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EVALUATION OF SPEED CONTROL SIGNS FOR SMALL RURAL TOWNS

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16. Abstract

This report describes the results of a comprehensive experiment dealing with speed control and driver behavior when approaching and driving through speed zones on a high speed, rural, two-lane highway. The basic objective of the experiment was to test the range of practical traffic control devices which alert drivers to the need for reducing speed when approaching concentrated areas of population and invoke voluntary compliance with the speed regulatory devices in a manner promoting increased safety in vehicle operation. Twelve different configurations of speed limit signs and warning devices were evaluated. All experiments were conducted at the Federal Highway Administration Maine Facility in the Town of Palmyra located along U.S. Route 2. The speed regulation in effect for all sign configurations was 35 mph (56 km/h). Results showed that:

- Active warning signs (i.e., signs with flashing beacons activated by vehicles violating the speed regulation) were the most effective (statistically significant) for both day and night
- During the day, flashing signs (i.e., signs with continuously flashing beacons) appeared to be second in effectiveness (after active signs).
- At night, pavement markings and rumble strips appeared to be next in effectiveness (after active signs).

17. Key Words
Speed Control, Safety, Rural Highways, Data Collection, Reduction and Analysis, Traffic Control Devices, Speed Zone.

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PREFACE

The problems associated with speed control in small villages and towns in rural areas are familiar to highway and traffic engineers throughout the country. These problems seem to become more acute on two-lane rural roads which also serve as the main street for the rural villages through which they pass. Little research has been done to evaluate driver compliance with various speed regulatory conditions under the small town, two-lane rural highway environment, although literally hundreds of towns and villages in the United States would potentially benefit from improvements in this one phase of speed control.

The authors express gratitude to the following individuals who worked diligently "behind the scenes" to bring this report to fruition: Maurice Lanman, who managed the data collection and data reduction activities at the Maine Facility; and Patricia Brown and Ann Fulchino, who participated in the data reduction and analysis and assembly of the report.

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1. SUMMARY

This report describes the results of a comprehensive experiment dealing with speed control and driver behavior when approaching and driving through speed zones on a high speed, rural, two-lane highway. The basic objective of the experiment was to test a range of practical traffic control devices which alert drivers to the need for reducing speed when approaching concentrated areas of population and invoke voluntary compliance with the speed regulatory devices in a manner promoting increased safety in vehicle operation. Twelve different configurations of speed limit signs and warning devices were evaluated.

The 12 configurations ranged from the minimum recommendations of the MUTCD (Manual on Uniform Traffic Control Devices)* to advance warning signs coupled with flashers, hereafter referred to as flashing or flasher signs, rumble strips, and pavement markings. The selected test configurations were intended to provide a practical variety with low cost and high likelihood of acceptance and application by the appropriate state agencies responsible for speed control and safety on rural highways.

The experiment was conducted at the Maine Facility, a research and development facility consisting of a 15-mile stretch of electronically instrumented rural two-lane highway located on a major artery (U.S. Route 2) in northern Maine. The instrumentation detects vehicles and tracks their positions as they travel along the highway. Speed profiles were automatically calculated using the Facility's instrumentation scheme, which provides consecutive vehicle elapsed time data between activated detector stations at 200- or 400-foot spacings. These speed profiles represented operational patterns depicting driver response (or lack of response) to the variety of signs and devices tested. As an aid in the analysis the speed profiles were converted to various measures of effectiveness. The basic measures of effectiveness employed in the study

*Federal Highway Administration, Manual on Uniform Traffic Control Devices: For Streets and Highways, U.S. Dept. of Transportation, Washington DC, 1971.

except the flashers and active warning signs showed less than 15 percent compliance. (The speed limit outside the town limits was 50 mph for all sign conditions except sign condition 1 - see section 3.)

Finally, numerous measures of effectiveness were employed and examined in this study (e.g., mean speed, compliance to the 35 mph speed regulation, speed reduction, and 85th speed percentile), and each measure showed basically the same general results delineated above in terms of sign effectiveness. Selection of the most appropriate measures for discriminating sign effectiveness was therefore not a critical matter in this study and may not be for future studies of this type.

3. EXPERIMENT DESIGN

This section describes the Maine Facility test site, the 12 sign configurations evaluated, experimental variables, data collection, and reduction procedures.

All tests were conducted at the Maine Facility, located along U.S. Route 2 between Newport and Canaan. Permanently installed (selectively activated) sensors detected vehicles and tracked their position as they traveled along sections of the electronically instrumented two-lane road. The collected vehicle imformation was transmitted by buried cable to a central station and there recorded on magnetic tape for subsequent off-line data reduction. Eastbound and westbound drivers on U.S. Route 2 entered the 35 mph town speed limit from a 50 mph speed zone for all sign conditions except sign condition 1. For sign condition 1, the speed limit outside the town limits was 60 mph. (The speed limit outside the town limits was changed from 60 to 50 mph between sign conditions 1 and 2 because of the energy crisis early in 1974.) The set of tests were directed at answering the following questions in assessing the relative effectiveness of the 12 sign configurations:

1. How effective were the sign configurations in terms of overall vehicle compliance within the town speed zone?

2. How effective was each sign in bringing about immediate and lasting compliance?

3. For each sign configuration, what was the overall average speed of vehicles not in compliance in the speed zone?

4. What speed reduction was brought about by each sign configuration?

5. Did time of day (day/night) effect driver behavior (in terms of compliance or speed reduction) for the different sign configurations?

These questions are specifically addressed in sections 4.3 through 4.9; a summary of the major points appears in section 4.10.

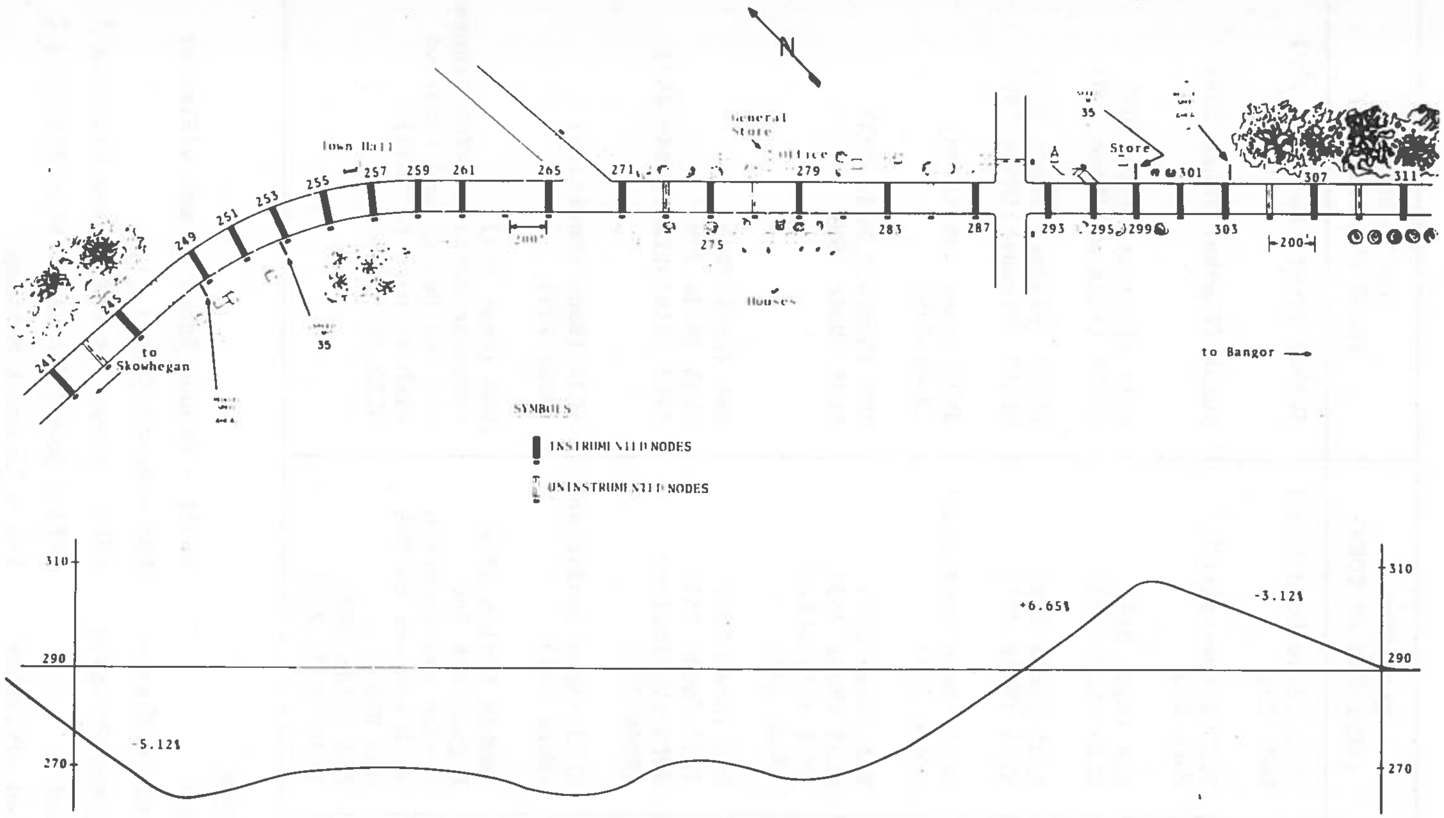
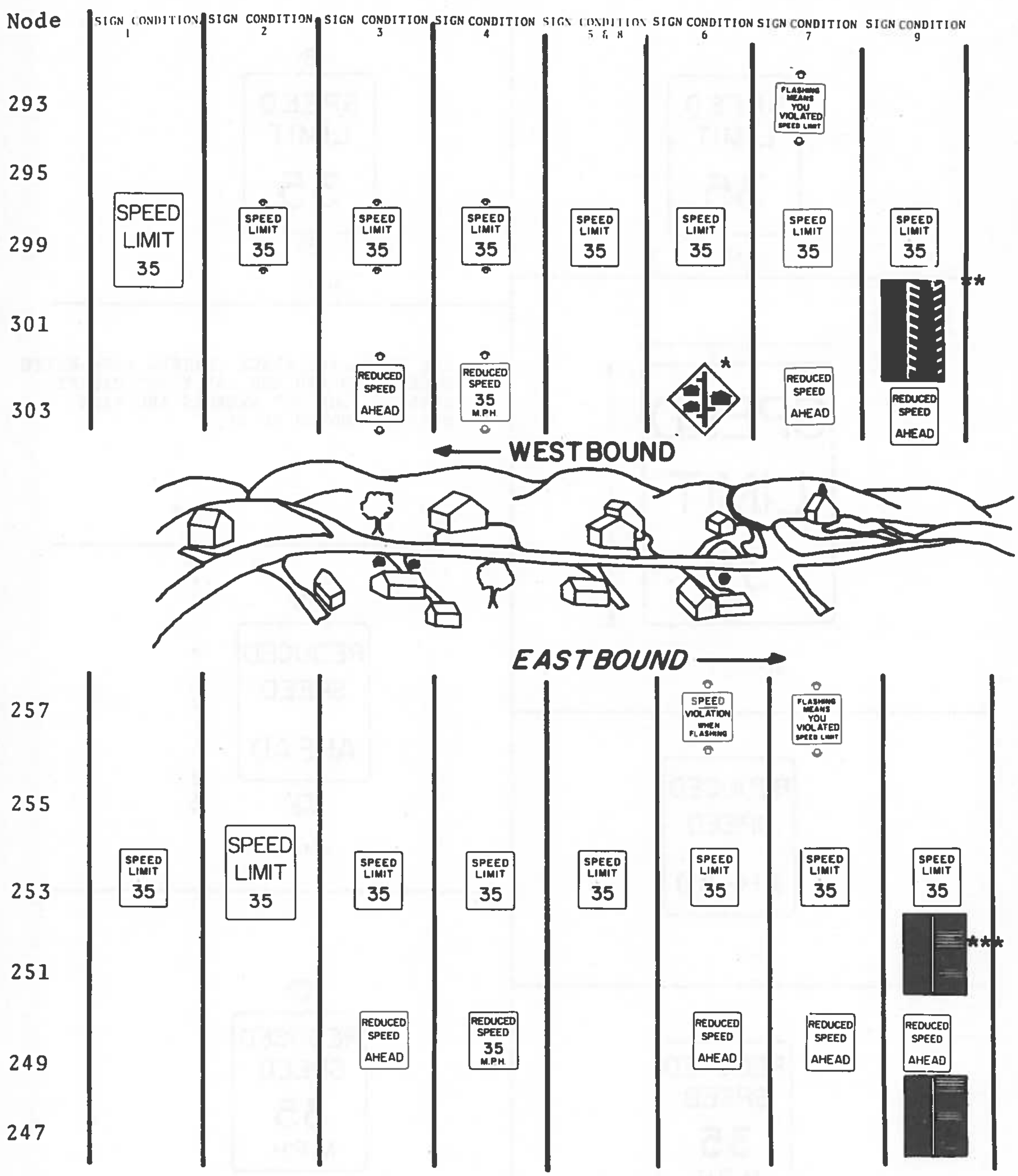
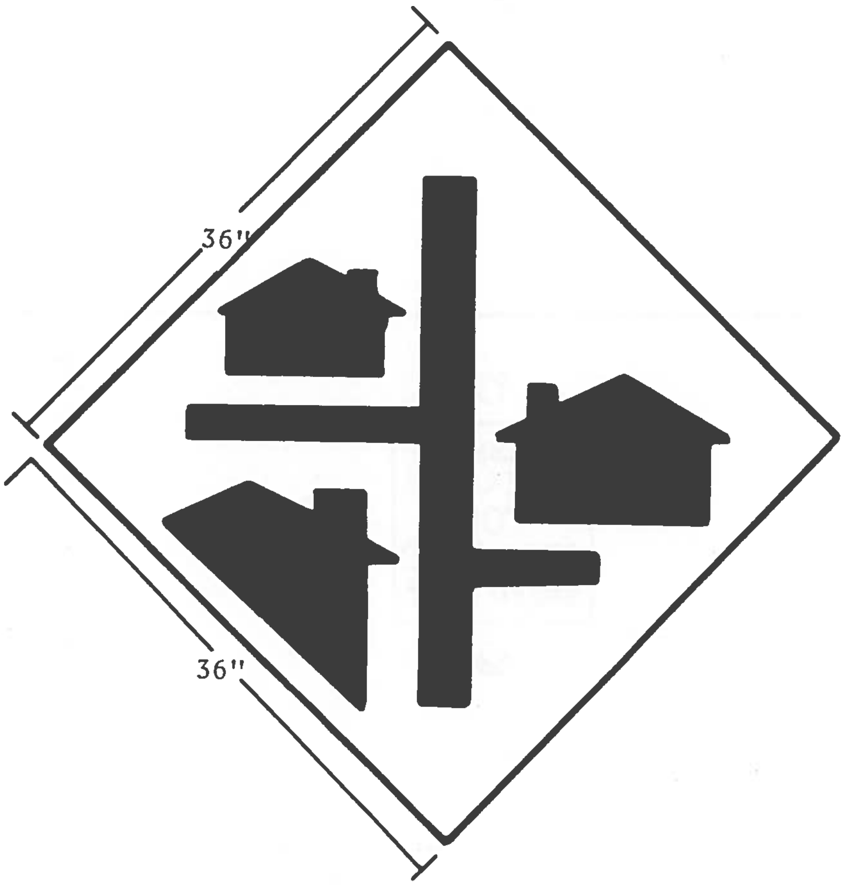


FIGURE 3-1. TEST SITE FOR PALMYRA TOWN EXPERIMENT (SIGN CONDITION 3 LOCATIONS SHOWN)



* Symbol Sign
** Road Markings
*** Rumble Strips

FIGURE 3-2. SIGN CONFIGURATION SEQUENCE



SYMBOLS ARE BLACK WITH A YELLOW BACKGROUND.

