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Speed Enforcement, Visibility, and Effects of Traffic Control Measures on Drivers

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Contents

Authors of the Papers in This Record

Davis, Thomas D., New Jersey Department of Transportation, 1035 Parkway Avenue, Trenton, NJ 08625
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Effectiveness of School Speed Zones and Their Enforcement

PATRICK T. McCOY, ABBAS K. MOHADDES, AND RICHARD J. HADEN

Results of a study to determine the effect of school speed zones and their enforcement on speeds at school crossings are reported. A series of spot speed studies was conducted at four similar school crossings in Lincoln, Nebraska. Two of the crossings were within school speed zones designated by 25-mile/h speed-limit signs with flashing yellow beacons. The other two crossings were not within school speed zones. The speed studies were conducted during the normal 45-min student crossing period and for 1 h afterward. During the five-week period of the study, various levels of enforcement were applied at two of the crossings (one within and one not within a school speed zone). The influence of the school speed zones and levels of enforcement was determined by an analysis of the differences in 85th percentile speeds among the crossings. At all four school crossings studied, traffic speeds were found to be lower under two conditions: (a) when pedestrians were present in the immediate vicinity of the crossing and (b) during the normal 45-min crossing period when pedestrians were not present. However, the degree to which each of these conditions reduced speeds was found to be influenced by the 25-mile/h school speed zones and enforcement at the crossings. It was concluded that both school speed zones and enforcement enhance the speed-reduction effects of pedestrian presence and the normal crossing period at school crossings. But, to achieve an acceptable level of compliance, the creditability of school-speed-zone enforcement must be established.

In 1976, in response to citizens' requests for the establishment of 15-mile/h speed zones in advance of school crossings on streets with speed limits of 35 miles/h or higher, the mayor of Lincoln, Nebraska, appointed a special ad hoc committee to study the need for such speed zones and recommend whether or not they should be used in Lincoln. This committee analyzed the pedestrian accident experience in Lincoln and surveyed experience with school speed zones in 25 other cities throughout the country. As a result of its investigation (1), the committee found that

1. Only 6 of the 156 children aged 5 to 14 years who were involved in pedestrian accidents in Lincoln during the previous four years were struck while crossing a street adjacent to their school that had a speed limit above 25 miles/h;
2. Of the 25 cities surveyed, none of the 10 that submitted radar studies were able to achieve a speed reduction approaching the level proposed for Lincoln, even with concentrated police enforcement; and
3. There was no significant difference in accident experience between the cities that used school speed zones and those that did not.

Consequently, the committee recommended that school speed zones not be used in Lincoln, contending that resources required to seriously maintain and control school speed zones could be better spent in areas of child pedestrian safety where there was a greater potential for reducing accidents.

However, some of the committee members did not support this recommendation. These members felt that it should not be necessary to show that lowering speed limits would reduce accidents because the "potential" conflict between schoolchildren and motor vehicles was itself sufficient need for reduced speed limits. They also felt that speeds could be reduced to the proposed level by enforcement of and publicity about school speed zones. Although in the minority, they felt very strongly about the need for school speed zones. They continued to express their views and solicit the support of parents. Thus, by 1979, the city of Lincoln had established school speed zones at 15 locations and had received requests for several more.

Although they agreed that lower speeds were desirable, members of the Lincoln School Crossing Protection Committee questioned the effectiveness of these zones in actually reducing speeds and expressed the concern that their use might even have an adverse effect by giving parents and children alike a false sense of safety. Consequently, a study was undertaken to determine the influence of school speed zones and their enforcement on speeds at school crossings in Lincoln. This study was conducted by the Civil Engineering Department of the University of Nebraska-Lincoln in cooperation with the Lincoln Transportation and Police Departments. A description of the study and its results are presented in this paper.

STUDY PROCEDURE

A series of six spot speed studies was conducted at one-week intervals at each of four school crossings in Lincoln over a five-week period. Speeds were measured in only one direction at each crossing under free-flowing traffic conditions during the time of day when students used the crossing and for 1 h afterward. Thus, each study lasted for 1 h and 45 min (i.e., the 45-min student crossing period plus 1 h after the crossing period). At each crossing, the same direction of traffic was always observed, and the studies were always conducted during the same time of day. The presence of students in the vicinity of the crossing was noted as each speed was recorded.

The posted speed limit on the street on which each crossing was located was 35 miles/h. However, two of the crossings studied were within 25-mile/h school speed zones, which were in effect only during the 45-min crossing period. The other two crossings were not within school speed zones. Therefore, the 35-mile/h speed limits posted on the streets were in effect during the 45-min crossing period as well as during the 1-h-after study period at these locations.

In addition, at two of the school crossings (one within and one not within a school speed zone), the level of enforcement was increased during the 45-min crossing period for the first three weeks of the study, and then no enforcement was applied during the last two weeks. At the other two crossings, no enforcement was applied during the 45-min crossing period for the entire five-week study period.

The influence of the school speed zones was determined by comparing the differences between the speeds observed during the 45-min crossing period and those observed during the 1-h period afterward at the two crossings within school speed zones with the corresponding speed differences at the other two crossings not within school speed zones. Similarly, the influence of enforcement was evaluated by comparing the five-week patterns of these speed differences at the two crossings where enforcement was applied with those at the other two crossings where enforcement was not applied.

STUDY SITES

In selecting the study sites, an effort was made to isolate as much as possible the effects of the school speed zones and their enforcement. Therefore, four school crossings were selected that were similar with respect to traffic and roadway condi-

Table 1. Characteristics of study sites.

School Crossing	School Speed Limit (miles/h)	Enforcement: Study	Enforcement: Prior Level	Traffic Control	Crossing Guard	Location	School Visible from Crossing	Crossing Period Studied	Street Crossed: Student Crossing Volume	Street Crossed: Avg Daily Traffic (no. of vehicles)	Street Crossed: Speed Limit (miles/h)	Street Crossed: No. of Lanes	Street Crossed: Parking	Street Crossed: Vertical Alignment
1	25	Yes	Min.	TS[a]	Yes[b]	Midblock	Yes	Morning	30-40	15 000	35	2[c]	None	Level
2	25	No	Min.	TS[a]	Yes[b]	Midblock	Yes	Afternoon	30-40	15 000	35	2[c]	None	Crest[d]
3	None	Yes	Min.	TS[a]	No	Corner	No	Morning	30-40	10 000	35	2	None	Level
4	None	No	Min.	TS[a]	No	Corner	No	Afternoon	30-40	10 000	35	2[c]	None	Crest[e]

[a]Pedestrian-actuated traffic signal with pedestrian signal indications.
[b]Student crossing guard actuated traffic signal during peak 15-min pedestrian volume.
[c]Plus a continuous two-way left-turn lane.
[d]Type 2 crest vertical curve with study approach on downgrade.
[e]Type 1 crest vertical curve with study approach on upgrade.

Figure 1. School crossing.

Figure 2. School speed-limit sign.

tions, pedestrian volume, control, and previous level of enforcement. Thus, the principal difference among them was that two of them were within school speed zones and the other two were not. The sites selected and their characteristics are given in Table 1.

The crosswalk at each crossing was marked on both edges with 6-in solid white lines and controlled by a pedestrian-actuated traffic signal with pedestrian signals (TS), as shown in Figure 1. School advance signs were located on the approaches to the crossings. The school speed zones were designated by 25-mile/h speed-limit signs with flashing yellow beacons, which operated only when the 25-mile/h speed limit was in effect during pretimed student crossing periods before and after school and at noontime. The speed-limit sign is shown in Figure 2.

Although every effort was made to find four identical crossings, it was impossible to do so. Perhaps the differences that could have had the most significant effects on the speeds observed were with respect to the locations and vertical alignments of the crossings selected. Crossings 1 and 2, the two crossings located within school speed zones, were located at midblock directly in front of the schools they served, whereas crossings 3 and 4 were located at the corner on streets not adjacent to the schools they served. Whether or not the school served was visible to traffic approaching the crossing could have affected drivers' perceptions of the need for caution and thus could have affected the speeds observed (2). Because the vertical alignments at crossings 2 and 4 were on crest vertical curves, the sight distances beyond the crossings on the approaches were limited. These limited sight distances could have affected the speeds observed at these two crossings.

In Tacoma, Washington, spot speed studies indicated that the presence of a student crossing guard (i.e., a school patrol boy or girl) reduced vehicle speeds at school crossings by 2-5 miles/h (1). Therefore, the fact that the crossings within school speed zones had student crossing guards and the other two crossings did not have them could also have affected the results of this study. The student crossing guards actuated the traffic signals to stop traffic and permit the students to cross. However, they were present only during the time when most of the students crossed, which amounted to about 10-15 min of the 45-min crossing period. To account for the effect of the crossing guards, speeds observed during their presence were recorded as though students were present.

The other differences among the study sites were judged to be inconsequential. For example, the fact that the street crossed by crossing 3 did not have a continuous two-way left-turn lane was determined to be unimportant because the amount of driveway traffic in the vicinity of crossings was negligible during the times when the speed studies were conducted.

ENFORCEMENT

The enforcement strategy applied at the two crossings that were enforced was developed in concurrence with the Lincoln Police Department. It was designed to enable the determination of the immediate and residual influences of the maximum feasible level of enforcement as well as to provide an indication of the influence of intermediate levels of enforcement. Therefore, it was decided to apply enforcement at the two crossings during the first three weeks of the five-week study and then apply no enforcement during the last two weeks. Over the first three weeks, the level of enforcement was increased each week from one day of enforcement in the middle of the first week to enforcement on every other day (i.e., three days of enforcement) during the second week to enforcement on all five weekdays during the third week.

On each day of enforcement, speeds were enforced during the same 45-min crossing period during which the spot speed studies were conducted (i.e., the morning crossing period at crossings 1 and 3). However, spot speed studies were never conducted on the same day that enforcement was applied.

Enforcement consisted of a uniformed officer in a marked police car that was equipped with a radar unit and was stationed in a position from which it was possible to monitor speeds at the crossing. The positions taken by the officers were not concealed from the view of approaching traffic. However, the positions used at crossing 1 were less visible to traffic on the approach studied than were those at crossing 3.

A record of the hours of enforcement and number of citations issued at each crossing was maintained.

FINDINGS

Nearly 8100 speeds were observed during the conduct of the 24 spot speed studies at the four school crossings. The speed data collected in each of these studies were stratified into the following four data sets according to the time of collection and the presence of students in the immediate vicinity of the crossings:

Data Set	Data Collected
1	Speeds during the hour after the 45-min crossing period, without students present
2	Speeds during 45-min crossing period, without students present
3	Speeds during 45-min crossing period, with students present
4	Speeds during the hour after the 45-min crossing period, with students present

The speeds for each study in data set 4 were not analyzed because the sample size was too small. For all 24 studies, the total number of speeds in this data set was only 73, an average of three observations per study. The speeds in the other three data sets were analyzed to determine the 85th percentile and mean speeds and the standard deviations. A summary of these sample statistics for each of the 24 studies is given in Table 2. Symbols used in Table 2 and in other tables in this paper to indicate study periods for which data are given are defined as follows:

Symbol	Definition
B	Before study

Table 2. Summary of sample statistics from spot speed studies.

	Data Set 1				Data Set 2				Data Set 3			
Study	X_{85}	$\bar{X}$	SD	n	X_{85}	$\bar{X}$	SD	n	X_{85}	$\bar{X}$	SD	n
Crossing 1 (S, E)												
B	36	33	±3.4	212	35	31	±4.4	188	32	28	±5.0	46
E_1	34	32	±3.5	292	32	29	±3.6	85	30	26	±4.6	91
E_2	35	31	±4.1	268	32	28	±4.3	181	29	26	±3.3	51
E_3	34	31	±3.9	300	30	27	±3.4	179	28	24	±3.5	76
A_1	35	33	±3.8	248	32	29	±4.5	159	28	24	±3.8	49
A_2	35	32	±3.9	260	32	28	±4.0	198	28	24	±2.6	67
Crossing 2 (S)												
B	34	31	±3.6	234	32	29	±4.4	152	30	27	±3.2	39
E_1	35	33	±3.5	236	33	29	±3.9	96	32	28	±4.4	106
E_2	34	31	±3.7	206	31	29	±2.9	120	30	27	±2.8	52
E_3	34	31	±3.6	251	32	29	±4.1	96	31	27	±3.7	84
A_1	35	30	±4.3	175	32	29	±3.6	124	30	28	±2.4	25
A_2	34	31	±3.5	193	32	28	±4.1	131	30	28	±2.0	24
Crossing 3 (E)												
B	38	34	±3.9	145	37	34	±4.2	89	36	30	±3.2	28
E_1	37	33	±4.2	137	36	33	±3.8	74	35	31	±3.8	50
E_2	37	33	±4.3	115	35	32	±4.4	91	33	30	±3.7	40
E_3	35	32	±3.8	125	34	30	±4.2	109	32	28	±3.1	27
A_1	36	33	±4.5	141	34	30	±4.3	125	32	28	±3.4	39
A_2	36	32	±3.9	118	36	33	±4.3	88	35	29	±3.0	27
Crossing 4												
B	31	28	±3.9	177	31	29	±4.0	104	30	28	±3.3	24
E_1	31	30	±3.2	188	32	29	±3.9	85	31	28	±3.7	32
E_2	32	29	±3.4	178	32	29	±3.8	108	32	28	±3.6	35
E_3	32	29	±3.6	184	32	28	±4.3	104	31	27	±2.4	43
A_1	32	29	±3.7	167	32	28	±3.6	123	32	28	±3.7	23
A_2	32	28	±4.2	203	32	28	±4.8	138	31	27	±3.6	33

Note: X_{85} = 85th percentile speed (miles/h), $\bar{X}$ = mean speed (miles/h), SD = standard deviation (miles/h), n = sample size, S = crossing within school speed zone, and E = enforcement applied at crossing.

Table 3. Errors in the estimates of 85th percentile speeds.

	Crossing 1 (S, E) by Data Set			Crossing 2 (S) by Data Set			Crossing 3 (E) by Data Set			Crossing 4 by Data Set		
Study	1	2	3	1	2	3	1	2	3	1	2	3
B	±0.6	±0.8	±1.8	±0.7	±0.9	±1.2	±0.8	±1.1	±1.5	±0.7	±0.9	±1.6
E_1	±0.5	±1.0	±1.2	±0.6	±1.0	±1.0	±0.9	±1.1	±1.3	±0.7	±1.0	±1.6
E_2	±0.6	±0.8	±1.1	±0.6	±0.7	±0.9	±1.0	±1.1	±1.4	±0.6	±0.9	±1.5
E_3	±0.6	±0.6	±1.0	±0.6	±1.0	±1.0	±0.8	±1.0	±1.5	±0.6	±1.0	±0.9
A_1	±0.6	±0.9	±1.3	±0.8	±0.8	±1.2	±0.9	±0.9	±1.5	±0.7	±0.8	±1.9
A_2	±0.6	±0.7	±0.8	±0.6	±0.9	±1.0	±0.9	±1.1	±1.4	±0.7	±1.0	±1.5
Total	±0.02	±0.03	±0.08	±0.02	±0.04	±0.08	±0.03	±0.05	±0.11	±0.02	±0.04	±0.12

Notes: Error = $\pm[(1.96)^2$ (sample variance) $(2 + 1.04^2)/(2)$(sample size)] in miles per hour.
S = crossing within school speed zone, and E = enforcement applied at crossing.

Table 4. Primary effects on traffic speeds at school crossings.

		Effect (miles/h)		
Crossing	Study	E_{PED}	E_{XING}	Total
1 (S, E)	B	3	1[a]	4
	E_1	2[a]	2	4
	E_2	3	3	6
	E_3	2	4	6
	A_1	4	3	7
	A_2	4	3	7
	Mean	3.0	2.7	5.7
2 (S)	B	2[a]	2	4
	E_1	1[a]	2	3
	E_2	1[a]	3	4
	E_3	1[a]	2	3
	A_1	2[a]	3	5
	A_2	2	2	4
	Mean	1.5	2.3	3.8
3 (E)	B	1[a]	1[a]	2[a]
	E_1	1[a]	1[a]	2[a]
	E_2	2[a]	2	4
	E_3	2[a]	1[a]	3
	A_1	2[a]	2	4
	A_2	1[a]	0	1[a]
	Mean	1.5	1.2	2.7
4	B	1[a]	0	1[a]
	E_1	1[a]	-1[a]	0
	E_2	0	0	0
	E_3	1[a]	0	1[a]
	A_1	0	0	0
	A_2	1[a]	0	1[a]
	Mean	0.7[a]	-0.2[a]	0.5[a]

Note: S = crossing within school speed zone, and E = enforcement applied at crossing.

[a]Not statistically significant at the 5 percent level.

Symbol	Definition
E_1	Study one week after enforcement applied at some crossings
E_2	Study two weeks after enforcement applied at some crossings
E_3	Study three weeks after enforcement applied at some crossings
A_1	Study one week after no enforcement at all crossings
A_2	Study two weeks after no enforcement at all crossings

The determination of the influence of the school speed zones and their enforcement was based on comparisons of 85th percentile speeds. Therefore, the error in the estimate of the 85th percentile speed at the 95 percent level of confidence was computed for each data set. The results of these calculations are given in Table 3. These results indicate that these errors were all within ±1.1 mile/h for data sets 1 and 2 for all crossings, which were without students present. In the case of data set 3, all but two of the errors were within ±1.6 mile/h. Therefore, it was concluded that the degree of statistical accuracy provided by the data was sufficient for the purposes of this study.

Primary Effects

One factor that has been found in previous research (1-3) to affect traffic speeds at school crossings was the presence of pedestrians (i.e., students and/or school patrol boys or girls) in the immediate vicinity of the crossing. These studies have found that the speed of traffic was from 2 to 5 miles/h lower when pedestrians were present. In fact, the presence of pedestrians was usually found to have more effect than school speed zones.

Another factor that was found to affect the speeds in this study was the 45-min crossing period. Even when pedestrians were not present, the speeds at the crossings were usually lower during the 45-min crossing period (i.e., data set 2) than they were during the 1 h afterward (i.e., data set 1). This was true whether or not the crossing was within a school speed zone.

Therefore, for the purposes of this study, the effects of these two factors were defined as the "primary effects" on speeds at school crossings, and the influences of school speed zones and their enforcement were evaluated with respect to these primary effects.

The primary effects were computed with the 85th percentile speeds, as follows:

$$E_{PED} = (\text{XING W/O PED})_{85} - (\text{XING WITH PED})_{85} \quad (1)$$

$$E_{XING} = (\text{NON-XING W/O PED})_{85} - (\text{XING W/O PED})_{85} \quad (2)$$

E_{PED} = effect of pedestrian presence (miles/h);
E_{XING} = effect of 45-min crossing period (miles/h);
$(\text{XING W/O PED})_{85}$ = 85th percentile speed of data set 2 (miles/h);
$(\text{XING WITH PED})_{85}$ = 85th percentile speed of data set 3 (miles/h); and
$(\text{NON-XING W/O PED})_{85}$ = 85th percentile speed of data set 1 (miles/h).

In addition, as measures of the overall influences of school speed zones and their enforcement, the means of the primary effects over the five-week study period were computed. The results of these computations are given in Table 4.

The mean primary effects were greatest at crossing 1, which was within a school speed zone and was subject to enforcement. At the other extreme, these effects were least evident--in fact, statistically insignificant--at crossing 4, which was not within a school speed zone and was not subject to enforcement. Comparison of the mean primary effects at the other two crossings indicated that, with respect to the "pedestrian effect", the influence of the school speed zone at crossing 2 was similar to that of the enforcement applied at crossing 3. However, with respect to the "crossing-period effect", the influence of the school speed zone was greater than that of the enforcement.

In addition, throughout the five-week study period, the primary effects at crossings 2 and 4, where enforcement was not applied, remained essentially unchanged. Whereas at crossings 1 and 3, where enforcement was applied, and particularly at crossing 1, which was within a school speed zone, the combination of the primary effects increased with enforcement. The influence of enforcement remained for one week after enforcement was removed at crossing 3 and for two weeks after it was removed at crossing 1. This suggests that, once the creditability of enforcement was established, a lower level of enforcement could be used to maintain the maximum influence of enforcement. It also indicates that the residual influence of enforcement is greater at crossings within school speed zones.

In studying these findings, it is necessary to recognize that it is to be expected that the crossing-period effect would be greater at crossings within school speed zones than at those not within school speed zones. It is desirable that the crossing-period effect at crossings within school speed zones be equal to the difference between the posted speed limit on the street and the limit for the school speed zone. Therefore, the desired crossing-period effect at crossings 1 and 2 would be 10 miles/h. Likewise, the expected crossing-period effect at the other crossings (3 and 4), which were not within school speed zones, would be zero because the same speed limit was in effect during both the crossing and noncrossing periods.

The findings given in Table 4 are consistent with these expectations. The crossing-period effect was greater at the crossings within school speed zones than at those not within school speed zones. However, on the average, this effect at the crossings within school speed zones was considerably less than desired. But, over the five-week study period, at crossing 1, which was within a school speed zone and received enforcement, the crossing-period effect increased from being not significantly greater than zero before enforcement was applied to 40 percent of the desired effects within the three-week period of enforcement. When this effect was combined with its respective pedestrian effect, the total effect achieved during the three-week enforcement period at this crossing was within 70 percent of the desired effect.

The crossing-period effect at crossing 3 was significantly greater than zero because the 85th percentile speeds during the 1 h after the crossing period at this crossing exceeded the speed limit on the street. Once these speeds are brought into compliance with the speed limit, the crossing-period effect at this crossing would approach zero.

Based on the analysis of the primary effects, it was concluded that both the pedestrian and crossing-period effects at a school crossing are enhanced by a school speed zone. In previous research (2), the pedestrian effect at school crossings has been attributed to the driver's perception of the need for caution. Apparently, when pedestrians are present in the vicinity of a school crossing, drivers perceive the need for caution and slow down. Consequently, school speed zones must in some way increase drivers' awareness of the need for caution when pedestrians are present. In addition, it was noted that enforcement did not have any noticeable influence on the pedestrian effect.

