proach was suggested to deal with the problem of selecting and programming different safety improvement projects. The model formulation included a basic model and a multiyear model with and without the flexibility of incorporating carry-over of funds. Finally, a stochastic version of the models was formulated to include the uncertainty in estimating cost and accident-reduction parameters. The objective function of the models considered the reduction in the total number of accidents, and the major constraint considered was the funding level.

A hypothetical example was provided to illustrate the use of the models. Through a series of sensitivity analyses, the effect of funding level on the effectiveness of a highway safety program can be determined. The model can also be extended to evaluate the effect of constraints associated with categorical funding of various safety programs.

The stochastic version of the multiyear model can be successfully used to determine what, when, and where safety improvement alternatives should be implemented in order to maximize the reduction of total accidents on an areawide basis, subject to the total funding constraint.

ACKNOWLEDGMENT

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Driver Compliance with Stop-Sign Control at Low-Volume Intersections

JOHN M. MOUNCE

The objective of the research was to determine whether stop-sign control under designated conditions was fulfilling the requirements for application as specified by the Manual of Uniform Traffic Control Devices. This was to be demonstrated by the percentage of observed motorist violations and compliance, assuming that these measures reflect confirmation of need and respect afforded by the public. The dependent variables of violation and compliance rate, conflicts, and accidents were compared in a factorial experimental design with the independent variables of major-roadway volume, minor-roadway sight distance, rural or urban traffic condition, and type of intersection geometry. Minor-roadway volume, signing control, roadway cross section, geography, and weather were all controlled variables. The results from 2830 observations at 66 intersections indicated that the violation rate decreases with increasing major-roadway volume and is significantly high ($p < 0.001$) up to the average-daily-traffic (ADT) level of 2000 and significantly low ($p < 0.001$) above the ADT level of 5000-6000. An interaction effect between major-roadway volume and minor-roadway sight distance results in a violation rate that is significantly higher ($p < 0.05$) when sight is unrestricted than it is when sight is restricted. No conclusive relationships could be established between violations at low-volume intersections either in the rural-urban traffic environment or in the intersection geometry type that had three to four legs. No correlation was established between violation rate and accidents across all study variables; however, conflict rate was reduced at the upper and lower major-roadway volume levels. It was concluded that the operational effectiveness of low-volume intersections could be enhanced with no observed safety detriment by the application of no sign control below major-roadway volume of 2000 ADT, yield-sign control at major-roadway volume between 2000 and 5000 ADT, and, depending on minor-roadway volume, stop-sign control or signalization above 5000 ADT. These recommendations should be modified based on adequate sight distance; yet the determination procedure used in this study seemed insufficient and requires further revision.

The options available for at-grade intersection control range from the right-of-way rule for extremely low volumes of traffic to computerized signals for extremely high volumes of traffic. The majority of intersections that fall between these extremes uses stop-sign control on the minor roadway. Low-volume intersections at which there is up to 500 average daily traffic (ADT) on at least one intersecting roadway account for literally millions of stop-controlled locations (1). Most of these stop signs at low-volume intersections may be unnecessary and unwarranted, however.

In its general provisions, the Manual of Uniform Traffic Control Devices (MUTCD) states that to be effective a traffic control device should meet five basic requirements (2):

1. Fulfill a need,
2. Command attention,
3. Convey a clear simple meaning,
4. Command respect of road users, and
5. Give adequate time for proper response.

The excessive use of stop control suggests a failure to fulfill a real need, and consequently the control's ability to command the respect of the road user is severely impaired. Such impairment is particularly noticeable where the stop sign has, in effect, become meaningless. Full voluntary compliance at stop signs has steadily declined and is practiced now by less than 20 percent of road users (3). This low compliance rate indicates a misapplication of traffic engineering principles.

Yet the stop sign is still perceived by traffic engineers and the public as desirable. Although both groups believe that everyone is safer if a stop is required on one of the roadways, few studies support this position, especially at low-volume intersections (4,5). In addition, the engineer favors the use of stop signs because they are perceived to be the ultimate safety measure, and this relieves engineer and employer from liability arising from accidents in which other types of controls are used (yield signs, crossroad warning signs, etc.).

In reality, however, the engineer need not take such unnecessary precautions. According to the Uniform Vehicle Code, all drivers on minor roads have similar responsibilities regardless of the sign type--to not enter the intersection when a major-road vehicle is close enough so that such entry would constitute an immediate hazard. To suggest that a stop sign better defines the driver's responsibility is incorrect. The difference is more logically a function of the available sight distance commensurate with a safe approach speed. But the stop sign seems easier to use, although it is not necessarily more efficient nor is it always demonstrably more effective. Since it is a familiar device, it can be employed without much engineering and offers a sense of legal security to the engineer. Many agencies avoid the engineering-judgment issue by applying stop signs indiscriminately.