FIGURE 3-4. SYMBOLIC ADVANCE WARNING SIGN

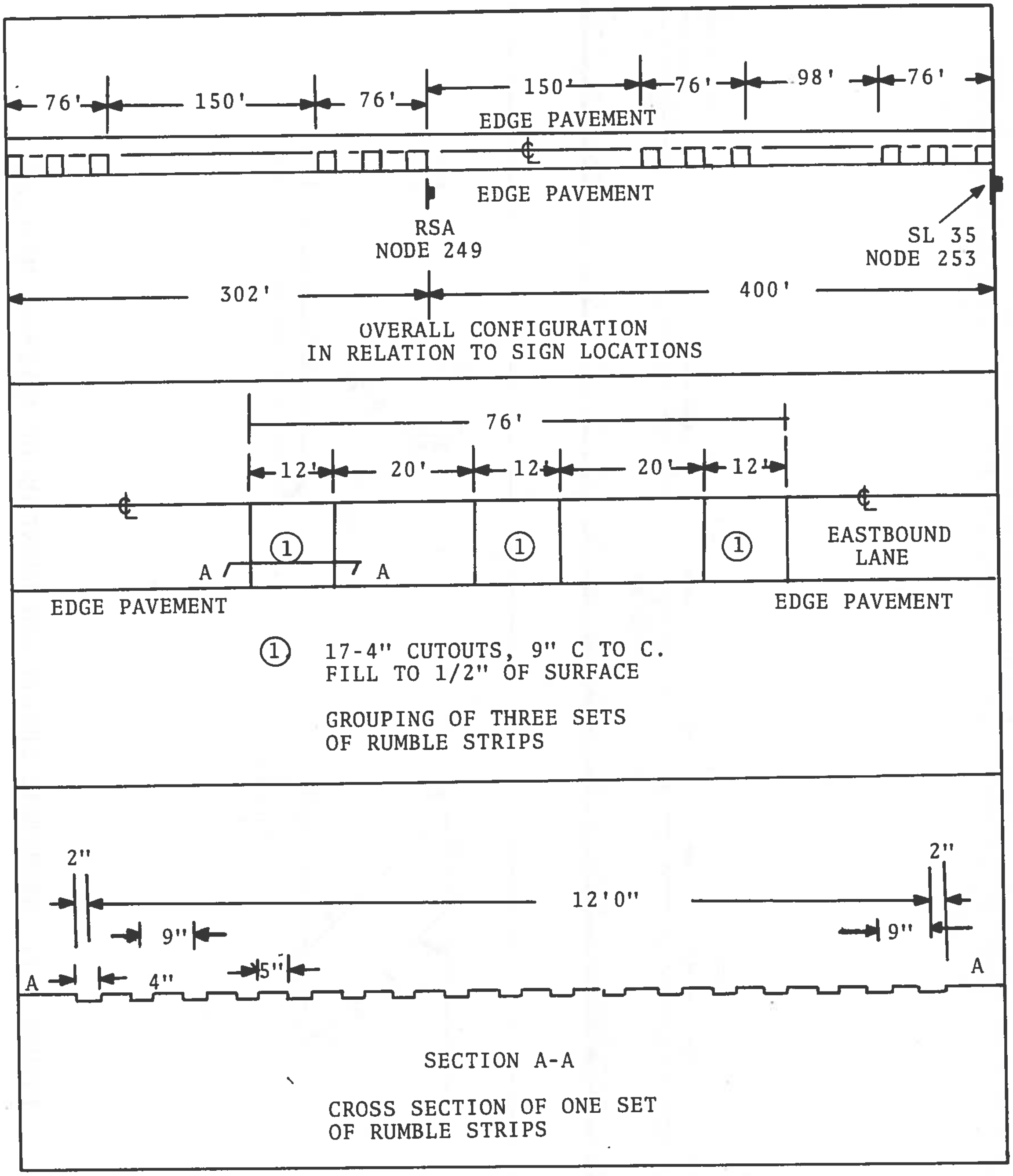


FIGURE 3-6. GEOMETRIC DESIGN AND LOCATION OF RUMBLE STRIPS

2. The flasher signs flashed at all times during the test period, even when data were not being taken.

3. The speed violation signs operated approximately 80 percent of the total time during the 2-week test period while actual data for subsequent analysis were being collected during selected time periods only (see Table 3-4).

4. The symbolic sign was intended, without any advance education, to be interpreted as "approaching built-up area, with entrances, side roads and buildings—prepare to slow down."

5. The speed violation signs operated as follows: When a vehicle speed of over 40 mph was computed at node 253 eastbound or at node 299 westbound, the speed violation sign would flash when the vehicle was between nodes 253 and 257, eastbound, or between nodes 299 and 293, westbound, respectively.

6. The speed violation sign for sign condition 7 was intended to test driver reaction to the use of "YOU" as a more "personal" motivation to slow down.

7. For sign condition 7, the same configuration was tested for both eastbound and westbound traffic to determine the effects of roadside geometrics at each side of town.

8. The rumble strips (sign configuration 9, eastbound) consisted of slots cut through the top course of the pavement and then filled neatly to within 1/2 inch of the surface. This provided the same effect on a vehicle as if the strips were raised 1/2 inch above the surface. This design gave an initial warning to a driver of a 50 to 55 mph vehicle of about 4 seconds or about 300 ft prior to the "Reduced Speed Ahead" (RSA) sign. The sequence was: 1 second "rumble," 2 seconds silence, and 1 second "rumble" as the vehicle passed the RSA sign. Slower vehicles produced a less distinct rumble, and a vehicle maintaining high speed produced the same "amplitude" of rumble for all sets of the strips.

9. The pavement markings were designed to provide a funnel effect and a sensation of increased speed as the driver moved through the markings because of the marks becoming closer together

1. Payment bare and dry*
2. Pavement bare and wet
3. Snow on pavement
4. Ice on pavement
5. Slush on pavement
6. Skid (determined with test vehicle).

h. Visibility—10 condition code:

1. Clear*
2. Partly Cloudy*
3. Cloudy*
4. Raining
5. Freezing Rain
6. Sleeting
7. Light Snow
8. Heavy Snow
9. Fog
10. Visibility < 500 ft.

This report examines the effects of vehicle type (auto/other); motorcycles were not included because of their low sample sizes) vehicle direction (eastbount/westbound), and time of day (day/night) for throughput vehicles with no conflict and during good weather conditions (i.e., road condition 1 and visibility conditions 1, 2, or 3). In addition, vehicle/vehicle interaction effects and time-of-day (hourly) effects are discussed separately in Appendixes C and D, respectively.

The dependent variables were those that varied from node to node. The dependent variables collected were:

a. Speed—calculated average speed between two nodes.

*Considered good weather condition in this report.

the average speed profiles and speed percentile profiles for a few test conditions are provided in Appendixes B and A, respectively.

The speed variance profiles and speed distributions as well as the headway variable were taken in this report to provide indications of vehicle/vehicle accident potential due to driver reaction to the various sign configurations. This information was considered of secondary importance in determining the effectiveness of the sign configurations. These measures are discussed and analyzed in Appendix C.

3.4 DATA COLLECTION

Electronic data were collected using the Maine Facility's existing instrumentation scheme, which tracked vehicles through the experimental layout and provided consecutive vehicle travel speed data between the nodes. The data collection schedule for the town experiment is shown in Table 3-2. Each sign condition was tested over a 2-week period. Data were collected daily, Monday through Sunday, to assure sample sizes sufficient for data analysis.

TABLE 3-2. DATA COLLECTION SCHEDULE

SIGN CONDITION	DATA COLLECTION PERIOD
1	Nov. 5, 1973 - Nov. 16, 1973
2	Nov. 26, 1973 - Dec. 7, 1973
3	Dec. 10, 1973 - Dec. 28, 1973
4	Jan. 3, 1974 - Jan. 16, 1974
5	Jan. 18, 1974 - Feb. 4, 1974
6	Feb. 5, 1974 - Feb. 22, 1974
7	Feb. 25, 1974 - Mar. 8, 1974
8	Mar. 13, 1974 - Apr. 1, 1974
9	May 13, 1974 - May 28, 1974

TABLE 3-3. SAMPLE SIZES OF ANALYSIS DATA

SIGN CONDITION	WESTBOUND VEHICLES			EASTBOUND VEHICLES		
	DAY-AUTO	DAY-OTHER	NIGHT-AUTO	DAY-AUTO	DAY-OTHER	NIGHT-AUTO
1	718	149	480	614	111	612
2	675	108	505	660	122	405
3	331	81	366	297	54	218
4	493	121	413	332	80	425
5	676	143	234	646	123	225
6	620	76	192	597	118	221
7	1020	176	192	1020	179	205
8	1040	170	165	1280	175	93
9	1420	212	159	1320	197	125

TABLE 3-4. TIME OF DAY CODE

TIME PERIOD CODE	TIME	DAY OF WEEK
1	0800 - 1000	Monday
2	1600 - 1800	
3	0600 - 0800	Tuesday
4	1200 - 1400	
5	1800 - 2000	
6	0800 - 1000	Wednesday
7	1400 - 1600	
8	2000 - 2200	
9	1000 - 1200	Thursday
10	1600 - 1800	
11	2200 - 2400	
12	0600 - 0800	Friday
13	1200 - 1400	
14	1200 - 1600	Saturday
15	1200 - 1600	Sunday

DATE	S.C.	ID	TIME	NODE	VEL.	HW	LV	L	CF	T.V.	<400	VT	TC	TUD	WKND	RC	VIS
2/12	6	4	61 8: 7	245	44.3	48.8	N/C		0	0E	NO	A,16	3	NHT	R=1		W=2
		4	61 8:14	249	44.6	49.7	N/C										
		4	61 8:17	251	42.6	50.2	N/C										
		4	61 8:20	253	39.4	50.8	N/C										
		4	61 8:24	255	35.5	51.3	N/C										
		4	61 8:28	257	33.6	51.8	N/C										
		4	61 8:32	259	32.8	51.9	N/C										
		4	61 8:37	261	32.3	52.0	N/C										
		4	61 8:45	265	31.6	53.0	N/C										
		4	61 8:55	271	29.8	52.2	N/C										
		4	61 9: 3	275	29.1	9.5	N/C										
		4	61 9:12	279	31.8	10.4	N/C										
		4	61 9:21	283	32.0	12.6	N/C										
		4	61 9:31	287	28.0	16.4	N/C										
		4	61 9:36	293	26.6	18.6	N/C										
		4	61 9:41	295	28.0	20.5	N/C										
		4	61 9:45	299	29.6	22.2	N/C										
		4	61 9:50	301	31.8	23.7	N/C										
		4	61 9:54	303	33.8	25.0	N/C										
		4	6110: 1	307	36.1	27.4	N/C										
		4	6110: 9	311	35.9	30.0	N/C										
2/12	6	5	61 8:59	245	37.9	51.7	N/C		0	0E	NO	A,15	3	NHT	R=1		W=2
		5	61 9: 7	249	36.1	53.2	N/C										
		5	61 9:11	251	34.4	54.0	N/C										
		5	61 9:15	253	33.3	54.6	N/C										
		5	61 9:19	255	31.8	55.0	N/C										
		5	61 9:23	257	32.1	55.2	N/C										
		5	61 9:28	259	32.3	55.3	N/C										
		5	61 9:32	261	33.8	55.1	N/C										
		5	61 9:39	265	36.3	54.0	N/C										
		5	61 9:47	271	36.4	52.3	N/C										
		5	61 9:54	275	36.5	50.5	N/C										
		5	6110: 1	279	38.1	49.0	N/C										
		5	6110: 8	283	40.7	47.2	N/C										
		5	6110:15	287	39.1	44.4	N/C										
		5	6110:19	293	37.4	42.9	N/C										
		5	6110:22	295	38.7	41.6	N/C										
		5	6110:26	299	38.0	40.6	N/C										
		5	6110:29	301	41.0	39.6	N/C										
		5	6110:33	303	41.8	38.8	N/C										
		5	6110:39	307	44.4	37.4	N/C										
		5	6110:45	311	42.3	36.3	N/C										
2/12	6	7	61 9: 9	245	53.9	9.5	N/C		0	0E	YES	A,18	3	NHT	R=1		W=2
		7	61 9:14	249	52.6	7.1	N/C										
		7	61 9:17	251	47.3	6.0	N/C										
		7	61 9:20	253	44.4	5.0	33.5										
		7	61 9:23	255	39.4	4.2	32.0										
		7	61 9:27	257	35.3	3.8	32.0										
		7	61 9:32	259	30.5	4.0	31.9										
		7	61 9:36	261	29.2	4.7	34.3										
		7	61 9:45	265	31.3	5.9	36.2										
		7	61 9:54	271	32.0	6.9	36.3										
		7	6110: 2	275	31.4	8.1	36.7										
		7	6110:11	279	31.6	9.6	N/C										
		7	6110:19	283	34.5	10.8	N/C										
		7	6110:27	287	35.8	11.5	N/C										
		7	6110:30	293	38.0	11.4	N/C										
		7	6110:34	295	39.4	11.3	N/C										
		7	6110:37	299	40.2	11.1	N/C										

FIGURE 3-9. SAMPLE PRINTOUT OF SORTED-DATA FILE

also separated the data by vehicle type (i.e., auto or other). The content of the "combined-statistic table" files was the same as that for the "statistic-table" files. (See above.)

The last stage of the data reduction provided various types of data presentations for interpretation and analysis. These methods of presentation were used in addressing the specific questions outlined above and are discussed in more detail in the next section.

4.2 ANALYSIS APPROACH

The analysis approach used in this evaluation was to compare the sign configurations in terms of the measures of effectiveness. In general, sign configurations that showed more compliance, greater speed reduction, and less average speed for those vehicles not in compliance were considered more effective. Those sign configurations that showed apparent conflicting results from one measure to another are discussed in detail when they occur.

It is not the primary purpose of this report to evaluate the importance of relatively small differences in effectiveness, but rather to evaluate their statistical significance and the extent to which observed differences are threatened by uncontrollable variability in experimental conditions. This is one of the reasons why the base sign is evaluated at both ends of town for two time periods (i.e., to provide a reference condition for examining uncontrollable experiment variability). The accuracy of the average measurement for the stated conditions is indicated by "error bars" in the data that follow. These are very conservative and determined by large sample formulas for 95 percent confidence intervals.

In other words, for large samples (say, larger than 25—note from Table 3-3 that all sample sizes for the data categories shown are much larger than 25), the "true" average value of the measure under the experimental conditions will be within the confidence interval 95 percent of the time. Usually, therefore, the estimate is considerably better than the error bars would indicate. (See Appendix E for the procedures for determining confidence intervals for a given data category).

In comparing two data points (average of a measure over a given data category) the statistical significance of the difference can be determined by the overlap of the error bars. This is demonstrated in Figure 4-1. If the error bars have no overlap (Case 1), the statistical significance of the observed difference is very high, and there is practically no threat from sampling error (which is what the error bars indicate). The only threat would then be through an uncontrolled variability of experimental conditions, and that is something which can only be evaluated by assessing a complex redundant pattern of tests—which is what is primarily done in this section. If the error bars overlap to the extent that the center point (observed mean) of one measure falls within the error bars of the other (Case 2), then the statistical significance of the result is considerably less than 95 percent and one can tentatively assume that no significant difference has been established. In the intermediate case of overlapping of error bars, but not of the error bars of one with the center point of the other (Case 3), a significant difference is suggested. The exact point where 95 percent confidence can be ascribed to the statement that the "population means differ by an amount exceeding zero"—the usual statement of a significant difference—can be of use in comparing the results with other experiments. Too much reliance on such an observation is cautioned against because (1) the case to test is usually chosen as the largest difference observed among several differences, and (2) uncontrollable experimental variability may be present, which must be estimated by other than sample accuracy formulas. Nevertheless, for this latter case, for large samples $N_1, N_2 > 25$ a 95 percent test of confidence for the difference in the observed means is $\mu_1 - \mu_2 > 2\sqrt{\sigma_1^2 + \sigma_2^2}$ where μ_i is the center point and σ_i half the distance from the center point to one end of the error bar. Three examples of overlapping error bars just meeting this test are given as Cases 4, 5, and 6 in Figure 4-1. These show which situations are significantly different in the conventional sampling theory sense.

In the following sections, the sign configurations are first examined in terms of the primary measures for each data category (Sections 4.3, 4.4, and 4.5) and then in terms of the secondary measures for each data category (Sections 4.6, 4.7, and 4.8). Section 4.9 examines potential learning curve effects. Section 4.10 summarizes the significant results (by data category) of each sign configuration.