It was also concluded from this analysis that the desired reduction in speeds at school crossings within school speed zones cannot be achieved without enforcement and the presence of pedestrians. Once the creditability of school-speed-zone enforcement was established, the combination of pedestrian and crossing-period effects amounted to 70 percent of the desired speed reduction. But, even when the creditability of enforcement had been established, the speed reduction attained when pedestrians were not present was only about 50 percent of that desired. Thus, school speed zones are only effective when both the need for caution and the creditability of enforcement are perceived by drivers. Therefore, school speed zones should not be installed unless they will be enforced, and they should not be in operation unless pedestrians are present.

Compliance with Speed Limits

Another basis on which the influences of school speed zones and their enforcement were evaluated was the degree to which traffic complied with the speed limit at the school crossing during the 45-min crossing period. In Figure 3, the 85th percentile speeds at the crossings during the 45-min crossing period are shown in relation to speed limits at the crossings during the crossing period. Figure 4

Figure 3. Relation of 85th percentile speeds and speed limits during crossing period.

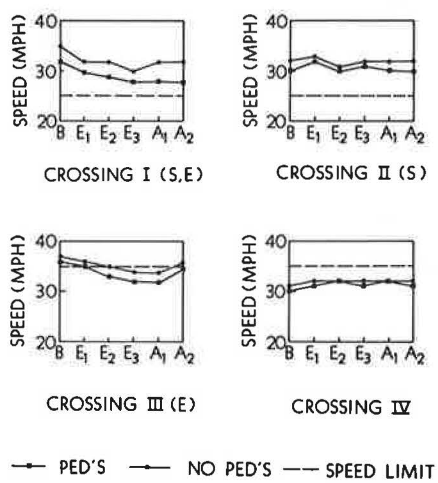

Figure 4. Compliance with speed limit during crossing period.

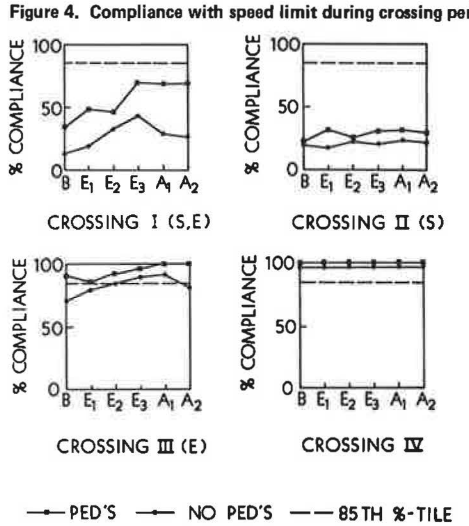

Table 5. Intensity of enforcement at two crossings.

Crossing	Traffic Volume (vehicles/h)	Speed-Limit Compliance (%)	No. of Expected Violations per Hour	Citations Issued: No. per Hour	Citations Issued: No. per 100 Expected Violations
1	480	33	320	5.7	1.8
3	210	84	34	0.8	2.4

shows the percentage of speeds at each crossing observed to be in compliance with (i.e., less than or equal to) the speed limit that was in effect during the crossing period. In both of these figures, two curves are shown for each crossing. One of the curves represents the speeds observed when pedestrians were not present at the crossing, and the other curve is for speeds observed when pedestrians were present.

At crossings 1 and 2, the two crossings that were within school speed zones, the 85th percentile speeds were always above the 25-mile/h speed limit even when pedestrians were present. The percentages of compliance at these two crossings were always below the desirable minimum of 85 percent. At crossing 2, where enforcement was not applied, the 85th percentile speeds remained essentially unchanged over the five-week study period, as did the percentages of traffic complying with the 25-mile/h speed limit. However, after three weeks of enforcement at crossing 1, the 85th percentile speeds were lower and the percentages of compliance were higher. At this crossing, speeds were reduced by 5 miles/h. The percentage of compliance without pedestrians present increased from 13 to 43 percent, and that with pedestrians present increased from 35 to 70 percent. These changes were found to be statistically significant at the 5 percent level of significance.

Although the 85th percentile speeds at crossing 1 remained above the 25-mile/h speed limit, the 85th percentile speed with pedestrians present at this crossing was reduced to less than 30 miles/h, which was within the tolerance used in issuing official speeding citations.

At crossing 3, which was not within school speed zones but did receive enforcement, the 85th percentile speeds were initially above the speed limits. However, after three weeks of enforcement, the 85th percentile speeds were in compliance with the speed limits. After the third week of enforcement, the percentage of compliance without pedestrians present had increased from 71 to 90 percent, and with pedestrians present it had increased from 91 to 97 percent. These changes were statistically significant at the 5 percent level of significance.

At crossing 4, which was neither within a school speed zone nor enforced, the 85th percentile speeds were below the 35-mile/h speed limit, and the percentages of compliance were at or just below 100 percent. As expected, these values did not change significantly over the five-week study period.

At crossings 1 and 3, the two crossings where enforcement was applied, the maximum influence of enforcement on 85th percentile speeds and percentages of speed-limit compliance occurred after the third week of enforcement. Two weeks after enforcement was removed, its influence was significantly diminished. At crossing 3, which was not within a school speed zone, the speeds had returned to their preenforcement levels. However, at crossing 1, which was within a school speed zone, the speeds two weeks after enforcement was removed were still significantly lower than those before enforcement was applied. This suggests that the residual influence of enforcement is greater at school crossings within school zones.

Intensity of Enforcement

Even though the same level of enforcement was applied at crossings 1 and 3, the difference in the residual influences of enforcement could have been due to a difference in the intensity with which enforcement was applied. Therefore, a comparison of the intensity of enforcement applied at these two crossings was made. Based on the average traffic volume and the average percentage of compliance during the three weeks of enforcement, the expected number of speeding violations per hour of enforcement was computed for each crossing as follows:

$$n = [1 - (PC/100\ \text{percent})]\ V \qquad (3)$$

where

n = expected number of speeding violations per hour,
PC = average percentage of compliance with the speed limit during the period of enforcement, and
V = average traffic volume at the crossing during the period of enforcement (vehicles/h).

Then, as a measure of enforcement intensity, the number of citations issued by the Lincoln Police Department per 100 expected violations was computed for each crossing. The results of these computations are given in Table 5.

Based on the number of citations issued per 100 expected speeding violations, the intensity of enforcement was higher at crossing 3 than at crossing 1. Therefore, it was concluded that the greater residual influence of enforcement at crossing 1, which was within a school speed zone, was not due to differences in the intensity of enforcement but was probably due to the influence of the school speed zone.

CONCLUSIONS

At all four school crossings studied, traffic speeds were found to be lower under two conditions: (a) when pedestrians were present in the immediate vicinity of the crossing and (b) during the normal 45-min crossing period when pedestrians were not present. However, the degree to which each of these conditions reduced speeds was found to be affected by the 25-mile/h school speed zones and enforcement at the crossings. The reduction was greatest at the crossing that was within a 25-mile/h school speed zone and was subject to enforcement. Conversely, the speed reduction was least at the crossing that was neither within a school speed zone nor subject to enforcement. However, at the crossing that was within a school speed zone and subject to enforcement, the 85th percentile speed during the 45-min crossing period was always greater than the 25-mile/h speed limit, even after the maximum level of enforcement had been applied. However, it was ultimately reduced to within the tolerance used by the Lincoln Police Department when enforcing speed limits.

At the two crossings where enforcement was applied, as would be expected, the maximum effect of enforcement was observed after the maximum level of enforcement had been applied. Then, after two weeks with no enforcement, this effect had essentially disappeared at the crossing that was not within a school speed zone and had been reduced by about 50 percent at the crossing that was within a school speed zone. Thus, the residual effect of enforcement was found to be greater at the crossing that was within a school speed zone.

Based on the results of this study, it was concluded that both school speed zones and enforcement enhance the speed-reduction effects of pedestrian presence and the normal crossing period at school crossings. However, to achieve an acceptable level of compliance, school speed zones must be enforced. Unless an adequate level of enforcement can be provided, a school speed zone should not be established. Although in this study everyday enforcement was required before an acceptable level of compliance was obtained, it seemed that, once the creditability of enforcement was established with the driving public, a lower level of enforcement would be required (e.g., one to two days per week).

Of course, a school speed zone is no different from any other form of traffic control in that, unless it is perceived by the driver as fulfilling a need, compliance will be poor. Therefore, school speed zones should be established only at those locations where pedestrian volumes are sufficient to convey this perception, which was assumed to be the case at the four crossings observed in this study.

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Visibility of Circular Traffic-Signal Indications

GERHART F. KING

An empirical determination of traffic signal visibility is presented. The study used subjects seated in stationary vehicles viewing standard, full-sized traffic-control signals at distances ranging from 370 to 1300 ft. Data, including response accuracy and response latency, were collected for both day and night ambient lighting conditions. It was found that currently used circular traffic-signal indications are generally adequate for nighttime service but their adequacy for daytime conditions is suspect. Signal visibility was found to be somewhat insensitive to signal lens size and illumination intensity for nighttime operations, which implies that even the dimmest signal tested (8-in lens with 67-W bulb) is above threshold visibility for all distances at night. The single most important factor affecting the visibility of traffic signals during the day is signal color. Green indications generally led to the poorest subject response, in terms of both response accuracy and response time, for the daytime observations. In relation to visibility considerations alone, the data obtained present strong support for the possibility of dimming all colors of 12-in signal indications at night.

A traffic control signal can be considered as an information-transmitting device that operates on the visual band. Its effectiveness at information transmission, and hence its effectiveness as a control device, can be determined on the basis of how well the device can be detected and how well the transmitted information can be perceived, interpreted, and responded to.

For any specific location and specific set of conditions, there is an optimum location at which the information should be received, information processing completed, and action initiated. If the vehicle is too close to the intersection when a red signal is first seen, a safe and comfortable stop may be impossible, and thus the potential for an accident may be increased and potential disobedience encouraged. On the other hand, signal indications that can be perceived from excessive distances serve to introduce potential confusion in the case of closely spaced intersections.

Traffic-control-signal installations should be designed so as to maximize the probability, given the expected distribution of the driver population, of the requisite control information being received at the optimum location by the largest possible number of drivers.

This paper contains a summary of an empirical study of the adequacy of currently used traffic-signal indications in inducing the required response on the part of motorists.

PREVIOUS RESEARCH

A comprehensive survey of the applicable literature has identified seven reports of previous studies of signal intensity requirements (see Table 1). The results of these studies, which varied widely, are summarized in Table 2.

Two of these studies used subjective judgments of conspicuity as a function of intensity, whereas the others used response latency and/or probability of detection. The two that used subjective judgment asked subjects to decide when a signal would be sufficiently conspicuous at a glance in traffic (1) or when it was bright enough to be unmistakable as a traffic signal and virtually impossible to miss (2). This approach suffers from all of the problems associated with category rating scales and more, since subjects were not rating signals but giving an absolute judgment. It is clear that subjects in such tasks use very different criteria as well as different dimensions in making their judgments (8). Jainski and Schmidt-Clausen's data (4) are based on a 50 percent level of color detection and extrapolated to a 90 percent level of conspicuity. The fact that the two sizes of stimuli used give such different values for the standard condition casts doubt on their procedure. Later research, on the subject of railroad crossing signals, has demonstrated a definite size effect (9). Boisson and Pages (3) examined the probability of detection for

Table 1. Research studies on signal intensity.

Researcher	Year	Size of Indication	Colors Included	Distance (ft)	Background Luminance (ft-L)	Type of Study[a]	Response Measure
Adrian (1)	1963	200 mm	Red, green	120	0.1-3000	Real signals	Subjective
Rutley, Christie, and Fisher (2)	1965	200 mm	Red, yellow, green	450-1200	0.1-3000	Real signals	Subjective
Boissin and Pages (3)	1964	11.3 and 35.7 mm	Red	66	420	Simulated signals, tracking task added	Reaction time, probability of detection
Jainski and Schmidt-Clausen (4)	1967	1°, 2 min	Red, yellow, green, black, white	6.6	10^{-8}-3000	Simulated signals	Fifty percent color detection
Cole and Brown (5)	1966	8 min	Red	6.6	1500	Simulated signals, tracking task added	Reaction time, probability of detection
Cole and Brown (6)	1968	4.1-16.5 min	Red	13	600	Simulated signals, tracking task added	Minimum reaction time, minimum reaction time plus 0.1 s
		5.5 min	Red	13	1.5-2250	Simulated signals, tracking task added	Minimum reaction time, minimum reaction time plus 0.1 s
Fisher (7)	1969	200 mm	Red, yellow, green	150	1370-5750	Real signals	Probability of detection

[a]All studies were static except that by Rutley, Christie, and Fisher (2), who used a nondriving observer.

Table 2. Results of studies of signal intensity.

Researcher	Required Intensity[a] (cd)	Required Intensity Ratio[b] Green	Yellow	Notes
Adrian (1)	1900	1.0	-	
Rutley, Christie and Fisher (2)	35	1.7	3.5	
Boissin and Pages (3)	200	-	-	
Jainski and Schmidt-Clausen	8	2.5	3.1	Based on 2-min data
	250	1.0	2.5	Based on 1° data
Cole and Brown (5)	160	-	-	
Cole and Brown (6)	70-120	-	-	Based on minimum reaction time plus 0.1 s
	250			Based on minimum reaction time
Fisher (7)	200[c]			

[a]Signal intensity required by observer at 330 ft with background luminance of 2900 ft-L.
[b]Red is 1.0.
[c]Maximum value of proposed intensity distribution.

all response times of 1 s or less. Cole and Brown (5,6) used two criteria for determining necessary signal intensity, both based on response time: (a) a "lenient" criterion of the intensity that yields response times 0.1 s over the minimum reaction time observed and (b) the more conservative criterion of the lowest intensity that gives the minimum reaction time.

However, these latter studies used only a single red signal. Thus, not only is the stimulus much less complex than normal, but also subjects made a detection response rather than the recognition response that they would have to make if other colors were included. The inclusion of other colors would have been expected to increase response times; in fact, Cole and Brown report increased times in a study that did include three colors, but they do not actually report the data from this study. In addition, all of these latter studies used simulated signals and the subjects observed from distances very near the display. This very restricted, homogeneous field of vision with a single fixed stimulus should also greatly reduce response time.

It should be mentioned that Boisson and Pages and Cole and Brown used a tracking task as a distractor. However, Fisher (7) argues that the primary function of these tasks has been merely to place the signal slightly out of foveal vision.

Finally, the three studies that included yellow and green signals yield varying estimates of the ratio of intensities of these signals compared with the red signal, although they do indicate that the yellow signal needs to be more intense than the green. These are also the three studies with the most suspect response measures.

The study being reported on here was designed in response to these apparent shortcomings and contradictions in the existing state of the art.

EXPERIMENTAL DESIGN

The experimental design was based on a complete factorial combination of all included variables: ambient lighting, viewing distance, and lens type, color, and lateral offset.

The experimental design included both between and within subject factors. Each of two ambient environments was assigned to each of two groups of subjects. The different ambient conditions required testing at different times of the day.

There were 45 stimuli defined by type, color, and offset location of a signal lens; these stimuli were presented in random order.

Subjects were tested at one distance at a time. In other words, while signal type, signal color, and offset were randomly varied, viewing distance was systematically ordered.

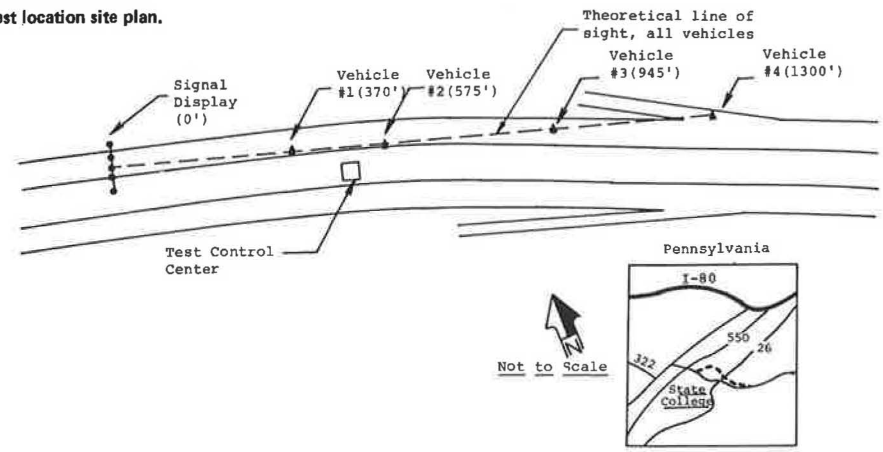
Experimental Variables

The number of levels of each variable and the description of each level are given below:

Variable	No. of Levels	Levels
Signal color	3	Red, yellow, green
Signal type	3	8-in lens, 67-W bulb; 12-in lens, 116-W bulb; 12-in lens, 150-W bulb
Offset	5	-50, -25, 0, 25, 50 ft
Distance	4	370, 575, 945, 1300 ft
Ambient illumination	2	Day, night
Sex	2	Male, female
Age	-	Continuous

Two dependent variables (response measures) were included in the experiment: (a) response latency, measured to the nearest 10 ms on a continuous scale from 50 to 5000 ms, and (b) correctness of response, expressed as a pass-fail dichotomy (data on the type of error made were collected and reduced but were not used in the analysis).

Figure 1. Test location site plan.



Subsidiary Task

To approximate the task loading involved in driving an automobile, subjects were asked to perform a subsidiary task. This task consisted of observing and reacting to a bank of lights placed immediately in front of the observer. Data on the performance of the subsidiary task were collected.

Test Statistics

The data collected for the two response measures were used to compute seven different test statistics: (a) mean response time (correct responses only), (b) standard deviation of response time (correct responses only), (c) standard score of response time (i.e., response time corrected for individual differences in average response time), (d) 90th percentile response time (correct responses only), (e) proportion of correct responses, (f) proportion of maximum-time responses (maximum time was set at 5 s), and (g) proportion of adequate responses (an adequate response was defined as a correct response of less than 1.5 s by a subject with a "passing" grade on the subsidiary task).

This paper discusses two of these test statistics: mean response time and proportion of adequate responses. A full presentation and discussion of all seven test statistics can be found in the project report (10).

DATA COLLECTION

Data were collected between October 29 and December 5, 1979. An unopened section of freeway designed to serve as a bypass around State College, Pennsylvania, was used as the experiment site. Figure 1 shows a plan view of the test site, including the orientation of the signal display and the location of the test vehicles.

Signal Display

A total of five assemblies, each containing nine signal indications, were used. Panel C, the center panel, was located at a lateral offset of 10 ft to the right of the sight line. The remaining four panels were located at 25 and 50 ft on each side of the central panel along a line perpendicular to the line of sight. Each type of signal indication occurred three times in each assembly, once for each of the three standard signal colors. Signal colors were displayed in their standard order (red, yellow, green from top to bottom). Indication types were randomized within each panel except that 8- and 12-in indications were not mixed in any vertical array. The signal heads were mounted at the normal mounting height for over-the-road indications and aligned in accordance with standard Pennsylvania Department of Transportation practices.

In relation to the geometrical and optical aspects of signal viewing, these maximum offsets do not represent a critical case. With one exception, the farthest left array at the closest viewing distance, all viewing angles fall well within the range of foveal vision. These angles are also such that no major fall-off in signal intensity can be expected according to the published specifications of the signal equipment used. Furthermore, the angles are so small that their effect, if any, is likely to be diluted by variations in alignment due to normal practices in field signal alignment.

The offset variable was added to the experimental plan primarily to add complexity to the task faced by the subjects and to enforce a scan pattern on them. Major effects of offset as a variable affecting signal visibility were not anticipated. The analysis presented in this paper therefore collapsed the data for the offset variable.

Subsidiary Task Display

A series of eight pairs of 7.5-W lamps (one white and one orange per pair) were mounted on a 16-ft-long aluminum channel and displayed in front of each test vehicle. The aluminum channels were supported 4 ft above the ground. These subsidiary lights were turned on and off in a pseudorandom manner, and one orange lamp was lighted for every eight white lamps.

Data-Collection Equipment

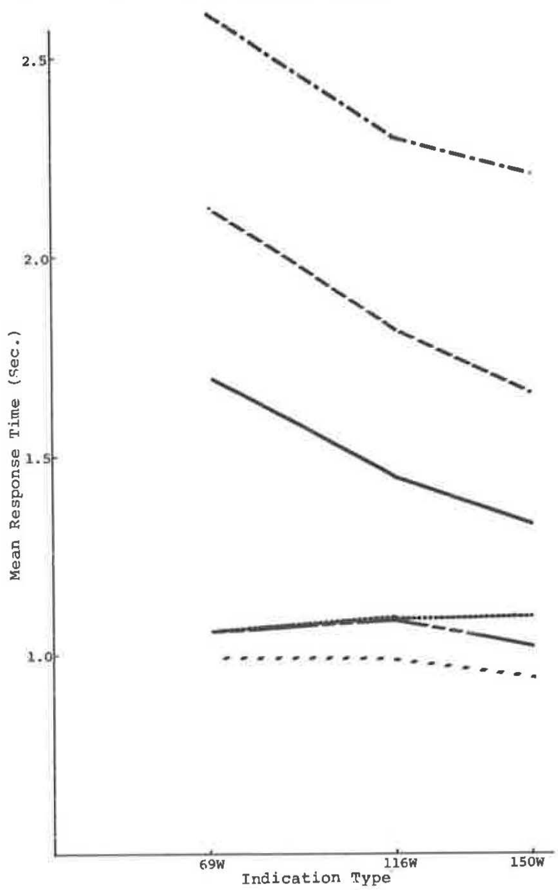
A response box and a board-mounted push-button (doorbell) switch were assigned to each subject. Each response box was equipped with three colored buttons (red, amber, and green). Subjects were instructed to press a button on their response box whenever a traffic-signal indication was illuminated. The color of the button pressed was to correspond to the color of the traffic-signal indication illuminated. They were also instructed to press the push button only when an orange lamp was illuminated on the subsidiary-task display.

Stimuli were initiated and data collected by a microprocessor-based data-collection system designed and built by the KLD Associates instrumentation laboratory. The system included the following components: microprocessor, cathode-ray tube, disc drive, and printer.

Table 3. Actual and desired age distributions of study subjects.

Subject Age (years)	Day Experiment Actual No. Male	Female	Total	Desired No.	Night Experiment Actual No. Male	Female	Total	Desired No.
<20	-	-	-	1	1	1	2	1
20-34	9	6	15	14	12	6	18	18
35-54	5	7	12	15	4	10	14	19
≥55	5	-	5	2	4	2	6	2
Total	19	13	32	32	21	19	40	40

Figure 2. Response latency versus type of signal indication.



