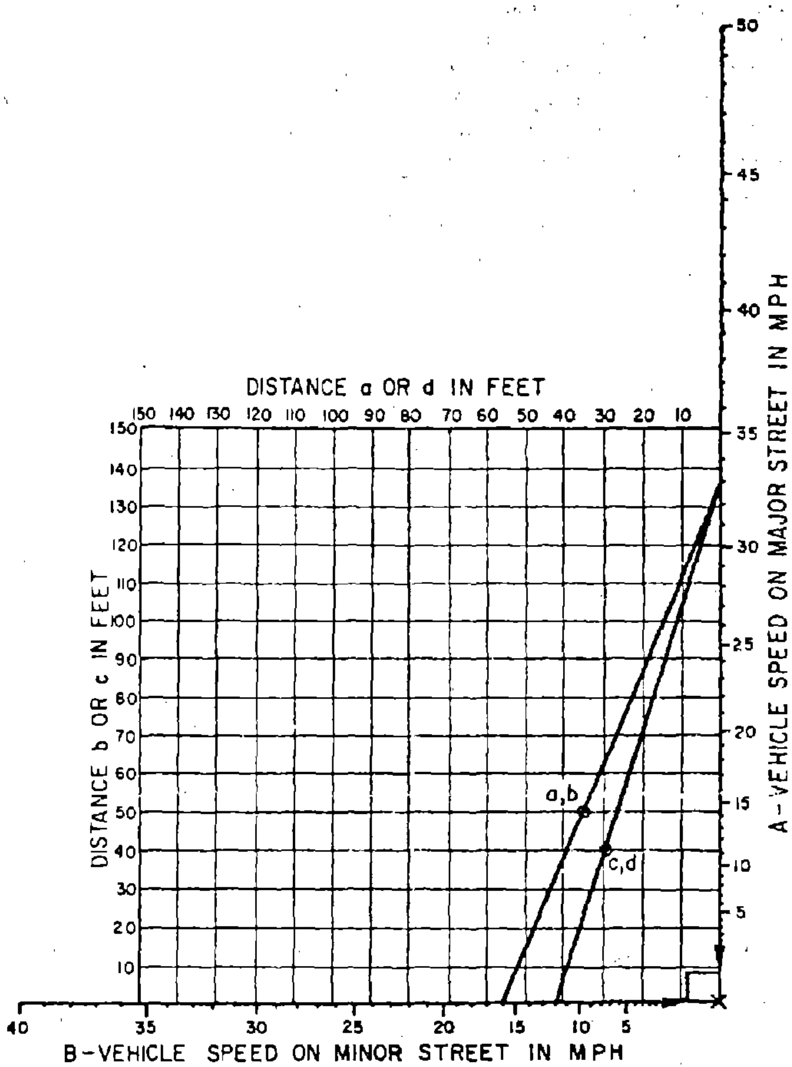
In addition to the location of sight obstructions and the speed of the fastest vehicles on the major street, a number of other factors affect the safe approach speed from the minor street. However, to evaluate each of these for every instance is likely to be cumbersome, and several conditions are therefore assumed: approaching vehicles are in the most dangerous legal position in respect to lateral placement on the roadway; driver reaction time is 1 sec; deceleration rate is 16 ft./sec^2 (4.8 m/sec^2); and the driver's eye is 7 ft. (2.1 m) behind the front bumper and 2 ft. (1.6 m) from the left side of the vehicle.

The chart shown in Figure 10 represents the solution which makes all the foregoing assumptions, and indicates a safe approach speed which will allow the vehicle on the minor approach to come to a stop 8 ft. (2.4 m) from the point where the two vehicle paths cross. The chart is used by plotting the coordinates (a,b) and (c,d). A line is drawn through each of these points to the appropriate major street vehicle speed scale A and extended until it intersects scale B for minor street vehicle speeds. The smaller of the two values on the latter scale is the safe approach speed for that approach. In the sample determination of safe approach speed, illustrated in Figure 10, the following steps were taken: (1) the coordinates [a = 35 ft. (10.5 m), b = 50 ft. (15.0 m)] and [c = 40 ft. (12.0 m), d = 30 ft. (9.0 m)] were plotted; (2) lines were drawn through each of these plotted points to the assumed 33 mph (11 km/h) major street approach speed on scale A; and (3) these two lines were extended until they intersected the minor street speed scale B at the values of 16 mph (26 km/h) and 12 mph (19 km/h), respectively. Thus, in this example, the smaller value of 12 mph (19 km/h) is the



(Source: Adapted from technique developed for the American Automobile Association by the Institute of Transportation and Traffic Engineering, University of California, Berkeley, California and reported in the Traffic Engineering Handbook, Institute of Traffic Engineers, 1965.