As a consequence, the driver has been led to think of stop control as the rule rather than the exception. The driver often finds stop signs where the potential conflict is known to be minimal or where it can easily be seen that there is no impending conflict due to exposure to major-roadway traffic. As a result, the driver develops a negative expectancy and begins to treat stop signs at low-volume intersections as yield signs, a reaction aptly shown by stop-control violation rates. The driver does not know immediately where a full stop is important; even worse, if there is not some type of control on the approach, the minor-roadway driver may assume that the other driver is controlled and no longer apply the right-of-way rule.

The overuse or unwarranted application of stop-sign control may be conducive to a complacent attitude toward traffic control in general. This complacency may manifest itself in increased accident frequencies that could be alleviated by more judicious installation of stop control and/or increased use of yield signs at intersections. The criteria for such installations would involve the identification of specific volume levels and sight-distance conditions under which drivers both need and would respect stop-sign control. In this way, only qualified intersections would receive stop controls, which would more closely conform to the intent of the MUTCD guidelines.

STUDY OBJECTIVES

The objectives of this study were to assess the effects of major-roadway volume and minor-roadway sight distance on driver compliance with stop signs at low-volume intersections. Driver compliance, which demonstrates obedience and respect, was assumed to be an indicative operational criterion measure of driver confirmation of the need for stop control at the intersection. This need would be dependent on exposure to major-roadway traffic or denial of sufficient sight distance. The hypotheses to be evaluated were that violations to stop-sign control on the minor approach increase as major-approach volume decreases and that violations across major-volume levels decrease with restricted sight distance on the minor approach. If there is a significant change in compliance below a designated volume level under conditions of unrestricted sight distance, then it may be demonstrated to be more practical to use some other form of intersection control on the minor approach to reduce needless stops that increase travel time, waste energy, and increase exhaust emissions. The substitution can be employed where there is no significant change in accident experience across the designated volume levels and where there are no sight-distance restrictions.

EXPERIMENTAL DESIGN

In accordance with the previously stated objectives, a quasi-experimental design was formulated to address the study variables shown in Table 1. The design is a 6 x 2 x 2 x 2 factorial that has the dependent variables of compliance rate and accident rate measured across the independent variables of six major-roadway volumes, two types of minor-roadway sight distance, two traffic conditions, and two types of intersection geometry. Specified variables such as minor-roadway volume, traffic-control regulation, and cross section were also controlled in the design. A minimum of five intersections was evaluated per level; however, the levels were not strictly balanced due to limited available data. Each variable is discussed in detail in the following paragraphs.

Independent Variables

Major-approach volume served as an independent variable; a range between 0 and 6000 combined two-way ADT (total of both approaches) was used. The upper volume limit constraint reflected the recommended minimum vehicular volume for consideration of signal installation due to intersecting traffic (2).

The 0-6000 range was broken down into 1000-ADT segments in order to provide an ordinal variable against which changes in the dependent variable could be measured. A minimum of 10 intersections was selected in each of the six groups of major-approach volume and then balanced as reasonably as possible between the rural and urban traffic conditions.

Traffic condition served as an independent variable to assess the nature of the differences in operating characteristics of drivers in urban and rural environments. For the urban condition, the contiguous cities of Bryan and College Station, Texas, were selected; they represent a combined population of 100 000. Those intersections within the metropolitan city limits were designated as urban intersections. Rural intersections were selected from a 10-county region of south central Texas under the jurisdictions of Districts 9, 12, and 17 of the Texas State Department of Highways and Public Transportation. These intersections were specifically restricted to locations outside city limits. Current published volume-count maps were used to locate candidate intersections that met both the volume and traffic-condition constraints.

The third independent variable was minor-approach sight distance along the major approach such that the sight triangle formed would allow the minor-approach vehicle to make a speed adjustment or come to a safe stop prior to the limits of the intersection and prevent an encroachment and/or conflict. This triangle is based on the operational speed of each approach and assumes a 3.0-s perception-reaction time by the driver. Ratios were calculated as previously outlined and based on the standards for intersection sight distance set forth by the American Association of State Highway and Transportation

Table 1. Experimental design.