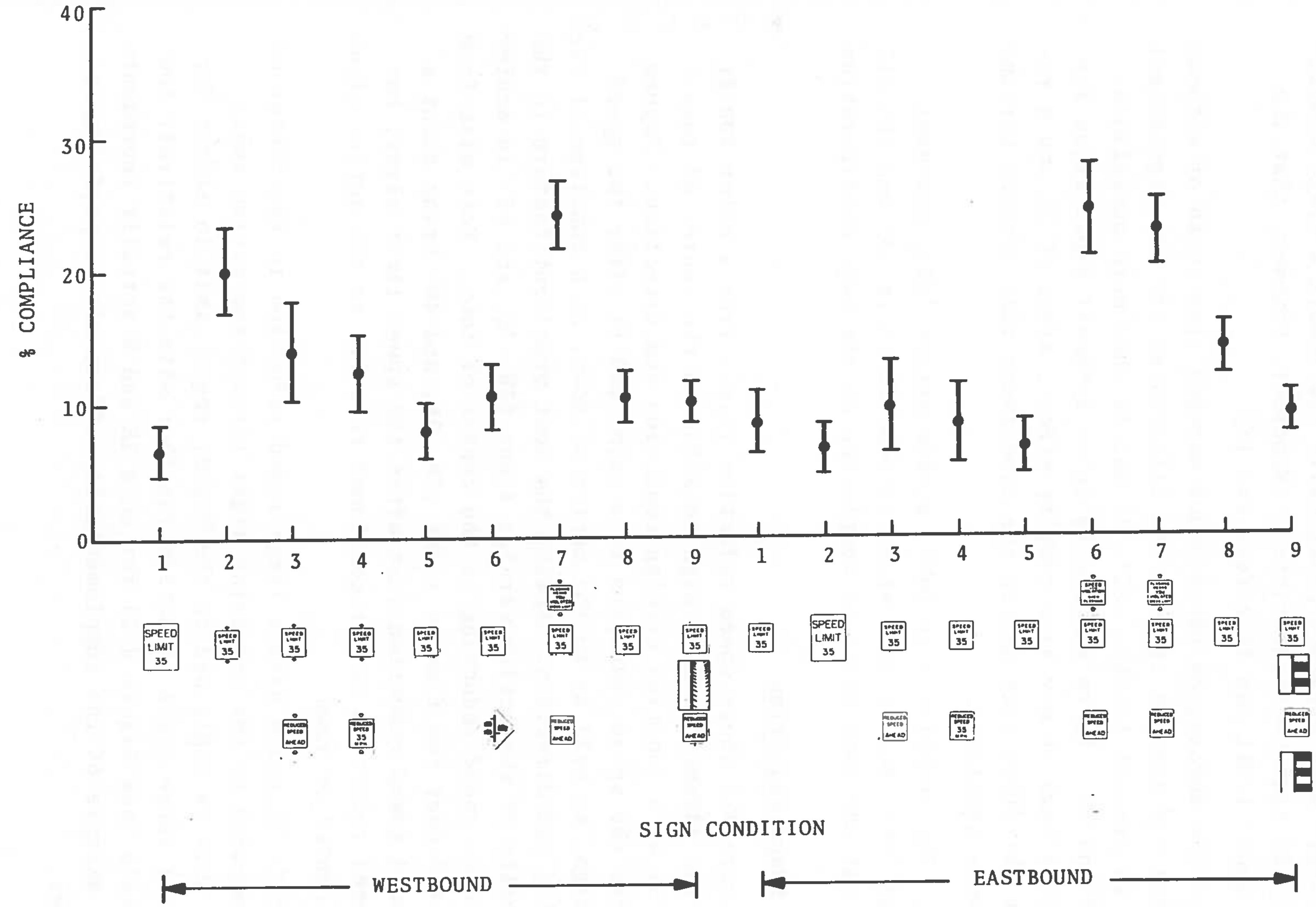


FIGURE 4-2. AVERAGE COMPLIANCE VS. SIGN CONDITION - DAY-AUTO

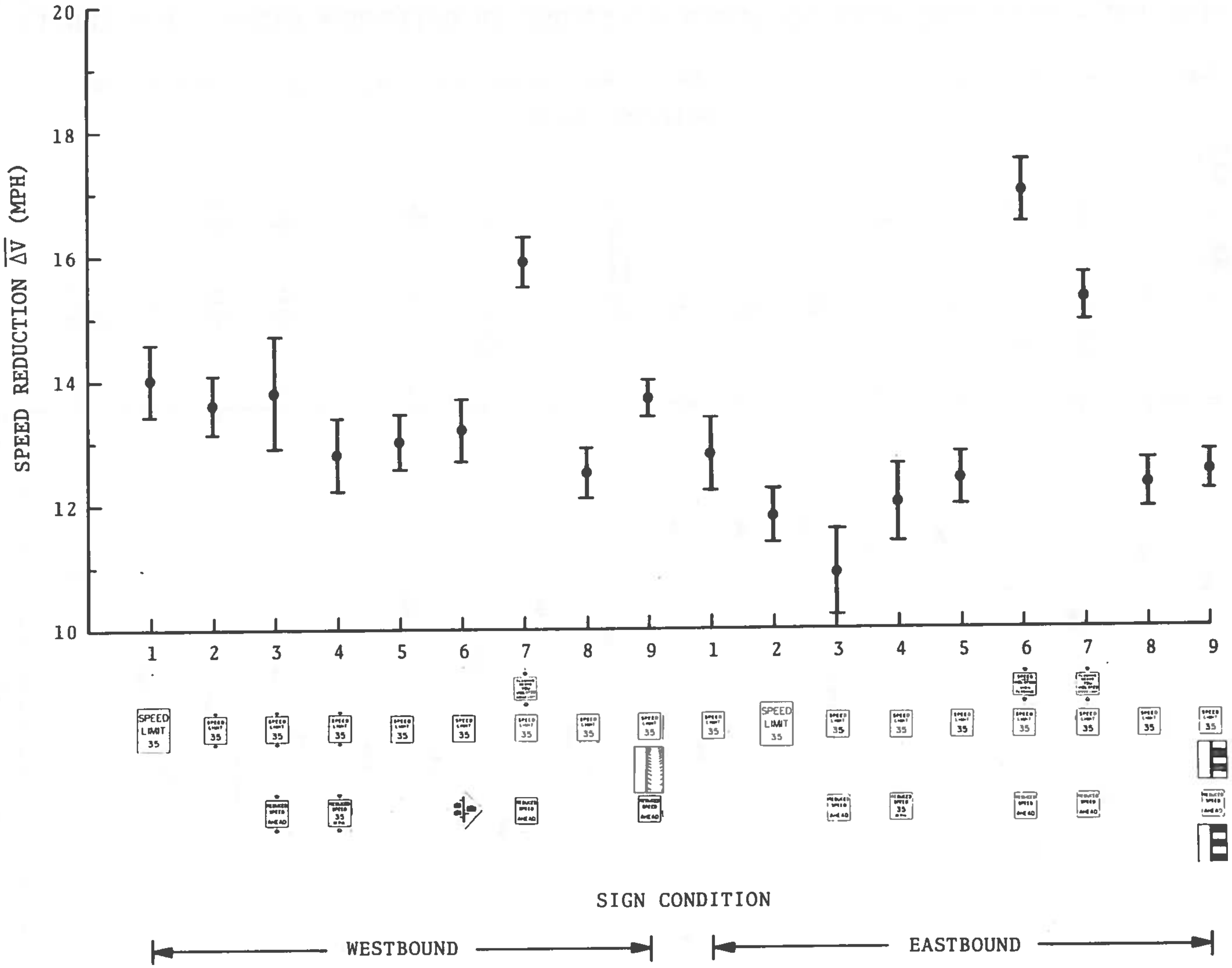


FIGURE 4-3. SPEED REDUCTION VS. SIGN CONDITION - DAY-AUTO

Other notable features displayed in Figure 4-3 are

a. The same sign configuration tested during the same time period (i.e., SC's 5, 7, and 8) receives more speed reduction in the westbound direction.

b. Signs that differ by flashers only show more speed reduction than their counterparts, thus reinforcing the compliance results. A double contrast test was performed (see Appendix F) to validate this statement (i.e., sign configuration vs. directional effects).

c. Enlarging the base configuration sign does not appear to be effective in terms of speed reduction. A lesser speed reduction to the center of town actually occurred in the eastbound direction.

d. The wording on the advance warning sign seems to have a slight effect in terms of speed reduction. E4 shows slightly more speed reduction than E3, but E3 shows more compliance. Therefore, no apparent advantage is indicated for either sign with respect to the other.

e. The symbolic sign (6W), rumble strips (9E), and advance warning signs without flashers (3E and 4E) in general do not bring about much more speed reduction than the base configuration.

f. The rumble strips (9W) in general show more speed reduction than the base configuration.

4.3.3 Average Speed of Vehicles Not in Compliance

Figure 4-5 shows the average speed of those vehicles not in compliance (see Section 3.3 for definition) as a function of sign condition and direction. The high average speeds for SC's 1E and 1W are readily apparent. As indicated earlier, this is because of the higher speed limit, 60 mph, that was in effect when SC's 1E and 1W were tested. Also, at the higher speed limit the oversize base configuration shows slightly less average speed than the base configuration. Other indications seem to suggest that this effect is probably more due to road geometry than to sign configuration. Also readily apparent is the superiority (low average speeds) of the active warning signs 7W, 6E, and 7E. Other points that should be noted are:

a. For westbound traffic, the base sign configuration shows significantly higher average speeds than the other configurations (except for SC 1W). This is not true for eastbound traffic.

b. The flasher signs (2W, 3W, and 4W) are more effective than all sign configurations except for the active warning signs.

c. The same sign configurations tested during the same time period show higher average speeds in the eastbound direction.

d. The wording on the advance warning sign shows no effect in terms of average speed of those vehicles not in compliance.

e. The rumble strips (9E), advance warning signs without flashers (3E and 4E), and enlarged speed limit sign (2E) all show about the same level of average speed as the base sign configuration (excluding 1E and 1W).

f. The symbolic sign (6W) and pavement markings (9W) are slightly more effective (in terms of the average speed measure) than the base configuration and about as effective as the flasher signs.

4.4 PRIMARY RESULTS, NIGHT-AUTO CATEGORY

4.4.1 Average Compliance

Figure 4-6 shows average compliance vs. sign condition and direction for the night-auto category together with the day-auto and day-other categories. The results for the night-auto category are similar to those for the day-auto category. The most notable exception seems to be SC 9 in both directions (rumble strips and pavement markings). These are more effective than all configurations except the active warning signs (7W, 6E, and 7E) and the first flasher sign (2W). The flasher signs (2W, 3W, and 4W) again display (at night) a novelty effect and/or the response to implied danger.

Curiously, the flasher sign (2W) gets less compliance at night than during the day (though not significantly), while 2E appears to be more effective at night. There is further evidence that the flashers are not more effective at night, because in general similar signs without flashers seem to produce a greater tendency towards more night effectiveness (i.e., compare 2W, 3W, and 4W, day vs. night to 5W and 8W, day vs. night).

4.4.2 Speed Reduction

Figure 4-7 shows speed reduction (i.e., from a point 400 ft before the advance warning sign locations to the center of town — node 275 — and to points 200 ft within the speed limit — node 295, westbound; node 255, eastbound) for the night-auto category. Here the only clear effect is the superiority of the active signs. The apparent effectiveness of SC's 1E and W is rejected because of their anomolous status (higher speed limit in effect).

For westbound traffic, the base sign configurations (5W and 8W) show more effectiveness than the flashers (2W, 3W, and 4W) or the pavement markings (9W). This contradicts any evidence for superior effectiveness for these latter signs. It is interesting to note, however, that the pavement markings do receive more early speed reduction (i.e., at node 295) than any sign configuration westbound, which indicates that drivers at night seemed to react quickest to the pavement markings. Further evidence for the lack of any significant effectiveness of the flashers is shown by the fact that SC's 2E, 3E, and 4E are about as effective or more effective in terms of speed reduction than 2W, 3W, and 4W, respectively.

The base sign configurations seem to indicate once again that westbound traffic slows down more than eastbound traffic (suggesting a possible directional or geometric effect), but paradoxically, the flasher signs are not as a group more effective at night than their counterparts without flashers.

Finally, the symbolic sign appears to be the least effective sign configuration at night, in terms of speed reduction.

4.4.3 Average Speed of Vehicles Not in Compliance

Figure 4-8 shows the average speed of those vehicles not in compliance vs. sign condition and direction. Further confirmation of the effectiveness of the active warning signs is again provided.

Although the flasher signs show some effectiveness in that SC's 2W, 3W, and 4W are well below 5W and 8W, the same is not at all true for the eastbound direction. The flasher signs also show more effectiveness at night (as opposed to day) in terms of average speed (compare Figure 4-8 to Figure 4-5). Thus, although these results conflict somewhat with the average compliance measure, the general conclusion is that flasher signs are demonstratably effective at night, since the average speed effect is stronger and highly significant compared to the compliance effect. The nighttime effectiveness of SC 9E and W is again demonstrated. Specifically, 9E is significantly better than 1E, 4E, and 5E, and is probably better than 2E, 3E, and 8E; while 9W is significantly better than 1W, 5W, 6W, and 8W.

4.5 PRIMARY RESULTS, DAY-OTHER CATETGORY

4.5.1 Average Compliance

The average complinace measure for the day-other category is shown in Figure 4-6, together with the other two categories: day-auto and night-auto. "Other" vehicles are defined as those vehicles greater than 20 ft in length and are therefore either trucks, buses, or other large vehicles. As such, they can be expected to follow a specific behavior pattern – namely, the speeds at which they travel will be determined to a much greater extent than for cars by the geometry of the roadway. In other words, large vehicles have a greater tendency to travel as fast as they can gathering speed going down hills and losing it while going up. The effect of speed control signs is therefore counteracted to a great extent by the desire of the driver of a large vehicle not to lose his momentum or to slow down in a situation that will make getting over an approaching hill difficult. Almost all the observed differences from auto behavior are accounted for by this phenomenom.

According to Figure 4-6, the active warning signs show special effectiveness even for large vehicles. In general, Figure 4-6 shows that the large vehicles behave very similarly to the autos in terms of average compliance with very little distinction between their reaction to the signs.

4.5.2 Speed Reduction

The speed reduction measure, Figure 4-9, shows some insensitivity of large vehicles to signs compared to autos. The superiority of the active signs is, in general, evident, but not to the same degree as for the other data categories. For example, 7W is the most effective westbound but almost equivalent to 9W; 7W is significantly better (in terms of speed reduction to the center of town) than all others westbound, except perhaps 6W. In the eastbound direction 6E is significantly better (again to the center of town) than all other signs; 7E is better than all the remaining sign configurations, but not significantly better than 2E. Figure 4-9 also shows an apparent anamolous effect in that 4W is significantly and strikingly lower in speed reduction to the center of town than all other sign conditions.

4.5.3 Average Speed of Vehicles Not in Compliance

The average speed measure, Figure 4-10, brings out once again the superiority of the active warning signs. Any indications of other more effective signs are rather muted (as shown by the large error bars). This is because of the effect of road geometry and is partly a result of the decreased sample size. The anomalous effect of SC 4W (in terms of speed reduction) is also brought out here. SC 4W has the second highest average speed (second to 1E). Not all anomalies are explainable; 4W is followed by 5W, which paradoxically appears as one of the most effective sign configurations even though it is the base condition.

4.6 SECONDARY RESULTS, DAY-AUTO CATEGORY

4.6.1 Early Compliance

Figure 4-11 shows early compliance (at the speed limit sign location — Nodes 253, eastbound, and 299, westbound; and 200 ft

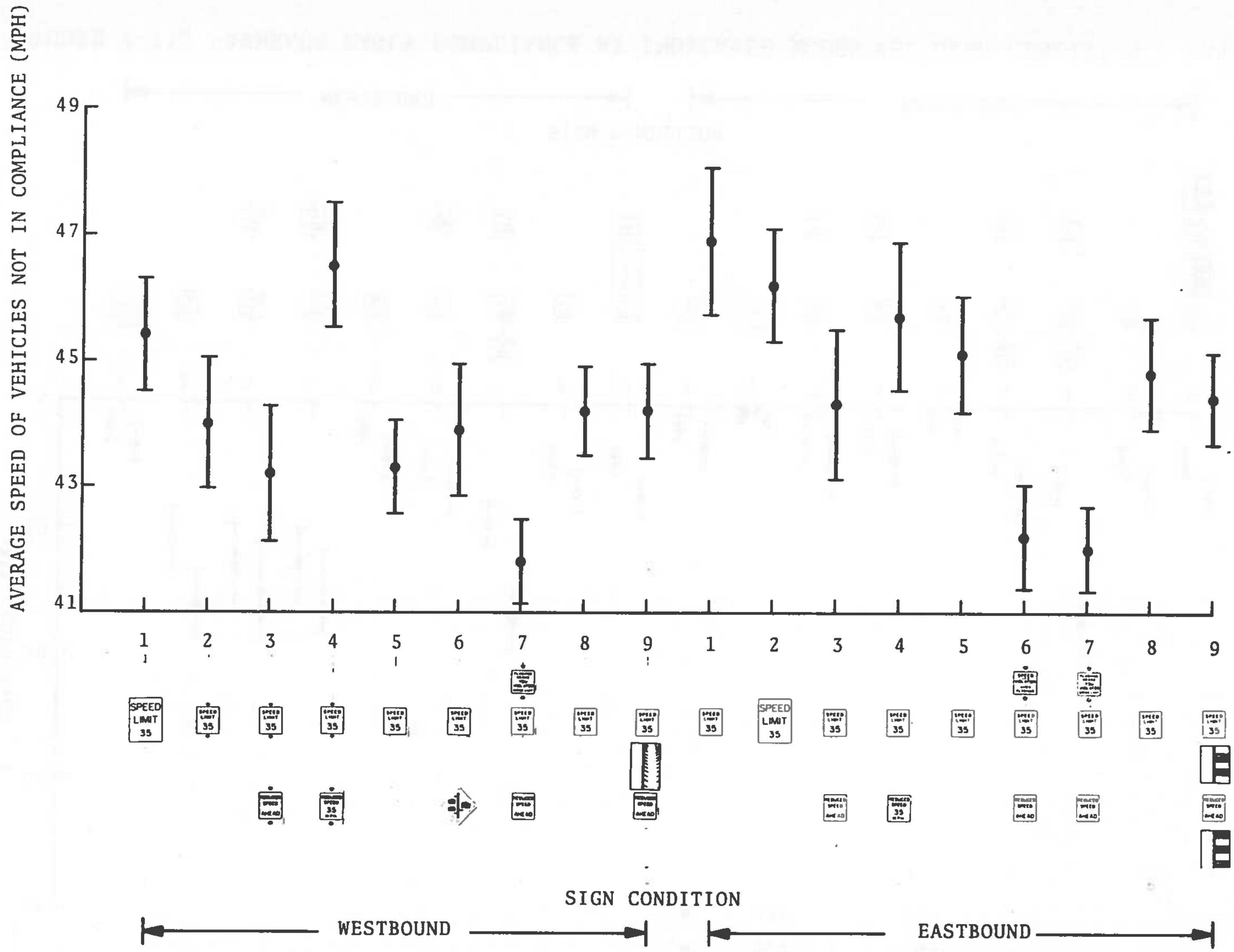


FIGURE 4-10. AVERAGE SPEED OF VEHICLES NOT IN COMPLIANCE IN SPEED ZONE VS. SIGN CONDITION - DAY-OTHER

within the speed limit—Nodes 255, eastbound, and 295, westbound) vs. sign condition and direction. Here, a strong effect for the flashers is indicated. The effect is not only statistically significant but striking. In terms of early compliance the flashers are equally as effective as active signs and superior to the other signs.

