Field Evaluation of Two-Way Versus Four-Way Stop Sign Control at Low-Volume Intersections in Residential Areas

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This study was conducted to acquire data that would assist in resolving the conflicting opinions and research results that exist about two-way versus four-way stop sign control at low-volume intersections in residential areas. A unique opportunity to compare operational issues at such intersections existed at a West Virginia municipality in which three intersections were regulated by two-way stop sign control during the winter months and then converted to four-way stop sign control during the summer. The experimental design was a before-and-after analysis with control intersections. Traffic volume, delay, speed, and observance data were collected, analyzed, and used to determine road user costs. Accident experience and potential legal issues were also investigated. At the three intersections studied, use of four-way stop control was found to cause unnecessary motorist delay and road user costs. A delay analysis found that the use of four-way stop control was 2.6 times less efficient than use of two-way control. Annual road user costs increased by $2,400 per intersection after installation of four-way stop control. Mean midblock vehicle speeds were not affected by the type of intersection control; however, 85th percentile speeds decreased by 2.3 mph after installation of four-way stop control. The driver observance study showed that the stop sign violation rate increased by 11 percent after installation of four-way control.

The degree of traffic control used at an at-grade intersection should reflect the volume and speed of traffic associated with the intersection. Intersections with high volumes, high speeds, or both demand a higher level of intersection control than those with low speed and low volumes. For a variety of reasons (e.g., lack of knowledge of warrants for traffic control devices, pressure from the general public or politicians, lack of data about traffic and speed conditions at a site, or a change in traffic conditions over time) the level of traffic control at an intersection may not be appropriate for the given volume and speed.

Many jurisdictions in the United States have installed four-way stop sign control at low-volume intersections in residential areas in an attempt to reduce speeds or to provide additional safety for children playing on or near the streets or both. According to the *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*), stop signs should not be installed for speed control because this misuse of traffic control devices probably promotes a lack of respect for all traffic control devices and may decrease driver compliance with all such devices. Recent research (*2–4*) has borne out the compliance problem. Other adverse consequences include the following:

- While several studies (*4–6*) have demonstrated the relative ineffectiveness of stop signs for speed control, there is some evidence (*5*) that drivers may actually increase their midblock speeds between signs;
- Use of four-way stop signs in place of two-way stop signs may cause substantial increases in automobile energy consumption, vehicle operating costs (*7–10*), and traffic delay; and
- Use of unwarranted stop sign control raises legal questions.

Findings concerning accident experience at two- and four-way stop controlled intersections are less definitive (*8, 11, 12*).

During the literature review, no studies could be located that utilized field data at low-volume (ADT less than 400 vehicles per day) stop-controlled intersections in residential areas. This is probably because of the difficulty in obtaining adequate sample sizes at this low volume level. Additional field research was needed, therefore, to provide a complete comparison of the actual operational characteristics associated with low-volume two-way and four-way stop-controlled intersections in residential areas.

A unique opportunity to compare operational issues at intersections under both two-way and four-way stop sign control was found in Star City, a town with a population of about 1,500 that is located north of and adjacent to Morgantown in north-central West Virginia. Three low-volume intersections in a residential section of the community were controlled by two-way stop sign control during the winter months and converted to four-way stop sign control during the summer months. This has been standard practice in the community for a number of years because it reduces vehicle speeds during summer months when children are playing in or near the street and allows vehicles to ascend grades when road surfaces are snow-covered. Since the site conditions and traffic volumes at the intersections remained constant during the use of the two-way and four-way stop sign control, variations in data obtained from studies conducted at the intersections would be attributable to the specific type of control being used and would not be influenced by extraneous factors such as variations in intersection geometrics and/or variations in sight distances. This latter situation would exist if a comparison were made of two-way versus four-way stop control at adjacent, similar intersections.

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STUDY OBJECTIVES

To accomplish the overall goal of the project, several specific objectives were established:

- To review previous research that has evaluated two-way versus four-way stop sign–controlled intersections;
- To collect traffic volume, spot speed, delay, compliance, and accident data at selected two-way and four-way stop sign–controlled intersections;
- To estimate and compare delay and road user costs at the selected two-way and four-way stop sign–controlled intersections; and
- To evaluate accident experience and legal aspects associated with alternating between two-way and four-way stop sign control.