Variable	Level
Independent	
Major-roadway volume (ADT)	0-1000
	1001-2000
	2001-3000
Traffic condition	Urban
	Rural
Minor-roadway sight distance	Restricted
	Unrestricted
Intersection geometry	Four approaches (cross)
	Three approaches (T)
Dependent	
Compliance rate	Full compliance [captive (forced) or noncaptive (voluntary)]
	Partial violation [pause or <8 km/h (roll)]
	Full violation [>8 km/h (run) or unsafe speed (flagrant)]
Accident rate	Property damage
	Injury
	Fatal
Minor-roadway volume[a]	0-500 ADT
Traffic-control regulation[a]	Stop-sign control on minor roadway (MUTCD standard)
Roadway cross section[a]	Two-lane undivided minor approach
	Two- or four-lane undivided major approach (no channelization)
Geography, climate[a]	South central Texas
	September-November
	Fair weather

Note: 1 km/h = 0.6 mph.
[a]Controlled variable (held constant throughout study).

Officials (AASHTO) (6,7). Available sight distance was compared with required sight distance to determine whether it was restricted or unrestricted.

Speeds were sampled by using radar and were measured at the maximum range of detection [due to equipment limitations, approximately 0.40 km (0.25 mile)]. These speeds were taken from inconspicuous positions adjacent to the intersections. Generally speaking, the radar-equipped vehicle was totally hidden from view when the approaching vehicle was at the maximum sight distance.

The sight distance along each minor approach to the stop sign was also measured as well as the stopping distance to the intersection surface. The measurements were recorded as a check to ensure that the visibility both to the traffic control device and to the intersection were adequate, so that violations were not due to detection or recognition problems. To some extent, this measurement acted as a control to the approach alignment, the placement of the traffic control device, and the maintenance of both the stop sign and the area adjacent to the stop sign.

The fourth independent variable was the geometry of the intersection. Both four-leg and three-leg intersections were studied, and turning movements were recorded on each. Obviously, movement and violation patterns are more limited at the three-leg intersection than at the four-leg intersection. The geometry was therefore evaluated in terms of its effect on compliance, conflicts, and/or accidents. No skew or nonstandard configurations were selected.

Dependent Variables

The dependent study variables included compliance rate and accident rate at each individual intersection. The compliance rate was assessed under three major categories: full compliance, partial violation, and full violation. Full compliance was defined for this study as the full observance of the legal requirement. Technically, this constitutes a visible state of deceleration to zero and acceleration by the vehicle. Full compliance was further categorized as being captive (forced) due to the presence of vehicles on the major approach of the intersection or noncaptive (voluntary) due to the absence of vehicles on the major approach and any safety or operational reason for the vehicle to stop. Physically forced compliance occurred within 2 s of the apex of the intersection along either approach at normal operating speed.

A partial violation was measured as either a near stop (pause) at some speed greater than 0 km/h (0 mph) or a moving stop (roll) at a speed between 0 and 8 km/h (5 mph). A full violation was defined as operational behavior that would warrant citation under the majority of municipal and state laws in the United States (8). Full violations were further divided into two categories: (a) vehicles that exhibited a speed greater than 8 km/h past the stop sign and (b) vehicles that exhibited speeds higher than previously specified and judged unsafe and in disregard of both the traffic control device and the right-of-way.

Conflicts were also measured within each compliance and violation category. A conflict occurs when a minor-approach vehicle causes a major-approach vehicle to noticeably decelerate or perform an avoidance maneuver. Nonconflicts represent no impediment to major-approach traffic.

Compliance differences were measured in the field after an appropriate period of observer training to ensure both consistency and reliability in categorization. Compliance and violation rates were determined for both of the minor approaches at four-leg intersections and for the single minor approach at three-leg intersections.

The accident rate was determined based on a three-year history (1976-1978). A mean annual rate was calculated from these data for property-damage, injury, and fatal accidents. Accident-report records were obtained from municipal police and county sheriffs' departments. The major approaches were restricted to two- or four-lane undivided roadways that had variable types of surface, cross-slope, shoulder, and ditch design. Geographical and climatic conditions were controlled as closely as possible. Data were collected at each study intersection for a minimum of 2 h during off-peak time periods of 9:30-11:30 a.m. or 1:30-3:30 p.m. on midweek days (Tuesday-Thursday).

All data were taken in south central Texas where the terrain was either level or gently rolling pasture and woodland. Data collection occurred during September, October, and November 1979 in fair weather. No measurements were recorded in rain, fog, or ice since these conditions might affect pavement friction or visibility.

DATA ANALYSIS

Parametric statistical methods were employed in analyzing the research data. These methods required that the scale of measurement be continuous and either a ratio or an interval. Violation rate, calculated as violations per observed volume, was taken as the comparative measure between variable configurations, and the data were assumed to be continuous by scale. The assumption that the data were normally distributed and homogeneous in variance was tested by using the Kolmogorov Smirnov test ($p > 0.05$) for normality and the F-ratio test ($p > 0.05$) for homogeneity.

