SPEED CONTROL IN RURAL SCHOOL ZONES

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Initial results are presented of a comprehensive experiment dealing with speed control in a rural school zone on a high-speed, two-lane highway. Data were collected in a school zone located on the Maine Facility, an electronically instrumented roadway where a 15-mph (24-km/h) speed limit is in effect during certain times of the school day. The experiment was to determine the effects on drivers of the Manual on Uniform Traffic Control Devices mandatory and advisory school zone signs, including beacon flashers, and the effect of a new, dynamic speed violation sign. Speeds for automobiles and large vehicles were measured for one dynamic and four passive sign conditions when the 15-mph (24-km/h) speed limit both was and was not in effect. No enforcement was used during the experiment. Results showed that (a) vehicle velocities at the school were less when the driver was advised by flashing beacons that the 15-mph (24-km/h) speed limit was in effect, (b) the average vehicle velocity was relatively constant at the school when the speed limit was not in effect, and (c) the lowest average speeds at the school [34 mph (55 km/h)] were obtained when the dynamic speed violation sign was used.

•WIDE noncompliance with state statutes covering speed limits in school zones is believed to be due to drivers either not seeing speed zone signing or not understanding the statute and thus not obeying the sign message. The effects of five school speed zone signs on driver behavior were examined to determine the most desirable speed limit for rural school zones and the most effective signing required to achieve driver compliance.

EXPERIMENTAL SITUATION

All experiments were conducted on the Maine Facility located along US-2 between Newport and Canaan. This facility is electronically instrumented to detect vehicles, track their positions as they travel along sections of the two-lane road, and store the collected vehicle information on magnetic tape for subsequent off-line data reduction (1). The site of the experiments, shown in Figure 1, was adjacent to the Palmyra Consolidated School, bounded on the north by US-2 and on the west by a state road. The driveway and parking lot for school buses and staff vehicles are located at the intersection of the two roads. A minor local road also intersects US-2 from the north.

At the start of the experiments in January 1973, the test site was instrumented with 10 vehicle detector stations. Two more stations were added during the experiments.

Although data were collected on all vehicles passing through the test site, only data collected on eastbound nonturning vehicles were used in the analysis. Drivers heading east on US-2 entered the school zone from a 60-mph (96-km/h) speed zone, which began 1.2 miles (1.93 km) west of the school. The legal vehicle speed limit through the school zone at any time of day during the school session was either 15 mph (24 km/h) or 60 mph (96 km/h) depending on school activity. The Maine statute (2) pertaining to speed reduction in school zones states:

> Speed in excess of 15 miles per hour when passing a school during a recess or where children are going to or leaving school during opening or closing hours shall be unlawful.

A preliminary survey indicated that well over 95 percent of the drivers did not comply with the statute.

Between 7:15 a.m. and 3:45 p.m., the 15-mph (24-km/h) speed limit was in effect during seven time periods at Palmyra Consolidated School as given in Table 1. Traffic volumes on US-2 at the school during the experiments varied from 600 to 800 vehicles for the $8\frac{1}{2}$-hour school day. The school had 164 students, aged 5 to 12, 7 teachers, and 5 additional staff. All students (except one family's, who walked) arrived and left by school bus. Four buses served the school, entering or leaving the school entrance 22 times during the school day. The buses also discharged and picked up students requiring transfer transportation to and from other schools in the area.

SIGN CONDITIONS

Five sign conditions, based on the school zone signs and flashing beacons in the Manual on Uniform Traffic Control Devices (MUTCD), were selected to determine driver compliance with the 15-mph (24-km/h) speed zone adjacent to the rural school and the effects of a dynamic speed violation sign. The five sign conditions used are shown in Figure 2 and are as follows:

1. Existing school signing, which conformed with the 1961 MUTCD;
2. The 1971 MUTCD mandatory school sign and the permitted speed limit sign with beacons;
3. Sign condition 2 and an advisory advance school zone sign;
4. Sign condition 3 and an advisory speed zone sign with beacons; and
5. Sign condition 4 and a speed violation sign with beacons.

For sign condition 2, the 1971 MUTCD states (3) that "the School Speed Limit sign shall be used to indicate the speed limit where a reduced speed zone for a school area... is specified for such areas by statute." (Shall, as used in the MUTCD, means mandatory, but should and may mean advisory and permissive respectively.) Since the Maine statute specifies speed limits for school zones, the school speed limit sign was used in sign condition 2. Speed limit signs with beacons and the words WHEN FLASHING, as permitted in the MUTCD, were activated by a time clock for those time periods when the 15-mph (24-km/h) limit was in effect. A 60-mph (96-km/h) speed limit sign was placed at the end of the school speed zone to show the speed limit for the next section of highway.

The 1971 MUTCD recommends a symbolic school advance sign for use before locations where school buildings or grounds are adjacent to the highway (3). The sign was used in sign condition 3. Since this sign was new to drivers at the test site, the word SCHOOL was used as well.

For sign condition 4, an MUTCD advance advisory sign for reduced speed ahead was added, which "... should be used in rural areas to inform the motorist of a reduced speed zone when an advance notice is needed to comply with the speed limit posted ahead" (3). Speed limit signs with beacons were also used to indicate when the reduced speed limit was in effect.

The fifth sign condition added a new (not covered in the 1971 MUTCD) speed violation sign with beacons to remind the driver who had exceeded the reduced speed limit that it was in effect. This sign flashed when a driver was electronically detected exceeding 20 mph (32 km/h) during the times that the speed limit signs with beacons were flashing.

The same sign conditions were installed for eastbound and westbound traffic concurrently at appropriate distances from the school zone for sign conditions 1 through 4. The dynamic speed violation sign was not used for westbound traffic. The size, color, and legend of each of the signs used are described in Figure 3.

Figure 1. Experiment test site and eastbound signs for sign condition 4.