DATA COLLECTION AND ANALYSIS

Experimental Design and Site Selection

A before-and-after analysis with control intersections was chosen as the experimental plan because use of control sites allows the evaluator to reduce the influence of other variables on study results. Traffic data were collected and analyzed during the before condition. The intersection control was then changed, and traffic data were collected and analyzed during the after condition. Control data were also collected and compared at other nearby intersections during both the before and after condition to take into account possible changes in traffic trends that could have influenced results at the study intersections. Note that in all cases, data collection studies were conducted at the same location, on the same day of the week, and at the same time of day during the before and after study conditions to minimize introduction of bias into the results.

The study intersections, designated S1, S2, and S3, were right angle intersections of two-lane intersecting streets located in a moderate-income residential section of Star City. Posted speed limits throughout the area were 25 mph. The north-south street was the major roadway at each intersection; stop signs were located on the east and west approaches during the use of two-way stop control. Sight distances varied considerably. The topography of the area was generally level to rolling; all three intersections had grades of about 6 percent on the north-south roadways. To provide adequate control, the researchers stipulated that one two-way stop intersection and one four-way stop intersection be used as control intersections.

Traffic Data

All data on the use of two-way stop control were collected during a four-week "before" period. City officials then converted the two-way stop sign control at each of the study intersections to four-way stop control. A waiting period of 6 weeks was allowed to permit traffic to adjust to the new control conditions. Data collection was then resumed. All data on the use of four-way stop sign control were collected during a 4-week "after" period. The amount of data that could be collected during the before and after conditions was constrained by the following factors: (a) the intersections that were being studied were on very low-volume streets and (b) there was only a limited amount of time available between the start of the study and the changeover date from two-way to four-way stop sign control.

Traffic Volume

Portable pneumatic tube traffic counters were used to acquire average daily traffic (ADT) volumes at the study and control intersections during both the before and after conditions. These data are presented in Table 1. In addition, counts of vehicle turning movement were made at each intersection before and after the conversion.

TABLE 1 AVERAGE DAILY TRAFFIC VOLUMES AT THE STUDY INTERSECTIONS

Intersection	Major Street ADT	Minor Street ADT	Total	Side Street Traffic (%)
S1				
Before	337	130	467	28
After	344	117	461	25
S2				
Before	333	130	463	28
After	255	117	372	31
S3				
Before	413	153	566	27
After	406	171	577	30

The average daily traffic on north-south and east-west streets did not change significantly between before and after conditions. Five of six before and after ADT comparisons indicated traffic volume variations of less than 10 percent. The exception occurred on the north-south street at Intersection S2; this 23 percent traffic volume decrease may be attributable to motorists choosing alternative routes in an effort to minimize delay. Hourly traffic variations on the north-south and east-west streets at the study intersections were similar during before and after conditions. Vehicle turning movement volumes were very similar during before and after conditions at the study intersections.

Traffic Delay

Two types of raw traffic delay data were collected for use in this study: (a) average intersection traversal time and (b) stopped time delay. Intersection traversal time was defined as the time required for a vehicle to travel from the midblock point on one approach to the midblock point on the approach directly opposite the point at which the vehicle entered the intersection. Average intersection traversal time was obtained by summing each individual intersection traversal time and dividing the sum by the number of observations. Four separate average intersection traversal time studies (i.e., one for each direction of travel) were conducted for each study and control intersection during each traffic control condition.

Stopped time delay data were collected on each intersection approach during both before and after conditions. To collect these data, an observer was positioned near the intersection approach under study. This observer used a stopwatch to record the amount of time that each entering vehicle was traveling at a speed of 3 mph or less.