Several types of statistical procedures were used in the analysis of the research data. These are listed as follows and are discussed relative to the results of the study:

1. Analysis of variance (ANOVA) for significance of both independent variables in isolation and interactive effects,
2. Duncan multiple-range test for significance between treatment levels of designated independent variables,
3. Linear regression, and
4. Correlation coefficients.

RESULTS

Examination of the ANOVA results indicates that both minor-approach sight distance ($p < 0.05$) and major-approach volume ($p < 0.001$) have a highly significant influence on total violation rate, which is the sum of partial and full violations. It can also be seen that the interactive effect of volume and sight distance are significant ($p < 0.05$). The multiple correlation coefficient of determination R^2 for the model that used total violation rate as the dependent variable is very high (0.8023), which means that at least some of these variables account for a large portion of the variation in the dependent variable. Table 2 presents a summary of the ANOVA results and levels of significance associated with the individual variables.

Only major-approach volume was found to be significant in the ANOVA model that used full violation rate as the dependent variable. This effect is exhibited by the F-ratio and corresponding significance levels ($p < 0.05$). Although the R^2-value for the model that used full violation rate is acceptable (0.6218), it indicates a weaker multiple correlation than that for the model that used total violation rate; indeed, too weak for use as a predictive model. An interactive effect between geometry and volume was also exhibited for the model that used the dependent variable full violation rate ($p < 0.05$). The model ANOVA that used forced compliance rate as the dependent variable shows the effect of major-approach volume to be highly significant ($p < 0.001$); sight distance also approached significance. Intersection geometry is also seen to be significant ($p < 0.05$), and the R^2-value is very high for that model (0.8238).

Intersection geometry and sight distance were also highly significant ($p < 0.01$) when measured by voluntary compliance rate; however, major-roadway volume was not found to be significant in the ANOVA model. Partial violation rate was not significantly related to any independent variable. This violation category is the most subjective of any, and the indicated effects may be confounded by other extraneous factors.

The ANOVA for the conflict-rate model indicates that geometry was significant ($p < 0.05$). Sight distance did not display a significant relationship in that model. The multiple correlation coefficient is acceptable (0.6731) but weak. No significant relationships were established by the full-model ANOVA that used total annual accident rate as the dependent variable across all independent variables because the multiple correlation coefficient was unacceptably low (0.3735).

The variable relationships were further analyzed by using the Duncan multiple-range test to determine the treatment ranges between which a designated significant ($p < 0.05$) difference in means existed. For the dependent variable total violation rate and the independent variable major-approach volume, these significant differences occurred between the volume ranges 0-2000, 2000-5000, and 5000-6000 ADT (Figure 1).

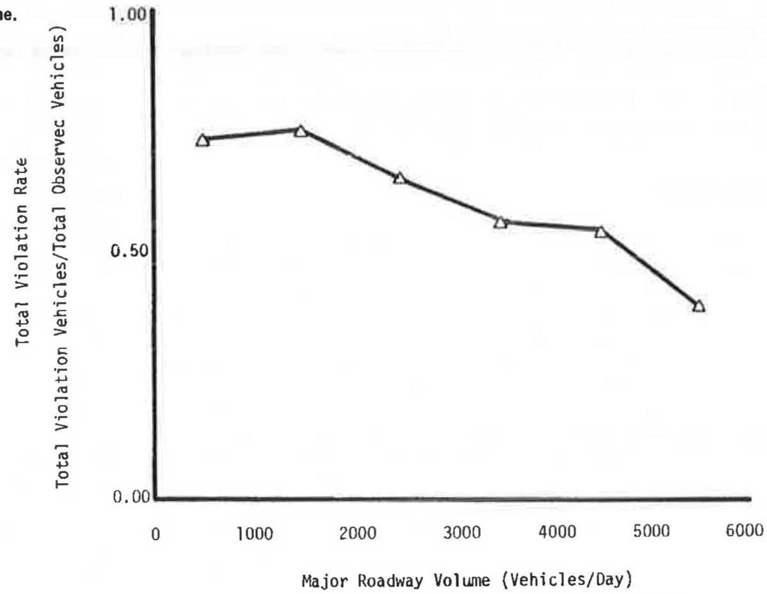
By using full violation and forced compliance rates as dependent variables, significant differ-

Table 2. ANOVA summary of variable relationships.