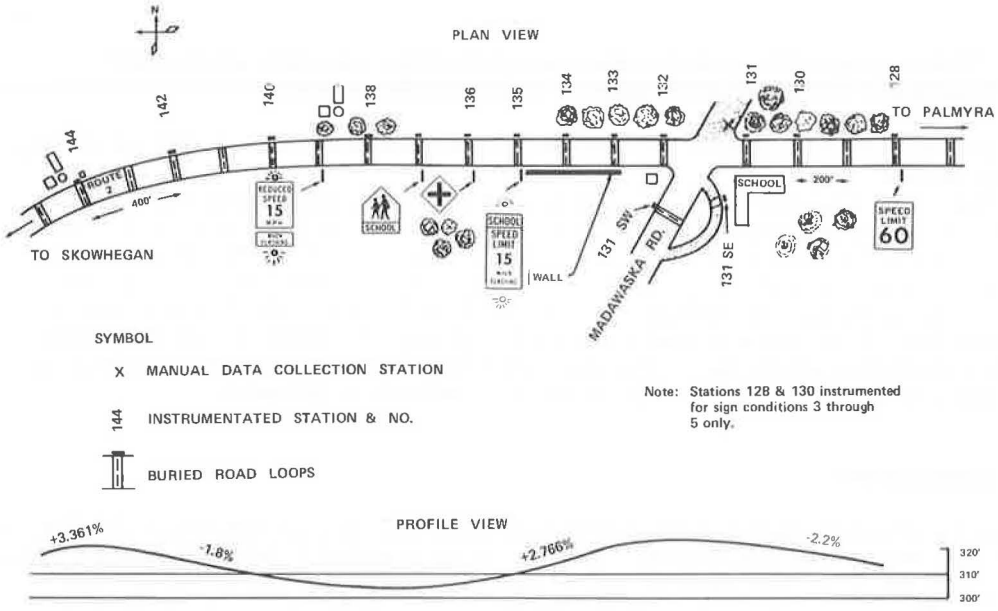
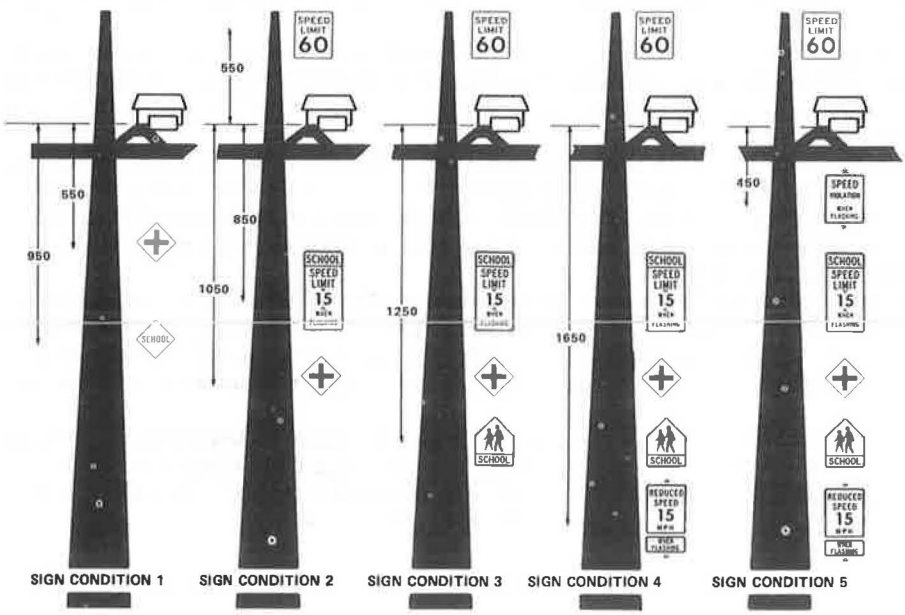


Table 1. Time periods during which Maine school zone speed statute in effect and not in effect.

Time Period	In Effect	Not in Effect
1		12 midnight to 7:15 a.m.
2	7:15 to 8:00 a.m.	
3	8:00 to 8:45 a.m.	
4		8:45 to 10:00 a.m.
5	10:00 to 10:25 a.m.	
6		10:25 to 11:00 a.m.
7	11:00 to 11:25 a.m.	
8		11:25 a.m. to 12 noon
9	12 noon to 1:15 p.m.	
10		1:15 to 2:00 p.m.
11		2:00 to 2:30 p.m.
12	2:30 to 2:50 p.m.	
13		2:50 to 3:15 p.m.
14	3:15 to 3:45 p.m.	
15		3:45 p.m. to 12 midnight

Figure 2. Sign conditions 1 through 5 for eastbound traffic.



EXPERIMENTAL VARIABLES

The primary objective of the experiments was to evaluate driver response and voluntary compliance with each of the five sign conditions. [No enforcement of the 15-mph (24-km/h) speed limit was used during the entire experiment.] As drivers traveled through the school zone test site, dependent and independent variables were measured and recorded either electronically by the Maine Facility system or manually by field observers.

The dependent variables used in the experiments were average speed, speed reduction, and variance between each pair of instrumented sensors for eastbound traffic [between sensors 144 and 131 for sign conditions 1 and 2 and between sensors 144 and 128 for sign conditions 3, 4, and 5 (Figure 1)].

Independent variables controlled or accounted for in the experiments are given in Table 2. The effects of only three independent variables—vehicle type, sign location, and sign and statute condition—on the dependent variables are discussed in this paper. Measured traffic volumes did not vary significantly during the hours dependent variables were measured.

EXPERIMENTS

Two categories of experiments were conducted at the Maine Facility school test site: driver speed reduction characteristics for the various sign conditions were analyzed, and different vehicle interactions were examined. The experiments were to answer the following questions:

1. Were vehicle types (automobiles and others) affected differently by various sign conditions?
2. Was there an adverse effect on drivers caused by certain sign conditions when the Maine school statute was not in effect [speed limit 60 mph (96 km/h)]? Did certain sign conditions cause drivers to drive at speeds lower than the posted speed limit?
3. If a significant number of drivers did not decrease their speed to 15 mph (24 km/h) for any of the sign conditions, what was the minimum velocity that these drivers deemed reasonable for passing through the school speed zone?
4. Where on the road did the speed reductions take place with respect to particular signs?
5. Did certain signs cause drivers to decelerate more rapidly than others?