Intersection traversal time and stopped time delay data were collected in conjunction with average daily traffic approach volumes or spot speed data (or both) to determine (a) total intersection delay, (b) stopped time delay, and (c) speed change delay for each traffic control condition and direction of travel at each intersection. Total intersection delay was defined as the total delay experienced by vehicles traveling through an intersection in a particular direction of travel. Total intersection delay was determined by first calculating intersection traversal time on the basis of average midblock speed. The intersection traversal time based on speed was then subtracted from actual intersection traversal time to obtain a total intersection delay expressed in seconds per vehicle. Total intersection delay expressed in hours per day was then calculated by multiplying total intersection delay expressed in seconds per vehicle by the appropriate average daily traffic approach volume. Total intersection delay was assumed to represent delays associated with all turning movements on a particular approach, even though intersection traversal time had only considered vehicles that were traveling straight through. The validity of this assumption was substantiated to some degree by traffic volume characteristics: vehicles traveling straight through constituted at least 71 percent of the total approach volume on the north-south approaches and at least 52 percent of the total approach volume on four of six east-west approaches.

Average total intersection delay on the north-south approaches at the study intersections increased from 0.4 to 5.0 sec per vehicle during the after condition (Table 2). Average total intersection delay on the east-west approaches decreased from 5.1 sec per vehicle during the before condition to 4.5 sec per vehicle during the after condition. The increased north-south street delays were expected; nominal average total intersection delay of less than 0.4 sec per vehicle, which resulted from vehicles exhibiting caution on entering the intersection, would inevitably increase after installation of stop signs on the north-south approaches. The decreased east-west street delays could have been caused by an increased sense of security experienced by motorists entering from the east and west approaches. If a motorist on the east or west approach of an intersection knew that drivers on the north and south approaches had to stop, the motorist might not be as concerned about north-south street traffic and might enter the intersection without exercising normal caution.

The before and after daily total intersection delays were also compared so that the differences in north-south and east-west street traffic volumes would be considered in the delay analysis. The before and after comparisons presented in Table 3 indicate that daily total intersection delay at the study intersections increased by approximately 12 min on each north and south approach during the after condition. Daily total intersection delay decreased by less than 1 min on each east and west approach.

TABLE 3 DAILY TOTAL INTERSECTION DELAY AT THE STUDY INTERSECTIONS

	North-South Street		East-West Street		Total	
Intersection	Two-Way	Four-Way	Two-Way	Four-Way	Two-Way	Four-Way
S1	4.4	27.5	11.8	12.2	16.1	39.8
S2	1.3	16.8	13.0	7.7	14.2	24.5
S3	0.0	32.1	11.6	12.5	11.6	44.6
Total, all	5.7	76.4	36.4	30.8	42.1	108.9
Average per approach	1.0	12.7	6.1	5.1	3.5	9.1

NOTE: Delays are given in minutes.

The total intersection delay analysis had already considered the overall effect of north-south and east-west street traffic volume differences. Stopped time (the average time that vehicles were stopped or practically stopped) and speed change (the average time required for vehicles to decelerate from average vehicle speed to a minimum speed or stop plus the time required to accelerate back to average vehicle speed) delays were therefore analyzed on a seconds per vehicle basis to obtain a more detailed and complete understanding of vehicle operational characteristics during the two-way and four-way stop control conditions. Stopped time delay was determined directly from stopped time delay data. Speed change delay was calculated by subtracting stopped time delay from total intersection delay.

In general, stopped time delay at the study intersections varied from 0.9 to 3.3 sec per vehicle during before and after conditions. During the two-way stop condition, average stopped time delay on the east and west approaches was 2.1 sec per vehicle. After installation of stop signs on the north-south

TABLE 2 TOTAL INTERSECTION DELAY AT THE STUDY INTERSECTIONS

Intersection	North Approach	South Approach	North-South Average	East Approach	West Approach	East-West Average
S1						
Two-way (before)	1.0	0.8	0.9	4.1	5.2	4.7
Four-way (after)	5.7	6.1	5.9	4.9	4.9	4.9
S2						
Two-way (before)	0.0	0.5	0.3	5.1	6.4	5.8
Four-way (after)	4.6	4.6	4.6	4.2	4.3	4.3
S3						
Two-way (before)	0.0	0.0	0.0	5.5	4.2	4.9
Four-way (after)	3.7	5.2	4.5	5.2	3.7	4.5
Overall average						
Two-way (before)	0.3	0.4	0.4	4.9	5.3	5.1
Four-way (after)	4.7	5.3	5.0	4.8	4.3	4.5

NOTE: Delays are given in seconds per vehicle.

approaches, average delay on the east-west approaches was reduced to 1.5 sec per vehicle. This reduction is overshadowed, however, by a 1.3 sec per vehicle increase in stopped time delay on the north-south approaches. Because the north-south streets were the major roadways at all study intersections, the 1.3 sec per vehicle increase in stopped time delay is far more important than the 0.6 sec per vehicle reduction.