Test Subjects

Test subjects were paid and were obtained through advertisements and announcements in local media. All subject candidates were required to have a valid driver's license, and the licenses were checked to determine whether corrective lenses were required. Where the licenses indicated such a requirement, subjects were obliged to wear the lenses during the experiment. Subjects with noncorrectable visual anomalies were rejected. Color vision tests were administered to each candidate to screen out color defects.

A total of 72 subjects, 40 male and 32 female, were employed. The age of subjects ranged from 17 to 72 years. An attempt was made to match the actual distribution of subject age to the estimated age distribution of U.S. drivers based on the number of miles driven. Both the actual and desired age distributions are given in Table 3. The mean age for each category is given below:

Experiment	Actual Male	Female	Total	Desired
Day	39.6	35.6	38.0	37.2
Night	36.0	37.1	36.5	37.5

There are no significant mean differences in age between the desired and actual subject groups nor between subject groups stratified by sex.

Data-Collection Runs

Data collection was performed only when good weather prevailed (i.e., no precipitation was perceptible on the windshield of the test vehicle). If precipitation started during a run, the subjects were instructed to turn on the windshield wipers simultaneously. Out of the nine tests (a total of 36 runs), seven tests (28 runs) were completed under good weather conditions and the remaining two tests (eight runs) were conducted under adverse weather conditions (i.e., precipitation was perceptible and required operation of windshield wipers).

After the conclusion of trial runs, the actual data runs were started. The 45 different signal indications were illuminated in random order for 5.0 s each. The interstimulus interval was varied from 5 to 19 s; the mean was about 9 s. The subsidiary task display changed approximately every 10 s, and the orange light appeared, on the average, every ninth time. The order of presentation of the stimuli was different for each run. The test was completed after data had been collected for four runs (i.e., after each subject was tested at each of the four distances).

EXPERIMENTAL RESULTS

The raw data were reduced and obviously erroneous data points were deleted. Data analysis was restricted to data collected in good weather. The data base available for analysis consisted of day data (4101 data points) and night data (5344 data points).

Mean Response Time

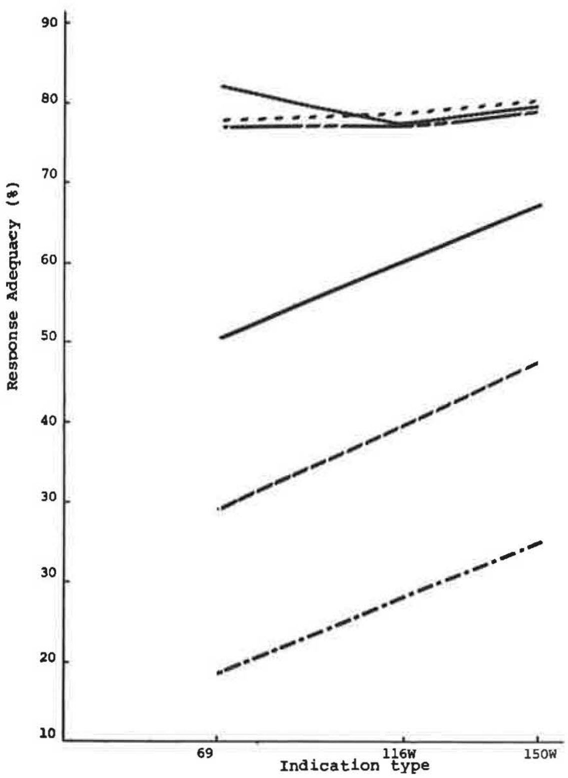
Mean response time as a function of the type and color of signal indication is shown in Figure 2. The calculation of mean response time included only those values that were less than the maximum time possible (5.0 s). Table 4 gives the proportion of the sample for which maximum time was recorded. Figure 2 shows a striking difference in response time between day and night data. The response-time distributions, aggregated over all variables, have the following parameters (180 data cells each for day and night data):

Parameter	Day (s)	Night (s)
Mean	1.830	1.033
Standard deviation	0.946	0.374
Coefficient of variation	0.517	0.362
Maximum cell mean	3.745	1.298

Table 4. Proportion of sample that yielded maximum response time.

Ambient Lighting	Indication Type: Lens (in)	Indication Type: Bulb (W)	Indication Color	Percentage of Sample by Viewing Distance: 370 ft	575 ft	995 ft	1300 ft
Day	8		Red	4.1	6.6	8.3	21.1
			Yellow	2.6	-	0.8	3.0
			Green	17.6	25.7	61.6	82.5
	12	116	Red	0.8	2.5	3.3	3.9
			Yellow	-	1.5	-	6.3
			Green	6.6	11.6	19.4	34.9
	12	150	Red	0.9	-	-	4.4
			Yellow	0.7	0.7	0.7	4.9
			Green	2.5	2.5	10.8	16.5
Night	8		Red	0.6	-	1.9	0.7
			Yellow	-	1.4	2.7	22.5
			Green	-	-	0.7	0.8
	12	116	Red	-	1.3	2.0	0.7
			Yellow	0.6	0.6	0.5	22.5
			Green	-	-	0.6	0.7
	12	150	Red	0.7	-	-	0.9
			Yellow	0.5	0.5	-	23.4
			Green	-	-	-	0.7

Figure 3. Response adequacy versus type of signal indication.



Parameter	Day (s)	Night (s)
Minimum cell mean	1.140	0.892
Maximum departure from grand mean	1.915	0.265

The ratio of maximum to minimum was 3.3 for day data and 1.5 for night data. The daytime data consistently show that the yellow indication yields the lowest response time and the green indication the highest.

All comparisons of response time between colors, within the same type of indication, are significant at better than α = 0.0001 for day data. All comparisons of response time between types of indication, within the same color, are significant at the same level for red and yellow indications. For green indications, the difference in response time between the 8-in indication and either of the 12-in indications is also significant at the same level; however, there is no significant difference between the two 12-in indications.

For nighttime data, the response time to yellow indications is significantly different from the response time to both the red and green indications for all types; however, there is no significant difference between red and green, except for the 12-in signal with 150-W bulbs. Three of the nine comparisons between signal indication types showed significant difference (α = 0.05): 67 versus 150 W for yellow indications, 116 versus 150 W for yellow indications, and 116 versus 150 W for red indications.

Examination of mean response time as a function of distance for each of the three indication types and colors shows that the general rank order of types and colors described above holds for all distances. Response time to red and green indications generally increases with viewing distance, especially during the day, whereas the response time to yellow indications is insensitive to viewing distance.

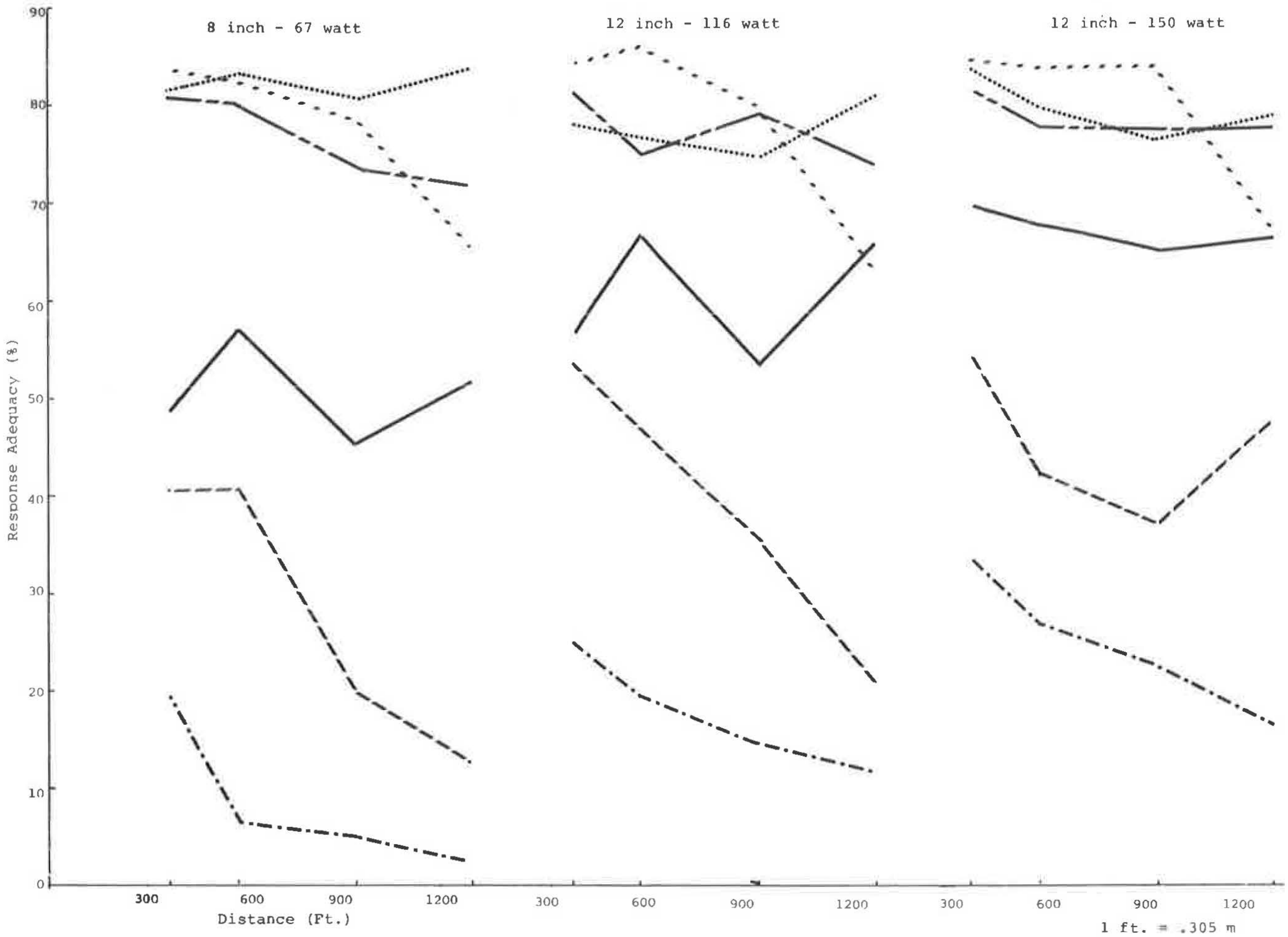
Response Adequacy

A traffic-control signal will fulfill its intended purpose if its message is received correctly, at the proper time, and while the driver is time sharing with his or her other responsibilities. The test statistic, response adequacy, is designed to combine these three aspects into one measure. A response is considered "adequate" if, and only if, all of the following criteria are satisfied: (a) the response is correct, (b) the response is made within a defined maximum response time, and (c) the response is made by a subject who gets a passing grade on the subsidiary task.

Data on subsidiary-task performance had been recorded manually. For each individual subject, these data consisted of the following counts: number of orange-light actuations per run, total number of push-button actuations per run, and correct (i.e., coincident) number of push-button actuations per run. Performance of the subsidiary task was scored manually through a subjective evaluation of these three counts. The criterion used was substantial agreement of the three numbers. Each subject was assigned a pass or fail grade for each run.

Data on the proportion of the sample with adequate responses are shown in Figures 3 and 4. For these graphs, 1.5 s was taken as the maximum permis-

Figure 4. Response adequacy versus viewing distance.



sible response time in accordance with current criteria of the American Association of State Highway and Transportation Officials (11).

Examination of the data in Figure 4 shows that a criterion of 75 percent response adequacy could be satisfied by all indications tested at night. None of the indications could satisfy this criterion during the day. A criterion of 50 percent response adequacy could be met, for daytime conditions, only for yellow indications with 12-in lenses and for red indications with 12-in lenses at the 370-ft distance (20-mile/h speed).

Significance tests for equality of proportions were made and showed that for daytime data all proportions were significantly different, except for the red indication in the two 12-in lenses.

For data taken at night, the only significant differences found were for (a) red versus green for the 8-in lens, (b) red versus yellow for the 12-in lens with 150-W bulb, (c) 12-in lens with 150-W bulb versus 12-in lens with 116-W bulb for all colors, and (d) 12-in lens with 150-W bulb versus 8-in lens with 116-W bulb for all colors.

To interpret these results, it is necessary to select a minimum acceptable threshold value for response adequacy. In picking such a value, it must be remembered that a maximum response time of 1.5 s represents an extremely conservative approach. The viewing distances used in the test were selected in accordance with an analysis of required viewing distance as a function of approach speed (12). This analysis used a total reaction-decision time component of 4.0 s. The extra 2.5 s were added to represent the additional reaction time of nonalerted drivers and the additional signal detection time required for low signal-noise ratios.

Relaxation of the stringent 1.5-s criterion would obviously serve to increase the properties of response adequacy. This increase is illustrated in Table 5, which gives data showing the effect of increasing the criterion value from 1.5 to 3.0 s. The average increase in response adequacy is 30.3 percentage points for day data and 5.4 percentage points for night data.

For a 3.0-s maximum response time criterion, 75 percent response adequacy is achieved by all indications tested at night and by all yellow indications tested during the day. Red indications, for daytime conditions, met the 75 percent criterion for all conditions except the longer distances with the smaller indication sizes. None of the green indications could satisfy this requirement at any distance in daytime conditions.

CONCLUSIONS

The results of the experiment presented in this paper provide the basis for postulating a number of conclusions:

1. Currently used circular traffic-signal indications are generally adequate for nighttime service,

Table 5. Effect on response adequacy of increasing the response-time criterion from 1.5 to 3.0 s.

Indication Type		Indication	370 ft		580 ft		945 ft		1300 ft	
Lens (in)	Bulb (W)	Color	1.5 s	3.0 s	1.5 s	3.0 s	1.5 s	3.0 s	1.5 s	3.0 s
Day										
8	67	Red	0.408	0.775	0.408	0.750	0.200	0.583	0.125	0.413
		Yellow	0.486	0.787	0.570	0.833	0.451	0.778	0.515	0.835
		Green	0.196	0.558	0.069	0.326	0.050	0.171	0.023	0.081
12	116	Red	0.537	0.815	0.466	0.771	0.355	0.754	0.205	0.686
		Yellow	0.569	0.884	0.664	0.882	0.534	0.813	0.657	0.873
		Green	0.250	0.625	0.191	0.600	0.144	0.389	0.116	0.271
12	150	Red	0.544	0.861	0.420	0.850	0.370	0.780	0.477	0.800
		Yellow	0.697	0.901	0.678	0.921	0.650	0.857	0.661	0.892
		Green	0.333	0.733	0.268	0.680	0.225	0.591	0.165	0.485
Night										
8	67	Red	0.809	0.850	0.801	0.847	0.738	0.823	0.717	0.786
		Yellow	0.839	0.867	0.823	0.852	0.786	0.841	0.653	0.709
		Green	0.818	0.855	0.832	0.868	0.807	0.864	0.837	0.914
12	116	Red	0.813	0.853	0.750	0.822	0.790	0.871	0.738	0.800
		Yellow	0.843	0.879	0.859	0.890	0.797	0.869	0.626	0.704
		Green	0.780	0.825	0.766	0.844	0.748	0.825	0.806	0.891
12	150	Red	0.816	0.839	0.776	0.823	0.772	0.840	0.777	0.851
		Yellow	0.847	0.864	0.838	0.861	0.838	0.890	0.671	0.677
		Green	0.838	0.896	0.798	0.857	0.761	0.819	0.789	0.909

but their adequacy for daytime conditions is suspect.

2. The single most important factor affecting the ability of traffic signals to transmit required information during the day is signal color.

3. Green signal indications generally lead to the poorest performance by subjects in terms of both response accuracy and response time during daytime conditions.

4. In daytime conditions, driver response to red and green traffic-signal indications generally deteriorates with increased viewing distance. Responses to yellow indications during the day, and to all colors of indication at night, are generally insensitive to viewing distance.

5. Signal type, a variable that combines both lens size and illumination intensity, has a significant effect on signal visibility for daytime operations. However, signal visibility is somewhat insensitive to signal type for nighttime operations, which implies that even the dimmest signal (8-in lens with 67-W bulb) is above threshold visibility.

6. The data presented provide strong support for the prospect of dimming all colors of 12-in signal indications at night. The actual feasibility of dimming signals without causing adverse effects on traffic safety and operations can only be definitely determined by full-scale field testing in real-world traffic environments. Similarly, the extent to which dimming can be undertaken cannot be determined on the basis of the data collected. This extent depends on the degree to which motorist responses are affected by actual field conditions: the driving task, driver attention, competing visual noise, and type of roadway facility.

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Throughout the entire period of experimental planning and data collection, the Institute for Research (IFR) of State College, Pennsylvania, acted as subcontractor to KLD Associates. IFR assisted in the conceptual planning of the experiment and was directly responsible for all subject selection and data collection. Robert S. Hostetter and Douglas R. Mace served as subcontract managers for IFR. Wayne Zweig supervised the field data collection.

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Abridgment

Standardization of Light Signals for Road Traffic Control

D. A. SCHREUDER

A recent technical report on road-traffic-control signals prepared by the International Commission on Illumination is briefly discussed. The report represents a first step toward international standardization of traffic signal lights in order to benefit trade and transportation. The principal subject areas of the technical report—color, luminous intensity, and luminous intensity distribution—are outlined. It is concluded that the report can be highly beneficial to road traffic and that official recommendations should be prepared.

Light signals for road traffic control are applied in an increasing number of cases to promote the flow of traffic at highly trafficked intersections. Although individual waiting times may increase, it is generally accepted that the capacity of intersections and road safety are increased.

International harmonization of industry and traffic requires standardization; lacking better grounds, these standards are usually based on the plausible assumption that road-traffic-control signals must be clearly visible for all road users. "Clearly visible" cannot be defined precisely, but it is usually understood as being well above the threshold of visibility found in a laboratory setup.

In recent years, a number of countries have set up national recommendations, regulations, or standards for traffic signals. Although they show a certain similarity, important discrepancies still exist that are unfavorable to trade and transportation. The International Commission on Illumination (CIE) took the initiative for further international harmonization. A technical report has been prepared and will be published in the near future (1). This paper briefly discusses that report.

The CIE report is restricted to those aspects of road-traffic-control signals that are directly seen by the users and are directly related to the signaling function. It does not cover other important matters concerning traffic signals, such as traffic engineering matters, the regulatory status, the legal obligations of local authorities and the road user, and electrical and mechanical engineering. The report deals with the color, the luminous intensity, and the luminous intensity distribution of signal lights. The "phantom effect" is also discussed. Since recognition of "cut-out" figures, or symbols, used with lights has become important, the report examines some details of their shape and size. Only lanterns of 20- and 30-cm diameter are considered.

COLORS

Road-traffic-control signal lights consist normally of three separate units that emit red, yellow (or amber), and green light. The colors given in the CIE technical report are in agreement with the 1975 CIE recommendation (2). In road traffic, people whose color perception is defective can take part as pedestrians and drivers. Therefore, even the "restricted" green was considered too wide, and further restrictions are given as follows (all boundary colors for the red signal and the yellow boundary for the green and white signals are restricted):

Color of Signal	Boundary	Equation
Red	Purple	$y = 0.990 - x$
	Yellow	$y = 0.320$
	Red	$y = 0.290$
Yellow	Red	$y = 0.382$
	White	$y = 0.790 - 0.667x$
	Green	$y = x - 0.120$
Green	Yellow	$y = 0.726 - 0.726x$
	White	$x = 0.650y$
	Blue	$y = 0.390 - 0.171x$
White	Yellow	$x = 0.440$
	Purple	$y = 0.047 + 0.762x$
	Blue	$x = 0.285$
	Green	$y = 0.150 + 0.640x$

The result is a rather bluish green, an amber yellow, and a light (nearly orange) red (3).

PEAK INTENSITY AND LIGHT DISTRIBUTION

For normal roads and for built-up areas, the rule-of-thumb value of 100 m has been adopted as the minimum distance from which signals must be (clearly) visible. When perceived from 100 m, lenses of 30- and 20-cm diameter have discernible dimensions. However, experiments did show that for viewing conditions that pertain to practical conditions of road traffic--notably taking into account the peripheral vision--the "power" of the beam can be described adequately in terms of the luminous intensity alone. Considerable research has indicated that under full daylight conditions a peak value (maintained value) of 200 cd ensures adequate visibility [see, for example, Adrian (4), Cole and Brown (5), Jainski and Schmidt-Clausen (6), and Fisher (7)]. It is desirable that at night the peak intensity should be between 50 and 100 cd; intensities of less than 25 cd or more than 200 cd should be avoided. At least 100 cd should be provided in directions making an angle of ±11° laterally or 8° down with the beam axis. Further research is required to find out whether a more detailed description of the beam and the light distribution is necessary.

SHAPE OF SYMBOLS

It is recommended that the signal be a light-emitting cut-out figure on a dark (black) background rather than a dark symbol on a bright background. Because the latter suffers from irradiation, the signal with a symbol can easily be confused with the roundel signal without a symbol. It is important to ensure that the luminance of the symbol is reasonably uniform.

PHANTOM EFFECT

When light enters the signal lantern from the outside, it may, after reflection and refraction, be emitted in a way similar to the way in which light is emitted from a signal in operation. These are called phantom effects. Their adverse consequences can be reduced in a number of ways:

1. By reducing the light that falls into the lens (e.g., by means of hoods or louvers),
2. By reducing the light emitted after refraction (e.g., by special optical construction of the lens or the mirror, by special lamps, and by additional, internal shields),
3. By ensuring that signals in operation are always considerably "brighter" than the phantom (e.g., the minimum value of 200 cd), and
4. By limiting the confusion by means of redoubling the signals and locating them in a less "vulnerable" position in the intersection.

Further research on this matter is desirable, particularly since it is not completely clear at this time at what level the phantom effect begins to be really disturbing.

ADDITIONAL EQUIPMENT AND SIGNAL LOCATION

Background screens help to identify and localize the signal in the road and, by reducing the glare from the sky, may reduce the requirement for the peak intensity. Background screens are considered an essential part of all road-traffic-control signal installations.

The location of the signals at the intersection is also important. However, because intersections may vary considerably in size, shape, and layout, general rules can hardly be given. Furthermore, there are legal differences in traffic regulations from one country to the other.