Subsequent analyses will deal with other questions relating to this experiment.

Data Collection

Data were collected from January 5 through June 8, 1973, when school was in session. Daily data collection (1 to 6 hours) was planned to ensure sample sizes sufficient for data analysis. Testing under each sign condition was scheduled to last for 4 weeks to allow drivers to become accustomed to the given sign conditions. This phenomenon is commonly known as the learning curve effect. At the conclusion of each 4 weeks of testing, the next sign condition was to have been installed. However, because of equipment failures at the site, data were not recorded on each school day. Thus, number of days for data collection and driver exposure under each experimental sign condition were not equally balanced. Treatment for this uncontrollable situation was handled during the data analysis and is discussed later. The schedule for data collection is given in Table 3. Hours during the day when data were collected are the same as those listed in Table 1.

During the experiments, all of the flasher beacons (Figure 2) were operated at all appropriate times even though data were not always being collected.

During selected time periods, both computer and manual data were collected. Maine

Figure 3. Experiment signs.

	MUTCD Year	No.	Size (IN)	Remarks
	1961	W9-1	30x30	Black letters on yellow background. Data collected using this sign served as the base from which improvement or degradation of traffic performance with other signs was measured
	1971	–	24x48	"School" black letters on yellow background. Remainder black letters on white background. Speed Limit Sign Beacons employed with sign to inform driver when Maine School Statute was in effect
	1971	S-1 S4-3	36x36 36x12	Black legends on yellow background. Used in advance of locations where school buildings or grounds were adjacent to the highway
	1971	R2-5 S4-4	24x30 24x10	Black letters on white background. Beacons, when flashing, informed drivers that a school zone speed limit lay ahead.
	–	–	36x36	Black letters on white background. Special design "reminder" sign. Beacons flashed when Maine School Statute was in effect and Maine Facility computer detected, in real time, a vehicle speed of 20 MPH or over.

Table 2. Experimental independent variables.

Name	Code	Description
Vehicle type	1	Automobiles and pickup trucks, or vehicle length = 5 to 20 ft
	2	Other, or vehicle length >20 ft (e.g., trucks and buses)
Sign location	1 to 10	Sign conditions 1 and 2 (see Figure 1)
	1 to 12	Sign conditions 3, 4, and 5 (see Figure 1)
Vehicle direction	1	Eastbound through vehicles on US-2
	2	Westbound through vehicles on US-2
	3	Vehicles turning onto or off of Madawaska Road (adjacent to school)
Conflict	1	Conflict, or vehicle headway at school ≤ 5 sec
	2	No conflict, or vehicle headway at school >5 sec[a]
Driver type	1	Drivers of vehicles with Maine license plate
	2	Drivers of vehicles with out-of-state license plate
Maine school	1	Times Maine school zone statute in effect
	2	Times Maine school zone statute not in effect
Sign condition	1 to 5	See Figure 2
Weather	1	Good—Visibility[b] and/or skid condition[c] met
	2	Bad—Visibility and/or skid condition not met
Week of test	1 to 4	Week of test when data collected
Day of test	1 to 5	Day of test (Monday through Friday) when data collected
Time of day	1 to 15	15 data collection time periods given in Table 1

Note: 1 ft = 0.3048 m. 1 mph = 1.6 km/h.

[a]Cause of vehicle deceleration, presence of school sign or proximity of leading vehicle, should be known.

[b]When observer at school could see traffic sign at 500 ft (152 m).

[c]If test vehicle did not skid when brakes were applied at 20 mph (32 km/h).

Table 3. Data collection periods for sign conditions.

Sign Condition	Data Collection Period	Days Data Collected	Days Data Analyzed	Weeks of Exposure[b]
1	January 15 to February 5	15	3	3
2	February 7 to March 13[a]	21½	3	6
3	March 13[a] to April 19	15½	4	5
4	May 7 to 18	9	9	2
5	May 25 to June 8	9	5	3
Total		70	24	19

[a]Half days. [b]Time during which drivers traveling on US-2 could have observed indicated sign condition.

Department of Transportation observers were stationed north of the school intersection (X, Figure 1) in an unnoticeable position to drivers on US-2. The observers recorded (a) time vehicle was observed, (b) vehicle direction, (c) vehicle type (e.g., automobile, bus, truck), (d) Maine or out-of-state registration, and (e) turning movements.

Data Reduction

The raw data tapes were run through a data reduction program that recognized vehicles; tracked vehicles through the test site; calculated vehicle parameters such as velocity, headway, and length of vehicle; and stored the reduced data on computer tape in a format for data analysis. The manually collected data were correlated and combined with the reduced data.

Data Analysis

Data from 24 days (Table 3) were selected for analysis to balance the exposure of drivers to the experimental signs, the time-of-day exposure, and the scheduled time periods of data collection. The specific days, the number of weeks that drivers could be exposed to each sign condition, and the proportion of the drivers of the 2,418 vehicles exposed to each sign condition are given in Table 4.

Table 5 gives the number of vehicles whose drivers were exposed to the sign conditions when the school zone speed statute was and was not in effect. Included are vehicles that could be tracked through most instrumented sensors (10 for sign conditions 1 and 2 and 12 for sign conditions 3, 4, and 5).

Data collected during nonschool hours (3:45 p.m. to 7:15 a.m.) were not used because it was felt that these data, taken during time periods when the speed statute was obviously not in effect, would bias the results. Only data for vehicles traveling in the eastbound direction under clear visibility and not impeded by leading vehicles or turning vehicles from either direction were used.

RESULTS

Table 6 gives the standard deviation SD (in mph), sample size N, and calculated average speeds $\overline{V}$ (in mph) for each sign and statute condition by distance from the school intersection. The instrumented station locations have been transformed into distances to the school for ease of discussion and illustration. All of the data in Table 6 are for the selected 24 data analysis days.