	Dependent Variable						
	Compliance Rate						
Independent Variable	Forced ($R^2 = 0.8238$)	Voluntary ($R^2 = 0.6720$)	Partial Violation ($R^2 = 0.4927$)	Full Violation ($R^2 = 0.6218$)	Total Violation ($R^2 = 0.8023$)	Conflict Rate ($R^2 = 0.6731$)	Total Annual Accident Rate ($R^2 = 0.3735$)
Condition	0.2444	0.2041	0.1546	0.1781	0.8085	0.4926	0.8421
Geometry	0.0126[a]	0.0082[a]	0.5986	0.8476	0.3656	0.0049[b]	0.8587
Sight distance	0.5509	0.0050[b]	0.1087	0.9587	0.0199[b]	0.8242	0.6757
Volume	0.0001[c]	0.2260	0.3560	0.0183[a]	0.0001[c]	0.0636	0.8170
Condition/geometry	0.3880	0.4381	0.7489	0.9720	0.6198	0.0872	0.2381
Condition/sight distance	0.5108	0.3436	0.5156	0.4545	0.9605	0.3082	0.9965
Condition/volume	0.6162	0.4426	0.8801	0.8659	0.6339	0.7270	0.6770
Geometry/sight distance	0.3362	0.9498	0.8858	0.3990	0.2501	0.8181	0.7505
Geometry/volume	0.1984	0.2839	0.5066	0.0448[a]	0.1728	0.2235	0.5071
Sight distance/volume	0.2501	0.2121	0.8108	0.5615	0.0126[a]	0.5232	0.5071
Condition/geometry/sight distance	0.6338	0.4459	0.5298	0.5941	0.9053	0.8658	0.8836
Condition/geometry/volume	0.8071	0.5928	0.9878	0.7348	0.8387	0.0915	0.9912
Condition/sight distance/volume	0.6755	0.6600	0.5291	0.9568	0.5506	0.9743	0.7893
Geometry/sight distance/volume	0.5104	0.5757	0.3655	0.4266	0.6999	0.1834	0.8550
Condition/geometry/sight distance/volume	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

[a] $p > 0.05$. [b] $p > 0.01$. [c] $p > 0.001$.

Figure 1. Mean total violation rate versus major-roadway volume.



ences in treatment means occur between 0-2000 ADT and 5000-6000 ADT. There are no significant differences between the volume-level means from 2000 to 5000 ADT. These designated volume breakpoints show no significance when partial violation and voluntary compliance rates are taken as dependent variables. The pattern of significant differences in treatment means by volume level is vastly altered in the conflict-rate model. No significance was established between total accident rate and major-roadway volume. Sight distance and major-roadway volume were found to interact significantly as measured against the dependent variable of total violation rate (Figure 2). Conflict rate and forced compliance rate both displayed a significant interactive relationship with type of intersection geometry and major-roadway volume.

A linear regression was performed based on total violation, full violation, forced compliance, and partial violation, all of which hold significant relationships as specified by the ANOVA. These were taken as the dependent variables with regression about the independent variable of major-approach volume. A linear regression with respect to conflict rate was not undertaken since cursory review indicated no linear relationship. The following equation clearly indicates that major-roadway volume is the best predictor of total violation: total violation rate = 0.794 889 - 0.000 063 (major-roadway volume). The correlation coefficient for this regression is approximately 0.70 and significant to the 0.01 level. A graphical comparison of the observed data and predicted regression line is shown in Figure 3.

SUMMARY

In summary, it may be stated that major-roadway volume and minor-roadway sight distance affect the violation rate of stop-sign control. Major-roadway volume and total violation rate hold a strong negative relationship: As volume increases, the total violations decrease. Full violations were also found to be significantly related to major-roadway volume and follow the same trend as total violations. However, there is a mean difference in driver behavioral response of approximately 40-50 percent between full and total violation rates.

The significant breakpoints along major-approach volume seem to occur around 2000 and 5000 ADT, and total violation rate stabilizes in the lower volume range at approximately 75 percent and drops below 50 percent in the higher volume range. One explanation for this is that approximately 25 percent of drivers that traverse low-volume intersections that have major-roadway volume less than 2000 ADT perceive the need for stop-sign control. Stated differently, only 25 percent of drivers accept stop signs at face value. Conversely, at low-volume intersections that have major-roadway volume that exceeds 5000 ADT, confirmation of this need for intersection control seems readily apparent due to major-roadway traffic exposure as exhibited by the decrease in total violations.

The influence of major-roadway volume on conflict rate shows that less than 2 percent of the vehicles on minor roads create conflicts with a major-road vehicle at both the low-volume (0-2000 ADT) and high-volume (5000-6000 ADT) ranges. Yet conflicts increase in the mid-ranges and peak at almost 7 percent with the 3000- to 4000-ADT level. An explanation for this may be that at the lower major-roadway volumes, the probability of conflict is extremely low, even with 100 percent violation. This explanation is consistent with a previous theoretical study reported by Stockton (9). As major-roadway volume and the probability of conflict increase, however, drivers are still unable to perceive the potential for conflict and continue to make violations, behavior that is reinforced at no risk under lower-volume intersection conditions. Thus, conflicts increase until a higher major-roadway volume level (3000-4000 ADT) forces the driver to perceive the greater risk of conflict, thus producing a decline in total violations and a subsequent reversal in the pattern of conflict rate.