CONCLUSION

The CIE technical report is the first attempt at international harmonization and standardization for road-traffic-control signal lights. The obvious next step is to prepare official CIE recommendations. As the results of the first tentative steps toward international cooperation already indicate, such recommendations can be of considerable benefit to road traffic.

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Abridgment

Construction-Zone Delineation

THOMAS D. DAVIS

A study conducted to find the need for improving delineation in construction zones with long-term lane closures or diversions is described. The need for improved delineation was established through two means: (a) a committee of traffic, construction, design, research, and specifications engineers and (b) positive guidance, a technique that develops improvements to the highway information system from the driver's viewpoint. Once the need was established, improved delineation concepts were developed and tested in actual construction zones and evaluated for effects on traffic performance and driver visibility. The experiments showed that (a) although 12.70 x 25.40-cm (5 x 10-in) yellow high-intensity reflectors were less expensive, more easily checked, and more reliable than steady-burn lights, reflectors did not change vehicle speed averages and variances or the proportions of vehicles using the lane adjacent to the reflectors; (b) although tall vertical panels used up less space and could be seen over the tops of lead vehicles when compared with type 3 barricades, panels decreased lane encroachments and did not change vehicle mean speeds or variances; (c) raised pavement markers as a paint supplement reduced undesirable lane weaves and encroachments, day and night; (d) removable traffic tape was easy to install and easy to remove and caused no problems while in use; and (e) raised pavement markers as a paint replacement were easy to install and easy to remove, and they reduced lane weaves day and night and reduced nighttime lane encroachments.

New Jersey's Construction-Zone Delineation Research Project is part of a national federal program to research many facets of construction-zone traffic and personal safety. The objective of this research is to improve delineation devices in safety zones where long-term diversions and lane closures are created by construction.

DETERMINATION OF DELINEATION NEEDS

Committee

Early in the project, a committee of traffic, construction, design, research, and specification engineers was formed. During the three meetings held, needed improvements in construction-zone delineation were presented and discussed, recommended experiments were reviewed and approved, and possible sites were discussed.

Table 1. Summary of driver performance measures.

Driver Performance Measure	Reflectors Versus Steady-Burn Lights		Vertical Panels Versus Type 3 Barricades		Raised Pavement Markers: As a Paint Supplement		Raised Pavement Markers: As a Paint Alternative	
	Day	Night	Day	Night	Day	Night	Day	Night
Mean speed		0	0	0	0	0	0	0
Speed variance		0	0	0	0	0	0	0
Lane weave			0	0	-	-	-	-
Lane encroachment			-	-	-	-	0	-
Brake-light application					0	0	0	0

Note: 0 = no change from base treatment, and - = decrease from (improvement over) base treatment.

Figure 1. Steady-burn light and 12.7x25.4-cm reflector.

Positive Guidance

Positive-guidance procedures (1) were followed.

First, key federal and state officials were interviewed to find out (a) what contributed to construction-zone accidents and (b) which devices they thought were most effective and least effective in delineating construction zones.

Then five active construction sites of the types recommended by the key personnel were selected, and individual accident reports were analyzed and judged as to whether or not the accidents were construction related. The accidents were summarized and plotted on a collision diagram and compared with accidents in the matching time period the year before. However, there were not enough night and rainy-night accidents to make statistical statements, and the reports were not detailed enough to relate the accidents to delineation.

For the reasons mentioned in the active-site study, the study of past site accidents was even less fruitful, especially since data were limited to comparing accident summaries.

Next, the five active sites were studied further through on-site investigations and personal observations of the project engineer to locate possible areas of improvement.

Finally, where accident and observation studies warranted, pilot studies of driver performance were performed by measuring vehicle speeds and lane distributions and motorist actions such as lane weaving and encroaching.

EXPERIMENTAL DELINEATION IMPROVEMENTS

The positive-guidance procedures, coupled with the involvement of the committee on construction-zone delineation, led to five experiments. Table 1 compares driver performance for four of the experiments.

Experiment A

The committee suggested that reflectors be used to supplement or replace steady-burn lights on construction-zone barrier curbs because reflectors are

1. Less expensive initially,
2. Not dependent on batteries and therefore require less maintenance and are more reliable,
3. Easily checked in the daytime, and
4. Apparently less likely to be vandalized.

Steady-burn lights were studied in the before condition, and 12.70x25.40-cm (5x10-in), yellow, high-intensity retroreflective reflectors were studied in the after condition (see Figure 1). A control site was used to account for changes in traffic performance due to factors other than the change from steady-burn lights to reflectors.

The results revealed that at the 95 percent level of confidence the reflectors caused no decrease in the proportion of vehicles using the lane adjacent to the barrier curb, based on the chi-square contingency table test, and caused no change in the average speed and variance, based on the t-test and the F-test. The steady-burn lights could be seen from a distance of 549 m (1800 ft), whereas the reflectors could be seen from a distance of 305 m (1000 ft), which is adequate according to Section 6D-2 of the Manual on Uniform Traffic Control Devices (2).

Experiment B

From personal observations, type 3 barricades appeared to be bulky and used up recovery area and work area. They restricted the view of adjacent merges, and they could not always be seen over the tops of lead vehicles, a disadvantage when drivers need advance knowledge of road geometry (see Figure 2).

A recent study (3) demonstrated that "for vertical panels, a tall, narrow shape is recommended over a shorter, wider device. This clear-cut lab result should be tested further in the field with the device located in an array and also in a visually cluttered work zone situation in the real world."

In research undertaken with the backing of the committee, a 2.13-m (7-ft) high, 20.32-cm (8-in) wide vertical panel was developed to replace type 3 barricades. The panels were made up of two 1.22-m (4-ft) long Syro Steel Company glare foils bolted together and faced with Reflexite Corporation microscopic vinyl cube corner striping. The panels were mounted in Lear Siegle, Inc., barrels weighed with sandbags, and a hole in the shape of the panel cross section was cut on top of the barrel to accommodate the panel. The panels

1. Took up less space horizontally,
2. Could be seen over the tops of lead vehicles (Figure 2),

3. Could be used in narrow median shoulders to close off a left lane,
4. Were less of a hazard on impact since all components were made of plastic, and
5. Were stackable.

To test the panels in a real-world situation, a state highway diversion was selected. During the before study barricades were installed as usual, and during the after study the barricades were replaced with panels. Mean speeds and variances were compared by using an analysis of covariances, and lane weaves and encroachments were tested for a difference in proportions. At the 95 percent level of confidence with the panels,

1. Lane weaves remained unchanged day and night,
2. Lane encroachments decreased from 13 to 7 percent during the day and from 14 to 7 percent at night,
3. During rain, lane weaves decreased from 6 to 3 percent during the day and from 8 to 3 percent during the night and lane encroachments decreased from 2 to 1 percent at night, and
4. Speed averages and variances remained unchanged day and night.

Experiment C

During the active-site study, pilot studies that used driver performance measures indicated that drivers had difficulty maintaining their lanes in construction-zone diversions. In one two-lane diversion, the left lane was closed and the shoulder was used as a lane. Nine percent of the right-lane vehicles failed to maintain their lane and use the shoulder, and vehicle mean speeds decreased by 9.6 km/h (6 miles/h) and vehicle speed variances increased by 24 km/h^2 (15 $miles/h^2$) from the beginning to the end of the diversion. A need for stronger lane delineation was suggested.

Raised pavement markers have been used in construction zones in various states, and reports indicate that their use is favorable in relation to cost, durability, installation and removal, and visibility. However, the markers were not evaluated by using driver performance measures.

Stimsonite 88 SS markers were installed as a paint supplement on an asphalt surface prepared with a liquid primer in a two-lane diversion. During the day the markers were barely visible, and at night they increased the visibility of the diversion (see Figure 3).

Mean speeds and variances were compared by using an analysis of covariance, and lane changes and encroachments were compared by testing for a difference in proportions. At the 95 percent level of confidence, the markers

1. Reduced lane weaves from 8 to 6 percent during the day and from 6 to 5 percent during the night,
2. Reduced lane encroachments from 2 to 1 percent during the day and from 1 to 0 percent during the night,
3. Caused no change in speed averages and variances,
4. Were maintenance free and experienced no vandalism over a three-week period, and
5. Were easily removed (two-thirds of them were removed unintentionally by a snowplow).

Since driver performance improved, raised pavement markers should be considered for use as a paint supplement.

Figure 2. Type 3 barricades: (top) fourth barricade blocked from view and (bottom) fourth barricade visible over top of car.

Figure 3. Visibility of raised pavement markers.

Experiment D

The committee on construction-zone delineation expressed concern over the difficulty of removing paint in construction-zone diversions. To fill the need, 3M Stamark removable traffic tape was installed in an Interstate diversion. The tape was applied by using a special tape-dispensing device and tamped by another device that looked like a hand truck loaded with sandbags (see Figure 4). Prior to installation, the concrete pavement was broomed. The tape was applied for 109.8 m (360 ft) of lane line, and installation took about 3 min. The rest of the diversion was delineated with ordinary traffic paint. During the day and night, the tape did not look any different from ordinary paint (Figure 4). During the 19 days the tape was in place, there were no tears, splits, cracks, or bubbles and the ends adhered firmly to the pavement. When the tape was removed, it came up intact, taking one laborer about 15 min to remove.

To test the long-term performance of the tape, samples were placed across the right lane of a state highway. Six thousand vehicles ran over the tape every day, and 12 percent of the vehicles were trucks. After 96 days, the tape still pulled up intact without causing any pavement damage.

Experiment E

In view of the need for stronger, yet removable, delineation, Permark P 15 reflective ceramic road markers were installed as a replacement for paint on a concrete pavement prepared with a liquid primer in an Interstate diversion. During the before study, the diversion was painted as usual. Then the paint

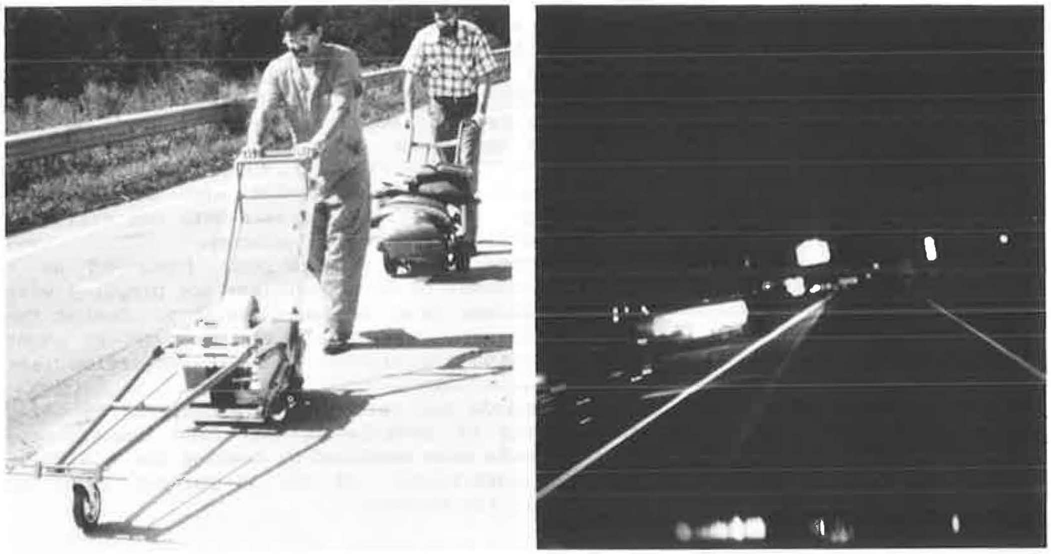

Figure 4. Removable tape: (left) installation and (right) visibility.

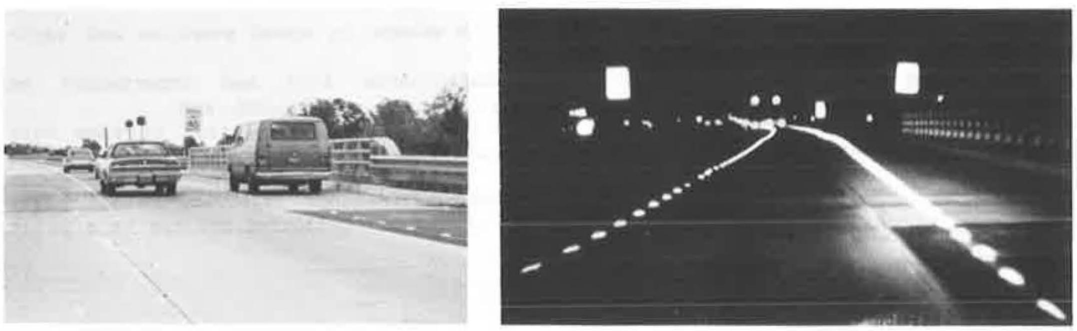

Figure 5. Ceramic markers: (left) daytime visibility and (right) nighttime visibility.

was sandblasted off and ceramic markers were installed at 1.83-m (6-ft) spacing throughout the transition for the after study. The pavement was concrete, and the shoulder was asphalt.

In the day the markers were not quite as visible as paint, and at night they increased the visibility of the transition (see Figure 5).

Mean speeds and variances were compared by using an analysis of covariance, and lane changes, encroachments, and brake applications were compared by testing for a difference in proportions. At the 95 percent level of confidence, the markers

1. Helped vehicles maintain their lane and use the shoulder (since lane weaves decreased day and night from 11 to 6 percent during the day and from 16 to 3 percent at night),
2. Decreased lane encroachments at night from 4 to 1 percent,
3. Did not change brake-light applications day or night, and
4. Did not change mean speeds and speed variances day or night.

When construction was completed, the markers were easily removed by laborers with shovels. No visible trace was left on the pavement.

SUMMARY AND RECOMMENDATIONS FOR FURTHER RESEARCH

The study described in this paper did find a need for improved construction-zone delineation. The meetings of the committee on construction-zone delineation and the application of driver-performance measures proved most useful in determining this need, whereas analysis of past and active construction-zone accidents proved least useful. Five experiments showed the following:

1. Since 12.70x25.40-cm (5x10-in) yellow retroreflective sheet reflectors did not change vehicle speed averages and variances and did not change the proportion of vehicles using the lane adjacent to the reflectors, they should be considered for use as a supplement or replacement for steady-burn lights on construction-zone barrier curbs.
2. Although tall vertical panels have many advantages over type 3 barricades and did decrease lane encroachments at night, they did not change mean speeds or speed variances.
3. Since raised pavement markers decreased lane changes and encroachments, they should be considered for use as a paint supplement.
4. Since removable tape was easy to install and remove and performed well, it should be considered for use as a paint replacement where paint removal would not be feasible.
5. Since raised ceramic markers decreased lane changes, night lane encroachments, and night brake applications, they should be considered for use as a paint replacement where strong, yet removable, delineation is called for.

Since the use of raised markers in construction-zone diversions proved favorable, low-priced, temporary markers should be developed. In addition, a faster, less labor-intensive method of marker installation is needed.

ACKNOWLEDGMENT

The contents of this paper reflect my views, and I am responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the New Jersey Department of Transportation or the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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Abridgment

Potential Adverse Impacts of Reflective Solar Spot Glare on Motorists: Seattle's Experience

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A discussion of reflected solar spot glare, based on research in Seattle, is presented. The topics discussed include the causes of reflected spot glare, when and where it is most likely to occur, how it can be predicted, how it can affect the vision of motorists and thereby pose a threat to the safety of the driving public, and how it can be avoided through sensitive environmental design. One factor that makes reflective spot glare a potential traffic problem is that unlike the sun, which we are generally accustomed to in the sense that we know its location in the sky, solar-caused spot glare is often visible where one least expects it, creating a surprise reaction for the unaccustomed viewer. Such impacts are often not easily mitigated and (because an offending structure may have a life expectancy of 50 years or more) should be considered long lasting. Experience in Seattle, Dallas, and other cities indicates a growing problem, with nationwide implications, due to the use of new, highly reflective building materials. By graphically depicting patterns of reflective spot glare during certain periods of the year near potential or suspected trouble spots such as heavily traveled urban arterials, one can predict fairly accurately the potential for adverse glare impacts, their duration, and their intensity before buildings are built. The Seattle study stresses that the solution is not to prohibit the use of highly reflective building materials but rather to ensure that they are installed or applied in such a way as not to create visible glare within the driver's task-oriented cone of vision.

Glare is a problem nearly all of us experience to one degree or another on a daily basis. The problem this paper addresses is solar-caused glare given off by specular surfaces, which can adversely affect the vision of motorists and thereby pose a threat to the safety of the driving public. Examples of such surfaces include bodies of water, shiny surfaces such as chromed car bumpers or window trim, and, lately, reflective coated glass that is used on the exterior of buildings. Although disabling solar-caused spot glare from these surfaces can be reduced for motorists--by using matt rather than glossy surfaces and highway alignments that help direct the motorist's line of sight away from sunlight reflecting off waterways and other highly reflective surfaces--it can never be fully prevented.

REFLECTIVE BUILDING MATERIALS AND SOLAR SPOT GLARE

A new glare source of substantial magnitude not previously anticipated in highway design is that caused by the increasing use of reflective coated glazing in buildings. Recently constructed buildings throughout the country are now using these and other highly reflective materials and, in some cases, even older buildings are being retrofitted with them. Experience in Seattle, Dallas, and other cities indicates a growing potential problem, with nationwide implications, as these buildings (depending on siting, orientation, and time of year) develop visible specular solar spot glare of sufficient magnitude and duration to impair the vision of motorists using nearby major arterials.

The glare caused by the recently opened Park Hilton Hotel in downtown Seattle adversely affects nearby freeway users traveling away from the sun in a northerly direction. A number of near accidents were reported by motorists because of alleged glare effects on their vision resulting from the building, and the speed of travel in the affected northbound freeway lanes dropped from 40-45 to around 25 miles/h when the problem was occurring.

Figure 1 shows the reflective solar spot glare caused by this structure. At 40 miles/h, motorists are exposed for more than 20 s; as traffic slows down, exposure increases (because of less intense background lighting and size of glare patterns, relative glare intensity was found to be greater for northbound traffic driving away from the sun than for southbound traffic driving in the direction of the sun).

The building's owners were directed to seek ways of removing the problem, since both the city and state departments of transportation believed that the building posed a hazard to the traveling public. Informal reports from other cities indicate that they are experiencing similar problems.

If reflected solar spot glare does pose a potential threat to the health and safety of the driving public, what can be done to lessen its impacts in the future? This paper discusses the causes of reflected spot glare, when and where it is most likely to occur, how it can be avoided through sensitive environmental design, and how it can be predicted by using simplified graphic techniques.

With increasingly stringent federal and local standards for energy conservation, we can expect to

Figure 1. Reflective solar spot glare on I-5 in Seattle.

see the continued use of highly reflective materials to lessen cooling requirements for new buildings, even though alternatives such as reduced window size, recessed windows, or solar sun screens may achieve the same end. It is to be hoped that, by understanding the environmental impacts of these and other highly reflective materials, architects and building designers will be able to mitigate adverse impacts before they occur. As a condition for the approval of such materials, highway engineers, after further research, may wish to require their use within a specified distance of major arterials to show that they are not apt to adversely affect the traveling public.

Light and glare are in the environment at almost all times and affect us to different degrees, depending on their intensity, the intensity of the background lighting, the angle at which they are viewed, and our susceptibility to them. The problem of glare resulting from reflected sunlight has been recognized as potentially serious enough to be addressed along with other types of impacts in the preparation of environmental impact statements in many states.

In September 1978, the city of Seattle adopted an ordinance establishing policies for the substantive implementation of the Washington State Environmental Policy Act of 1973. Specifically, in terms of light and glare, this ordinance authorizes the responsible city official or authorizing agency to require mitigation of the adverse impacts of lighting and glare by measures such as

1. Limiting the reflective qualities of surface materials that can be used in development;
2. Limiting the area of intensity of illumination; and
3. Limiting the location or angle of illumination.

One of the difficulties with considering the adverse impacts of glare, and particularly specular glare from reflected sunlight, was that tools for disclosing these impacts did not exist. With sunlight the problem of disclosure was even greater than with other sources, since the sun is not stationary but constantly changing its location throughout the day relative to objects on earth.

Besides impairing a person's ability to see detail clearly, bright light sources such as the sun or its reflected image can actually create visual discomfort or impair one's vision. Glare itself usually refers to the condition of lighting that causes eyestrain or discomfort and reduces visibility. Usually, unexpected, bright, unscreened sources of light are considered to be a visual nuisance; in some cases, they are debilitating enough to be considered a threat to an observer's well-being, especially if the observer is carrying out a task such as driving a motor vehicle at high speed or in crowded conditions that require good visibility of directional signs or nearby traffic conditions. Glare sources that distract drivers or blur their vision should be avoided whenever possible.

The sun is the greatest single source of both visual discomfort and disability due to glare in the environment. Reflected specular glare from the sun is most noticeable during the early or late hours of the day, when the altitude of the sun is still relatively low, or during the winter months at latitudes greater than 40°, where the sun is continuously at an angle of less than 30° with the horizon. Cars, because of their reflective bumpers and windshields (which, because of their slanted angle, often reflect sunlight that normally would not be visible), are often common sources of visible specular glare from the sun.

The major determinants of how adverse the impacts of solar-caused glare will be are (a) the intensity (luminance) of the sun, (b) the intensity of the surroundings in which it is seen, and (c) the reflectivity of the surface giving off the light.

The luminance of the sun and, subsequently, its reflected glare are affected by its altitude. The sun has its lowest luminance at sunrise and sunset, when it approximates a 100-W tungsten bulb. As the sun rises above the horizon, the amount of atmosphere its rays must pass through is reduced, and this results in a significant increase in luminance--e.g., from approximately 3870 cd/in^2 near the horizon to nearly 1 million cd/in^2 above the horizon (1, Figure 8).

In terms of visual impacts on motorists, specular surfaces such as reflective coated glass are worse than opaque porous surfaces, even though the former may reflect a smaller percentage of the sun's rays back toward the observer. This is because the rays from reflective coated glass are reflected back in a near-parallel fashion, maintaining much of the integrity and intensity of the original light source, whereas the opaque porous surface scatters the sun's rays. The reflectivity of a specular surface is also affected by the angle of incidence of the light rays striking it. As this angle increases to more than 70°, even nonreflective glass takes on approximately the same degree of reflectivity (±90 percent) as reflective coated glass that has an average daily reflectance of 35-44 percent.