Analysis of speed change delays at the study intersections, presented in Table 4, indicated that average speed change delay for the north-south directions of travel was only 0.4 sec per vehicle during the two-way stop control condition. An average speed change delay of 3.7 sec per vehicle was evident after installation of four-way stop control. Analysis of speed change delay for the east-west directions of travel showed that no significant trends occurred during before and after conditions.

Spot Speed

Spot speed data were collected for both directions of travel at the midblock point on all four approaches of each intersection during both the before and after conditions. In general, mean speeds on the north-south streets were consistently greater than those on the east-west streets. The average mean speed on the north-south streets, presented in Table 5, decreased from 23.0 to 21.9 mph after installation of four-way stop sign control. Average mean speed on the east-west streets decreased from 18.6 to 18.3 mph. These differences were not statistically significant. Thus mean speeds on the north-south and east-west streets can be said to be relatively unaffected by the use of two-way and four-way stop control.

The 85th percentile speeds on the north-south streets decreased by an average of 2.3 mph after installation of four-way stop sign control. The 85th percentile speeds on the north-south streets, presented in Table 5, were 2 mph in excess of the 25-mph speed limit during the before condition and identical to the 25-mph speed limit during the after condition. The 85th percentile speeds on the east-west streets remained constant at 21.7 mph during both before and after conditions.

In general, the limits of the 10-mph pace decreased and the percentage of vehicles traveling within the 10-mph pace increased

TABLE 4 SPEED CHANGE DELAY AT THE STUDY INTERSECTIONS

Intersection	North Approach	South Approach	North-South Average	East Approach	West Approach	East-West Average
S1						
Two-way (before)	1.0	0.8	0.9	2.7	3.2	3.0
Four-way (after)	4.6	4.9	4.8	3.6	3.3	3.5
S2						
Two-way (before)	0.0	0.5	0.3	3.3	4.8	4.1
Four-way (after)	3.3	2.7	3.0	2.4	3.2	2.8
S3						
Two-way (before)	0.0	0.0	0.0	2.4	0.9	1.7
Four-way (after)	2.8	3.9	3.4	3.6	2.0	2.8
Overall average						
Two-way (before)	0.3	0.4	0.4	2.8	3.0	2.9
Four-way (after)	3.6	3.8	3.7	3.2	2.8	3.0

NOTE: Delays are given in seconds per vehicle.

TABLE 5 OVERALL VEHICLE SPEED CHARACTERISTICS AT THE STUDY INTERSECTIONS

Intersection	Orientation	Stop Control In Use	Mean Speed X (mph)	Standard Deviation S (mph)	Median Speed (mph)	85th Percentile Speed (mph)	15th Percentile Speed (mph)	Limits of 10 mph Pace		Percent Vehicles Within 10 mph Pace
								Lower (mph)	Upper (mph)	
S1	N-S	2-Way	24.0	4.4	24.0	28.8	19.1	19.3	29.3	74
		4-Way	23.0	3.6	22.4	25.6	18.1	17.5	27.5	87
	E-W	2-Way	19.5	3.2	19.5	22.4	15.6	14.0	24.0	92
		4-Way	18.9	3.4	18.7	22.4	15.0	13.5	23.5	94
S2	N-S	2-Way	21.6	4.1	21.6	25.8	16.6	16.0	26.0	78
		4-Way	20.6	3.5	20.4	23.7	16.7	15.0	25.0	88
	E-W	2-Way	18.1	2.8	17.6	21.2	15.2	12.5	22.5	94
		4-Way	18.1	3.1	17.9	21.2	14.6	13.5	23.5	96
S3	N-S	2-Way	23.3	4.6	23.2	26.5	18.4	18.3	28.3	75
		4-Way	22.2	4.2	22.1	24.7	18.0	17.3	27.3	82
	E-W	2-Way	18.1	3.4	17.1	21.4	15.0	13.3	23.3	94
		4-Way	18.0	3.0	17.6	21.5	14.9	12.3	22.3	95
Total All	N-S	2-Way	23.0	4.4	22.9	27.0	18.0	17.9	27.9	76
		4-Way	21.9	3.8	21.6	24.7	17.6	16.6	26.6	86
	E-W	2-Way	18.6	3.1	18.1	21.7	15.3	13.3	23.3	93
		4-Way	18.3	3.1	18.1	21.7	14.8	13.1	23.1	95