Speed Profiles

Average speed profiles from Table 6 are shown in Figures 4, 5, 6, 7, and 8. Each figure shows profiles by a specific sign condition for both statute conditions. At the top of each figure, the experimental sign condition is shown. Average speeds for automobiles are plotted separately from other vehicles, which include trucks and buses.

When the speed reduction statute is in effect, the slope of these profiles markedly increases from about 1,200 ft (368 m) from the school as experimental sign conditions are made more dynamic. The slight grades of the highway correlate with the upward and downward slopes of the profiles when no speed reduction statute was in effect. However, the experimental signs also appear to influence the slopes of the profiles for the no-speed-reduction-statute condition.

The following observations can be made from the comparison in Figure 9 of the five automobile speed profiles for the time the school speed statute was in effect.

1. The flashing school zone speed limit sign (1971 MUTCD) is much more effective

Table 4. Analysis data.

Sign Condition	Days Selected	Weeks of Exposure	Sample Represented (percent)
1	January 18, 26; February 1	1, 2, 3	15
2	February 27, 28; March 2	4	20
3	March 29, 30; April 3, 13	2, 3, 4	21
4	May 7 to 11, 14, 16 to 18	1, 2	28
5	May 31; June 1, 4, 5, 6	2, 3	16

Table 5. Number of vehicles used.

Sign Condition	Statute in Effect			Statute Not in Effect		
	Automobile	Other	Total	Automobile	Other	Total
1	167	26	193	138	40	178
2	216	43	259	172	49	221
3	178	50	228	220	55	275
4	239	49	288	325	72	397
5	140	40	180	154	45	199
Total	940	208	1,148	1,009	261	1,270

Table 6. Average speed, sample size, and standard deviation.

Item	Distance to School (ft)	Sign Condition 1			Sign Condition 2			Sign Condition 3			Sign Condition 4			Sign Condition 5		
		$\bar{V}$ (mph)	N	SD (mph)	$\bar{V}$ (mph)	N	SD (mph)	$\bar{V}$ (mph)	N	SD (mph)	$\bar{V}$ (mph)	N	SD (mph)	$\bar{V}$ (mph)	N	SD (mph)
Automobiles																
Statute in effect	2,600	55.01	159	8.29	54.58	213	8.19	55.90	175	8.30	54.65	240	7.75	54.84	138	7.03
	2,200	56.57	168	8.62	55.80	217	7.99	56.87	177	6.11	54.20	242	7.65	52.84	145	8.58
	1,700	56.55	167	10.48	55.73	218	9.01	57.04	177	8.83	51.43	237	8.78	49.58	141	9.11
	1,300	57.36	167	9.54	54.98	216	8.98	55.93	178	9.34	47.58	241	10.57	46.86	142	10.65
	1,100	56.82	166	8.90	52.08	215	9.98	52.83	180	9.33	44.92	235	10.97	44.30	141	10.70
	900	56.46	169	8.18	49.02	216	10.89	49.45	179	9.99	42.43	241	11.40	41.64	139	11.20
	700	55.40	168	8.29	45.58	217	11.28	45.44	178	11.07	39.94	240	11.23	38.49	137	11.39
	400	54.47	169	7.86	42.71	217	11.59	42.27	181	11.99	37.83	240	11.04	35.03	141	11.33
	200	53.41	168	7.79	40.68	216	11.90	40.29	178	12.08	36.54	241	10.93	34.23	139	10.46
	0							41.33	178	12.05	37.95	234	10.71	35.55	138	10.13
	-200							43.93	176	10.98	40.96	234	9.19	39.01	134	8.94
Statute not in effect	2,600	56.63	134	8.56	55.16	172	8.40	56.04	220	8.16	55.88	321	8.73	54.01	154	8.88
	2,200	57.38	137	9.09	56.80	173	8.85	57.21	223	8.76	57.24	327	8.40	55.78	154	8.74
	1,700	57.89	140	9.37	57.49	172	9.59	58.32	221	8.03	56.83	326	8.49	55.26	155	9.33
	1,300	58.06	136	8.78	57.77	172	8.96	58.37	221	7.94	56.08	326	9.19	54.38	155	10.19
	1,100	57.96	140	8.34	56.90	172	9.11	57.35	221	8.54	55.32	327	9.58	52.93	155	10.42
	900	57.29	138	8.46	55.59	172	9.07	56.09	220	8.43	54.23	326	9.87	51.66	154	10.18
	700	56.05	139	8.25	54.08	171	9.45	54.19	220	8.79	52.91	326	10.14	49.90	154	10.56
	400	54.73	139	8.15	52.58	171	9.89	52.46	221	9.04	51.33	328	10.61	47.80	155	11.29
	200	53.81	140	8.42	51.45	171	9.84	51.26	221	9.07	50.51	327	10.55	46.77	154	11.23
	0							52.44	218	9.16	51.61	325	10.30	48.26	152	11.06
	-200							52.92	215	8.72	52.57	317	9.19	49.30	153	10.20
Other vehicles																
Statute in effect	2,600	48.77	25	10.52	49.38	43	8.51	51.35	49	11.22	48.83	51	8.92	48.22	38	7.42
	2,200	49.69	27	10.91	51.71	43	8.04	54.26	48	8.06	50.16	50	7.12	49.37	39	6.67
	1,700	52.73	26	10.37	52.89	43	7.45	55.08	50	7.49	48.71	50	6.39	47.07	38	8.74
	1,300	53.06	27	9.57	52.83	43	7.44	53.41	51	7.59	47.27	49	6.64	45.63	40	9.47
	1,100	52.36	27	9.63	49.95	43	7.33	49.31	51	8.99	44.90	49	7.14	43.09	40	9.83
	900	51.76	27	9.97	46.96	43	7.97	45.91	51	9.84	43.46	48	7.20	40.87	41	9.90
	700	49.57	26	10.39	42.62	43	8.24	41.88	51	9.89	40.58	49	8.04	38.26	39	10.25
	400	48.54	27	11.11	39.02	43	9.03	38.99	51	10.32	39.19	48	8.01	35.16	41	10.69
	200	47.72	27	10.99	36.37	43	9.58	37.08	51	10.24	37.83	48	8.46	34.39	40	10.38
	0							38.46	49	10.36	39.16	47	8.35	35.22	40	10.72
	-200							41.22	48	8.88	40.49	46	7.84	37.70	39	8.80
Statute not in effect	2,600	49.38	39	9.70	47.77	47	9.02	51.08	54	8.14	49.12	67	9.68	51.11	47	8.10
	2,200	52.78	40	7.79	50.28	49	8.47	53.74	56	7.71	51.91	71	8.64	53.09	47	8.02
	1,700	54.65	40	7.29	52.37	49	7.63	55.18	56	7.21	53.01	72	7.81	52.76	47	8.51
	1,300	55.01	40	6.90	52.88	49	6.97	55.43	56	7.16	53.11	72	8.17	52.67	46	8.96
	1,100	54.62	39	6.60	52.33	49	6.87	54.61	56	7.40	52.42	72	8.49	51.18	46	9.25
	900	53.62	40	6.86	51.41	49	6.83	53.40	56	7.94	51.55	72	8.56	50.22	45	10.14
	700	52.25	39	6.87	49.86	49	6.59	51.91	56	8.44	49.68	72	8.90	48.46	45	10.29
	400	51.18	40	7.09	48.46	49	6.72	50.81	56	8.67	48.05	73	9.18	46.94	45	10.97
	200	50.31	40	6.73	47.28	49	6.76	49.88	56	8.51	47.17	73	9.46	45.93	45	10.81
	0							51.63	55	8.78	48.32	73	9.42	48.00	44	10.96
	-200							51.91	54	7.80	49.23	71	8.49	48.51	43	10.14