In evaluating the impacts of glare on people, normal viewing angles should be used. This is defined as an angle 30° above the horizontal and an angle of 65° to the right or left of a forward line of sight. For motorists, a more narrow cone of vision can be defined depending on the speed of travel. The higher the speed, the narrower is the cone of vision and the farther ahead one's eyes focus on the roadway.

Since spot glare reflected off large specular surfaces was known to be a potential problem that could at times impair the vision of motorists and pedestrians alike by forcing them to look away from the glare source, there was a need to develop an easily usable technique for disclosing the geographic extent of glare at a particular time and its probable intensity or brightness. It was found that much of the existing disclosure was superficial and did not adequately convey graphically or verbally the geographic extent of the effects of glare. As a result, a methodology similar to that used for depicting shadows caused by buildings and other objects was developed to allow one to diagram sunlight reflected off mirrored or specular surfaces.

Weather also plays an important role in the frequency of occurrence of reflective glare from sunlight. Although November, December, January, and February have only about half as many clear days (34) as the months of May, June, July, and August (84), in the Seattle area the sun was found to pose a much greater threat at this time of year, because of its low altitude in the sky and subsequent visibility, than during other months, when it shines more but is at a higher altitude in the sky and therefore is less visible.

By graphically depicting reflective spot glare patterns during certain periods of the year, especially when the altitude of the sun is less than 30° above the horizon, and by paying particular attention to potential trouble spots, such as heavily traveled urban arterials and nearby residential areas, the potential for adverse glare impacts, their duration, and their intensity can be predicted with a fair degree of accuracy.

The impacts of unanticipated reflective glare are often not easily mitigated. Since an offending structure may have a life expectancy of 50 years or more, the impacts on the environment should be considered long lasting. Had Seattle's new Park Hilton Hotel across the street from I-5 been diagrammed for the morning rush hours--say, on December 22--it would have been apparent before the building was constructed that the south facade would be reflecting visible spot glare from the sun in and parallel to the northbound lanes of the freeway for a distance of more than 0.5 mile (approximately 1200 linear ft) during the morning rush hour. It would also have been known that the angle of reflectance of the glare was much less than 30° and that the resulting glare would be continuously visible by motorists in the task-oriented line of sight for as long as 30 s. Persons on the freeway who experienced the reflective solar spot glare from this building in January 1979 indicated that their visibility was reduced dramatically, in some cases to about two car lengths.

Had this glare problem been identified earlier, mitigating measures could have been taken. A slight reorientation of the windows on the south facade from their present southeast orientation to a southern orientation would, it was shown, have substantially reduced the geographic extent and time of exposure of the glare experienced by northbound motorists. In addition, the angle of reflectance would have been such that drivers could have blocked much of the glare by using their sunvisors.

Since visible reflected spot glare resulting from direct sunlight is invariably less intense than looking at the sun itself, some people question whether or not we should be concerned about it. Even at low levels of reflectance, reflective spot glare from the sun is enough at nearly all times to create sufficient visual discomfort to cause the observer to either look away from it or block it from view. Even when the sun's image is seen reflected off clear glass that has an average daily reflectance of, say, only 8 percent, its intensity or luminance is nearly 10 000 times greater than the borderline of comfort-discomfort measured for interior light sources (2). In addition, the sun is a natural phenomenon that we have little control over, whereas a lot of visible reflective glare is manmade. Another factor that makes reflective spot glare a potential traffic problem is that unlike the sun, which we are generally accustomed to in the sense that its location in the sky is known, spot glare from the sun is often visible where least expected, creating a surprise reaction for the unaccustomed viewer.

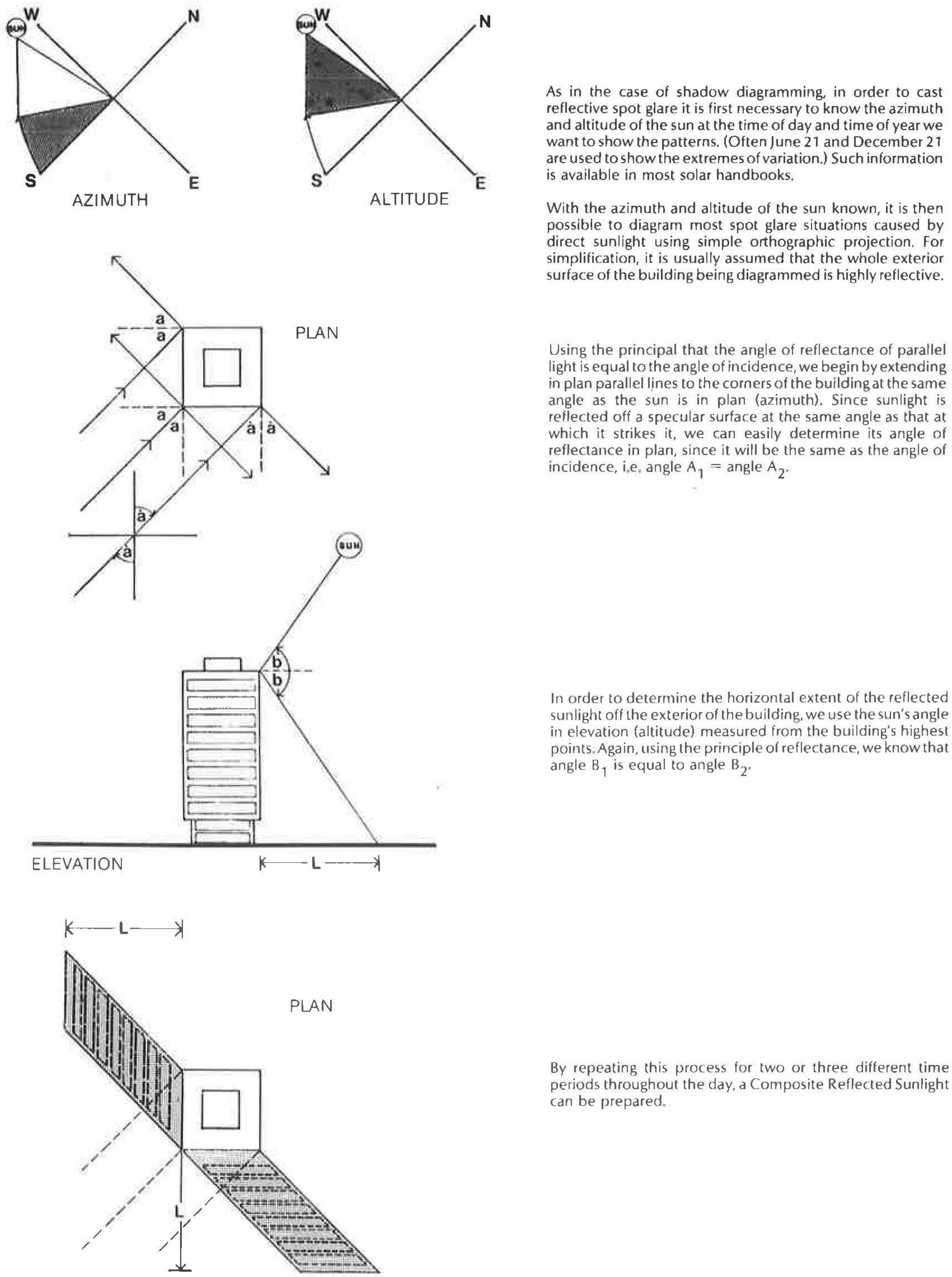
SOLUTIONS TO THE PROBLEM

Many of the problems arising from the use of highly reflective materials on new buildings near major urban arterials can be avoided by the proper design of these structures. The Seattle Light and Glare Study (3) stressed that the solution was not to prohibit the use of these materials but rather to ensure that they were installed or applied in such a manner as not to create visible glare within the driver's task-oriented cone of vision.

By using the simplified solar glare diagramming technique shown in Figure 2, the reflected glare patterns of a building can be projected before it is built to determine their physical extent during different periods of the year. From this, one can tell whether any major arterials and lanes of travel nearby would be affected. Where adverse impacts are indicated, modifications should be made before the structure is erected.

Besides changing the orientation of the building or the reflective surface on it, another way of controlling reflected solar glare off specular surfaces is to shield these surfaces or to intercept the reflected rays before they can affect the observer. Glare off water can often be reduced by landscaping with trees and shrubs or by using screening devices. Glare off smooth, reflective

Figure 2. Simplified methodology for solar glare diagrams.



surfaces such as glass can be prevented much or all of the time by the use of screening devices that intercept the sun's rays before they can reflect off the surface.

One of the major recommendations coming from the Seattle study would require the owners of any new or remodeled structure on which reflective coated glass or other highly reflective specular surfaces are to be installed (when the structure is located within 400 ft of a designated urban arterial that has posted speeds of 40 miles/h or greater and carries at least 20 000 vehicles/day) to have such materials applied or installed in a manner that would not adversely affect the vision of motorists. As a means of showing that solar-caused reflective spot glare would not occur within a driver's normal cone of vision, applicants for building or use permits would be required to submit diagrams of reflective solar spot glare for the winter and summer solstices. Where problems are indicated, mitigating measures are required. The type of mitigating measure really is a function of the particular glare problem identified. It is for this reason that full, definitive disclosure should be provided at an early stage in the design process so that solutions are incorporated architecturally in the design of the structure. We are also learning, by looking at examples of structures already built, that certain architectural configurations, like certain materials, pose greater visual hazards than others and should be avoided in environmentally sensitive areas such as along freeways.

Highly luminous light and reflected solar spot glare pollute the visual environment in much the same way that loud noises pollute the auditory environment. The solution is not reflecting it onto one's neighbors but rather trying to control it at the source or intercepting (absorbing) it before it does harm. Where neither of these solutions works, glare should at least be reflected away from those areas where it can do the greatest harm.

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Effects of Turning Off Selected Roadway Lighting as an Energy Conservation Measure

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In early 1973, the continuous roadway lighting on the southbound main lanes of Interstate 35 through Austin, Texas, was turned off as a power-saving measure in response to a critical area energy shortage. Analyses of accident data revealed that this cutback in roadway lighting significantly increased the frequency, rate, and severity of nighttime accidents in the affected freeway sections. The most notable increases were associated with a sharp rise in nighttime rear-end and pedestrian-related accidents. The cutback in roadway lighting saved approximately 450 000 kW·h of electrical power per year, enough to maintain 20 all-electric homes of average size for the same time period. In terms of energy cost savings to the city, this reduction amounted to $25 250/year. In addition, estimated savings of $2500/year in lamp-replacement costs were realized through the cutback. However, increases in accident costs after the lighting cutback were conservatively estimated to be slightly less than $17 000/year. Therefore, although positive energy conservation gains were made through the lighting cutback, these gains were accompanied by a measurable decrease in motorist safety.

On January 3, 1973, the Texas State Department of Highways and Public Transportation (TSDHPT) granted the city of Austin permission to turn off the continuous roadway lighting on the southbound main lanes of Interstate 35 through the city. The city requested the lighting cutback in response to a critical shortage of electrical power in the area. After the department's authorization was received, the lighting cutoff was carried out by city technicians between January 9 and 15, 1973.

The lighting reduction affected only the main lanes in three freeway sections that had a total length of 7.2 miles. Section 1 had median-mounted lighting and all lighting for the southbound lanes was turned off. Sections 2 and 3 had shoulder-mounted lighting on both northbound and southbound lanes and, again, all lighting for the southbound lanes was turned off. Ramp and frontage road lighting in the three sections was not affected by the cutback.

All three sections had four 12-ft travel lanes (two lanes per direction) with inside and outside shoulders. A 30-ft clear ditch median separated opposing traffic in section 1. A 20-ft raised median and semirigid barrier (W-beam section) separated traffic in sections 2 and 3.

Table 1 summarizes the roadway lighting characteristics of each of the three sections and also gives the average daily traffic (ADT) for each section averaged over the four-year study period. There were light to moderate increases in traffic volume on the three sections during the four-year study period, ranging from 6 percent for section 2 to 32 percent for section 1. In the computation of accident rates, 28 percent of the ADT was assumed to be nighttime traffic for all sections.

ACCIDENT STUDY

An extensive analysis of accident data gathered from all three study sections was conducted to determine the effects of the lighting cutback on motorist safety. The data, furnished by the Austin Transportation Department, consisted of computerized coded records of all accidents that occurred in the three sections during the study period. These records included information on accident location, type, and severity as well as lighting conditions during each accident. Two years of before data and two years of after data were evaluated.

The accident study revealed that 296 accidents were reported to have occurred on the main lanes of I-35 during 1971 and 1972 and 254 accidents during 1973 and 1974. It should be noted that, since entrance and exit ramp lighting was not reduced in the after period, accidents that occurred at the ramps were omitted from consideration.

Accident Frequency

Table 2 summarizes the changes in accident frequency that occurred between the before and after periods. The data in the table indicate that there was a significant decrease (-22.1 percent) in accident frequency in the after period except on the unlighted southbound side at night (1,2), where there was a significant increase in accident frequency (+47.1 percent) in the after period. The same trends were observed for all three study sections

Table 1. Lighting and traffic characteristics for three study sections.

Section	ADT (no. of vehicles)	Lighting Location	Lighting Mounting Height (ft)	Lighting Spacing (ft)
1	22 300	Median	50	300
2	52 580	Shoulder[a]	30	175
3	42 050	Shoulder[b]	30	175

[a]Opposite. [b]Staggered.

Table 2. Statistical analysis of changes in accident frequency observed in after period.

Accident Group	No. of Accidents in Before Period	Change in After Period (%)	Confidence Level at Which Change Is Significant (%): Chi-Square Test	Poisson Test
Lighted side				
Day	140	-24.2	95	99
Night	35	-25.7	85	95
Unlighted side				
Day	87	-17.2	85	95
Night	34	+47.1	95	99
All except unlighted night accidents	262	-22.1	95	99

individually. The overall trend toward decreasing accident frequency is attributed, at least in part, to adoption of the 55-mile/h speed limit in 1974. The significant increase in the frequency of nighttime accidents on the unlighted side in the after period is attributed to the cutback in roadway lighting.

Accident Rates

The same trends observed in accident frequencies were also noted in accident rates despite moderate to light increases in traffic volume in the after period. For example, the accident rate on the unlighted southbound side at night increased from 1.51 accidents/million vehicle miles in the before period to 1.91 in the after period, a 27 percent increase. However, accident rates for all other accident groups (northbound day, northbound night, and southbound day) decreased significantly in the after period. As noted earlier, in the computation of accident rates, 28 percent of the ADT was assumed to be nighttime traffic.

Accident Severity

The severity of accidents also increased on the southbound side in the nighttime after period. Although the frequency of fatal accidents remained stable in the before and after periods, the frequency and rate of injury accidents rose sharply in the after period, the frequency by 129 percent and the rate by 96 percent. In comparison, the number and rate of injury accidents in all other accident groups declined in the after period.

Accident Type

All types of accidents on the unlighted southbound side increased in the nighttime after period. There were 30.0 and 18.2 percent increases in sideswipe and one-car accidents, respectively. The most significant increases, however, were recorded for rear-end and pedestrian-related accidents. Nighttime rear-end collisions increased by 125 percent on the southbound side in the after period; the number of pedestrian-related accidents rose from zero to six. In comparison, nighttime rear-end and pedestrian-related accidents decreased in the after period on the northbound (lighted) side.

Accident Costs

From an economic standpoint, the cost of nighttime accidents on the unlighted side increased by $33 880 in the two-year after period. This amounts to an increase in accident costs of approximately $17 000/year. The cost of accidents in the other accident groups, however, decreased by $71 640 in the two-year after period. These accident cost figures were computed by using average accident costs for 1972 published by the National Safety Council (3).

ENERGY SAVINGS

An evaluation of the energy savings resulting from the lighting cutback was also made. The number of mercury vapor lamps, by wattage, that were cut off is given below:

Type of Lamp (W)	Number Cut Off	Power Reduction (W)
250	8	2 000
400	100	40 000
700	1	700
1000	69	69 000
Total	178	111 700

These data indicate that 178 lamps were turned off and that this resulted in a reduction of 111 700 W of power demand. Assuming 11 h of on time per day, this reduction yielded a savings in power consumption of 448 475 kW•h/year (the assumption of 11 h of on time is based on an average day length for central Texas of 13 h).

Based on the cost of electrical power in the area at the time of the lighting cutback (fuel cost of $0.029/kW•h and fuel adjustment charge of $0.025/kW•h), the reduced power consumption resulted in a savings of $24 200/year to the city. If one relates these savings in electrical power to other uses, the power saved in one year by the lighting cutback could have been used to maintain 20 all-electric homes of approximately 1500 ft^2 for the same time period. This approximation is based on an average rate of electrical power use of 1958 kW•h/month for all-electric homes in the central Texas area.

LAMP-REPLACEMENT COSTS

Although not extensively analyzed, the savings in lamp-replacement costs resulting from the lighting cutback were also considered. The costs of mercury vapor lamps used in computing these savings are given below:

Type of Lamp (W)	Cost ($)
250	15.5
400	18.0
700	23.0
1000	28.0

A liberal replacement rate of 33 percent/year was assumed. The costs for labor and installation equipment were assumed to be equal to the lamp costs; therefore, the total yearly cost savings for lamp replacement were roughly estimated to be two times the cost of the lamps that would have needed replacement each year. By using these assumptions, combining the data from the two tables above yields an estimated savings in lamp-replacement costs of $2500/year. Although this figure is only approximate, it indicates that lamp-replacement cost savings are a relatively minor consideration. In fact, the savings represent only 10 percent of the savings realized from reduced power consumption.

PUBLIC ATTITUDE

At the time the city made its request for reduced roadway lighting, the Austin area was experiencing a severe energy shortage. The shortage was brought about by the failure of the city's contracted natural-gas supplier to furnish sufficient quantities of natural gas to meet all of the area's electrical power needs. It appeared that the shortage would be long term and that there would be critical peaks dependent on environmental conditions. In response to the energy shortage, the city launched an extensive campaign for energy conservation. The lighting cutback on I-35 was a sincere attempt by the city to make apparent its willingness to contribute to this conservation program.

A critical concern, then, is the effect that the reduction in roadway lighting had on public attitude toward energy conservation. Unfortunately, very few conclusive data were available on public reaction to the lighting cutback. Personnel of the Austin Transportation Department and TSDHPT who were interviewed in conjunction with this study indicated that they received only a minimal amount of reaction from the public in the form of complaints or praise.

CONCLUSIONS

Based on the findings of the research reported in this paper, a substantial cutback in roadway lighting on urban and suburban freeways may not be a satisfactory energy conservation measure. The savings in electrical power consumption associated with such a cutback are offset to a large extent by significant increases in accident frequency and severity resulting from the added hazard of nighttime driving on an unlighted or partly lighted roadway. In addition, the savings in lamp-replacement costs and gains made toward increasing public awareness of the energy problem appear to play only a minor role in determining the effectiveness of a lighting cutback to conserve energy.

It should be noted that this study only addressed one strategy for conserving energy consumed by roadway lighting installations--i.e., turning off the lighting. There are other conservation techniques--e.g., conversion to high-pressure sodium lamps and staggered lighting cutbacks--that may result in substantial energy savings without adversely affecting traffic safety. In addition, no attempt was made to measure or calculate lighting levels in the affected sections.

In 1975, the findings of the study were forwarded to the Austin Transportation Department. Since then, the roadway lighting on I-35 through Austin has been returned to its full level of operation.

ACKNOWLEDGMENT

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Abridgment

Operational Field Study of Urban Freeway Guide Signing in Dallas

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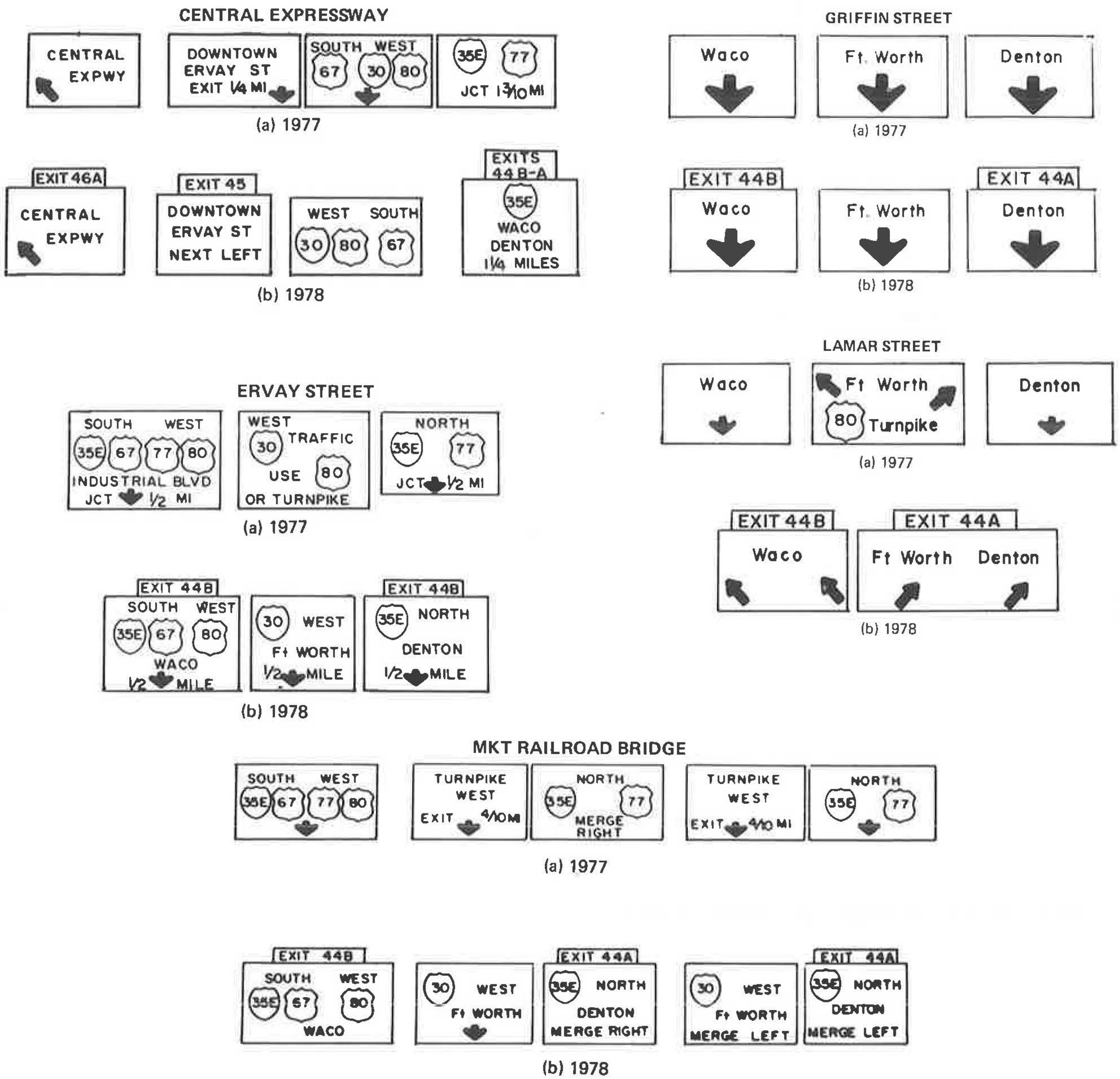
A traffic operational field study conducted on an urban freeway in Dallas, Texas, is described. Major signing modifications were made to the freeway guide signing by state forces exogenous to the research effort. Before and after study data on lane volumes, lane changes, and erratic maneuvers were collected and evaluated. Some specifics and a few general conclusions and recommendations are offered. The operational field study was conducted along westbound I-30 near downtown Dallas. The before study was conducted during 1977 and the after study in 1979. During this period, the freeway guide-signing system was updated to 1970 Manual on Uniform Traffic Control Devices standards. Operational studies of volumes, lane changing, and erratic maneuvers were made to determine what effects might be attributed to the signing and what changes, if any, occurred as a result of these changes. Some positive operational changes were noted, but the causal relations were clouded by the fact that the Dallas-Fort Worth Turnpike was made into a toll-free road (I-30) between the before and after studies.