after installation of four-way stop control. Before and after upper limits on the north-south streets averaged 27.7 and 26.6 mph, respectively (Table 5). The percentage of vehicles traveling within the 10-mph pace on these streets increased by 10 during the after condition. The changes in the 10-mph pace on the east-west streets were insignificant.

Traffic Control Device Compliance

Traffic control device compliance studies were conducted at each of the study and control intersections during both the before and after conditions. The percentage of nonstopping drivers increased from 14.1 percent during the before condition to 25.1 percent during the after condition (Table 6). During the four-way stop sign control condition, 26.4 percent of the north-south street traffic did not stop and 23.8 percent of the east-west street traffic did not stop. The percentage of drivers performing a voluntary full stop and the percentage of drivers stopped by traffic remained essentially constant during before and after conditions. Approximately 15.7 percent made a voluntary full stop, and 3.5 percent were stopped by traffic. The percentage of drivers who practically stopped (0–3 mph) decreased from 65.7 to 55.8 during the after condition. Note that driver compliance percentages on the north-south and east-west streets were approximately equal during the four-way stop sign control condition.

Control Intersections

Analysis of traffic volume, delay, speed, and observation data from the control intersections indicated that before and after traffic characteristics (specifically, through volumes, turning movements, spot speed parameters, intersection traversal times, and driver compliance characteristics) at the control intersections did not change significantly. Because traffic characteristics were similar during before and after conditions, it was felt that data differences at the study intersections could be directly attributed to the type of stop control utilized at the intersections.

Accident Experience and Legal Cases

Accident data at each of the study intersections were obtained by reviewing the accident file for the town of Star City. Preliminary accident data evaluation indicated that only three accidents were recorded at the study intersections during the 5-year period from May 1979 to May 1984. None of the accidents was attributable to the use of a particular type of stop sign control; either the accidents were known to be caused by other events or the accident report forms did not provide needed information. Therefore accident data at the study intersections were deemed to be insufficient for the performance of a reliable accident analysis.

A search of legal cases was performed to identify cases that could be used to evaluate the legal aspects associated with using four-way instead of two-way stop signs at intersections. Special attention was given to locating cases that involved low-volume intersections at which (a) alternating two-way and four-way stop sign controls were used, (b) two-way stop sign control was replaced by four-way stop sign control, and (c) four-way stop control was replaced by two-way stop control. No relevant cases involving these issues were located, however. Apparently, any cases must have been decided in a trial court and were not appealed; consequently, they were never published.

ROAD USER COST ANALYSIS

The study compared before and after road user costs to determine the relative economy associated with the use of both two-way and four-way stop control. Costs considered for analysis were (a) daily motorist delay costs, (b) daily idling costs, and (c) daily speed change cycle costs. In all cases, procedures recommended by the AASHTO "Red Book" (*13*) were utilized. Cost factors were updated to current conditions by using the AASHTO-recommended procedures (*13*). Accident costs could not be calculated because there were insufficient accident data; environmental costs (associated with air and noise pollution) were determined to be negligible at the study intersections.