Figure 4-11 also shows an anamolously low early compliance for 6E. The explanation could well be a learning effect (see also Section 4.9). Since the violation sign is located after Node 255, it may be that it brings about early compliance—compliance in anticipation of the speed violation sign—only after the sign has a number of days of exposure. Since Figure 4-11 is the average over a 2-week period, the net result was a relatively low compliance.

4.6.2 Late Compliance

Figure 4-12 shows late compliance (essentially at the opposite end of the speed zone from where the signs are displayed) vs. sign condition and direction. Late compliance, even at Node 255, which is within the town speed zone, is virtually nonexistent westbound except for SC 7. This is evidently a road geometry effect, caused by this edge of the town being at the end of the slight downgrade and at the beginning of a sharper upgrade. Eastbound, the geometry is reversed and late compliance is sharply higher (relatively speaking), but still quite low. Figure 4-12 shows an apparent anomaly in the high late compliance for 8E. This may be a holdover learned effect from the very effective active warning signs.

4.7 SECONDARY RESULTS, NIGHT-AUTO CATEGORY

4.7.1 Early Compliance

Figure 4-13 shows early compliance vs. sign condition and direction for the night-auto category. There is virtually no early compliance for SC 1E and W. The westbound direction shows clear advantages, with the flashers having an advantage, the pavement markings a greater advantage (but not at the 95 percent confidence

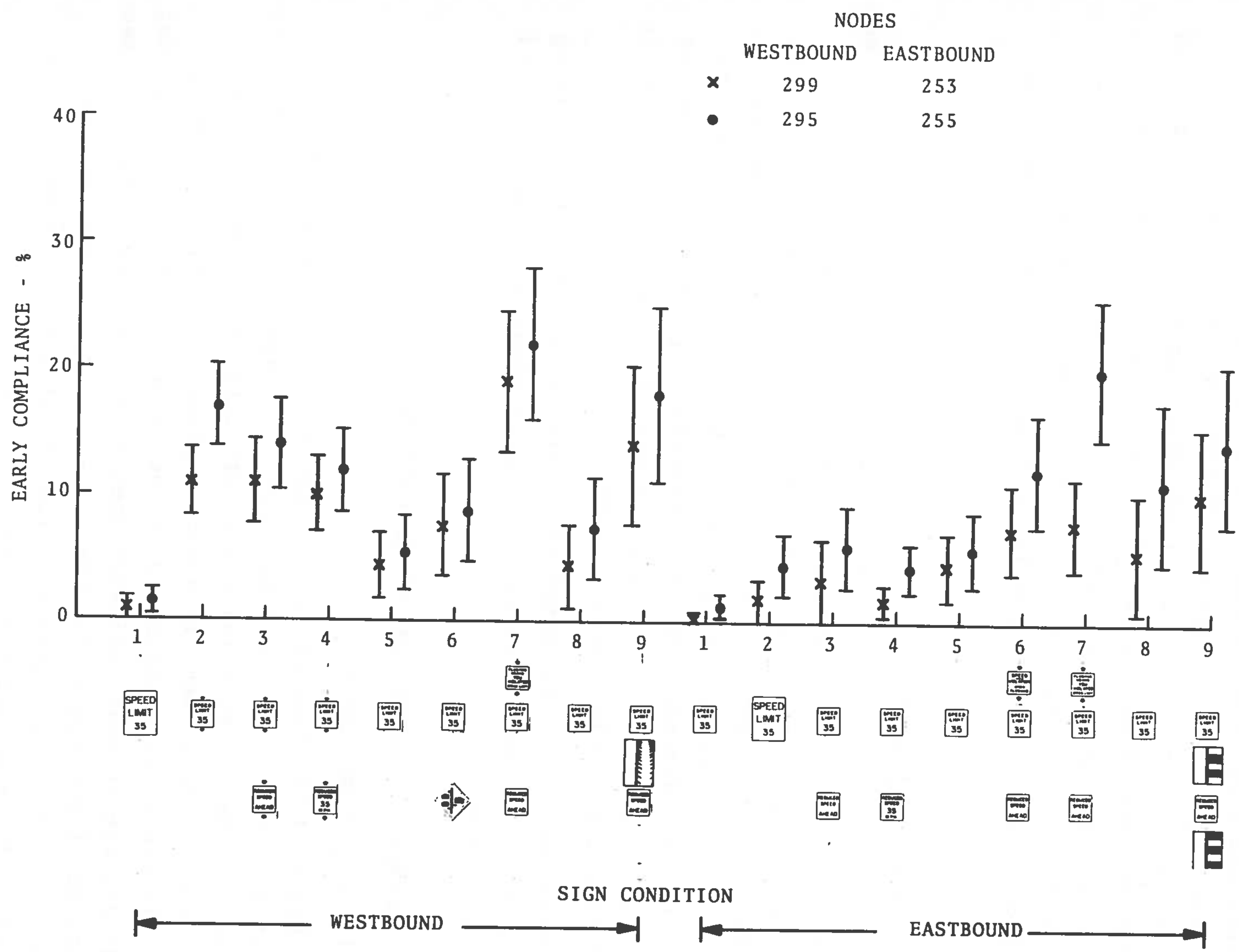


FIGURE 4-13. AVERAGE EARLY COMPLIANCE AT INDICATED NODES VS. SIGN CONDITION - NIGHT-AUTO

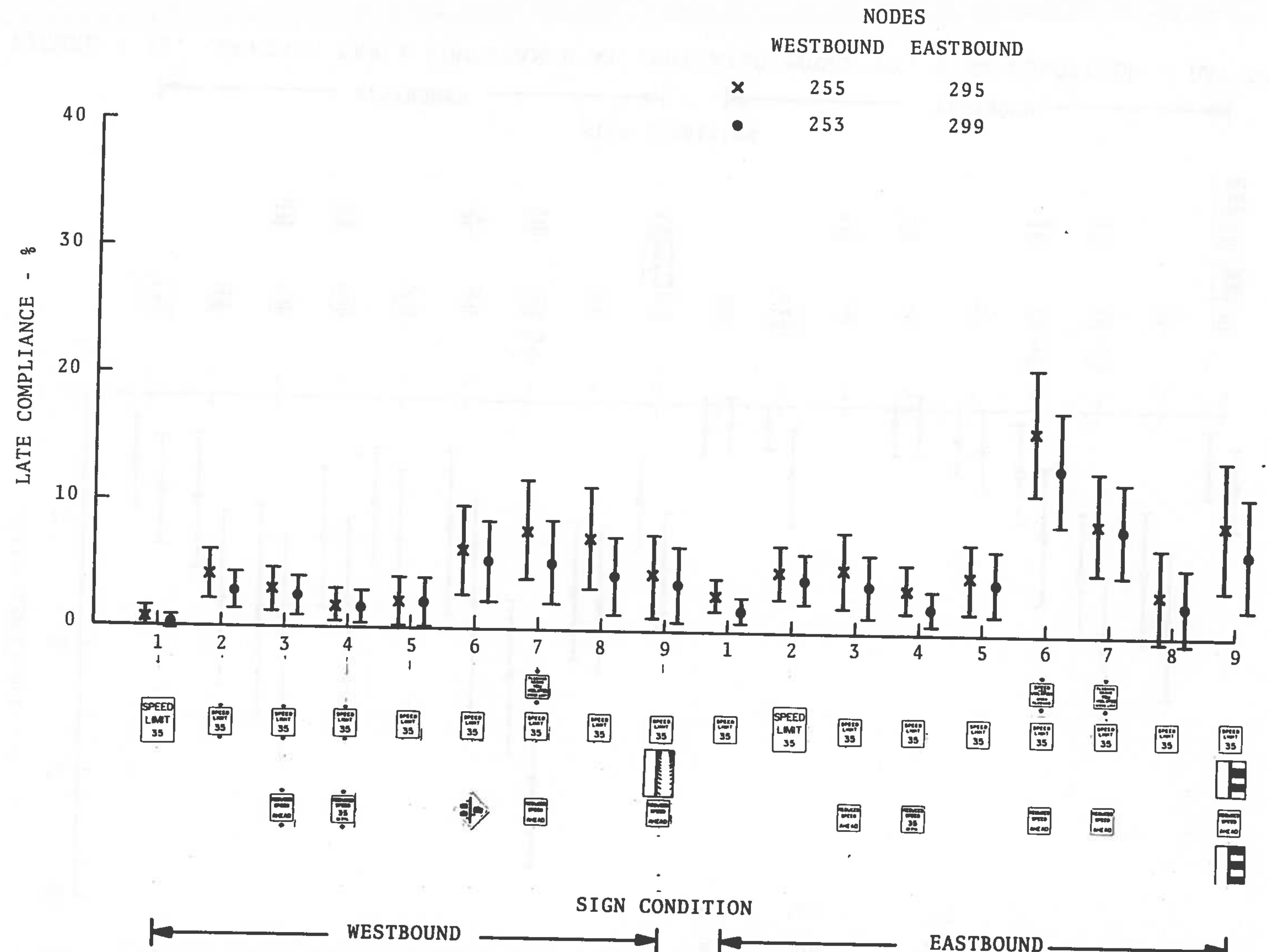


FIGURE 4-14. AVERAGE LATE COMPLIANCE AT INDICATED NODES VS. SIGN CONDITION - NIGHT-AUTO

4.8.2 Late Compliance

Figure 4-16 shows late compliance vs. sign condition and direction for the day-other category. Here again, the most striking effect is due to road geometry. Westbound has very low late compliance; eastbound, late compliance, being measured near the crest of a hill, is much higher. A characteristically higher effectiveness is shown by 7W than by other westbound signs. Also, 6E and 7E show characteristically higher effectiveness than other eastbound signs. Finally, the rumble strips show relatively high effectiveness in terms of late compliance, but with the wide error. Also, bars for all eastbound signs, the added information of the late compliance day-other category is only auxiliary evidence (i.e., most of the observed differences between sign configurations are not significant at the 95 percent level).

4.9 LEARNING CURVE EFFECT ("NOVELTY EFFECT")

This section examines potential learning curve effects; that is, how a driver's reactions to particular sign configurations are influenced by his familiarity with the sign configurations. Since the Maine Facility has a high percentage of repeat drivers (more than 40 percent of the drivers used this section of highway more than once per month, according to one study), familiarity with a new sign configuration for the driving population as a whole increases with time once the new sign is installed. The effect of familiarity can therefore be studied by examining the behavioral measures on a daily basis.

The three primary measures are used to evaluate potential learning effects for SC's 6E and 7E. These sign configurations were chosen because of their demonstrated superiority. In addition, they were tested consecutively and proved quite similar, thus providing a potential data base for evaluating possible extended (in time) learning effects.

Figures 4-17, 4-18, and 4-19 show the average compliance, average speed of those vehicles not in compliance, and speed reduction to the center of town, respectively, plotted vs. day of test and over the complete period the two signs were tested.