Traffic operational field studies were conducted along Interstate 30 in Dallas to determine what changes, if any, occurred in the traffic flow due to changes made in freeway guide signing. Operational performance measures used to determine operational changes included lane volumes, lane changes, and erratic maneuvers.

LOCATION OF STUDY SITE

The study site was located along westbound I-30 near

Figure 1. Before and after signing at five locations approaching I-35E interchange in Dallas.



downtown Dallas. The study section began at the Good-Latimer overcrossing and proceeded westbound past the Missouri-Kansas-Texas (MKT) railroad bridge to the I-35E interchange. The overall length of the study section was 1.2 miles. The geometrics of this section of I-30 are basically a six-lane depressed freeway with parallel feeder roads in the depressed section.

BEFORE-AFTER SIGNING

The new 1978 signing system included revised freeway guide signing from I-635 through downtown Dallas, a distance of about 10 miles. Most of the critical signing changes, however, were made in the study section. The before (1977) and after (1978) signing for the last locations approaching the I-35E interchange are shown in Figure 1.

STUDY METHODOLOGY

To determine whether any detectable operational changes had occurred that might be attributed to the new signing system, a relatively large-scale field study was conducted. To make this determination, changes in lane-volume distribution, lane changing, and erratic maneuvers were observed at selected locations.

Several methods were used to record the operational data. A 10-member study team was used to observe traffic operations. Six members made manual traffic-volume counts by lane at the Good-Latimer, Griffin, and Lamar Streets bridges. Lane volumes and lane changes were recorded by using a portable television video recording system at the Ervay Street bridge. A similar video recording system was operated by two people at the MKT railroad bridge adjacent to the I-35 interchange.

Data recording was coordinated by the study supervisor by means of walkie-talkie communication with each location. Personnel at each manual-count station made cumulative counts each 5 min beginning on the hour or the half-hour as appropriate.

Table 1. Chain sequence of highest traffic volume in lane 3 for either before or after study by 1-h time periods.

	Study Location				
Starting Time	Good-Latimer Streets	Ervay Street	Griffin Street	Lamar Street	MKT Bridge
2:30 p.m.	B	A	B	B	A
3:30 p.m.	B	A	B	B	B
9:30 a.m.	A	A	A	A	A
10:30 a.m.	B	A	B	B	B

Note: B = lane 3 highest in before study, and A = lane 3 highest in after study.

The Ervay Street video recordings were the only sources of lane-changing data. Erratic maneuvers were studied at the junction of I-30 and I-35E at the MKT railroad bridge with another video recorder. These maneuvers were classified as to level of severity as follows:

Level of Severity	Maneuver
1	Minor gore penetration
2	Heavy gore penetration
3	Driver completely missed route and backed up the shoulder to change direction

The before studies were conducted primarily on Friday, April 8, 1977, from 2:30 to 4:30 p.m. and on Saturday, April 9, 1977, from 9:00 to 11:00 a.m. The after studies were conducted on Friday, April 6, 1979, and on Saturday, April 7, 1979, at the same times.

RESULTS

Lane-Volume Distributions

Traffic-volume counts by lane were converted into percentages of total flow to discount the effects of possible variations in the general volume levels between the before and after studies. First, a fairly consistent trend toward increasing volumes in the shoulder lane (lane 3) at Ervay Street is noted during the after study over the four 1-h study periods. A chain sequence of the highest percentage lane 3 volume level (of total volume) during either the before or after study by 1-h time periods illustrates this point (see Table 1). Of the nine cases in which lane 3 lane-volume-distribution percentages increased, four were at Ervay Street. The median lane (lane 1) shows a rather consistent reduction in the percentage of the total traffic using it between the two studies.

Similar comparisons at the Lamar Street and MKT (at I-35E) bridges show increasing concentrations of traffic in the middle lane (lane 2) during the after study as compared with heavier traffic found in the outer lanes in the before study. An analysis of these data reveals that a greater percentage of traffic is now headed toward Fort Worth on I-30 than toward Waco on I-35E.

Lane Changing

The data show that the percentage of total lane changing increased slightly from right to left, but only from lane 3 to lane 2. No change in lane changing from left to right was observed.

Overall, a 28 percent drop in lane changing was observed in the section between the before and after studies. The largest percentage reduction consistently was right to left from lane 2 to lane 1 (median lane). These reductions were caused primarily by the change in status of the Dallas-Fort Worth Turnpike to I-30.

Erratic Maneuvers

The frequency of erratic maneuvers is about the same in the before and after cases. A total of 79 were observed in the before study and 73 in the after study. The directional distribution of erratic maneuvers (to right or to left) also remained about the same. However, the level of severity of erratic maneuvers is lower in the after study. During the before study, a total of 18 vehicles were observed making some type of backup at the I-35E junction to correct their route choice. Not one case of a missed route and backup was observed during the after study. Overall, the severity of erratic maneuvers was reduced but remains higher than desired, especially in view of the 13 level-2 erratic maneuvers observed on Saturday morning.

It would appear that the impact of converting the Dallas-Fort Worth Turnpike into a free road (I-30) had a beneficial impact on traffic operations in the study area and explains much of the change in traffic phenomena observed between the before and after studies. However, the new signing system appears to be directing traffic adequately into the appropriate lanes as they approach the I-35E interchange. Improvements to the signing system are still needed, however.

Several improvements to the new signing system are recommended for westbound I-30 in Dallas:

1. Add a post-mounted median sign at Grand Avenue that gives mileage to I-45 and U.S-75 as well as to I-35E.
2. Redesign (or eliminate) the I-30 PULL THRU sign at Fair Park to be consistent with the others.
3. Eliminate the I-30 PULL THRU sign at the Central Expressway and enlarge I-35E advance guide sign.
4. Close the gap in the triple overhead at Akard Street to improve readability.
5. Replace both sets of destination signs at Griffin Street and at the MKT railroad bridge with the route numbers and destination names as well as lane assignment arrows. Visual coding of the PULL THRU sign at Akard Street is misleading and should be corrected and then reinforced at Griffin Street and the MKT bridge.

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Driver Knowledge of Grade-Crossing Information

JOHN E. TIDWELL, JR., AND JACK B. HUMPHREYS

Questionnaires were completed by 829 licensed drivers or candidates for licenses in an effort to ascertain their level of knowledge concerning highway-railroad grade-crossing information. Questions were asked concerning traffic-control devices, facts relating to grade-crossing hazards, and driver responsibilities at grade crossings. Respondents were stratified by age and elements of training and/or experience. Major findings of the study include the following: (a) Collection of interview data at a driver's-license examining station is an effective method of determining driver knowledge, (b) more than 50 percent of all respondents believed that all grade crossings except those rarely used by trains have active warning signals, (c) most drivers have adequate knowledge concerning the hazards of grade crossings, (d) most drivers do not know the required driver response at passive grade crossings, (e) drivers perceive little law enforcement related to driver actions at grade crossings, and (f) driver knowledge and/or understanding of the traffic-control devices used to warn of grade crossings is inadequate. Recommendations are made regarding driver knowledge items that should be considered for inclusion in public information campaigns on grade-crossing safety. Future research regarding different advance warning signing for active and passive crossings and enforcement as a countermeasure is also recommended.

When traffic engineers call for traffic-control devices to be erected, it is always with the intent that the driver understand the message conveyed. Enforcement officials must assume that drivers understand their responsibilities. Nowhere are these two assumptions more critical to safety than at the intersection of a roadway with a railroad, hereafter referred to as a grade crossing. Assumptions concerning driver knowledge of grade-crossing information have been investigated by Sanders (1) and Dommasch and others (2). Their investigations included the administration of questionnaires at grade crossings. Due to the need to minimize delay to motorists, the subject areas addressed by these questionnaires were limited. These studies dealt primarily with facts concerning the crossing the driver had just negotiated. This research attempts to infer the level of driver knowledge of grade-crossing information from data obtained in a more controlled environment.

During the summer of 1979, drivers arriving at a Tennessee Department of Safety driver's-license examining station were administered a questionnaire to determine their level of knowledge concerning highway-railroad grade crossings, facts relating to grade-crossing hazard, and driver responsibilities at grade crossings. Demographic information and data on driver exposure to various efforts to educate drivers about grade crossings were also obtained.

METHODOLOGY

One driver's-license examining station operated by the Tennessee Department of Safety was selected for the interview site. The researchers consider that this site is reasonably representative of examining stations in urbanized areas. The sampling plan required that 400 responses be randomly obtained. This would allow 95 percent confidence that the aggregated responses were within 5 percent of the true knowledge level of the universe of drivers arriving at this examining station.

The questionnaire used to obtain the data on driver knowledge is shown in Figure 1 (asterisks have been added to indicate the correct responses). It should be noted that data were obtained from both drivers coming to obtain a license and escort drivers (or others) who accompanied the license candidates. Drivers were advised that this questionnaire was for research purposes only and would not affect the licensing procedure.

CONDUCT OF STUDY

The driver's-license examining station for the Knoxville, Tennessee, area was selected for the interviews. Data were collected during a one-week period in June 1979. During this period, all drivers coming to the station were asked to participate in the study. Only licensed drivers or those expecting to be licensed as a result of testing on the day of the interview were given questionnaires. A total of 1011 drivers were contacted during this period. Completed questionnaires were obtained from 829 drivers, for a response rate of 82 percent. All completed forms were returned before the respondent left the interview station.

The responses were separated into groups for analysis to determine whether there were significant differences in responses among the groups. Groupings were made and analysis was performed for each of the following stratifications:

1. Drivers who recalled grade-crossing instructions from safety campaigns (174) versus those who did not recall instructions from that source (655),
2. Drivers who recalled grade-crossing instructions from driver training courses (290) versus those who did not recall instructions from that source (539),
3. Drivers who recalled grade-crossing instructions from the driver's handbook (547) versus those who did not recall instructions from that source (282),
4. Drivers who recalled instructions from other sources (99) versus those who did not recall instructions from those other sources (730),
5. Male drivers (414) versus female drivers (415),
6. Drivers who came to the examining station prepared to take a written driver's test (257) versus those who were not prepared (escort drivers or friends of candidates) (572),
7. Drivers who had reviewed the driver's handbook within the past two weeks (191) versus those who had not reviewed the handbook (638),
8. Drivers who had completed a driver education course within the past year (75) versus those who had not completed a course (754), and
9. Five age groups: under 25 (340), 25-34 (216), 35-44 (165), 45-59 (83), and over 59 (25).

The responses from each of the nine groups were analyzed by using the chi-square test and a 95 percent confidence level. This analysis was made to determine whether or not the responses to the individual questions differed significantly among the groups.

RESULTS

The overall responses for all of the 829 drivers are shown in Figure 1 in the form of percentages adjacent to each of the possible responses for each question. These percentages indicate the proportion of the 829 drivers who indicated that the associated response was the correct answer to the question.

All of the stratifications were subjected to a

Figure 1. Questionnaire used to determine driver knowledge of grade-crossing information.

Asterisks have been added to indicate correct answers. The overall responses (percentages) are indicated in the circles.

Your answers to the following questions will be used in a research project which is attempting to find a way to improve highway safety.

We need to have all questions answered, so please answer to the best of your present knowledge. Thank you for your assistance.

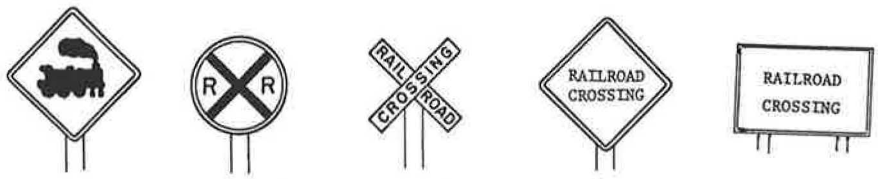
1. Do you recall specific instructions concerning driving safety at railroad crossings from any of the following sources? Check only those you remember something from.

   Safety Campaign (Radio, TV, etc.) 21 % Tennessee Driver's Handbook 66 %

   Driver's Education Course 35 % Don't recall any instructions 12 %

   Other 7 % ______________________ specify

2. Which of the following is actually placed just at the point where the railroad tracks cross the highway? Check only one.

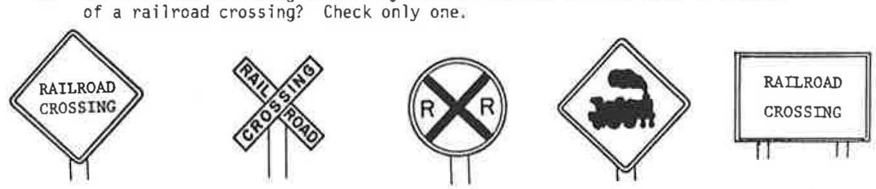


0.3 % 21 % 71 %* 2 % 0.1 %

3. Are you male or female?

   Male 50 % Female 50 %

4. Which of the following is usually located several hundred feet in advance of a railroad crossing? Check only one.



19 % 15 % 62 %* 1 % 0.1 %

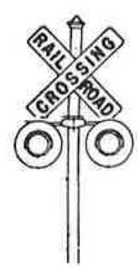
5. What does it mean when this railroad signal is flashing? Check only one.

   You are approaching a crossing 2 % This is a warning to the train engineer 0.2 %

   Slow down for rough crossing 0.1 % Don't know 0.2 %

   A train is coming 97 %*

6. At which railroad crossings is this railroad signal usually placed? Check only one.



   All railroad crossings 35 % Only the most dangerous crossings 27 %*

   All except the ones rarely used by trains 19 % Crossings with more than one track 13 %

   Crossings where there have been fatal accidents 4 %

7. How long does it generally take for a train to reach the crossing after the railroad signal begins to flash? Check only one.

   A flashing signal has nothing to do with a train coming 4 % 10 - 30 seconds 22 %

   0 - 10 seconds 7 % 30 - 60 seconds 37 %

   Over 1 minute 30 %

8. In general, how does the distance needed to stop a train compare with that needed to stop a large truck traveling at the same speed? Check only one.

   Same 2 % Train needs more distance to stop 93 %*

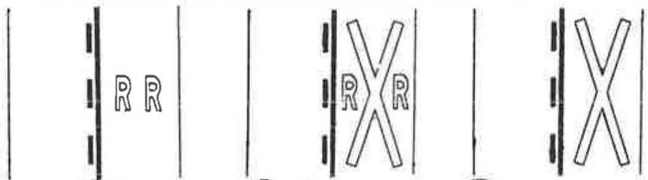
   Truck needs more distance to stop 4 %

Figure 1. Continued.

9. What does this sign mean? Check only one.

Slow down to 20 miles per hour (mph) due to rough crossing	24 %	Slow down to 20 mph and look for a train	72 %*
The trains that use this crossing travel at 20 mph	3 %	Drive faster than 20 mph to cross safely.	0.6 %

10. Which of the following are the standard marking painted on the pavement in advance of most railroad crossings? Check only one.



Don't Know

7 %   70 %*   5 %   18 %

11. What should you do when approaching a crossing that does not have a railroad signal? Check only one.

Not applicable, since all crossings have railroad signals	3 %
Maintain speed, but be ready to stop if you see or hear a train	2 %
Slow down and be ready to stop if you hear or see a train	38 %*
Speed up and cross the tracks quickly to avoid an accident	0.7 %
Stop at the crossing and look for a train	56 %

12. What should you do when approaching a crossing that has a railroad signal? Check only one

Slow down, look to see if the signal is flashing and look for a train	43 %
Slow down and be ready to stop if you hear or see a train	16 %
Slow down and look to see if the signal is flashing	11 %*
Maintain speed, but be ready to stop if you see or hear a train	3 %
Stop at the crossing and look for a train	26 %

13. Approximately how many motorists were killed in accidents at railroad crossings lastyear in the United States? Check only one.

10	2 %	10,000	38 %
100	13 %	100,000	5 %
1,000	40 %*		

14. What should you do when approaching a railroad signal that is flashing? Check only one.

Slow down and look for a train	7 %
Stop at the crossing and wait for the signal to quit flashing unless after stopping you are positive that no train is approaching	81 %*
Maintain speed and go through the crossing unless a train is already there	1 %
Stop at the crossing and wait for the train to cross unless it appears you can cross before the train arrives	11 %
No action required, since this signal just alerts you to the crossing	0.3 %

15. What is you age?

Under 25 41 %   25-34 26 %   35-44 20 %   45-59 10 %

Over 59 3 %

16. Are you satisfied with the current signs, signals, and pavement markings used at railroad crossings? If not what additional traffic related measures would you like to see taken to improve safety at railroad crossings?

Present system satisfactory	49 %
Other measures needed	50 %

29%
Specify

Figure 1. Continued.

		YES	NO
17.	Are you at the Driver Examining Station to take a test?	31 %	69 %
18.	Have you reviewed the Tennessee Driver's Handbook in the last two weeks?	23 %	77 %
19.	Have you or someone you know ever received a traffic citation (ticket) for improper driving at a railroad crossing?	4 %	96 %
20.	Have you completed a Driver's Education course within the past year?	9 %	91 %
21.	Are you licensed to drive (other than just a driver's permit) in Tennessee or some other state?	84 %	16 %

If you received this questionnaire at a Driver Examining Station, please wait to complete the last question until you have finished all tests. Thank you.

chi-square analysis (α = 0.05) by forming contingency tables. The independent variable in the table was the group the respondent fell into (age, sex, etc.). The dependent variable was whether or not the respondent answered the question correctly. This was done for all of the nine stratifications. Each of the 11 gradable questions was analyzed in this manner. This analysis indicated that there were several groups that had significantly different knowledge concerning specific questions.

When compared with the group that did not recall instructions on grade-crossing safety from a safety campaign, the group that did recall such instructions gave a significantly higher proportion of correct answers to questions 4, 10, and 14. This means that those who recalled instructions on grade-crossing safety knew more about the advance-warning sign, pavement markings, and driver responsibility at a flashing railroad signal. The type of campaign the drivers were exposed to was not identified. However, this finding suggests that the campaigns these drivers were exposed to may have contributed to their greater knowledge in these three areas.

When compared with the group who came to the station not expecting to be tested, the group that was expecting to be tested gave a significantly higher proportion of correct answers to questions 9 and 11. This means that the drivers who expected to be tested were more knowledgeable concerning the meaning of an advisory speed sign used with an advance-warning sign and the driver's responsibility at a passive crossing. However, the drivers who were expecting to be tested gave a significantly lower proportion of correct answers to question 6 (extent of active protection). This indicates that the materials and reviews that drivers are exposed to in preparing for testing are (apparently) significantly helpful in the two areas addressed by questions 9 and 11.

When compared with the group who had not reviewed the driver's handbook in the past two weeks, the group who had reviewed the handbook gave a significantly lower proportion of correct answers to questions 6 and 13. This means that those who had reviewed the handbook were less knowledgeable concerning the extent of active protection at crossings and annual grade-crossing fatalities.

When compared with the group that had not completed a driver education course within the past year, the group that had completed a course gave a significantly lower proportion of correct answers to questions 6 and 14. Thus, drivers who had taken a driver education course within the past year were less knowledgeable concerning the extent of active protection and driver responsibility at a flashing railroad signal. Researchers had expected the group that had attended a driver education course to perform significantly better. The fact that they did not may indicate the lack of coverage that is given to grade-crossing-related matters in driver education courses.

The significantly poorer performance on certain questions by the drivers who came expecting to be tested, who had reviewed the driver's manual, or who had recently completed a driver education course may be attributable to the fact that they were probably less experienced drivers than the escort drivers.

When compared with women, men gave a significantly greater proportion of correct answers to questions 6, 10, and 11. This means that men have significantly greater knowledge concerning the extent of active protection, pavement markings, and driver responsibility at passive crossings.

When the different age groups were examined, it was found that drivers under age 25 gave a significantly lower proportion of correct answers to questions 6 and 14. This indicates that young drivers are less knowledgeable concerning the extent of active crossings and driver responsibility at a flashing railroad signal. Here again, driving experience may be the important variable. Drivers in the 25-34 age group answered question 11 with a significantly higher proportion of correct answers. This indicates that the 25- to 34-year-old driver knows more about driver responsibility at passive crossings. These findings may be the result of the younger drivers' lack of exposure to grade crossings. Because the 25- to 34-year-old drivers have had more exposure to grade crossings, their knowledge in the area of question 11 is greater.

The sample was also compared with the population of licensed Tennessee drivers. The male-female ratio of the sample was compared with that of licensed Tennessee drivers by using chi-square analysis. This analysis indicated that there was no significant difference in the male-female ratio (λ^2 = 2.384, df = 1; $\lambda^2_{0.05,1}$ = 3.841).