Note: 1 mph = 1.6 km/h. 1 ft = 0.3048 m.

Figure 4. Sign condition 1 speed profiles.

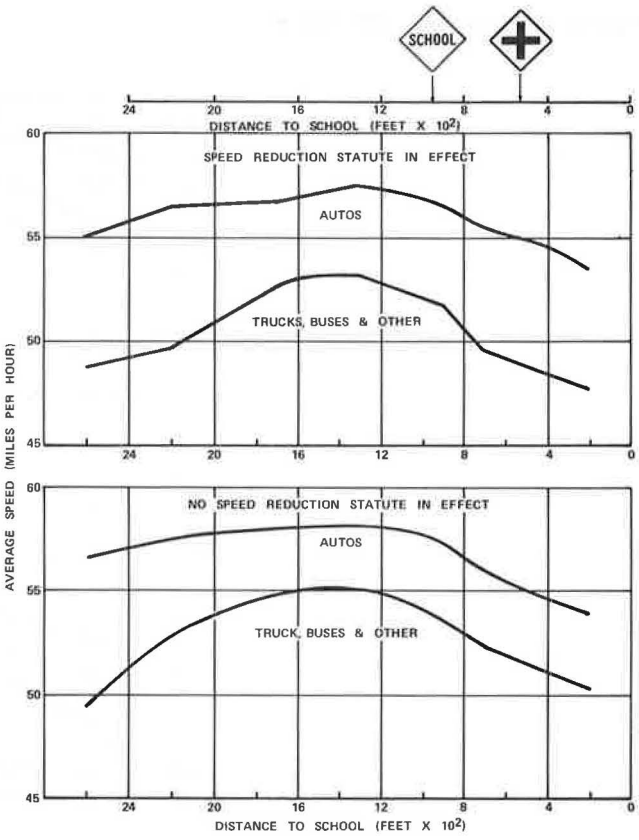


Figure 5. Sign condition 2 speed profiles.

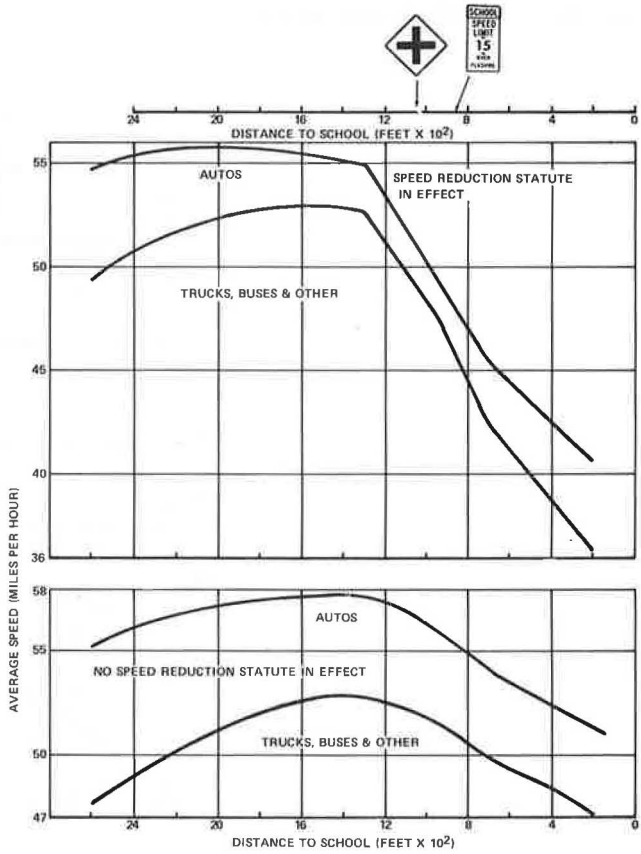


Figure 6. Sign condition 3 speed profiles.