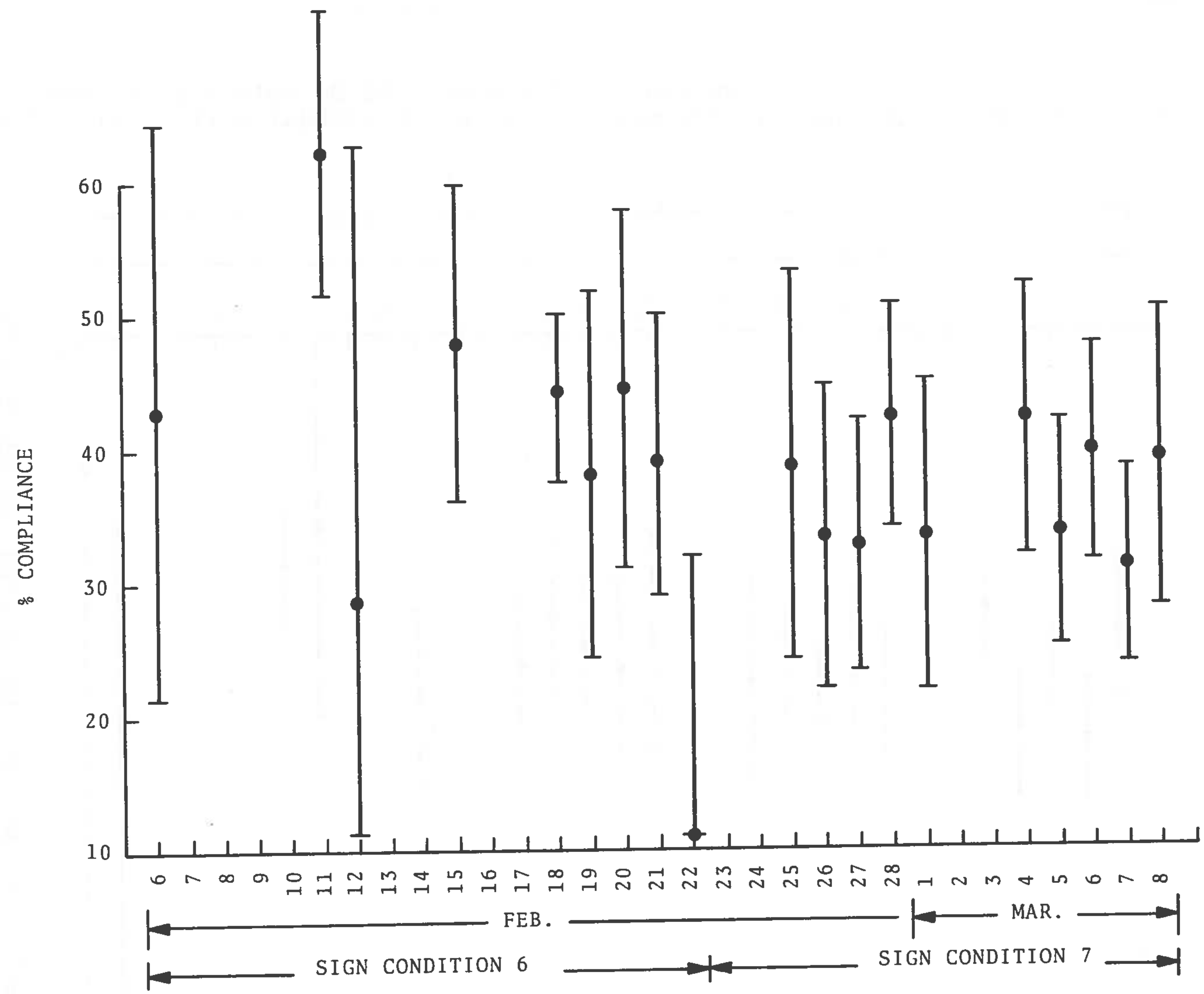


FIGURE 4-17. DAILY AVERAGE COMPLIANCE FOR NODE 275, EASTBOUND, ACTIVE SIGN CONDITIONS 6 AND 7 - DAY-AUTO

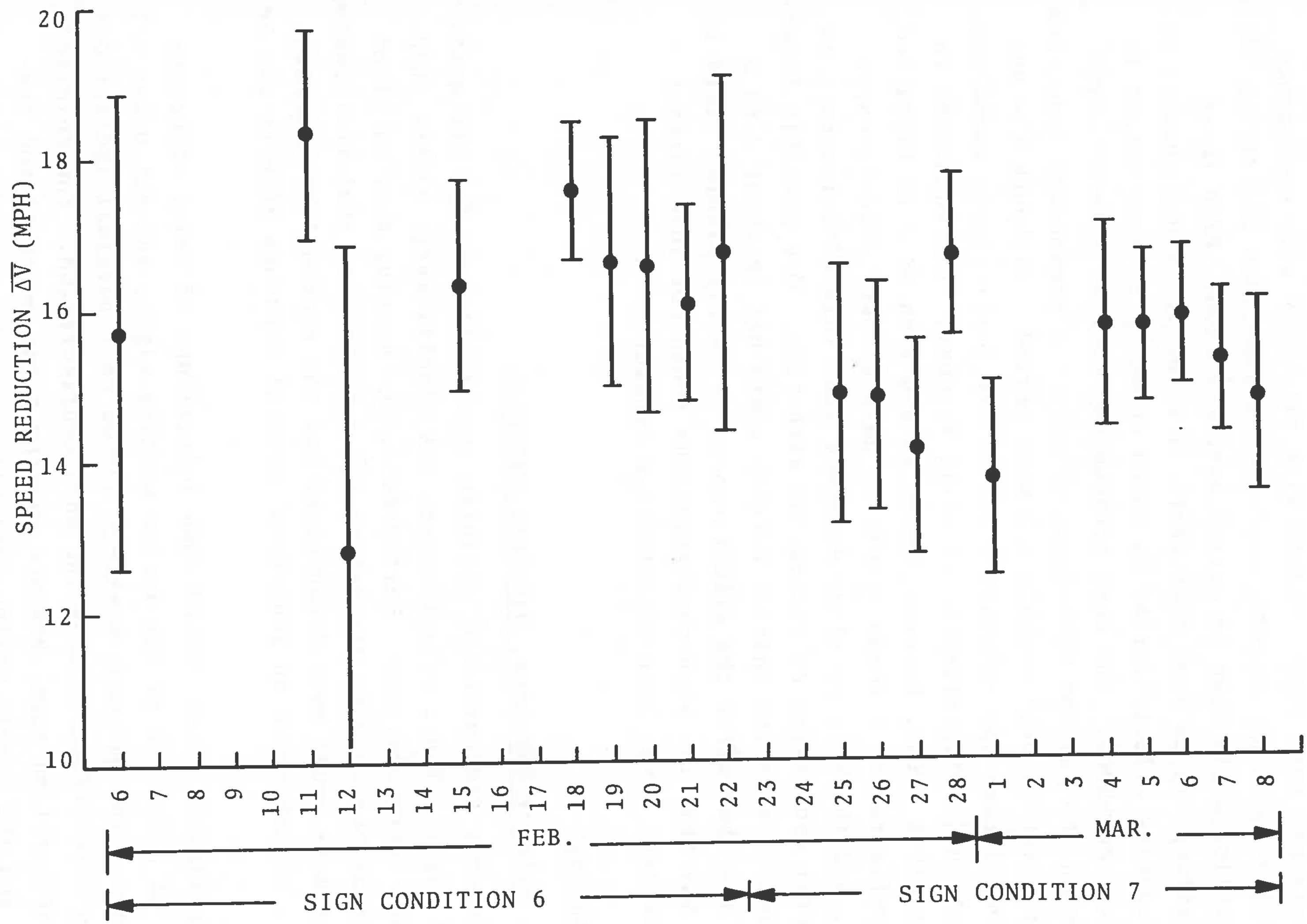


FIGURE 4-19. DAILY SPEED REDUCTION FOR NODE 275, EASTBOUND, ACTIVE SIGN CONDITIONS 6 AND 7 - DAY-AUTO

4.10.2 Primary Measures, Night-Auto Category

The major difference for the night-auto category was the unambiguous effectiveness of the pavement markings and rumble strips. Although they may not be significantly better than the flasher signs, only the active warning signs showed more effectiveness. The pavement markings and rumble strips were roughly equal in their demonstrated effectiveness.

4.10.3 Primary Measures, Day-Other Category

Once again, the active warning signs showed definite superiority. The other sign configurations were either no more effective than the base configuration or the inherent variability in the data—due to smaller sample sizes and geometric effects—masked any differences. There appeared to be definite similarity in response to the sign configurations between "autos" and "other" vehicle types.

4.10.4 Secondary Measures, Day-Auto Category

The active warning signs and flasher signs showed definite and comparable superiority in terms of early compliance (although in one case a learning period requirement was suggested). No other sign configurations showed any more effectiveness than the base configuration. Only the active warning signs showed any indications of being effective in terms of late compliance. Late compliance was relatively low for all sign configurations, especially westbound.

4.10.5 Secondary Measures, Night-Auto Category

Again, in terms of early compliance, the active warning signs showed definite superiority with a learning period requirement suggested in one case. The flasher signs, pavement markings, and rumble strips all rated about equal and next in effectiveness. In terms of late compliance, only one of the active warning signs showed definite indications of being more effective. Again, late compliance was relatively low for all sign configurations, making any comparisons difficult.

5. CONCLUSIONS

An experiment examining speed control and driver behavior when approaching and driving through speed zones on a high speed, rural, two-lane highway has been described. From the results of this experiment the following significant findings were noted:

a. The active warning signs showed superior effectiveness in all measures under all conditions.

b. Advance warning signs without flashers — symbolic or otherwise — did not show increased early or lasting effect.

c. Flasher signs were particularly useful in bringing about early compliance. Their effect on lasting compliance was less pronounced.

d. The pavement markings and rumble strips showed nighttime effectiveness, especially in terms of early compliance. They were not shown to have special effectiveness during the day.

e. The flasher signs were about as good during the day as during the night in terms of compliance.

f. Large vehicles responded similarly to autos in all cases, but were very clearly affected by road geometry.

No attempt was made during the valuation to define absolute criteria for the measures (the existing speed regulation of 35 mph was in itself a criterion), since this was considered beyond the scope of the present work. Furthermore, this study was primarily concerned with obtaining basic performance data and evaluating the relative effectiveness of the 12 sign configurations. It is therefore recommended that highway engineers and planners extend the present effort to determine the requirements for new signing configurations for wide application by assessing the results presented in this report, together with cost/benefit tradeoffs. In addition, further research on flasher signs and active warning signs for rural highway applications is recommended, since these would appear to offer the most potential safety benefits.

APPENDIX A
SPEED PERCENTILE PROFILES

This appendix presents and discusses selected speed percentile profiles (i.e., speed percentiles vs. nodes through the test area) for various sign conditions. The 15th, 50th, and 85th speed percentiles for all sign conditions are available from the authors.

Figure A-1 shows the 85th percentile profile for westbound traffic during the day and for autos only; Figure A-2 shows the 85th percentile profile for westbound traffic at night.

It should be pointed out that no data were plotted at node 251 for sign condition 9. The node was inoperative because of the installation of the rumble strips.

It should also be noted that for all the sign conditions, no data were plotted at the initial nodes in each direction (node 241, eastbound, and node 311, westbound) because of the nature of the tracking algorithm. The speed at each node for each vehicle actually represents the average speed between that node and the prior node. Care should therefore be used when attempting to reference a particular speed to a specific point along the roadway.

The speed percentile results shown in Figures A-1 and A-2 strongly support the findings based on the performance measures presented in the body of this report, namely,

a. The active warning signs were the most effective.

b. The flasher signs appeared to be next in effectiveness and tended to reduce speeds earlier in the approach to the town.

c. There were very few differences among the passive signs.

d. Sign condition 1 showed the highest speeds due to the higher speed limit that was in effect for that condition.

There does appear to be a minor discrepancy between the results for the pavement marking configuration. Although this configuration was considered next in effectiveness after the active signs at night based on the performance measures in the body of this

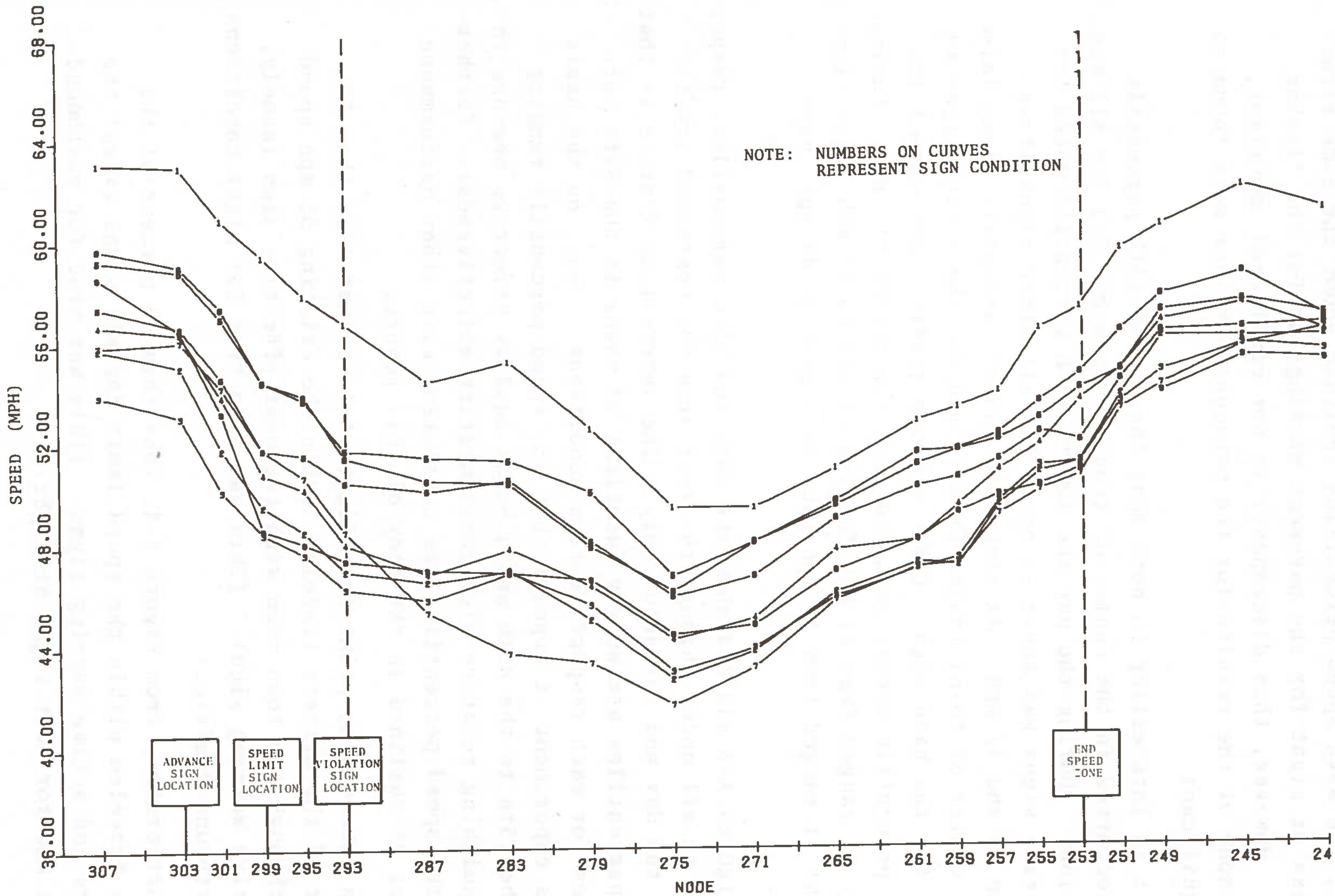


FIGURE A-2. EIGHTY-FIFTH PERCENTILES VS. NODE, WESTBOUND — NIGHT-AUTO

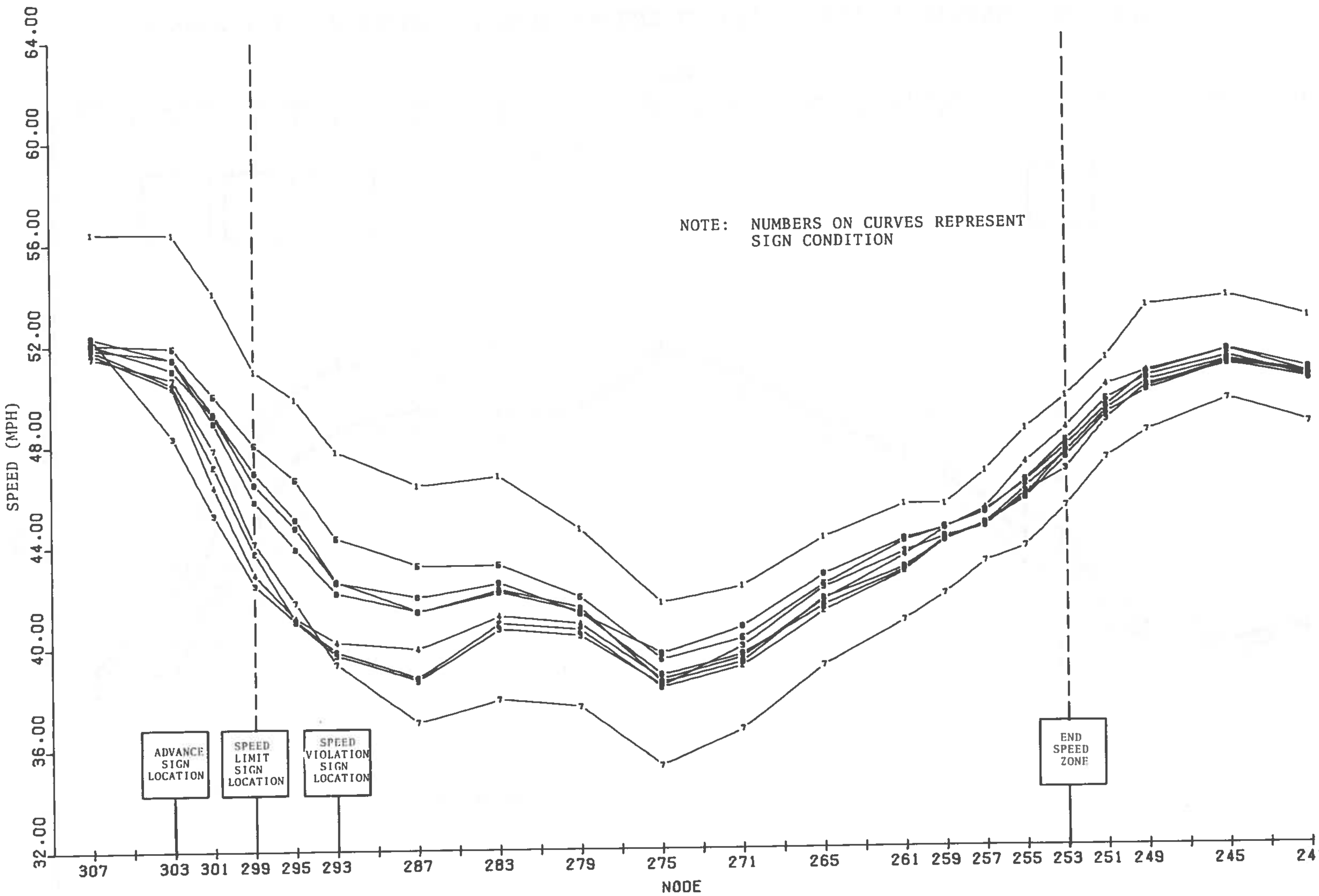


FIGURE A-3. FIFTIETH SPEED PERCENTILE VS. NODES, WESTBOUND — DAY-AUTO

APPENDIX B
AVERAGE SPEED PROFILES

This appendix examines selected speed profiles (i.e., average speed at each node vs. nodes through the test area) for sign conditions 3, 5, 7, and 9 in the west direction for autos both day and night. These sign conditions were chosen for examination here because they are representative of the various types of signs studied in this report. In general, the speed profiles for all sign conditions strongly support the findings presented in the body of this report. The speed profiles for all sign conditions are available from the authors.

The speed profiles are shown in Figures B-1 to B-8 together with the 95 percent confidence intervals (dashed lines). Figures B-1 and B-2 represent westbound autos for day and night, respectively, for sign condition 3 (i.e., flasher signs). Figures B-3 and B-4 represent the same for sign condition 5 (i.e., base sign condition). These figures show that: (1) flasher signs were particularly useful in bringing about early speed reduction although their effect on the speeds near the end of the speed zone was less pronounced; and (2) the flasher signs were about as effective during the day as during the night. The figures show the lowest average speed for sign condition 3 to be 38 mph. The lowest average speed for the base signs was only 1 mph more or 39 mph. These speeds occurred in the center of the town (node 279).

Figures B-5 and B-6 show sign condition 7 west for day and night, respectively. This was an active warning sign condition and was in effect for both eastbound and westbound traffic. In terms of average speeds in the speed zone, the active warning signs were clearly more effective than the flashers (Figures B-1 and B-2). The active warning signs had the lowest average speeds of all the sign conditions. The lowest speed was 35 mph (at node 279). The active warning signs were also equally effective in the night as in the day.