The age distribution of the sample was compared with that of licensed Tennessee drivers. The Tennessee drivers were aggregated into the same five age groups established in the questionnaire. A chi-square analysis of the age distribution of the sample and the Tennessee drivers indicated that the age distribution was significantly different (λ^2 = 251.689, df = 4; $\lambda^2_{0.05,4}$ = 9.488). The sample was skewed toward younger drivers, which is to be expected because the driver's-license testing system is oriented toward testing younger drivers and because younger age groups are more mobile in our society. This difference should be considered when the results of this research are applied.

CONCLUSIONS

1. Data collection at a driver's-license examining station is a good method for obtaining information on driver knowledge. Drivers are conditioned for testing in that environment and are generally cooperative.

2. A total of 35 percent of the drivers tested indicated that all grade crossings have active protection; another 19 percent indicated that all grade crossings except those rarely used by trains have active protection. It can therefore be concluded that drivers' knowledge of these matters at the Knoxville driver's-license examining station was very inadequate (only 27 percent answered correctly). These responses indicate that 54 percent of the drivers contacted believe that, if a crossing does not have a signal, it is rarely used by trains. This may affect the driving behavior of those drivers as they approach passive crossings. Drivers who believe that signals are placed at all crossings that are regularly used by trains would logically be expected to drive as if they had the right-of-way unless they see a flashing signal or a lowered gate. However, this hypothesis would have to be tested by further research. It should also be noted that drivers who had reviewed the driver's handbook, were prepared to take a test, or had completed a driver training course in the past year actually did worse in this area.

3. Driver responses to the questions concerning the number of grade-crossing fatalities and relative stopping distance for trains indicate that drivers have adequate knowledge concerning these two measures of the hazards of highway-railroad grade crossings. Of course, the lack of knowledge concerning the extent of active protection indicates a great lack of knowledge of the true hazard at grade crossings.

4. An unusually high proportion of drivers (56 percent) indicated that they should always stop at passive grade crossings, and 26 percent indicated that they should stop at active crossings. This indicates that these drivers believe that more is required of them than actually is required. To use a marketing analogy, the customer (driver) may perceive that the price is too high for the product (safety) and therefore refuses to purchase the product. If drivers know that a cautious approach to a passive crossing, not a mandatory stop, is the actual requirement, they may be willing to pay that price. In other words, if drivers know that a legal requirement that is less restrictive than a stop is in effect, they may be willing to obey the lesser requirement. Future research would be needed to test this hypothesis.

5. Only 4 percent of the drivers were aware of an enforcement action relating to grade crossings. This indicates that enforcement as a countermeasure may produce benefits, since for all practical purposes it is not currently perceived as being used as a countermeasure.

6. A substantial portion of the drivers (±30 percent) could not correctly answer questions 2, 4, 9, and 10, which relate to traffic-control devices. This indicates a deficient knowledge and/or understanding of the commonly used uniform warning devices.

7. Forty-three percent of the drivers indicated that when approaching an active crossing they should look for trains as well as look at the signal. Here again, drivers may perceive that an unreasonable requirement is placed on them and simply opt to do nothing. Drivers should be advised that as they approach an active grade crossing they should carefully examine the signal to see whether it is activated. Apparently, many drivers do not place complete confidence in active protection.

RECOMMENDATIONS

To the extent that one is willing to apply the results of this effort to the entire universe of drivers, the following recommendations appear to merit consideration:

1. In the development of educational efforts such as driver training courses, driver's handbooks, and public safety campaigns, to improve safety at grade crossings the following should be clearly conveyed: (a) Only the more hazardous crossings have active protection; (b) standard traffic-control devices should be described and their placement discussed; (c) drivers are required to slow down, look, and listen for trains at passive crossings, and a stop is not required except for certain vehicles or at crossings where public authorities have erected a standard stop sign; (d) drivers are required to always examine railroad signals to determine whether they are flashing before traversing the crossing, and a stop is not required unless the signal is activated; and (e) knowledge concerning the hazards of grade crossings is apparently adequate and does not need to be overly emphasized in an education effort.

2. Consideration should be given to developing unique advance signing to inform drivers that they are approaching a passive crossing. Currently, advance signing and pavement marking are the same for both active and passive crossings even though vastly different driving behavior is desired at the two types of grade crossings. Drivers approaching passive crossings are expected to slow down, look, and listen for trains; when approaching active crossings, they are expected to maintain their speed and carefully observe the signal. This study revealed the low level of knowledge concerning which crossings have active protection.

3. Enforcement as a countermeasure should be evaluated as part of a future research effort, since it is not being perceived as a countermeasure at this time.

ACKNOWLEDGMENT

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Abridgment

Characteristics of Urban Freeway Guide Signing in Selected Cities

CARROLL J. MESSER AND ROGER W. McNEES

The results and findings of a physical inventory of selected attributes of freeway guide signing found in 10 major cities in the United States are described. Four of these cities were located in the state of Texas and six were outside the state. Data were collected on numerous physical design features, including number of sign panels, number of concurrent routes, and bits of information. The results of the study include tabular comparisons of a number of attributes together with comparisons between Texas and out-of-state signing systems. Information load was defined as the total number of bits of information presented on all overhead sign panels on the main lanes of the freeway. The 50th percentile information load level was found to be 10 bits, the 85th percentile level was found to be 15 bits, and the 95th percentile level was determined to be 18 bits. Most of the high-bit-level signs (those having bit rates in excess of 16 bits) were located in Texas. Another signing variable for which comparisons were made between Texas and non-Texas signing systems was concurrent signing. A dramatic finding of this evaluation was the tremendously large number of concurrently marked Interstate and U.S. routes basically found only in the Texas cities.

The motoring public traveling urban freeways has a wide variety of driving experiences and navigational information needs. Local motorists are usually very familiar with the freeway networks within the metropolitan area and therefore use freeway guide signing only to a modest extent, primarily as landmarks used in initiating actions they have already planned. The semifamiliar freeway driver requires more time to read and respond to the signing and may become confused by unexpected, complex operational circumstances. The out-of-state driver would have maximum information needs and therefore would have to rely totally on the guide signing to navigate through the freeway network.

Where Texas urban freeway guide signing is significantly different from signing in other cities of the country, these differences cannot be anticipated by out-of-state motorists and will surprise the unfamiliar motorist. The result is increased response times and probabilities of driving errors (1).

STUDY DESCRIPTION

Objective

The objective of this study was to determine the basic design characteristics of urban freeway guide signing found in Texas cities and in selected cities around the United States that have similar population and geographic features.

Scope

An inventory of selected physical design characteristics of urban freeway guide signing was conducted in 10 major cities during 1979. Six cities were located outside the state of Texas: Atlanta, Chicago, Denver, Kansas City, Los Angeles, and New Orleans. The four Texas cities inventoried were Dallas, Fort Worth, Houston, and San Antonio. A total of 2292 signs were inventoried.

Measurement Procedure

All observations of freeway guide signing were obtained by making routine travel runs along the freeways in standard automobiles. Mileage measurements were read from the odometer. The physical characteristics and message design of each guide sign were inventoried.

Data were collected on the following guide-sign features: location of sign structure, cross-section position (median, overhead, and shoulder), number of sign panels, total bits of information on the panel, number of concurrent route sign panels, and, finally, the total number of concurrent routes on a panel.

The unit used to measure information load on a freeway guide sign was called a "bit". A bit of information on a freeway guide sign in this study was defined as the existence on a guide sign of each of the following items: route number; cardinal direction; destination name; route name (one or two bits); street name; next right (left) (two bits); junction, to, next; exit number; command; exit mileage; exit only; mileage; all lane-use arrows; and business.

Excessively long or possibly confusing route names may be considered two bits of information or load in relation to estimating the degree of difficulty in the reading task. Concurrent route markings are a troublesome signing problem in most Texas cities, since many urban freeways are often marked as Interstate as well as U.S. highway routes.

STUDY RESULTS

The results of the inventory effort are described according to the basic measures previously described. A more detailed analysis of information statistics follows.

Inventory Mileage

A total of 1053 miles of freeways were inventoried in the 10 cities. The total mileage within Texas was approximately equal to the out-of-state mileage. The mileages shown represent almost all radial-oriented freeways in each city. Very little loop (beltway) freeway mileage around the cities was observed. A breakdown of these data is given below (note that signs are the same as sign structures in this paper and that a sign structure may have more than one sign panel):

Name of City	Miles of Inventory	No. of Signs	No. of Signs per Mile
Out of state			
Atlanta	59.0	142	2.41
Chicago	103.5	249	2.41
Denver	69.0	176	2.55
Kansas City	66.7	192	2.88
Los Angeles	187.1	220	1.18
New Orleans	35.9	84	2.34
Subtotal	521.2	1063	2.04
Texas			
Dallas	151.2	280	1.85
Fort Worth	106.1	310	2.92
Houston	97.7	308	3.15
San Antonio	176.9	331	1.87
Subtotal	531.9	1229	2.31
Total	1053.1	2292	2.18

The average number of sign structures per mile in the Texas inventory was found to be 2.31 sign structures/mile while the out-of-state sign density was 2.04 sign structures/mile.

The data show that Houston and Fort Worth have the highest density of signing: Sign density for Fort Worth is 2.92 signs/mile, and Houston's average sign density of 3.15 signs/mile is the highest value. It should be noted that the sign densities in Dallas, San Antonio, and Los Angeles--1.89, 1.87, and 1.18 signs/mile, respectively--are a little misleading. All three of these cities have undeveloped belt routes, which results in very few signs. In general, the most severe sign-density problems are found near the downtown area of the central city due to the unusually high frequency of access ramps and freeway-to-freeway interchanges. Near the downtown areas, sign densities of more than 4.0 signs/mile are likely to occur.

Sign Types

Median signs (151) included all guide signs located in the median of the freeway. The most common median signs observed were the ground-mounted exit and distance sequence signs. Shoulder signs (1117) included all single ground-mounted signs located on the right shoulder of the freeway, all T-mounted exit gore signs, and all ramp exit signs. All signs located on a single overhead sign bridge over the freeway main lanes were classified as "overhead" (1024).

The primary purpose of this phase of the inventory was to determine the usage characteristics of the median-mounted exit and distance sequence signs. The results show that Los Angeles and Houston have the most median signs. Except for the use of median-mounted signing in Los Angeles and Houston, the aggregate usage characteristics per mile of freeway inventoried were very similar.

Information Load

A study of the accuracy of route selection and reading times in a human factors laboratory (2) indicated that overhead sign structures with one or more panels that have more than 20 bits of information are unsatisfactory and that guide signs that have more than 16 bits are not desirable. The sign inventory determined that the 50th percentile (median) information load is 10 bits. The modal, or most frequently observed, value was also 10 bits. The table below gives the rank order of the cities that had signs with 16 bits of information or more:

Rank Order	Name of City	No. of Signs
1	New Orleans	0
2	Denver	3
3	Los Angeles	4
4	Atlanta	8
5	Kansas City	8
6	Chicago	13
7	Fort Worth	14
8	Dallas	14
9	San Antonio	16
10	Houston	18

The data also indicate that the 85th percentile level of the signs was about 15 bits of information or less. The 95th percentile level was determined to be 18 bits; that is, 5 percent or less of all signs had 19 bits or more. Less than 1 percent of all signs had more than 21 bits of information.

A more detailed breakdown of the distribution of information loads on signs reveals that the Texas cities tend to be the leaders in information loading. Every Texas city inventoried had more than one guide sign with more than 20 bits on it.

Since the total in-state and out-of-state freeway miles of inventory are about equal (532 versus 521), direct numerical comparisons are justifiable on an aggregate basis. A total of 15 signs in the four Texas cities had information loads of greater than 20 bits. Only 6 signs in the six out-of-state cities were observed to be so cluttered.

Number of Panels

The Texas cities have a slightly larger percentage of three- and four-panel applications on their urban freeways. In total, Texas had about 25 more four-panel signs than did the out-of-state systems, and nearly 70 or more three-panel signs.

Information Load per Panel

The average number of bits of information per sign panel was determined for each of the 10 cities inventoried. The four Texas cities all had average levels per panel less than any of the remaining five out-of-state cities.

It can be observed that the median information bit level (50th percentile) for the "busiest" sign panel per sign is about five bits; whereas the 85th percentile busiest panel would contain about seven bits in all of the cities. Dallas and San Antonio have 19 signs between them that have more than eight bits of information on one sign panel. Only a few of the large California sign panels in Los Angeles came close to being so loaded.

Concurrent Signing

Concurrent signing occurs when a freeway is included in more than one route-numbering system. A dramatic finding of this evaluation is the tremendously large number of Interstate and U.S. concurrent freeway routes (sign panels) found in Texas in comparison with the out-of-state systems. In the four Texas cities, there are 392 panels that have Interstate-U.S. concurrent signing compared with only 73 panels in the out-of-state systems (see Table 1). Only one Interstate-U.S. concurrent sign was found in five of the six non-Texas cities.

One may note that 18 percent of Texas signs have two concurrent routes (panels) signed and about 4 percent of the total Texas population of overhead freeway guide-sign structures have three concurrent routes.

CONCLUSIONS

The following conclusions are drawn from the field inventory data of the 10 selected cities in the United States and previously reported research (2) and are founded heavily on basic precepts of driver expectancy (1):

1. Fort Worth and Houston have more signs per mile than would be expected by most out-of-state drivers.
2. Los Angeles and Houston are the only two cities that extensively use median-mounted destination and distance sequence signs. Denver has installed these signs along one freeway.
3. The 85th percentile and 95th percentile bit levels of all overhead guide signs, excluding the ramp exit panel, were found to be 15 and 18 bits, respectively.
4. Texas cities tend to have most of the large, cluttered signs observed in the United States.

Table 1. Number of urban freeway guide-sign panels with concurrent route signing.

Inventory Location	Number of Guide-Sign Panels: Interstate-Interstate	Interstate-U.S.	U.S.-U.S.	Interstate-State	U.S.-State	None[a]	Total
Out of state							
Atlanta	20	0	1	0	0	57	78
Chicago	44	0	15	3	4	104	170
Denver	6	1	4	0	4	77	92
Kansas City	11	72	9	0	0	116	208
Los Angeles	3	0	0	0	0	159	162
New Orleans	0	0	0	0	0	64	64
Subtotal	84	73	29	3	8	577	774
Texas							
Dallas	23	93	1	0	0	105	222
Fort Worth	0	69	19	0	6	75	169
Houston	0	95	0	0	9	89	193
San Antonio	4	135	5	2	0	105	251
Subtotal	27	392	25	2	15	374	835
Total	111	465	54	5	23	951	1609

[a]None = one route number (no concurrent signing).

5. Texas stands almost alone in the continued use of redundant concurrent signing of an Interstate freeway with U.S. route numbers.

6. There are a few signing locations in Texas where the combination of a large number of concurrently signed intersecting routes are combined with a high-speed, large, multilane freeway facility, which results in signing plans that are likely to surprise and overload out-of-state motorists who are unfamiliar with them.

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Traffic Control and Geometrics for Weigh-in-Motion Enforcement Stations

CLYDE E. LEE AND RANDY B. MACHEMEHL

A discussion of geometric design concepts for weigh-in-motion (WIM) enforcement stations is presented. In-motion weighing techniques for trucks have been developed in recent years by which estimates of static axle weights can be made reliable to within 10 percent for trucks running at speeds of 60 km/h (37 miles/h) and perhaps higher and within about 2 percent for trucks running at speeds of 20 km/h (12 miles/h) or lower. High-speed weighing can be used to screen out only the suspected weight-limit violators and allow the obviously legally loaded trucks to pass without stopping and waiting to be weighed. Suspects can be checked for actual violation by a low-speed WIM system at rates up to 10 trucks/min without stopping or by static scales at perhaps 20 trucks/h with stopping required. A number of WIM enforcement-station layouts are possible. Two configurations are suggested. A recommended system of signs, pavement markings, and traffic-control signals that will guide the driver smoothly through the WIM enforcement station at reduced speed, but without stopping, is presented. It is concluded that weight-enforcement operations can be accomplished safely, efficiently, conveniently, and economically with properly designed WIM equipment, weigh stations, and traffic-control systems.

The current energy situation and rising economic pressures have, in recent years, fostered demands for increases in commercial vehicle sizes and weights. The resulting use of larger, heavier trucks is causing planners, engineers, economists, and enforcement personnel to realize the importance of having adequate, current information on truck size and weight available. Such data have historically been collected by stopping trucks at weigh stations or at the roadside for weighing and measurement. Both the quantity and the quality of the data obtained by this method have generally been somewhat limited, mostly because of the very high user and collection-agency costs associated with vehicle deceleration, waiting, and acceleration maneuvers required for static weighing. Site-construction costs and safety have also been considerations.

Electronic in-motion weighing equipment is now available to supplement or replace static weighing devices. Such equipment makes it possible to collect the needed vehicle weight and dimension data without requiring trucks to stop. Eight states are currently using in-motion weighing systems for enforcement purposes, weight surveys, or both (1). The geometric configuration of the weighing sites and the provisions for traffic control range from simple installation of in-motion weighing equipment in the main lanes of highways with no traffic control to rather elaborate off-road enforcement stations with traffic-control signs, markings, and signals. For a variety of reasons, the concept of the off-road weigh station has generally been found to be most appropriate where enforcement is a primary function.

The geometric design of an off-road weigh-in-motion (WIM) enforcement and/or survey station is highly dependent on site conditions and intended function. Although some standardization of the geometrics of such facilities is appropriate, traffic-control concepts need to be standardized as soon as possible so that safety, efficiency, and economy can be realized in the early years of implementing the WIM concept. Experience with the operation of WIM enforcement stations to date has indicated that traffic control is a problematic feature.

This paper presents a recommended design concept for WIM enforcement sites. The geometric features presented exemplify potential design concepts, but the suggested traffic-control concepts are more rigorously developed on the premise that the truck drivers who pass through the weigh station must be provided with the required information at the right time if they are to respond properly.

CONCEPTS OF IN-MOTION WEIGHING OF VEHICLES

The dynamic behavior of a truck wheel traveling over an irregular pavement surface is a very complex physical phenomenon. Force applied to the road surface at a particular instant by the tires of a moving truck can vary from zero when the tire bounces off the road to as much as twice the static weight. All in-motion weighing techniques use a sample of this continually varying dynamic tire force as an estimate of the static wheel force or weight. Under ideal conditions, there is no vertical acceleration of the truck, and therefore dynamic force exactly equals static force. Such ideal conditions never exist in the real world due to the effects of air flow over the vehicle, irregularities in the pavement surface, and imperfections in vehicle wheels and suspension systems.

Despite the complex problems associated with estimating static vehicle weights from dynamic force measurements, accuracies in the range of 10-12 percent with confidence levels of 80-90 percent are attainable for vehicles moving at high speed. Much greater accuracy is feasible at low speed.

In addition to producing estimates of static wheel weights from dynamic force measurements, WIM systems can provide additional traffic survey information. Inductance loop detectors installed adjacent to the in-motion force-sensing device can produce measures of vehicle speed and vehicle length, and measurements of time between force pulses can give measures of axle spacing. This information can be combined to yield a classification of each vehicle surveyed by the system. Practically attainable levels of accuracy and statistical confidence levels for each of the commonly obtained items of truck-traffic survey data are given in Table 1.

Table 1. Accuracy attainable in truck-traffic surveys by use of WIM systems.

	High-Speed WIM[a]		Low-Speed WIM[b]	
Measured Parameter	Accuracy	Level of Confidence (%)	Accuracy	Level of Confidence (%)
Vehicle speed	±2 km/h	95	±1 km/h	95
Weight of single axle	±10 percent	90	±2 percent	99
Weight of axle group	±10 percent	90	±2 percent	99
Total weight of vehicle	±10 percent	90	±2 percent	99
Spacing between axles	±0.1 m	95	±0.1 m	95
Wheelbase of vehicle	±0.2 m	90	±0.2 m	90

Note: 1 m = 3.3 ft, and 1 km = 0.62 mile.
[a]Speed < 60 km/h.
[b]Speed < 15 km/h.

IN-MOTION WEIGHING FOR ENFORCEMENT PURPOSES

Data on vehicle size and weight are usually collected for two related but somewhat different purposes. Statistical survey data are normally used for highway planning, design, and maintenance, whereas specific data about a particular vehicle are required for the enforcement of vehicle size and weight regulations. In nonenforcement applications, stochastically developed statements about the population of trucks, or selected strata of this population, are desired. Variability in weight measurements may be effectively managed by increasing sample sizes. For enforcement applications, however, variability is a significant problem.

Therefore, if in-motion weighing is used for enforcement purposes, requirements for reduced variability must be met through a combination of high-speed and low-speed weighing. Use of such a two-stage process might consist of installing a WIM system in or near the regularly traveled way in order to sort vehicles into those that are suspected of exceeding weight regulations and those that are obviously legally loaded. That portion of the traffic stream that is suspect may then be forced to decelerate and be weighed again under less variable low-speed conditions.

In such a two-stage weighing arrangement, only those vehicles that approach or exceed legal weight limits would be required to decelerate greatly below desired speeds. Only those vehicles that actually exceed legal limits would be required to stop and await legal action.

Under current state laws, WIM devices are not legally certified for enforcement applications. National Bureau of Standards Handbook 44 (2) states acceptance and maintenance tolerances for axle-load scales as 0.1 and 0.2 percent of applied load. However, 18 states currently have statutory tolerances that range from 2 to 10 percent of legal limits for axle weights. Such tolerances are established to account for the possible inaccuracies of weighing devices (1).