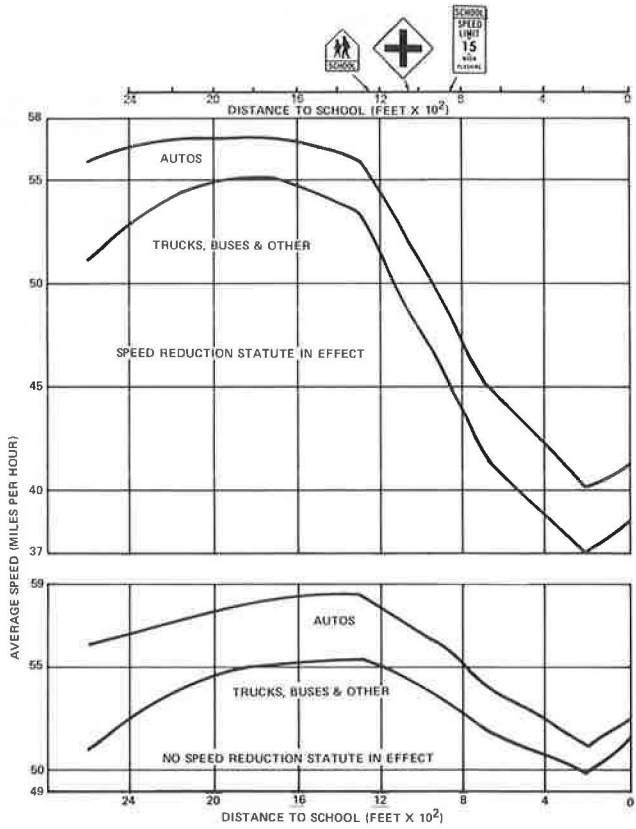


Figure 7. Sign condition 4 speed profiles.

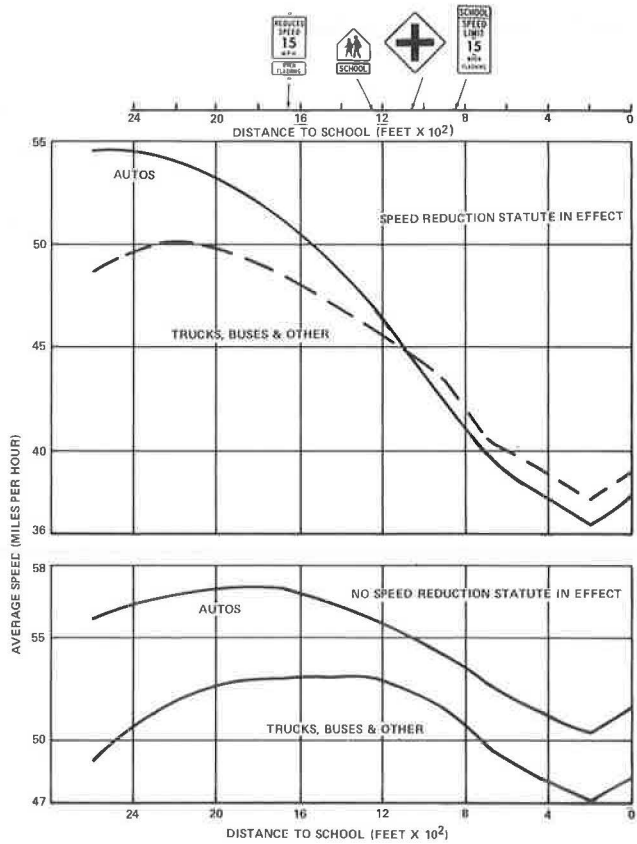


Figure 8. Sign condition 5 speed profiles.

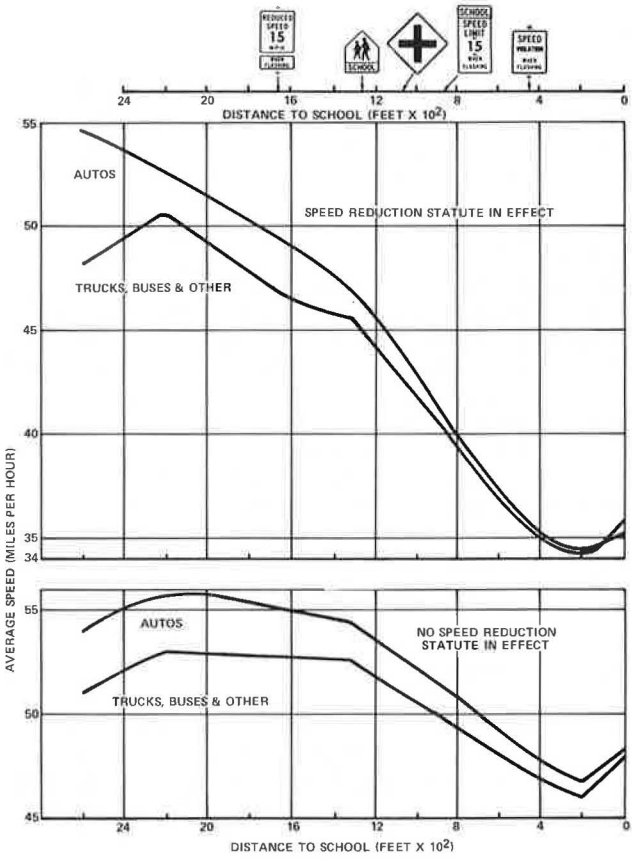
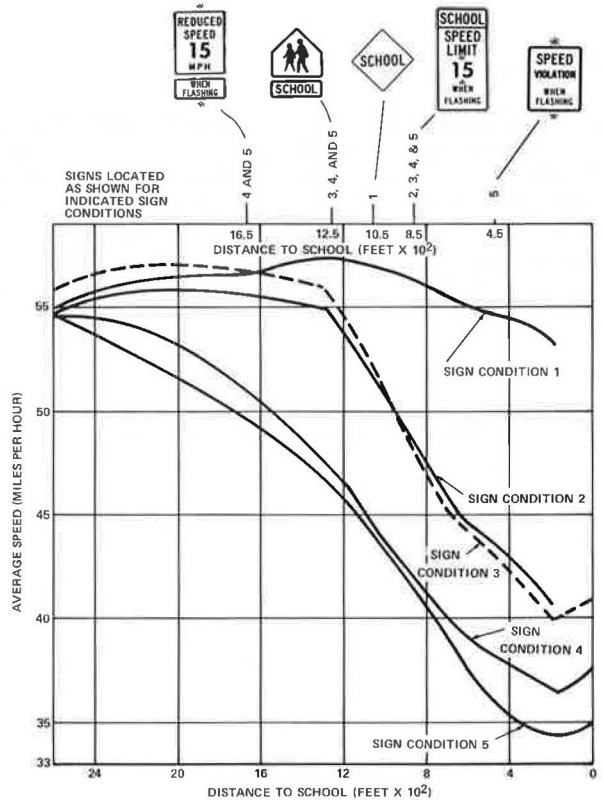