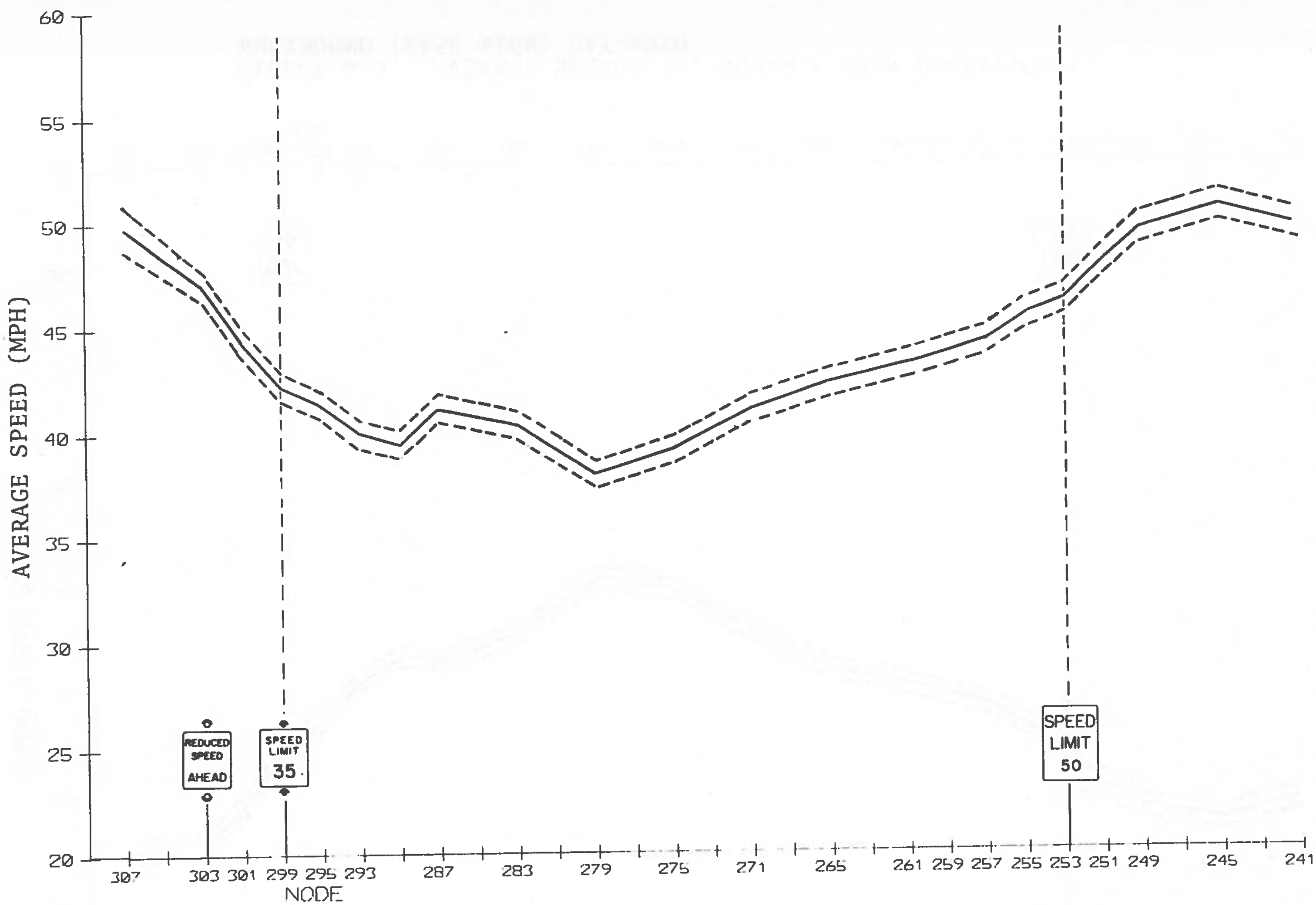


FIGURE B-2. AVERAGE SPEED VS. NODES - SIGN CONDITION 3, WESTBOUND (FLASHER SIGNS) NIGHT-AUTO

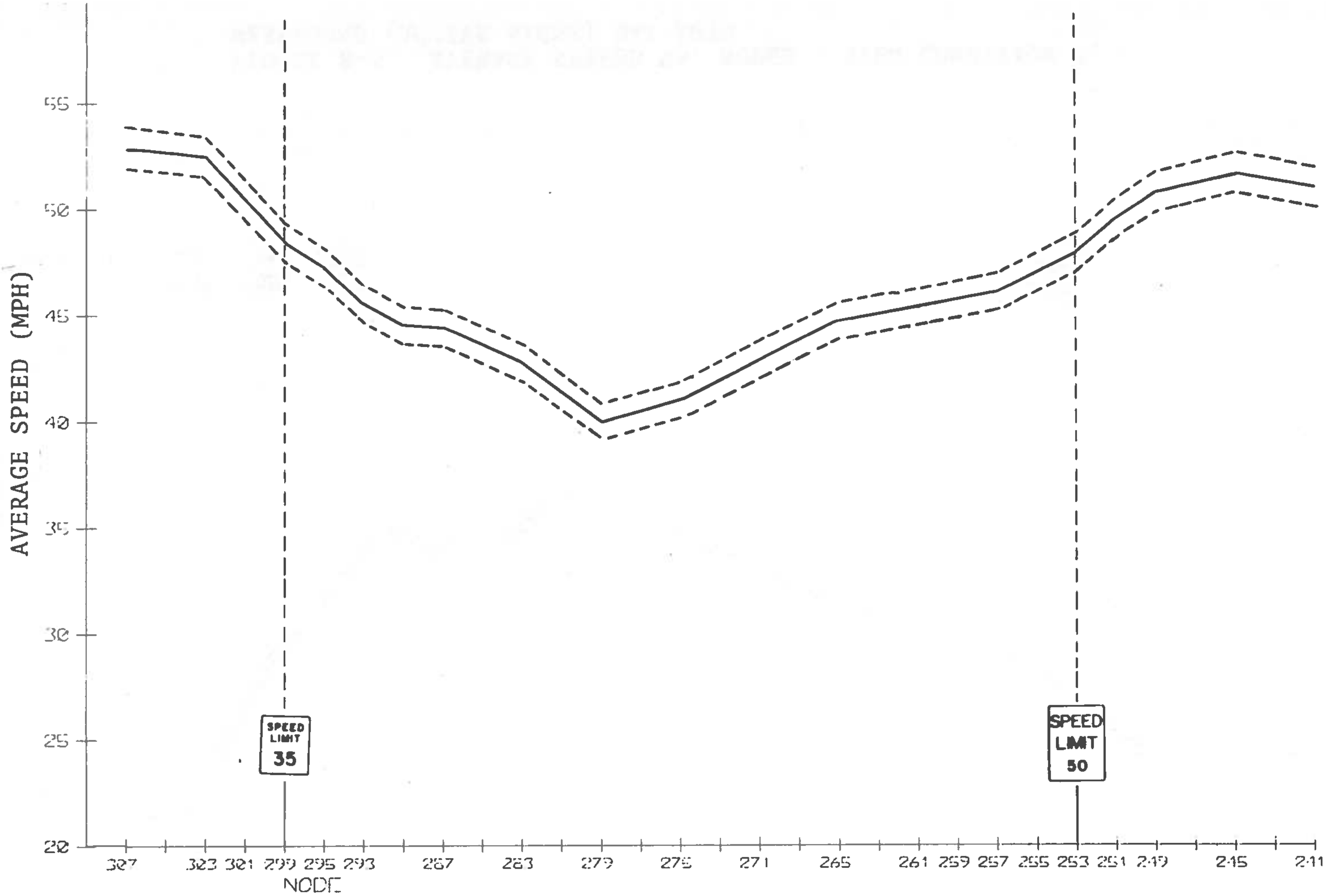


FIGURE B-4. AVERAGE SPEEDS VS. NODES - SIGN CONDITION 5, WESTBOUND (BASE SIGN) NIGHT-AUTO

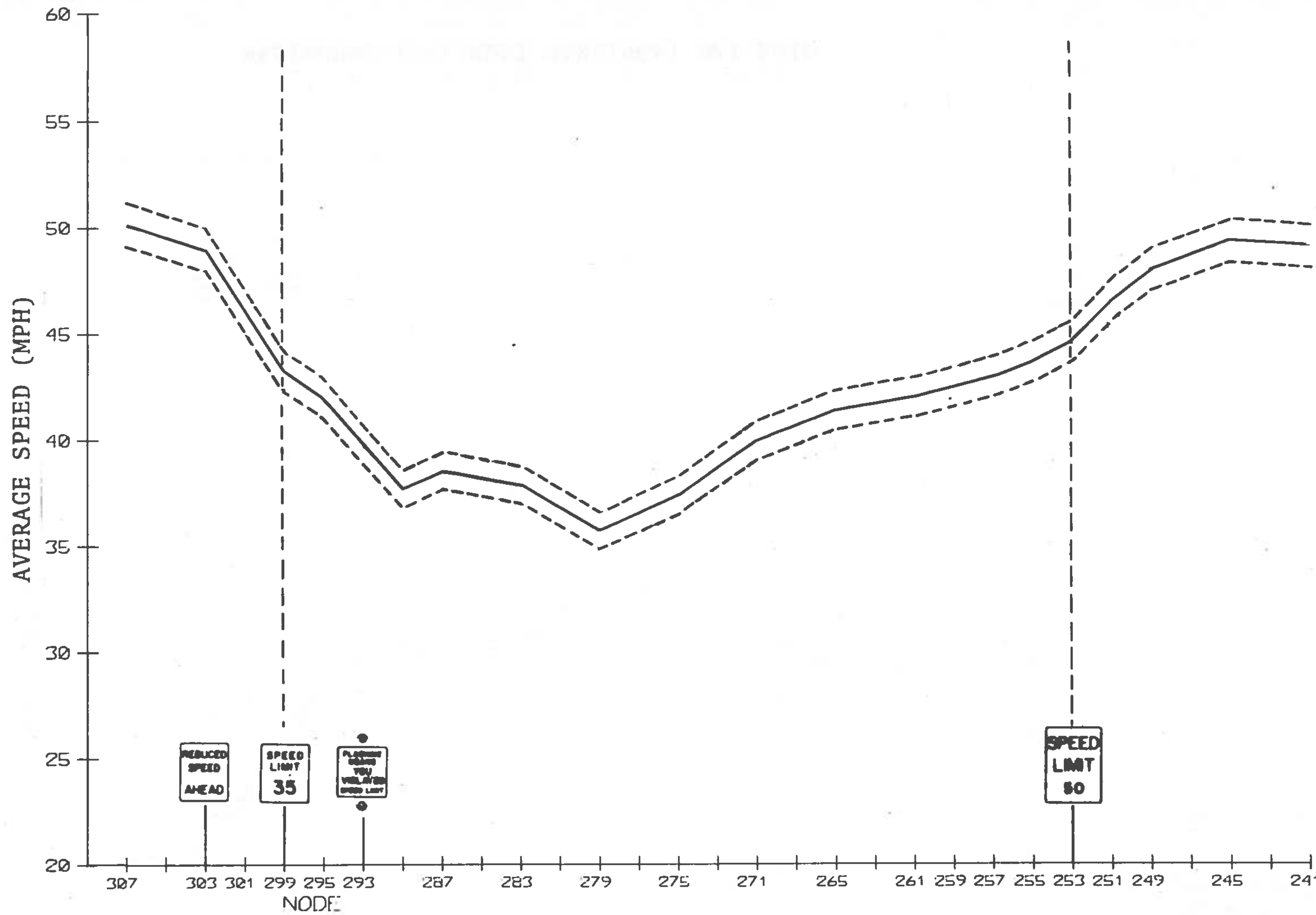


FIGURE B-6. AVERAGE SPEEDS VS. NODES - SIGN CONDITION 7, WESTBOUND (ACTIVE SIGNS) NIGHT-AUTO

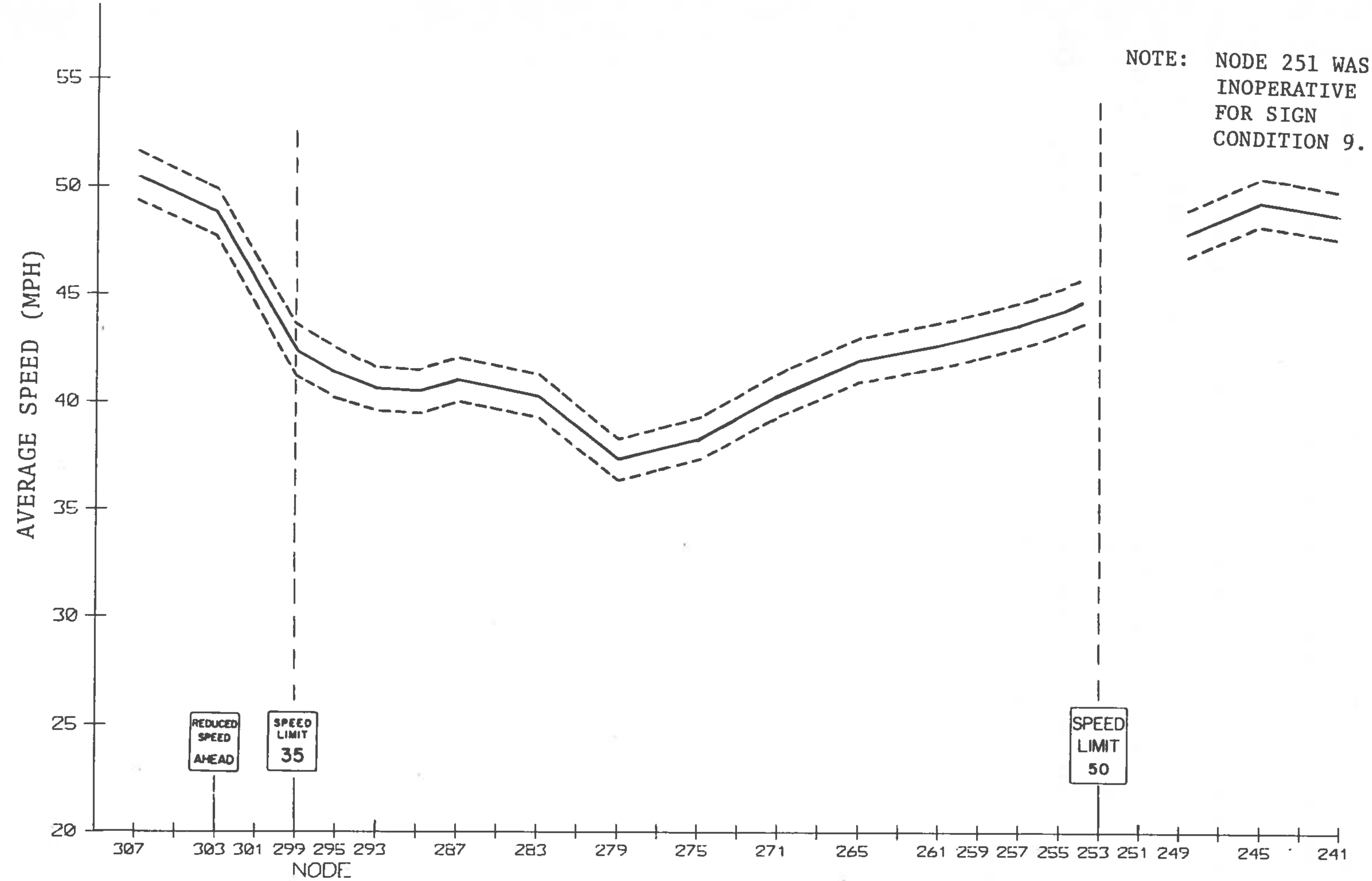


FIGURE B-8. AVERAGE SPEEDS VS. NODES - SIGN CONDITION 9, WESTBOUND (PAVEMENT MARKINGS) NIGHT-AUTO

APPENDIX C
VEHICLE/VEHICLE INTERACTION EFFECTS

This appendix examines the potential vehicle/vehicle hazards due to drivers responding and overreacting to the various sign conditions. Three general measures were employed to study this hazard potential: time headway, speed distribution, and speed variance.

Headways provided direct indications of the interactions between two vehicles. Speed distributions and speed variances provide information on the uniformity of flow. In this study, it was assumed that small headways and nonuniform flow was undersirable and would increase the vehicle/vehicle hazard potential.

C.1 HEADWAY

The headway variable was represented by unsafe headway profiles—percent of low time headways (i.e., less than 3 seconds, less than 2 seconds, and less than 1 second) occurring at each node through the test area for each sign condition. The unsafe headway profiles for sign conditions 7 and 8, eastbound, and for 7 and 8, westbound, are shown in Figures C-1 through C-4, respectively. Sign condition 7 was the active warning sign and sign condition 8 was the base sign. These sign conditions were selected for review here because they illustrate the important findings. The unsafe headway profiles for all sign conditions are available from the authors.