Figure 9. Analysis of Safe Approach Speed for Vehicle on Minor Street Approaching A Major Street

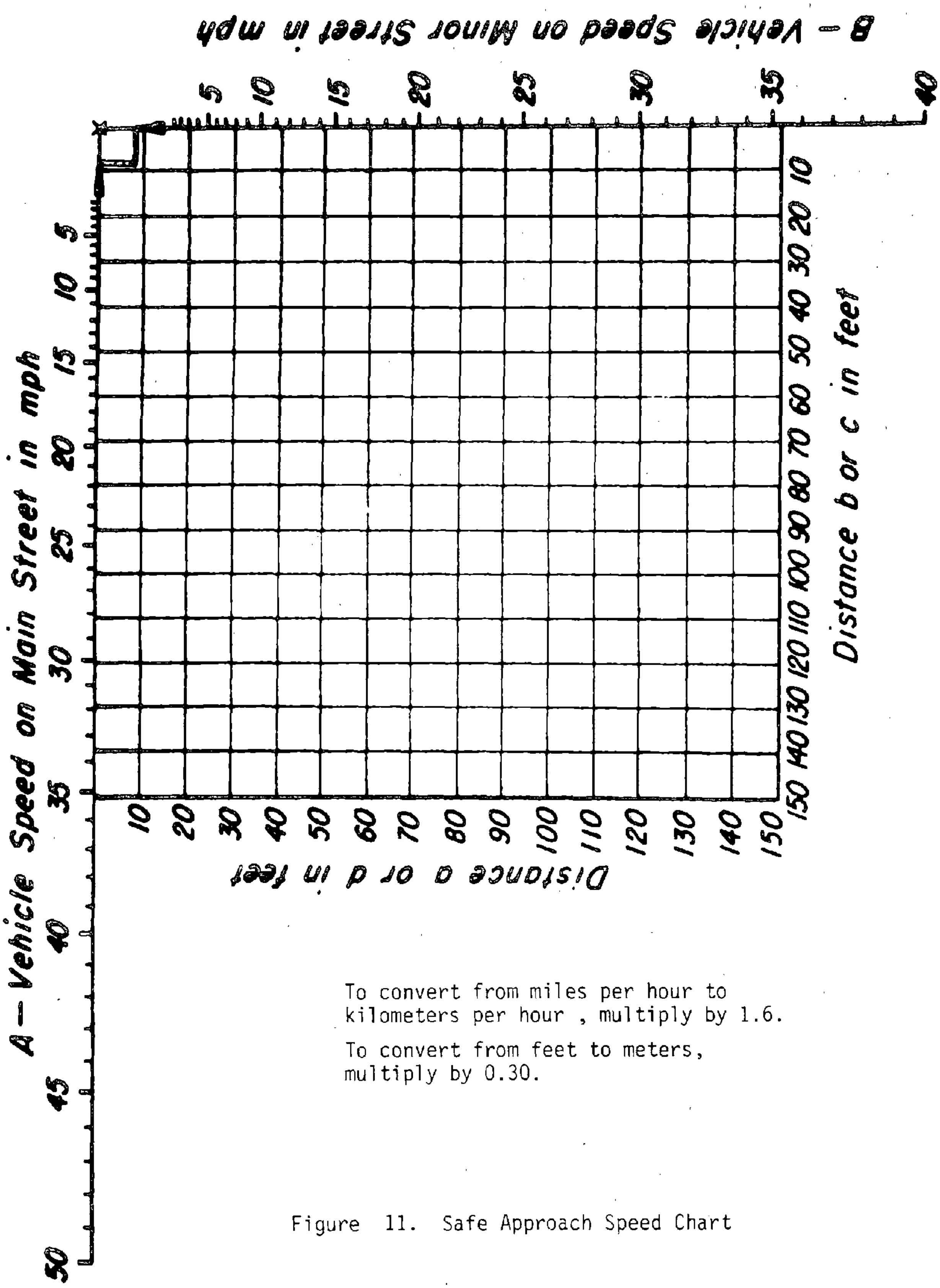


(Source: Adapted from technique developed for the American Automobile Association by the Institute of Transportation and Traffic Engineering, University of California, Berkeley, California and reported in the Traffic Engineering Handbook, Institute of Traffic Engineers, 1965.)

Figure 10. Safe Approach Speed Chart Illustrating Analytical Example

critical safe approach speed for this minor street approach.

A similar analysis is conducted for the other minor street approach. If the two intersecting streets have almost equal traffic volumes, the entire procedure may have to be repeated after the designations for major and minor streets have been interchanged. Figure 11 is a blank safe approach speed chart for determining safe approach speeds.



To convert from miles per hour to kilometers per hour , multiply by 1.6.

To convert from feet to meters, multiply by 0.30.

Figure 11. Safe Approach Speed Chart

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590