Figure 9. Automobile speed profiles when statute in effect.



than the passive, diamond-shaped school sign (W9-1, 1961 MUTCD). Drivers start to reduce their speed sharply at about 400 ft (122 m) in advance of the sign when it is the only dynamic sign present.

2. The symbol type of school advance sign does not cause drivers to further alter their speed when it is used with the flashing speed limit sign.
3. The rate of speed reduction effected by sign conditions 2, 3, 4, and 5 is approximately 1.25 ft/sec^2 (0.38 m/s^2), which is approximately the deceleration rate achieved with the engine engaged and without brakes used (4).
4. The flashing reduced speed ahead sign causes drivers to begin to reduce their speed as much as 800 ft (244 m) before the sign. When this sign was located 800 ft (244 m) in advance of the flashing school zone speed limit sign and the drivers decelerated at 1.25 ft/sec^2 (0.38 m/s^2), 3- to 5-mph (4.8- to 8.0-km/h) lower average speeds were experienced at the school intersection.
5. The flashing speed violation sign produced an additional 2-mph (3.2-km/h) lower average speed at the school intersection than the sign for the combined flashing reduced speed ahead and school zone speed limit signs.

A more detailed examination of where significant speed changes occurred for each sign condition is discussed below.

Speed Reductions

Table 7 gives the average absolute speed reduction for each sign condition as measured from 2,600 ft (793 m) to 200 ft (61 m) from the school intersection. Experimental signs 2, 3, 4, and 5 produced lower speeds for both speed statute conditions and for all vehicles. None of the signs produced the posted speed of 15 mph (24 km/h) when the speed statute was in effect. The lowest speed, approximately 34 mph (54 km/h), and the greatest amount of speed reduction, approximately 20 mph (32 km/h), occurred when the most dynamic sign condition was used.

Speed Variance

In Table 6, a trend can be seen toward increases in SD as sign conditions were made more dynamic under both statute conditions. Although most of the vehicles in the data analysis sample were operating under unimpeded conditions, this increased variance in speed and decrease in average speed must be related to the possible critical conditions that could arise under more congested traffic conditions.

Table 7 gives overall average speeds (average for all vehicles in a classification group over all instrumented stations) and speed variance for each vehicle type under each sign and statute condition. The overall average speed performances were tested

Table 7. Speed reduction, overall average speeds, and speed variance by sign condition.

Speed Statute	Sign Condition	Speed Reduction (mph)		Average Speed (mph)		Speed Variance (mph)	
		Automobiles	Other	Automobiles	Other	Automobiles	Other
In effect	1	1.6	1.1	55.8	50.5	8.8	10.4
	2	13.9	13.0	50.1	46.9	11.5	9.9
	3	15.6	14.3	49.2	46.1	12.1	11.4
	4	18.1	11.0	44.2	43.8	11.9	8.7
	5	20.6	13.8	43.0	41.3	12.2	10.8
Not in effect	1	1.8	-0.9	56.6	52.6	8.7	7.5
	2	3.7	0.5	55.3	50.3	9.5	7.5
	3	4.8	1.2	55.2	52.7	8.9	8.1
	4	5.4	1.9	54.1	50.3	9.8	8.9
	5	7.2	5.2	51.5	49.9	10.6	9.9

Note: 1 mph = 1.6 km/h.

to determine whether automobile drivers differed significantly ($\alpha = 0.05$) from truck, bus, and other vehicle drivers. The test was made for both statute conditions. The results show that the average performance of automobile and other vehicle drivers differed for all but sign condition 4 when the statute was in effect. This is a curious result. However, the exposure of drivers to sign condition 4 was the least and may not reflect the longer term effects of that sign condition. The opposite condition may be true; i.e., sign condition 4 may lead to the more uniform average speed performance of the two classes of vehicle drivers.

Differences in speed variability were also tested by using an F-test ($\alpha = 0.05$) to compare sign conditions. Sign conditions were compared for each vehicle type when the speed statute was in effect. The results in Table 7 show that the performance of automobile drivers differed with regard to variability for sign conditions 3, 4, and 5. There is no reason to infer differences in performance variability among sign conditions 3, 4, and 5. Performance of truck, bus, and other vehicle drivers differed with regard to variability for sign conditions 1 and 2 when compared with sign conditions 3 and 4. Performance of drivers did not show significant differences in variability for sign condition 5 compared with all other sign conditions.

Vehicle Location

A one-way analysis of variance was run with vehicle location as the treatment factor (the vehicle was over the instrumented station). The F-tests showed significant differences among the effects of vehicle location on average speed for all sign condition, vehicle type, and statute status combinations except for the combination of sign condition 1; trucks, buses, and other vehicles; and the statute in effect. It is not clear why these vehicles operating with only sign condition 1 were unaffected by their location along the roadway except that the old diamond-shaped school sign had no effect on the drivers of such vehicles. The number of vehicles in this combination was only 26, a much smaller sample size than for other combinations (Table 5).

Statistical t-tests ($\alpha = 0.05$) were conducted next to determine the exact locations at which changes in the average speeds became significant within each sign condition when the speed statute was in effect. For each sign condition, no significant differences in average speed changes occurred closer than 700 ft (214 m) to the school for either automobiles or other vehicles.