The main feature displayed in Figures C-1 through C-4 is that the headway variables (i.e., percent of headways less than 3 seconds, less than 2 seconds, and less than 1 second) are affected more by road geometry and direction rather than sign configuration. (Note that the headway variables at the initial nodes - 245 eastbound and 507 westbound - differed from sign condition to sign condition. Thus only the relative changes from these nodes were important.) In general, the variable tends to increase for both directions as drivers approach and pass through the town speed zone. This may be

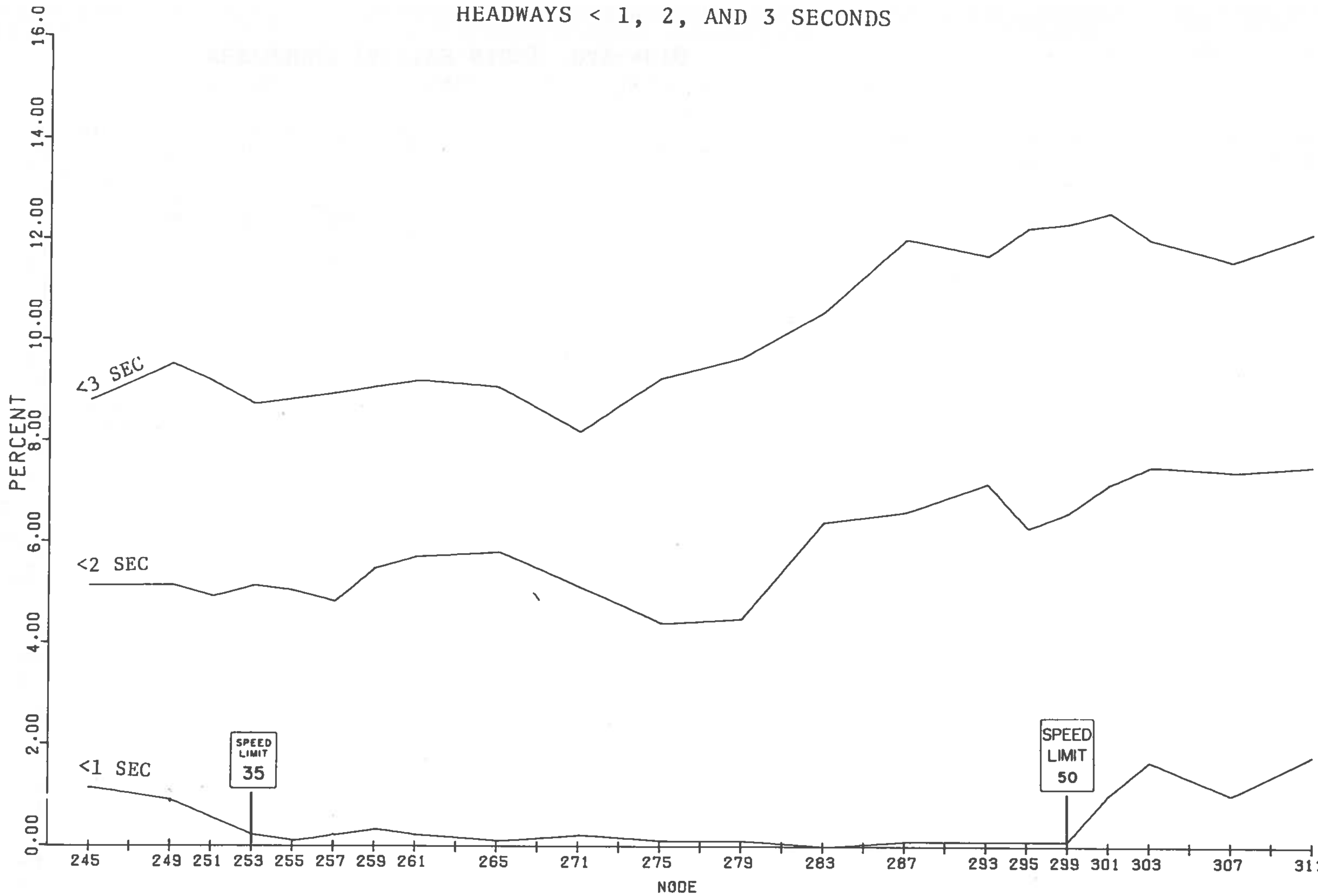


FIGURE C-2. UNSAFE HEADWAY PROFILES, SIGN CONDITION 8, EASTBOUND (BASE SIGN) DAY-AUTO

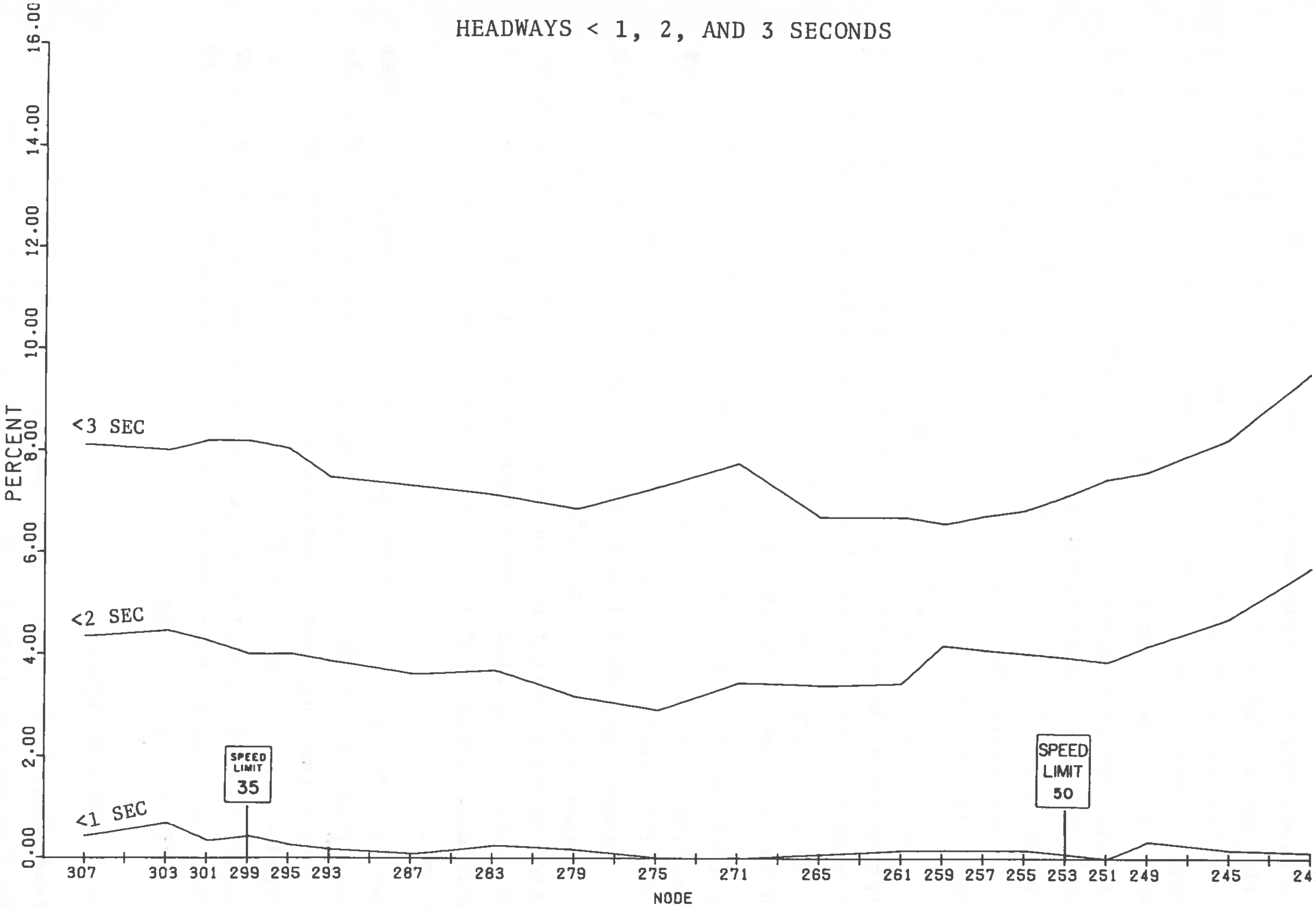


FIGURE C-4. UNSAFE HEADWAY PROFILES, SIGN CONDITION 8, WESTBOUND (BASE SIGN) DAY-AUTO

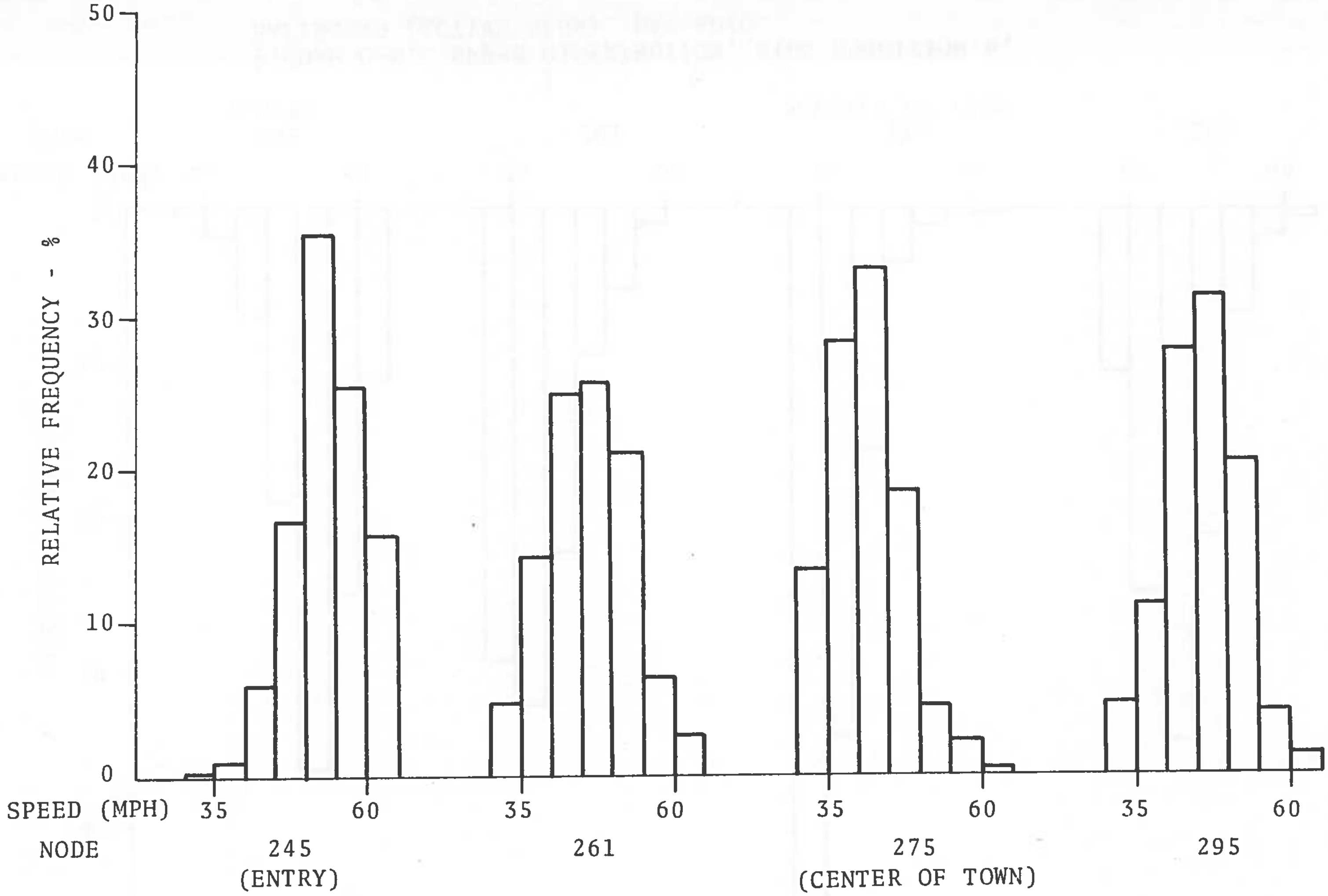


FIGURE C-5. SPEED DISTRIBUTIONS SIGN CONDITION 5, EASTBOUND (BASE SIGN) DAY-AUTO

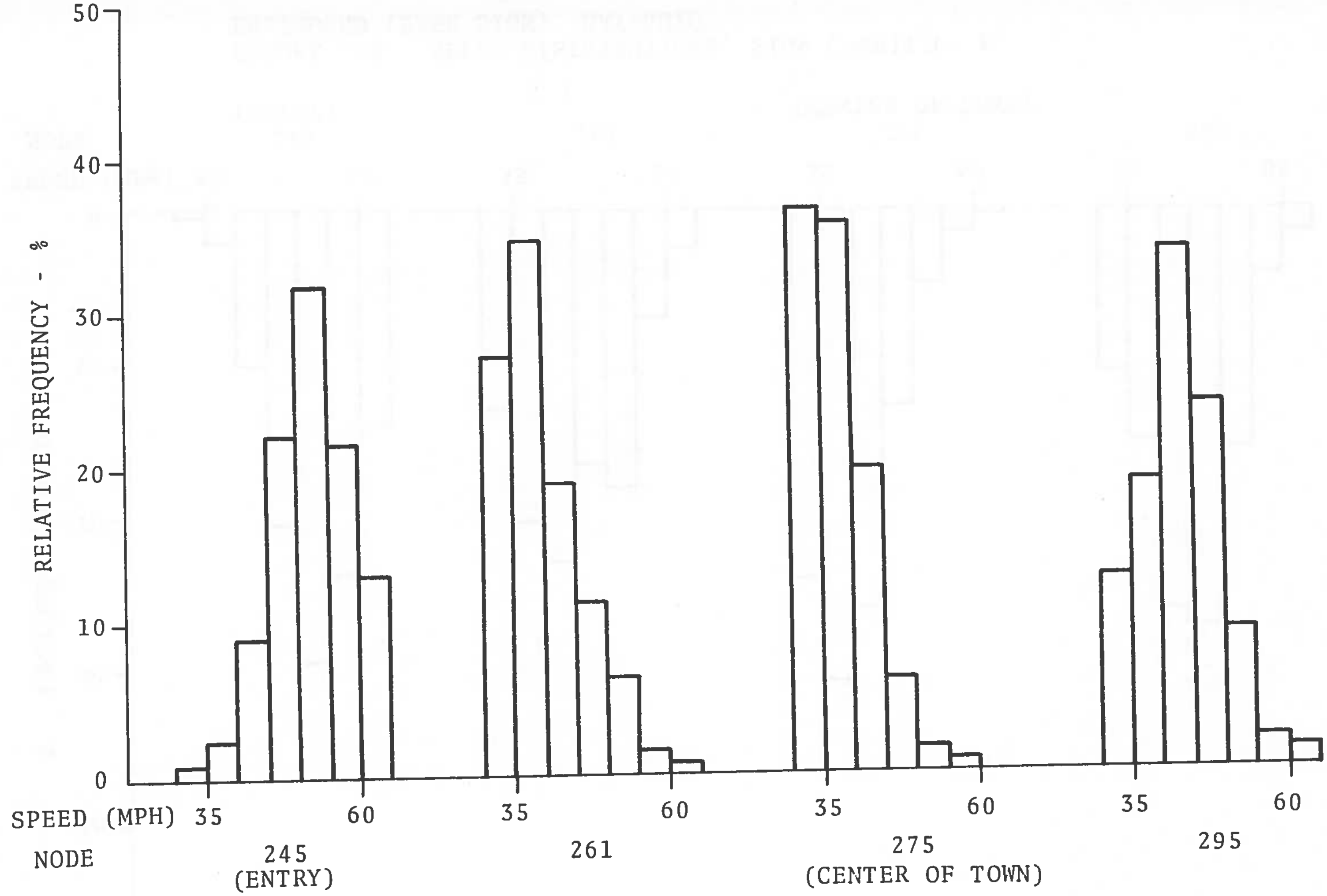


FIGURE C-7. SPEED DISTRIBUTIONS, SIGN CONDITION 7, EASTBOUND (ACTIVE SIGN) DAY-AUTO for eastbound traffic during the day, autos only, at nodes 245, 261, 275, and 295 and were represented in 5 mph increments except for the extremities, which were for all vehicles less than 55 mph and all vehicles greater than 60 mph. Sign conditions 5 and 8 were the base signs; sign conditions 6 and 7 were the active warning signs. Thus, the sequence of testing represented a mini before-after study.

From these figures, it was clear that the active warning signs caused more drivers to slow down as they passed through the town. Also, there was a tendency for more drivers to travel at or about the same speeds. This was shown by the peaking effect in the shape of the distributions from base signs to the active signs (it should be cautioned that part of the apparent peaking effect was due to the speed increment extremity in the speed distributions for all vehicles less than 35 mph.)