Daily motorist delay costs were determined for each direction of travel and stop control condition at each intersection. These costs represent the dollar value of time lost due to total intersection delay. Comparison of before and after daily motorist delay costs indicated that average daily motorist delay costs on the north-south streets increased from \$0.03 to \$0.32 during the after condition. Average daily motorist delay costs on the east-west streets decreased from \$0.15 to \$0.14 during the after period. Total daily motorist delay costs at the three study intersections increased from \$0.54 per day during the two-way stop condition to \$1.39 per day during the four-way stop condition. Daily vehicle idling costs were also calculated. Before and after daily idling costs were less than \$0.07 for each direction of travel.

Daily speed change cycle costs were calculated for each direction of travel and stop condition at each intersection. Daily speed change cycle costs for the north and south directions of travel at the study intersections were assumed to be zero during

TABLE 6 OVERALL DRIVER COMPLIANCE CHARACTERISTICS AT THE STUDY INTERSECTIONS

Driver Compliance Category	Percent of Drivers Within Each Driver Compliance Category					
	North-South Streets		East-West Streets		All Streets	
	2-Way	4-Way	2-Way	4-Way	2-Way	4-Way
Voluntary full stop	NA[a]	16.3	15.2	15.9	15.2	16.1
Stopped by traffic	NA	1.3	4.6	3.6	4.6	2.4
Practically stopped	NA	54.6	65.7	56.9	65.7	55.8
Nonstopping	NA	26.4	14.1	23.8	14.1	25.1

[a]Not applicable.

the two-way stop sign control condition because north-south street traffic was not required to stop. The average total daily speed change cycle cost on the north-south street at each study intersection was $6.34 per day after installation of four-way stop control. The average total daily speed change cycle cost on the east-west street at each study intersection remained essentially constant at approximately $2.38 per day during both before and after conditions. The installation of four-way stop sign control at the study intersections increased the total daily speed change cycle cost by $18.73 per day.

Daily motorist delay costs, daily idling costs, and daily speed change cycle costs were summed to obtain the total daily road user costs for each intersection and study condition. The daily speed change cycle cost was the most significant cost component in the road user cost analysis. During the two-way stop sign control condition, 91 percent of the total road user cost was attributable to speed change cycle costs, 7 percent was attributable to motorist delay costs, and the remainder was attributable to idling costs. Similarly, during the four-way stop sign control condition, 94 percent of the total road user cost was attributable to speed change cycle cost, 5 percent was attributable to motorist delay cost, and the remainder was attributable to idling costs.

The average total daily road user cost per study intersection increased by $6.58 per day after the conversion from two-way to four-way stop sign control (Table 7). The primary cause of this increase was the additional road user cost on the north-south street at each intersection. The average total daily road user cost on the north-south streets increased by $6.71 per day, while the average total daily road user cost on the east-west streets decreased by a negligible $0.13 per day. The installation of four-way stop sign control resulted in an average annual road user cost increase of $2,402.92 per study intersection, or an overall annual increase of $7,208.75 at the three study intersections. It was concluded that the use of two-way stop control was 3.5 times more efficient economically than the use of four-way stop control.

CONCLUSIONS AND RECOMMENDATIONS

Previous evaluations of two-way and four-way stop control used intersection delays, road user cost analysis, vehicle speeds, driver compliance to stop signs, accident analysis, or a combination of those factors as their basis. However, in a literature review, no studies were located that utilized field research along with all of these criteria to provide a complete comparison of the actual operational characteristics associated with low-volume two-way and four-way stop controlled intersections in residential areas.

The following specific conclusions derived from this study are applicable to intersections similar to the ones studied:

- Use of four-way stop sign control at low-volume residential street intersections causes unnecessary motorist delay and creates additional road user costs. In this case, use of two-way stop control was 3.5 times more efficient economically than the use of four-way stop control.
- Mean midblock speeds did not change significantly between the two-way and four-way stop conditions. However, use of four-way stop control resulted in a lower 85th percentile speed and a higher percentage of vehicles traveling within the 10-mph pace.
- The percentage of nonstopping vehicles was 11 percent higher during the four-way stop condition, indicating a general lack of respect for unwarranted four-way stop sign control.
- Accident data were insufficient to perform a reliable accident analysis.