There is also the possibility that driver expectancy may be an influencing factor in this pattern of data. Drivers on the minor road are generally familiar with the major road and judge its potential conflict on the basis of previous experience. Between 2000 and 5000 ADT on the major roadway, there seems to exist a situation of indecision and risk behavior by the driver on the minor raodway. The driver's expectancy of the probability of conflict that was learned at low-volume intersections at which there was 0-2000 ADT on the major roadway is not necessarily confirmed. At some point within the

Figure 2. Mean total violation rate measured against sight distance and major-roadway volume.

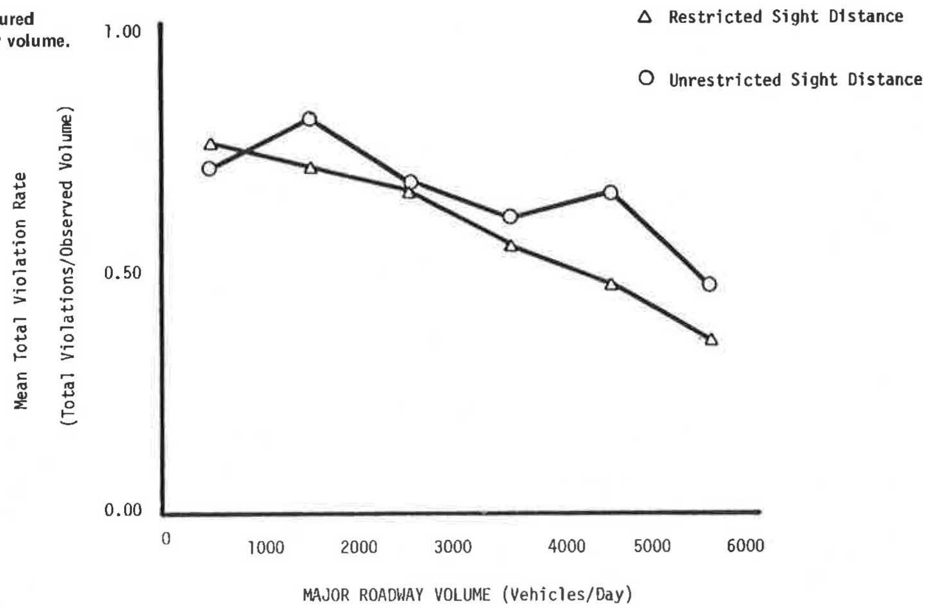
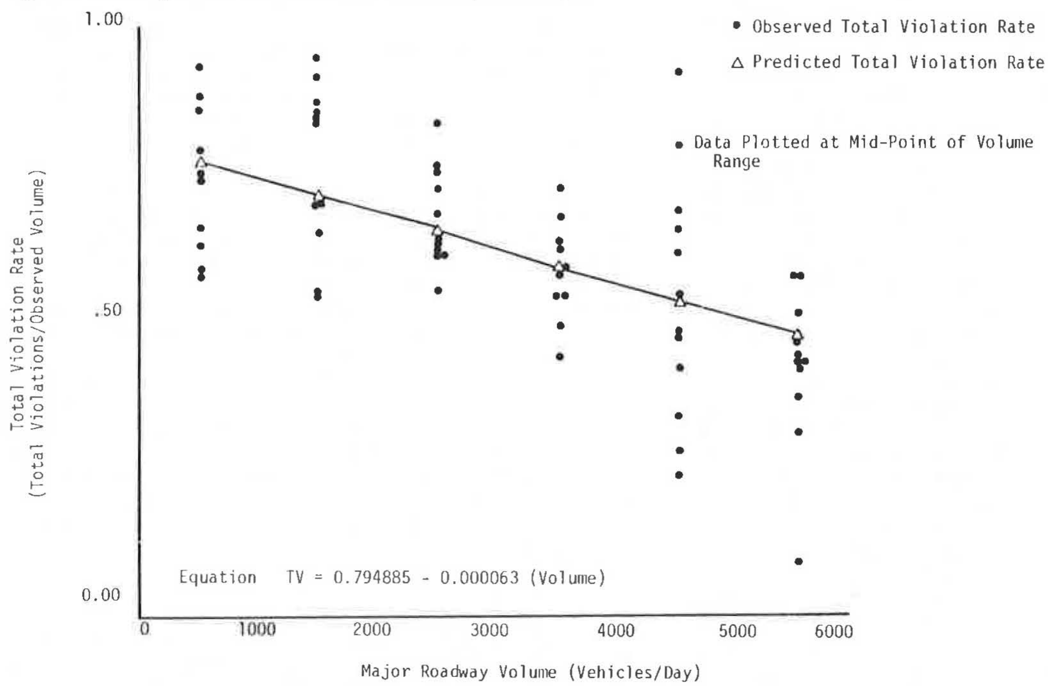