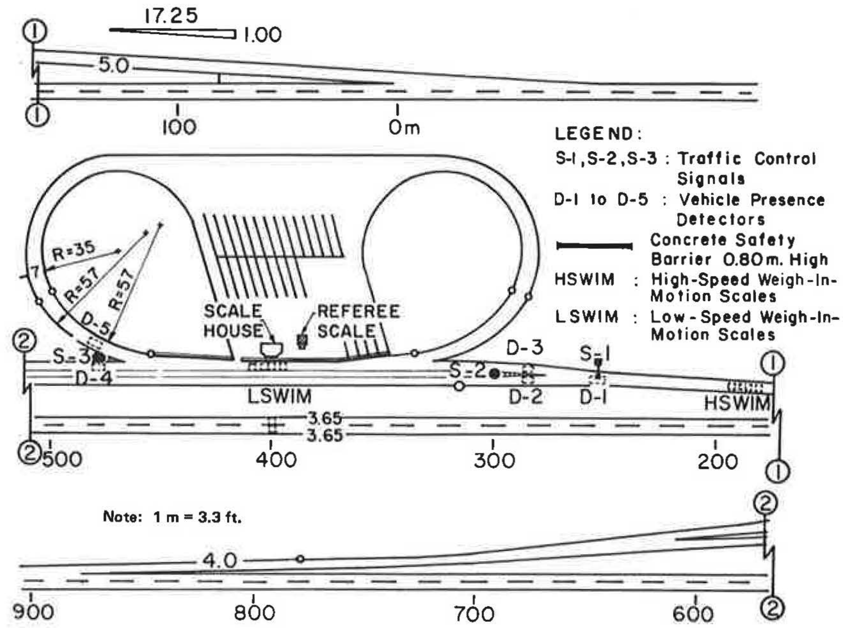
As noted previously, vehicle speed affects the variability (or accuracy) of static weight estimates obtained by using WIM devices. Manufacturers of in-motion equipment, however, indicate that, if vehicle speeds are 16 km/h (10 miles/h) or less, dynamic weights within 1 percent of static weights are easily attained (1).

Legislative action by the states will probably provide certification of in-motion equipment in the near future. Due to the nature of the interaction between vehicle speed and accuracy, certification will probably be provided for low-speed (less than about 16 km/h) weighing. Assuming that this does occur, the stage will be set for use of in-motion equipment in a high-speed-sort, low-speed-weighing mode.

GEOMETRIC DESIGN FEATURES OF WIM STATIONS

Use of WIM devices for vehicle weight enforcement will require geometric and associated traffic-control features that enable efficiency and encourage

Figure 1. Suggested configuration for vehicle-weight-enforcement station.



operational safety. Conceptual geometric features of a permanent WIM enforcement station are shown in Figure 1. This facility provides a deceleration lane in which trucks can decelerate prior to initial weighing at the high-speed weigh-in-motion (HSWIM) scale. Speeds for high-speed weighing should desirably be less than about 60 km/h (37 miles/h) in order to provide the accuracy noted in the high-speed portion of Table 1. All truck traffic will be channeled over the HSWIM system. This system will identify each truck as legally loaded or suspected of being overweight. Marginal or overweight vehicles will be sent to the low-speed weigh-in-motion (LSWIM) system for more precise weight measurement; from there they will be directed either into a parking area for ticketing, unloading, or load redistribution or back to the main highway lanes. The signing and signalization needed to facilitate these maneuvers are discussed below.

Exit and Entrance Ramps

Exit and entrance ramps connecting the weigh station to the highway main lanes should be of conventional design. Since heavy commercial vehicles will be expected to exit at highway speeds, the taper on the ramp should be quite gentle. A taper value of about 17 or 18 to 1 is recommended.

Deceleration and Acceleration Distances

The facility must provide sufficient space for two crucial deceleration maneuvers. The distance from the gore of the exit ramp to the HSWIM system should be not less than approximately 190 m (625 ft), which is generally an adequate distance for vehicles to decelerate from 100 to 60 km/h (60-35 miles/h) with minimal braking. Sufficient distance must also be provided for deceleration from 60 km/h at the HSWIM with minimal braking to a speed of approximately 16 km/h (10 miles/h) at the LSWIM. A minimum of 75 m (250 ft) is recommended for the distance between the HSWIM and LSWIM systems. Minimum distance requirements are computed on the basis of deceleration rates of 1.2 m/s^2 (4 ft/s^2), which can generally be obtained with minimal braking.

A minimum acceleration distance from the location of the LSWIM scale to the gore of the entrance ramp along the highway should be approximately 400 m (1300 ft). This distance is computed by assuming initial and terminal speeds of 15 and 80 km/h (10 and 50 miles/h) and a 0.6-m/s^2 (2-ft/s^2) acceleration rate.

Ingress and Egress to Parking and Reloading Area

The circular ramps leading into and out of the parking area shown in Figure 1 should be provided with a sufficient curve radius to accommodate maximum vehicle speeds of 40 km/h (25 miles/h). The minimum radius of the curves in Figure 1 is approximately 35 m (115 ft); this will accommodate 40-km/h speeds with no superelevation.

The physical size of the parking area is largely a function of the quantity of expected truck traffic. It also depends, however, on the nature of the functions to be performed. If overweight trucks are expected to unload or redistribute loads before being allowed to proceed, delay times will be greater and more space will be required.

Alternative Configurations

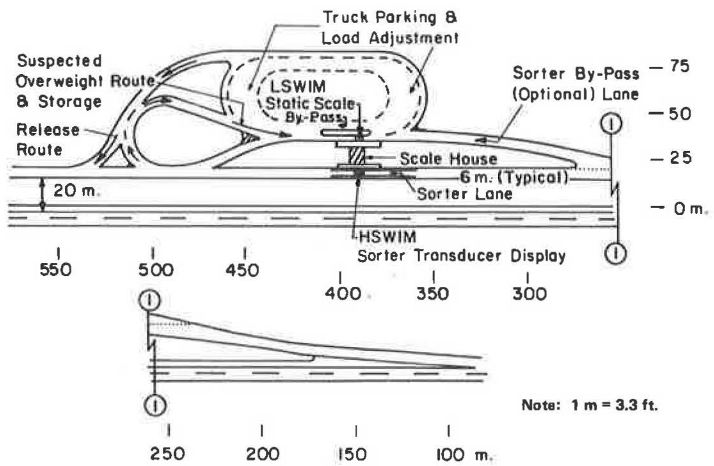
Many alternative configurations for WIM enforcement stations can, and no doubt will, be developed. One problem associated with the scheme presented in Figure 1 is the 200-m (650-ft) distance between the system operator in the scale house and the HSWIM system sensors. The operator cannot easily maintain visual surveillance of the HSWIM sensors. Under some conditions, this can be a serious problem.

Figure 2 shows an alternative configuration scheme that places the HSWIM and LSWIM systems (or a static scale) within easy view of the operator. This scheme also, in effect, forces vehicles to decelerate before they pass over the LSWIM system. Although it does offer these advantages, this configuration might represent a greater capital investment and would likely require somewhat more lost user time.

TRAFFIC CONTROL

At conventional weigh stations, each axle, or axle

Figure 2. Alternative configuration for vehicle-weight-enforcement station.



group, of every truck must be weighed while the truck is stopped on a static scale in order to determine whether or not the axle weight and the gross vehicle weight are within the applicable legal limits. Traffic control within this type of station involves, first, telling the truck driver when and where to stop for weighing and dimensioning and then advising the driver whether to proceed back to the through roadway or to a parking area for violators.

The use of in-motion weighing and dimensioning techniques at enforcement stations requires considerably different traffic controls within the station. As explained earlier in this paper, the accuracy with which static axle weights can be estimated from samples of the varying wheel force of a moving truck is limited by factors that influence the dynamic behavior of the truck, such as speed, road roughness, and the condition of the truck tires. These limitations on accuracy can, however, be recognized, and the technique can provide a safe, efficient, economical means of detecting weight-limit violators without harassing the legally loaded truck operators.

At a WIM enforcement station, appropriate traffic controls must be provided so that weighing can be accomplished in two stages. First, an HSWIM system determines within, say, ±10 percent the weight of each axle and axle group on the truck as it travels at about 60 km/h (35 miles/h). If, after this rough screening, the truck is suspected of violation, a more accurate weight determination must be made. The suspected violator will be directed by a traffic-control signal into a lane where further weight examination can be accomplished. If the truck is obviously legally loaded, the traffic-control signal will guide the truck into a bypass lane where it can accelerate and return to the through roadway without stopping.

The second stage of weighing, which involves only those trucks that approach or exceed the legal limits, must be accomplished within appropriate legal tolerances. Either conventional static weighing or LSWIM techniques can be used at this stage. Since axle weighing and dimensioning with conventional methods normally takes about 1-4 min, depending on the equipment used, the operator's proficiency, the skill and cooperation of the driver, the weather, and other factors, storage space must be provided for a queue of trucks waiting to be weighed. Traffic-control signs or signals are required to advise the drivers when and where to stop. The location of the end of the queue must be considered in designing the traffic-control system as well as the geometric configuration of the static weighing lane.

Even though it is not legally recognized at this time, the LSWIM technique offers significant advantages over static weighing for second-stage weighing, particularly when it is combined with HSWIM sorting, as described above. LSWIM measurements are made with the truck moving at less than about 25 km/h (15 miles/h). At these slow speeds, the dynamic behavior of the vehicle is such that estimates of static axle weight can probably be made reliably within 2 percent when proper equipment and techniques are used. Because the truck brakes are not in use during LSWIM sampling and the load transfer through suspension-system friction is perhaps reduced by the slow forward motion of the truck in comparison with the stopped condition, two of the major sources of static-weighing error are eliminated. Experience has shown that successive static weighings of the same truck axle frequently vary by more than 20 percent even though the scales are certified to 0.2 percent maintenance tolerance. It is probable that an LSWIM system certified to, say, 1 percent tolerance would consistently produce axle-weight estimates that are at least as accurate as weights obtained by a single static axle-load scale used in the usual way. Comprehensive testing is needed to determine the actual accuracy within which a high-quality LSWIM system can operate under field conditions. Legal acceptance of in-motion weighing for enforcement purposes can then be gained for a proven system.

Another advantage of LSWIM relates to traffic-handling capacity. With trucks passing over the sensors at 16 km/h (10 miles/h) on 6-s average headways, 10 trucks/min can be processed. A single axle-load scale can process only about 20 trucks/h and there are long delays for the trucks waiting in the queue. These are, of course, maximum rates, but stochastic arrival times at the scales can produce high demand for short periods of time. LSWIM can handle the peak demands much more effectively than a static axle-load scale.

Traffic flow through an LSWIM system is smooth and uninterrupted. Signs advise drivers of the maximum speed [e.g., 25 km/h (15 miles/h)], and a post-mounted traffic-control signal beyond the LSWIM sensors directs them either back to the through roadway if the truck is legally loaded or into a parking area if it is in violation. A legally loaded truck that is determined to be suspect by HSWIM loses only a few seconds of total time while it is being checked by LSWIM. An illegally loaded truck is detected quickly by LSWIM and directed to

Table 2. Types and locations of traffic-control devices for WIM enforcement station.

Objective	Traffic-Control Device	Location
Direct all trucks from roadway into weigh station via exit ramp	Advance sign (D8-1)[a]: WEIGH STATION 1 MILE	1600 m before exit gore
	Weigh-station sign: ALL TRUCKS COMMERCIAL VEHICLES NEXT RIGHT	1200 m before exit gore
	Exit direction sign: WEIGH STATION NEXT RIGHT (OPEN/CLOSED)	450 m before exit gore
	Gore sign (D8-3)[a]: WEIGH STATION	In exit gore
Effect speed reduction to steady speed of <60 km/h when truck crosses HSWIM sensors, located approximately 190 m beyond exit gore	Speed-limit sign (R2-1)[a], 92x123 cm: SPEED LIMIT 35	Right-hand side of ramp, 20 m beyond exit-gore sign
Advise drivers to maintain 35-m clear spacing between trucks	Special sign, 92x123 cm, white on black: KEEP 100 FEET SPACING	Right-hand side of ramp, 60 m beyond exit-gore sign
Center truck laterally in lane so it passes over HSWIM sensors	Pavement edge lines: yellow on left, white on right, 15 cm wide	Beginning at lane edge 50 m in advance of HSWIM sensors and tapering inward to edge of sensors
After HSWIM sorting, guide legal-weight trucks into bypass lane, where they can accelerate and return to roadway	Traffic signals: upward-pointing green arrows rotated 45° to left	Overhead signal 75 m beyond HSWIM sensors and post-mounted signal in gore 120 m beyond HSWIM sensors
	Special sign, 92x123 cm, white on black: WEIGHT O. K. RESUME SPEED	Left-hand side of bypass lane, 50 m beyond gore
After HSWIM sorting, direct suspected weight violators into LSWIM lane (alternatively, static scales can be located in this lane)	Traffic signals: upward-pointing green arrows rotated 45° to right	Overhead signal 75 m beyond HSWIM sensors and post-mounted signal in gore 120 m beyond HSWIM sensors
Effect speed reduction to steady speed of <25 km/h when suspected weight-limit violator crosses LSWIM sensors, located approximately 130 m beyond gore to bypass lane[b]	Speed-limit sign (R2-1)[a], 61.5x77 cm: SPEED LIMIT 15	Right-hand side of lane, 70 m beyond gore at bypass-LSWIM lane
Center truck laterally in lane so it passes over LSWIM sensors[b]	Pavement edge lines: yellow on left, white on right, 15 cm wide	Beginning at lane edge 50 m in advance of HSWIM sensors and tapering inward to edge of sensors
Advise drivers not to stop on LSWIM sensors[b]	Special sign, 61.5x77 cm: DO NOT STOP ON SCALES	Right-hand side of lane, 10 m in advance of LSWIM sensors
After LSWIM weighing, guide legal-weight trucks back to roadway	Traffic signal: upward-pointing green arrow rotated 45° to left	Post-mounted signal in gore beyond LSWIM sensors
	Special sign, 61.5x77 cm: WEIGHT O.K. RESUME SPEED	Left-hand side of return lane, 100 m beyond gore
After LSWIM weighing, direct weight-limit violators into parking area for load adjustment, unloading, or ticketing	Traffic signal: upward-pointing green arrow rotated 45° to right	Post-mounted signal in gore beyond LSWIM sensors

Note: 1 km = 0.62 mile, 1 cm = 0.39 in, and 1 m = 3.3 ft.
[a]Designations from Manual on Uniform Traffic Control Devices (3).
[b]Objective does not apply if static scales are used. Appropriate signs, signals, and voice commands will be used to position each truck on the scales.

an area where appropriate enforcement measures can be taken.

PRINCIPLES OF TRAFFIC CONTROL IN USE OF WIM

The following discussion is predominantly related to the station configuration shown in Figure 1, which uses both HSWIM and LSWIM systems, but the principles of traffic control that are presented are applicable to the configurations shown in both Figures 1 and 2. Traffic control associated with the HSWIM system is unique and thus of major concern.

In-motion weighing is a new concept for truck drivers. Through prior knowledge and experience, they expect to stop at a weigh station. The traffic-control system at a WIM enforcement station must, therefore, overcome this preconceived notion and cause the driver to travel confidently through the station at appropriate speeds with safe clearances between trucks. The desired objectives for the traffic-control system are given in Table 2 along with suggested traffic-control devices and locations for the devices. The devices conform to provisions in the Manual on Uniform Traffic Control Devices (3) as much as is practicable.

The geometry shown in Figure 1 provides appropriate distances between decision points for the driver and suitable locations for the required devices described in Table 2. It will be instructive to track the progress of a vehicle through the WIM enforcement station and analyze the suggested traffic-control system.

Conventional weigh-station signing directs all trucks onto a standard, tapered exit ramp where a SPEED LIMIT 35 regulatory sign informs the driver of the maximum permitted speed. Sufficient distance beyond the exit gore is provided for the truck to decelerate comfortably and attain a steady speed before reaching the HSWIM sensors ahead. About 2 s later, a special KEEP 100 FEET SPACING sign advises the driver to keep a safe following distance. The limited speed allows the HSWIM system to make better estimates of static axle weights, and the suggested spacing allows the driver adequate signal-viewing time before reaching the bypass-LSWIM gore ahead. The HSWIM system measures speed and acceleration as well as axle weights. If a truck exceeds the posted speed limit or accelerates or decelerates excessively, the weight estimates may not be as good as desired; therefore, the control system will automatically signal the truck into the LSWIM lane for further examination. The HSWIM system is capable of properly making all measurements of each truck unless the clear spacing between trucks is less than about 10 m (33 ft); however, an unsafe, clear spacing of 1 s at 60 km/h [17 m (56 ft)] will allow the driver only 2.8 s to view the traffic-control signals described below (see Figure 3). This is perhaps adequate time in these extreme circumstances. At the normally recognized safe spacing between vehicles of 2 s at 60 km/h [33 m (100 ft)], the driver of a very long [20-m (65-ft)] truck will have 3.9 s to view the signals and steer to one side or the other of the bypass-LSWIM gore. Shorter vehicles and those going slower than 60 km/h will have more signal-viewing time (Figure 3).

The suggested traffic-signal arrangement that is controlled by the HSWIM system is shown in Figure 4. A three-section signal face, S-1, is mast-arm mounted overhead 75 m (250 ft) beyond the HSWIM

Figure 3. Time-space diagram for signals controlled by HSWIM system.

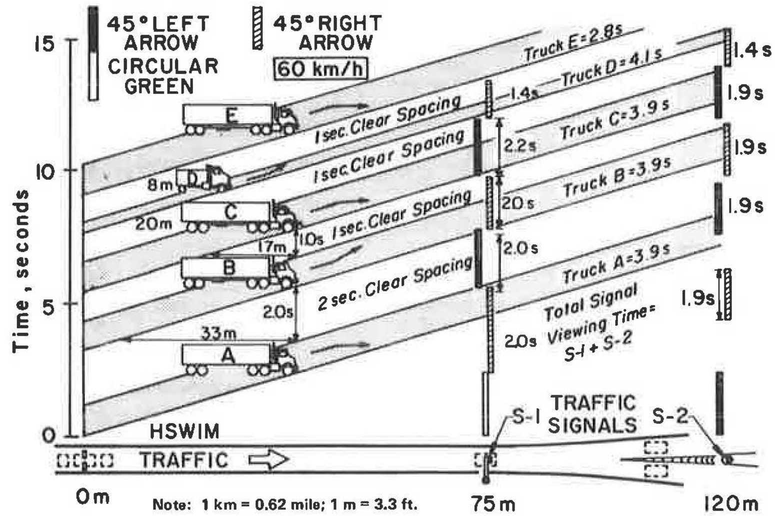
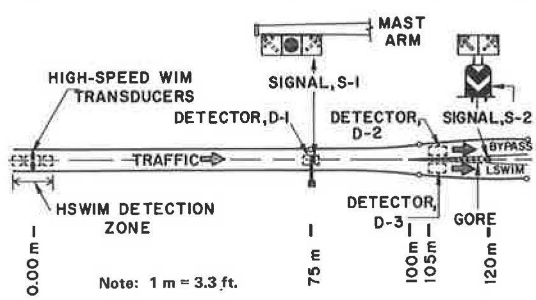


Figure 4. Arrangement of traffic signals controlled by HSWIM system.



sensors. One signal indication is illuminated at all times to attract the attention of the approaching driver to the signal. Circular green is presented at all times when HSWIM is not calling for an arrow indication for a specific truck; this locates the signal in the space ahead and encourages the approaching driver to keep moving. The left-pointing green arrow at S-2, which is a post-mounted (breakaway), two-section signal in the bypass-LSWIM gore 120 m (400 ft) beyond the HSWIM detectors, will be illuminated simultaneously with the circular green at S-1.

Within 1 s after a truck clears the HSWIM detection zone, the system determines whether any limiting speed, acceleration, single-axle weight, axle-group weight, gross vehicle weight, wheelbase, or position of tires on the transducers has been violated and illuminates the appropriate green arrow at S-1. This indication continues until detector D-1 underneath the signal is actuated by the approaching truck. The actuation frees S-1 and transfers the same arrow indication to S-2 in the gore directly ahead for continued viewing by the driver. When the truck actuates either detector D-2 or D-3, the indication at S-2 is terminated. Optically programmed signals are recommended for S-2 so that, after the driver has passed D-2 or D-3, any subsequent arrow indication will not be visible to cause confusion. The HSWIM system determines from detector D-2 or D-3 actuation whether the driver obeyed the arrow signal; if not, an alarm is given in the scale house to alert enforcement personnel. Signals S-1 and S-2 thus safely guide the driver into either the bypass lane or the LSWIM lane as appropriate. Conventional arrow signal indications, with which all drivers are familiar, are used. Provision of adequate signal-viewing time and driver reaction time results in a minimum chance of confusion. The driver simply obeys the traffic-signal indication that appears directly ahead.

The driver of a truck that is not suspected of weight-limit violation is directed into the left-hand or bypass lane and is free to accelerate and return to the through roadway. A special WEIGHT O.K. RESUME SPEED sign located beyond the gore communicates this message to the driver.

The suspected violator in the LSWIM lane is advised of a reduced speed limit by a SPEED LIMIT 15 sign located some 70 m (230 ft) beyond the gore. A sign DO NOT STOP ON SCALES informs the driver that it is not necessary to stop for weighing at this location.

After the LSWIM system has determined whether or not the suspect is, in fact, in violation of the legal weight limits, a gore-mounted signal, S-3, directs the truck to either return to the through roadway or go into a parking area for enforcement action. A special WEIGHT O.K. RESUME SPEED sign is provided for the legally loaded trucks that are released by the LSWIM system. At the lower speeds, one signal face at the gore provides adequate time for driver response.

SUMMARY

In recent years, in-motion truck weighing techniques have been developed to the stage that estimates of static axle weights can be made reliably to within approximately 10 percent for trucks traveling at speeds as high as 60 km/h (37 miles/h) or even higher, and much more accurately at speeds below, say, 20 km/h (12 miles/h). These techniques can now be applied for purposes of weight-limit enforcement in a two-stage weighing process to sort obviously legally loaded vehicles from suspected violators with high-speed weighing and then check the suspects for actual violation by either accurate low-speed weighing or static weighing. Legally loaded vehicles need not be subjected to the safety hazards or costs associated with stopping and waiting for static weighing, and the enforcement agency can practically and economically examine every truck that passes on the highway for possible weight and length violations.

Various geometric configurations for WIM enforcement stations are possible; two arrangements are given in this paper. Since drivers expect to stop at a weigh station, new traffic-control schemes are needed at all WIM enforcement stations to guide each driver through the station at appropriate speeds and appropriate spacings from the vehicle ahead. A combination of signs, pavement markings, and traffic-control signals is recommended for this purpose.

Overall safety, efficiency, convenience, and economy in truck-weight-enforcement operations can be achieved with properly designed WIM equipment, weigh-station layouts, and traffic-control systems. The weigh-station features suggested in this paper are chosen to foster these objectives.

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