It was concluded that in general, four-way stop sign control at low-volume residential street intersections should be changed to two-way stop sign control. The use of two-way stop sign control in place of four-way stop sign control minimizes delay and road user costs. Traffic engineering studies should be conducted, however, to take into account environmental and/or geometric conditions that may differ from those of the intersections described in this study.

Although accidents were not a problem at the intersections evaluated in this study, there are serious safety concerns associated with the practice of using alternative types of intersection control for different time periods during one year. These safety concerns focus on the time periods that follow the stop sign conversion. Accidents could result if drivers accustomed to proceeding through an intersection without being required to stop did not notice a recently installed stop sign. Similarly, accidents could result if drivers on cross streets proceeded into an intersection after removal of stop signs on a major street. Therefore it was concluded that the practice of using alternating types of intersection control for different periods of time during one year should be eliminated. Although the legal review revealed no relevant cases associated with alternating two-way and four-way stop control, good engineering judgment and sound risk management principles would indicate that four-way stop sign control should not be used at the study intersections.

TABLE 7 SUMMARY OF TOTAL ROAD USER COSTS AT THE STUDY INTERSECTIONS

	Daily Cost ($)								
	North-South Street		East-West Street		Total		Annual Cost Total ($)		Annual Increased Cost ($)
Intersection	Two-Way	Four-Way	Two-Way	Four-Way	Two-Way	Four-Way	Two-Way	Four-Way	
S1	0.06	6.34	3.02	2.06	3.08	8.94	1,124.20	3,263.10	2,138.90
S2	0.02	4.40	2.23	1.96	2.25	6.36	821.25	2,321.40	1,500.15
S3	0.00	9.47	2.67	2.98	2.67	12.45	974.55	4,544.25	3,569.70
Total, all	0.08	20.21	7.92	7.54	8.00	27.75	2,920.00	10,128.75	7,208.75
Average	0.03	6.47	2.64	2.51	2.67	9.25	973.33	3,376.25	2,402.92

Some additional research should be done to verify the results of this study. Additional study intersections in other geographic areas should be incorporated into future work so that the results can be deemed independent of local traffic trends and driver behaviors. A larger study area should also be used to obtain additional accident data so that a complete accident analysis can be performed.

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DISCUSSION

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Claims of statistical significance appear throughout the manuscript without sufficient clarification. Since a great deal of effort was expended in assuring a valid experimental design, it is logical that some statistical use was made of this design in the analysis. There is no mention, however, of the statistical method used in making these claims, nor of the level of significance. Also, there is no indication of sample size. How many vehicles are included in the tables? Although Table 5 is the most comprehensive by far, the numbers of vehicles are omitted. Since the authors recognize that the intersections in this study are low-volume, sample size could be critical to this study. As chair of the A3B11 Subcommittee on Statistical Methods in Accident Analysis, I felt compelled to make these comments.

AUTHORS' CLOSURE

We appreciate Pendleton's constructive comments on our paper. In responding to reviewers' comments on the original manuscript about the need to shorten the paper significantly and to orient it toward a user audience, we obviously neglected to include some necessary statistical information about our study. Pendleton deserves thanks for seeing to it that this information is presented.

Although it is not evident from the paper, we recognized that sample size was critical to a study of this type. One of the first steps in this work was to determine sample size requirements. For intersection traversal time and stopped time delay, minimum sample size requirements were obtained using the sample size requirements for travel time and delay studies contained in the *Manual of Traffic Engineering Studies* (4th ed., P. C. Box and J. C. Oppenlander, Institute of Transportation Engineers, Washington, D.C., 1976) for a confidence level of 95 percent.

For the spot speed and driver compliance data, we used the *Manual of Traffic Engineering Studies* sample size requirements for a confidence level of 90 percent. Because there was only a limited amount of time available between the start of the study and the traffic control changeover date, the desired level of confidence (95 percent) had to be reduced in the speed and compliance studies so that data requirements would be reasonable, given the time constraints imposed.

Sample size requirements were met or exceeded for all studies: sample sizes were in the range of 30 to 50 vehicles in all cases. In all cases, the t-test at the 95 percent level of significance was used.

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