Thus, instead of producing an expected adverse overreaction response, the active warning signs showed a tendency to promote safer driving conditions by causing drivers to travel at or about the same speeds throughout the town (in addition to lowering the average speeds). This characteristic was also true for westbound traffic and for nighttime conditions, but was not evident for any of the remaining sign conditions. Distributions of all sign conditions and data categories are available from the authors.

C.3 SPEED VARIANCE

Speed variance profiles (i.e., variance of speed at each node vs. nodes through the test area) for sign conditions 5, 6, 7, and 8 are shown in Figures C-9 through C-12. The variance profiles were for eastbound traffic during the day and for autos only.

There was, of course, some redundancy between the speed variance measure and speed distribution measure (the speed variance profile provided an index of speed dispersion for all nodes through the test area; the speed distributions provided more descriptive information of speed dispersion at a few nodes). The overlap of information is evident from Figures C-9 through C-12—the speed variances for the active warning signs were lower than that for the

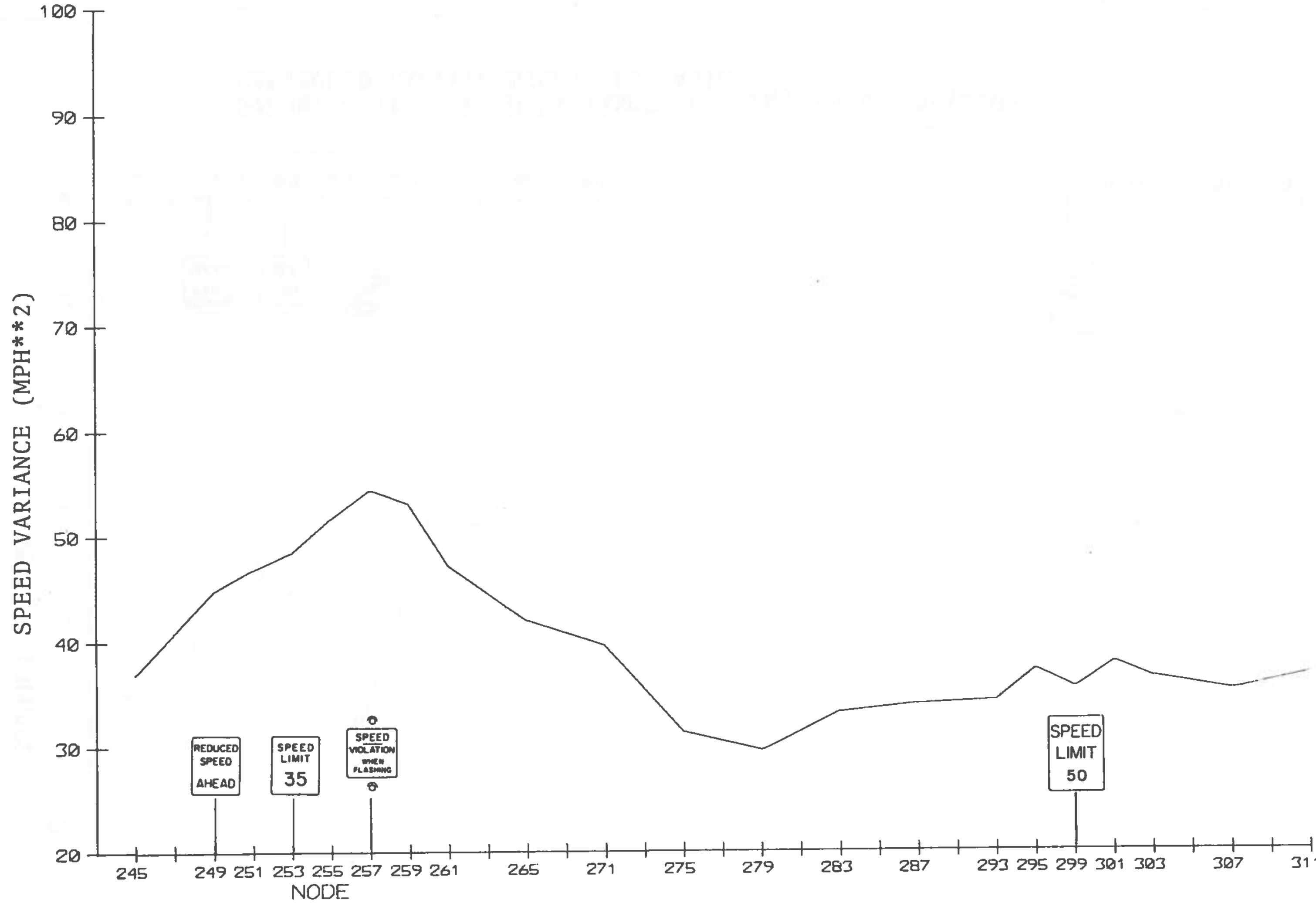


FIGURE C-10. SPEED VARIANCE PROFILE, SIGN CONDITION 6, EASTBOUND (ACTIVE SIGN) DAY-AUTO

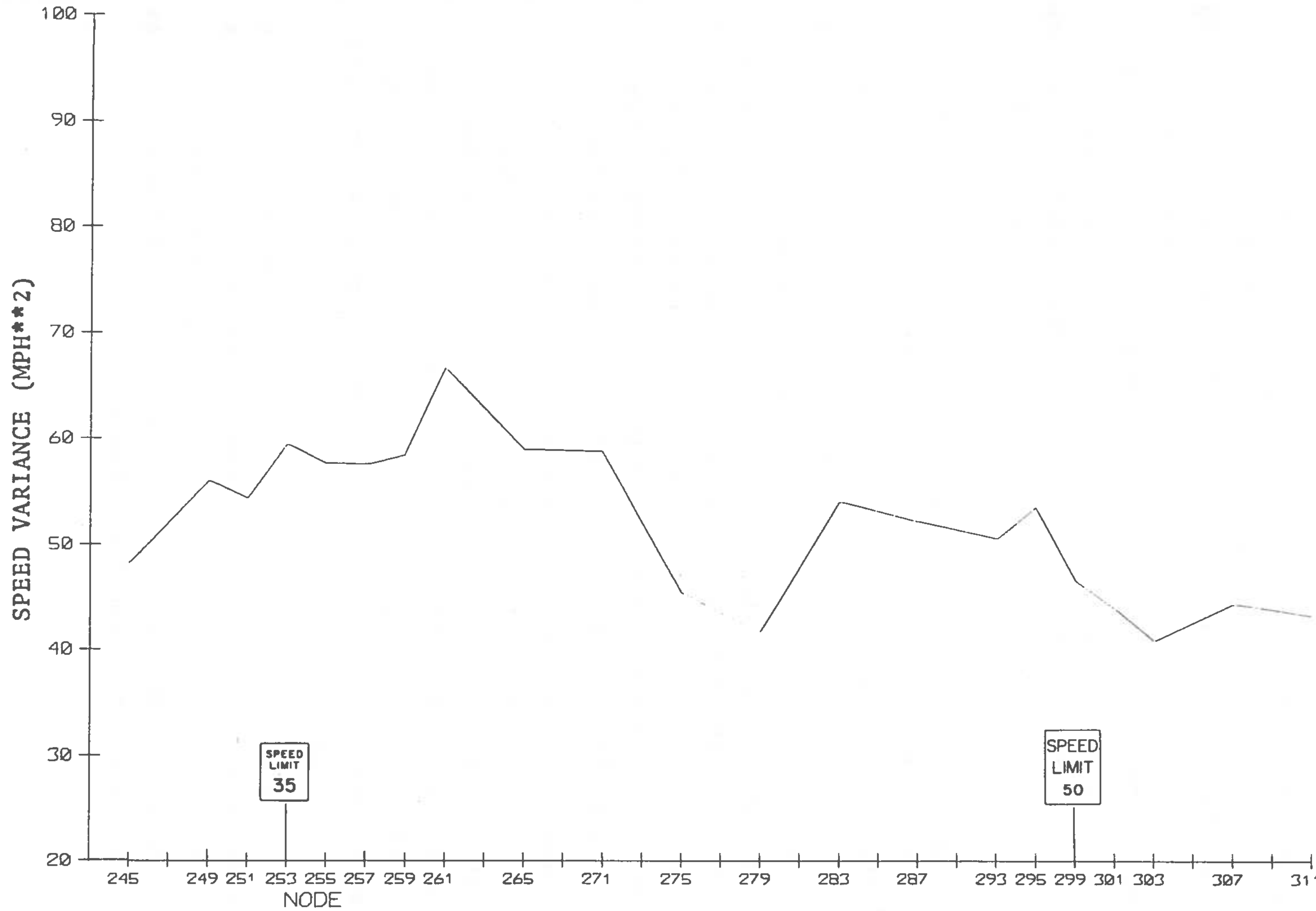


FIGURE C-12. SPEED VARIANCE PROFILE, SIGN CONDITION 8, EASTBOUND (BASE SIGN) DAY-AUTO

APPENDIX D
TIME OF DAY EFFECTS

This appendix examines the hourly variations in driver performance during the experiment to determine if there was any unique time of day behavior, either sign condition dependent or independent. Compliance to the existing 35 mph speed limit in the town was chosen as the discriminating measure because it was effective in discriminating other effects (e.g., signs, day/night, and vehicle type).

Figure D-1 shows compliance vs. hour of day for all vehicles eastbound. Figure D-2 shows the same for all vehicles westbound. The compliance measure in each case was averaged over all vehicles and all sign conditions.

The figures show a slight increasing trend in compliance from the morning hours to the evening hours. An analysis of variance (ANOVA) was performed with hour of day as an independent variable and showed that the time of day effect for westbound traffic was not significant, and the time of day effect for eastbound traffic was only barely significant. The fact that the eastbound results were barely significant may have been primarily a result of the relatively low compliance during the seventh hour. This in turn probably reflected an early morning driving behavior (i.e., a tendency for drivers to travel faster because of less perceived danger and less anticipated hindrance from other vehicles) and the fact that glare from the rising sun may have diminished the effectiveness of the signs.

Figure D-3 shows compliance vs. hour of day for each sign condition eastbound. There was obviously a large variation from hour to hour, and it is difficult to discern an increasing trend in compliance for all sign conditions. However, the basic feature of Figure D-3 is that the active warning signs were the most effective signs for all hours and there did not appear to be any unique time

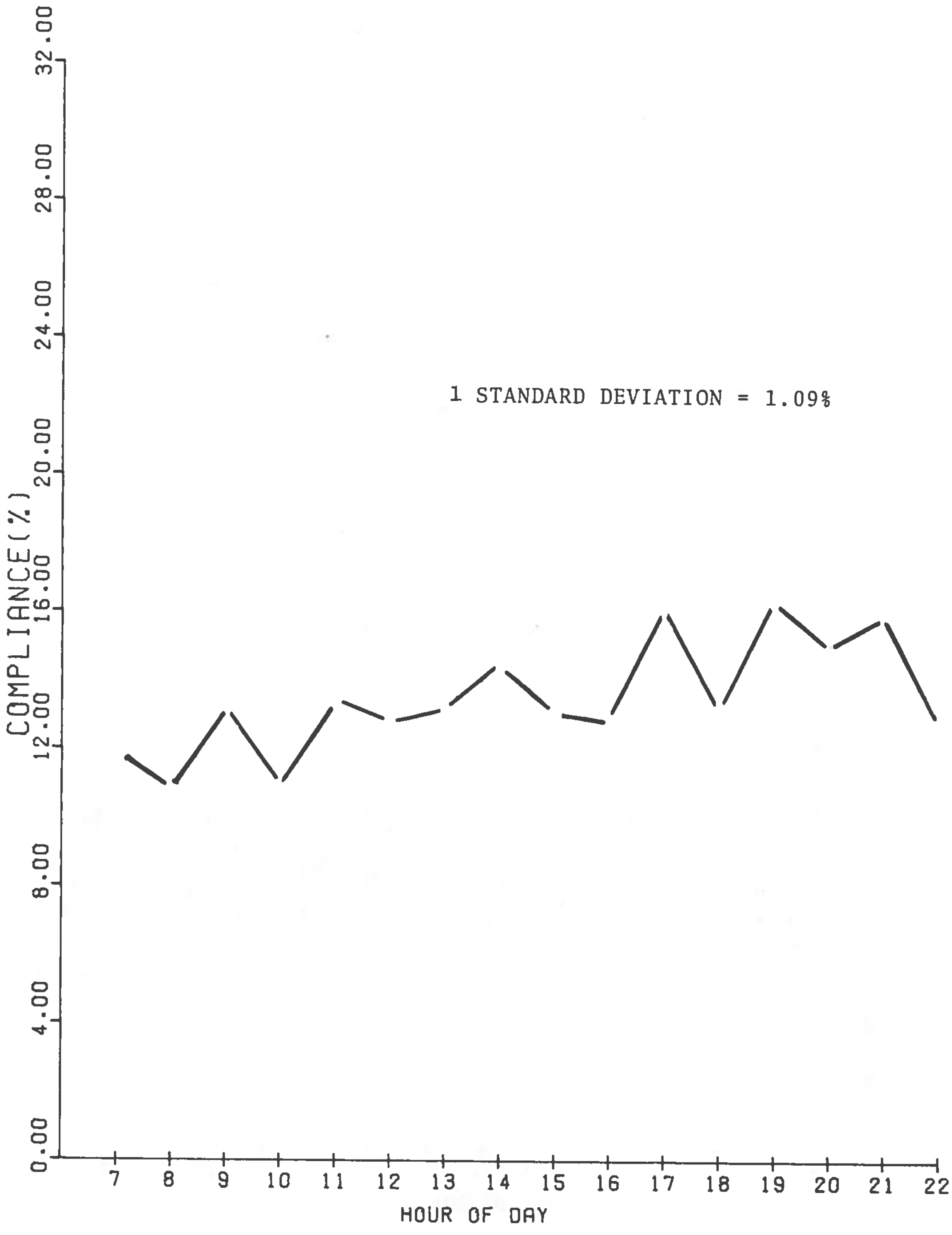


FIGURE D-2. AVERAGE COMPLIANCE VS. HOUR OF DAY - ALL VEHICLES, ALL SIGN CONDITIONS, WESTBOUND of day effects for the individual sign conditions. The relatively large compliance values for sign condition 3 were probably due to sample size effects. Similar results were found for westbound traffic.

Thus, on the basis of this evaluation, it does not appear that driver behavior was affected significantly by time of day (during daylight hours). The design of this experiment—eliminating data collected near sunrise and sunset from the analysis in order to minimize potential adverse influences and providing for a balanced distribution of data during the other daylight time periods—seems to have been a sound approach and is recommended for future experiments of this type.

TABLE E-1. AVERAGE COMPLIANCE WEIGHTS

NODE	WEIGHT	NODE	WEIGHT
253	1.	275	2.
255	1.	279	2.
257	1.	283	2.
259	1.	287	2.
261	1. E Bound	293	2. E Bound
	2. W Bound		1. W Bound
265	2.	295	1.
271	2.	299	1.

For example:

$$C_{299} = N < 35/N$$

at node 299
and

$$S^2_{299} = N < 35\ (N\text{-}N<35)/N^3.$$

The error bars were computed from:

$$C_{299} \pm 2S_{299}.$$

The late compliance measures were calculated similarly but at the last two nodes in the town speed zone: 295 and 299, eastbound, and 255 and 253, westbound.

TABLE F-1. CONTRAST CALCULATION FOR AVERAGE COMPLIANCE (COMP) MEASURE. DAY-AUTO CATEGORY

S.C.	$Comp._W$	$Comp._E$	Delta	$Delta^2$	$\left[\Sigma\Delta^2 - (\Sigma\Delta)^2/N\right]$
2	20.1	6.59	13.51	182.5201	
3	13.9	9.70	4.20	17.6400	
4	12.3	8.52	3.78	14.2884	
			$\Sigma\Delta = 21.49$	$\Sigma\Delta^2 = 214.4485$	
			$\overline{\Delta\ Comp_F} = \frac{\Sigma\Delta}{3} = 7.1633333$		60.50846674
1	6.56	8.78	-2.22	4.9284	
5	7.93	6.71	1.22	1.4884	
7	24.10	22.80	1.30	1.6900	
8	10.40	14.00	-3.60	12.9600	
			$\Sigma\Delta = -3.30$	$\Sigma\Delta^2 = 21.0668$	
			$\overline{\Delta\ Comp_N} = \frac{\Sigma\Delta}{4} = -\ .825$		18.34430000

$$\frac{60.50846674 + 18.3443}{5} = 15.770524 \qquad \hat{\sigma} = \sqrt{\frac{7}{12}\ (15.7705534)} = 3.03306601$$

$$\Delta\ Comp._F - \Delta\ Comp._N \pm 2\hat{\sigma} = 7.98833333 \pm 6.06613202 \quad \text{(95\% confidence interval)}$$