Figure 3. Linear regression: total violation rate versus major-roadway volume.



range 3000-4000 ADT, the driver apparently begins to form a new expectancy due to increasing exposure to major-roadway traffic, and a new behavior pattern results, which causes a reduction in conflicts. As this expectancy of encountering traffic on the major roadway is fulfilled, compliance increases, violations decrease, and the preservation of inappropriate action for intersection conditions is reduced.

Minor-roadway sight distance was found to affect the total violation rate significantly and, conversely, the total compliance rate. Total violations were higher at low-volume intersections at which there was unrestricted sight distance and lower at locations at which there was restricted sight distance. It must be kept in mind that the classification of sight restriction was based on the calculation of a composite ratio between available and required intersection sight distance for all sight-triangle quadrants. This technique is questionable and possibly creates bias because an intersection is rated by sight distance as a whole entity rather than by individual sight-triangle quadrants.

There was also an interaction effect between sight distance and volume for total violation rate. For both restricted and unrestricted conditions, the total violation rate decreases as major-roadway volume increases. The most visible decline in violations again occurs at approximately 2000 and 5000 ADT. These breakpoints also display the greatest effects of sight-distance restriction as a modifier of violations.

Total violation rate is reduced by up to 20 percent by restricted intersection sight distance within these volume ranges, whereas mid-range major-roadway volumes show maximum declines of only 10 percent. No other category of dependent variable was significantly affected by minor-approach sight distance. Apparently, minor-approach sight distance affects the violation and compliance classifications in general, whereas its effect on any one classification remains insignificant.

It may also be reasonable to assume that at the low-volume range on the minor roadway and at the high-volume range on the major roadway at which driver expectancy is predominantly confirmed by the presence or lack of traffic, unrestricted sight distance acts as a further confirmation that leads to higher violations or compliance. Within the mid-range, unrestricted sight distance may only confirm to the driver that his or her preconception of acceptable risk behavior based on experience at lower-volume intersections is now inaccurate.

Intersection geometry was found to be significantly related only to compliance measures. A greater mean percentage of observed vehicles was in forced compliance at three-leg intersections than at four-leg intersections. The only possible explanation for this would involve a disproportionate number of turning movements between three- and four-leg intersections.

Conflict rate was also discovered to be significantly affected by intersection geometry. The mean percentage of conflicts on three-leg intersections was lower than that on four-leg intersections. This confirms published information on differences in potential conflict points. Thus, a higher level of conflicts is consistent with four-leg intersections since these intersections have more conflict points.

No significant relationship could be established between any dependent variables and the independent variable of traffic condition. No significant differences in response between rural and urban intersections were displayed by the data. Although not directly evaluated by a single previous study, other studies implied that violation rates would differ between rural and urban areas (11).

The other primary dependent measure, accident rate, was not significantly affected by independent variables. No correlation could be established between accidents and any other violation measures or with conflict rate at any volume level on major and minor roadways. This finding may be caused by the fact that at these low-volume levels for both major and minor roadways, a three-year accident history is not sufficient to establish trends.

It should be noted that it could not be determined that increased violation rate caused an increase in accidents for the intersection volume parameters studied. Therefore, if violation and compliance are assumed to depict driver operational behavior at an intersection, then low-volume intersections (0-2000 ADT on major roadway) are being used as if there were no traffic control present, yet with no detriment to safety. Within the middle of the volume range, the motorist needs to be informed of the increased probability of conflict, but again, as shown by the violation rate, there is no operational requirement that all minor-roadway vehicles must be stop-controlled. The conflict rate does increase; however, accident experience at these volumes does not warrant stop-sign control; yield signing could be a more meaningful and warranted control. Even at the highest major-roadway volume studied, only 10 percent of minor-roadway traffic voluntarily recognized and obeyed the stop sign in the noncaptive situation. Based on the findings of this study relative to violation and compliance rates, conflict rates, and accidents as the operational and safety criteria for the effective application of low-volume intersection signing control, the following warrants are recommended for consideration by traffic and transportation officials:

1. No signing control is justified or should be employed at those intersections at which the major-roadway volume is 2000 ADT or less, the minor-roadway volume is 500 ADT or less, and there have been no accidents within a three-year period. This warrant is also contingent on whether the available sight distance along all quadrants of the intersection exceeds the requirement of AASHTO case 1 guidelines. If any of these conditions cannot be met, a more positive form of intersection signing control should be used.