Further t-tests ($\alpha = 0.05$) were run to compare the vehicles' average speeds under differing experimental sign conditions on an instrumented station basis; i.e., speeds at the same location were compared across sign conditions. As is shown in Figure 9, significant differences in average speed were found at all locations except for the instrumented station farthest from the school. The speed response of drivers to sign conditions 2 and 3 was statistically the same. Significant differences between sign conditions 1 and 2 first occurred 1,300 ft (396 m) from the school for automobiles and 900 ft (313 m) before the school for other vehicles. Significant differences between sign conditions 1 and 3 first occurred 1,100 ft (335 m) from the school for all type vehicles. At the school, the automobile driver response to sign condition 3 was statistically different from that to sign conditions 4 and 5, but the response to sign condition 4 was significantly different from the response to sign condition 5 for all vehicle drivers. Sign conditions 4 and 5 differed statistically from sign conditions 1, 2, and 3 for automobiles up to 200 ft (61 m) from the school and for other vehicles up to 900 ft (274 m) from the school.

Finally, statistical tests for significant differences ($\alpha = 0.05$) were conducted to determine the points at which the vehicles differed in average speed when the statute was both in effect and not in effect. The results are given in Table 8. These results show a high correlation between the location of the first sign that the driver sees in a sign condition and the point at which significant differences occur. Such correlation is encouraging in that drivers are reacting to the signs at the proper time; i.e., they obey them when the statute is in effect and ignore them when the statute is not in effect.

Table 8. Statistically significant speed differences for various sign conditions.

Vehicle	Sign Condition	Location of First Sign (ft from school)	Significant Differences (α = 0.05)
Automobiles	1	1,100	None
	2	1,100	Significant from 1,300 ft to school
	3	1,300	Significant from 1,300 ft to school
	4	1,700	Significant from 2,200 ft to school
	5	1,700	Significant from 2,200 ft to school
Other	1	1,100	None
	2	1,100	Significant from 900 ft to school
	3	1,300	Significant from 1,100 ft to school
	4	1,700	Significant from 1,700 ft to school
	5	1,700	Significant from 2,200 ft to school

Note: 1 ft = 0.3048 m.

SUMMARY AND CONCLUSIONS

This paper has focused on the effectiveness of five rural school zone signing conditions in achieving driver compliance with a 15-mph (24-km/h) school zone speed limit. Although the total objectives of the experiments must await further analysis and refinement of the data, a number of useful conclusions can be made now.

1. The 1961 MUTCD school signing (sign condition 1) is inadequate for informing drivers of existing school zone speed limits.
2. The 1971 MUTCD mandatory school signing when combined with beacons and the words WHEN FLASHING (sign condition 2) made the drivers reduce their speeds but only to about 40 mph (64 km/h), which they may have felt was reasonable and proper for the observed condition.
3. The addition of the MUTCD advance school zone sign (sign condition 3) with both the symbol and the word SCHOOL included had no significant additional effect on speed reduction over that experienced with the speed limit sign as given above.
4. An advance sign advising drivers of the reduced speed limit ahead (sign condition 4) did cause an earlier and somewhat more gradual speed reduction when compared with the abrupt reduction obtained by using the school speed limit sign with beacons and the words WHEN FLASHING (sign condition 2) or with the advance school zone sign (sign condition 3). The average speed was reduced to approximately 37 mph (59 km/h) near the school with the advance reduced speed limit sign.
5. The addition of a dynamic speed violation sign resulted in an average speed of 34 mph (55 km/h), a further speed decrease of about 3 mph (4.8 km/h).

By reviewing the effects of the five sign conditions discussed above, we can further conclude that the speed limit sign introduced in sign condition 2 produced a consistent average speed reduction and profile that indicated the sign, reinforced by the flashing beacons, was being recognized by the drivers. It also appears, from the speed reduction achieved, that the drivers did not recognize the need for a speed limit of 15 mph (24 km/h), but were willing to slow down to what seemed to them to be a reasonable speed [35 to 40 mph (56 to 64 km/h)] for the road and surrounding conditions as they saw them.

The effect of the introduction of the school zone symbol sign on drivers could not be interpreted. Drivers may have thought that it was advisory only and that no additional action was required. The speed limit sign with flashing beacons had the same effect with and without the symbol sign. Further experimentation would be necessary to determine the need for and efficacy of the symbol sign.

The advance sign advising drivers of the reduced speed of 15 mph (24 km/h) ahead caused an earlier reaction by the drivers. Although traveling at an average speed of 55 mph (88 km/h) 800 ft (244 m) in advance of the sign, they had reduced their speed

to about 50 mph (80 km/h) at the sign and further reduced their speed to about 42 mph (67 km/h) as they passed the speed limit sign. The combined effect of the two signs was significant and appears to indicate that the maximum speed reduction was achieved on a voluntary basis through an understanding of the signs. However, it should be noted that this sign condition was observed only over a 2-week period.

The ultimate value of the dynamic speed violation sign could not be determined from this analysis. Although the average speed achieved was the lowest, down to 34 mph (55 km/h), this sign was used during the last 2 weeks of the school session (May 25 to June 8, 1974), and the extent of the learning process is not known, i.e., how much lower speed might have been obtained.

Finally, it now appears that

1. The 1961 MUTCD school sign was not adequate.
2. The 1971 MUTCD school speed limit sign when combined with beacons and the words WHEN FLASHING is effective in achieving a reasonable speed reduction.
3. The advance school zone signs, with the symbol and with the word SCHOOL, may not be of sufficient value for use at all locations. Further study may show that it could be effectively combined with speed advisory information to form one sign.
4. The advance reduced speed advisory sign with beacons caused drivers to reduce their speeds more in advance of the intersection.
5. The dynamic speed violation sign will require further study before a decision can be reached about its total effectiveness.

A speed of 15 mph (24 km/h) for rural school zones where there are very few children walking to the school area and where adjacent posted speed limits are 50 to 60 mph (80 to 96 km/h) cannot be achieved by the MUTCD signing and the auxiliary signing used for the experiments. The most desirable speed limit for such zones, based on these data, is 35 mph (56 km/h).

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