2. For those intersections at which the major-roadway volume is between 2000 and 5000 ADT, minor-roadway volume is 500 ADT or less, and there have been less than two accidents within a three-year period, yield-sign control should be employed. This warrant is also contingent on whether the required available sight distance along all quadrants of the intersection exceed the requirement of AASHTO case 2 guidelines. If any of these conditions cannot be met, a more positive form of intersection signing control should be used.

3. Stop-sign control should be employed at those intersections at which the major-roadway volume is 5000 ADT or more, minor-roadway volume is 500 ADT or less, and there have been two or more accidents within a three-year period. This warrant stands regardless of sight distance availability or requirements. Signalization may be employed as an alternative if justified by other warrants.

Table 3 summarizes the conditions listed above under which each control type should be applied at low-volume intersections. The accident frequencies shown represent a reasonable level of safety. Because of the essentially random nature of accidents observed for all low-volume intersections, a single accident at an intersection is not by itself indicative of a need for greater control. Even two accidents at an intersection represent a marginal condition regarding safety and therefore only a mere hint of a need for more-restrictive control. It is also recognized that as exposure increases, the potential for accidents increases. Therefore, the recommended criteria provide for some margin of error in the direction of more-restrictive control as exposure increases.

RECOMMENDATIONS

It is recommended that implementation of the proposed low-volume intersection control warrants be considered in a priority order for two categories: new intersections and existing intersections. New intersections are those created by the opening of new streets, either singly or in subdivisions. For new intersections of low-volume streets that enter major streets at intersections that have less than 5000 ADT (primarily collector streets in urban areas), yield control should be installed soon after the opening of the street. The only analyses required will be an estimate of major-roadway volume and the adequacy of sight distance for proper yield operation. Intersections at which new local streets cross other local streets in a subdivision should be left uncontrolled, provided there is adequate sight distance and no other circumstances that require control.

At existing intersections, control changes at locations at which conditions are known to be within the recommended criteria should be implemented immediately. At all other locations, estimates of

Table 3. Recommended control warrants for low-volume intersections.

Control Warrant	Sight Distance	Accident History	Major-Roadway Volume (ADT)
None	Adequate	None in three years	0-2000
Yield	Adequate	Less than two in three years	2000-5000
Stop	Adequate or inadequate	Two or more in three years	5000+
Stop	Inadequate	-	All

traffic volumes, sight distance, and a determination of accident history must be made prior to putting control changes into effect. For situations in which a citywide or countywide 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.

It is also recommended that further research be undertaken to address still-questionable issues relative to the proposed warrant for low-volume intersection signing control. These topics are as follows:

1. The legal consequences of several points should be evaluated: the responsibilities of the driver, the misapplication of intersection signing control through a policy that uses the safest device at all locations, and the potential inabilities to put the proposed warrants into effect because of statutory restrictions.
2. A larger sample of low-volume intersections should be taken and reviewed to further substantiate the findings of this study and the significant relationships identified among the variables.
3. An extension of the study to major-roadway volume levels beyond 6000 ADT would indicate whether the reversal trend in the conflict rate is truly significant or an anomaly shown by further increases in observed conflicts as both potential conflicts and volume increase.
4. Even though minor-roadway sight distance was shown to affect selected operational measures significantly at low-volume intersections, the assessment technique used in this study needs to be evaluated and refined to reflect existing conditions more accurately. The relationship among sight distance, volume, and violation and compliance rates could then be more accurately established.
5. An extension and stratification of minor-roadway volume levels would provide further insight into the effects of this variable on conflicts and accidents.

CONCLUSION

These warrants require that a jurisdiction make an assessment of both the combined volumes and sight distances in order to make decisions concerning signing control at low-volume intersections. Such assessment would require more effort from the decision maker, but the savings to the public would be obvious and substantial. It is hoped that more-judicious and more-definitive application of both stop- and yield-sign control will alleviate the confusion now displayed by drivers, diminish the unsafe behavior, and minimize current violation rates.

The expected result of more-thoughtful sign applications is the heightened attention and respect given sign control by the motoring public. Thus, when the purpose and need for both stop and yield control are more readily perceived by the public, greater public compliance will occur. In order to achieve this end, it is first necessary to realize that universally applied stop control is not the safest or the most-efficient solution to low-volume intersection control.

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