Traffic Operations and Driver Performance As Related to Various Conditions of Nighttime Visibility

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During the summer months of 1959 the Traffic and Planning Division of the Minnesota Highway Department and a manufacturer of highway sign materials conducted a joint field study of an experimental reflectorized color guidance system installed in the cloverleaf interchange at the intersection of US 61 and Minn 36. This is a report of the experimental results of traffic surveys and driver interviews made for the study. A description of the reflectorized system is included.

• A STUDY PROGRAM designed to evaluate the use of reflectorized materials for information and guidance through a major highway interchange was undertaken over a seven-week period during the summer of 1959 at the intersection of US 61 and Minn 36. The reflectorized treatment, described fully by Fitzpatrick (1), consisted of the use of colored, reflectorized material combined to distinguish clearly the significant features of an interchange. Signs, pavement markings and delineators were used for the system.

Yellow, consistent with its note of caution, was used to indicate on-ramp and acceleration lanes. The pavement of the acceleration lanes is treated with yellow reflective material paralleled by yellow delineators along the entering ramp and acceleration lane. Yellow delineators also parallel the right-hand edge of the through highway preceding merging zones.

Devices and markings indicative of the exit areas, including deceleration lanes, used blue as the identifying color. The traveled roadway surface of deceleration lanes and exit ramps are treated with blue reflective material and paralleled by blue delineators. Guide signs, appropriate to the particular exit, also use blue reflective material.

An existing pavement lighting installation permitted the study of various combinations of day and night visibility conditions. Five nighttime visibility conditions and two daytime visibility conditions were evaluated for this study. The conditions and dates of the tests are given in Table 1.

Because of the desire to keep the total test period to a minimum, the time between changes in the different conditions was limited to 3- or 4-day weekends. This requirement was in direct conflict with the desire to give drivers more time to adjust to the changing conditions. The only publicity informed the public that the lights at the interchange were to be turned off for a period of five to six weeks so that the Highway Department might conduct a series of tests on new devices for nighttime traffic operations.

Study Site

The intersection of US 61 and Minn 36 is a four-leg, cloverleaf interchange (Fig. 1) immediately north of St. Paul, Minn. Observations were made on the off-ramp from US 61 northbound to Minn 36 eastbound and the on-ramp from Minn 36 eastbound to US 61 northbound. US 61 at the study site has a four-lane portland cement concrete pavement with a median divider. Speed limits on US 61 were 60 mph during the daytime and 50 mph at nighttime. No speed limits were posted for ramp traffic, but

TABLE 1

Condition	Date	Description
I. Night lights on	June 8-12	Intersection operated as before test period. Lighting consisted of mercury vapor luminaires at approximately 200 ft spacing and designed to provide an average illumination on the pavement of 0.6 to 0.8 footcandles. Only interchange was lighted, US 61 and Minn 36 were unlighted.
II. Lights off	June 16-18	No special treatment added and lighting turned off. Existing signs remained unchanged.
III. Interstate delineation—lights off	June 22-26	Lights remained off; delineators placed according to (2). (Standards modified to correct for radii of curves at interchange.)
IV. Full reflective treatment—lights off	July 13-16	Lights remained off, blue and amber delineators and blue and yellow reflective pavement paint added. Blue delineators and reflective paint represented exit ramps. Blue reflective signs replaced green reflective signs at nose of exit ramps. Yellow reflective pavement paint and amber delineators placed at entrance ramps.
V. Full reflective treatment—lights on	July 20-22	Same as Condition IV except lights turned on as in Condition I.
VI. Daytime before treatment	July 12-18	No changes made in signs, delineators, or pavement markings. Same as Conditions I and II except lights not required.
VII. Daytime after treatment	July 9-14	Signs, delineators, and reflective pavement markings arranged as in Conditions IV and V.

yield-right-of-way signs were posted at points where ramp traffic entered through lanes.

Speed change lanes for the off-ramp and the on-ramp are of limited design, but a 10-ft bituminous concrete shoulder immediately adjacent to the through lanes on US 61 was available to road users at the two ramps. Both ramps had bituminous concrete pavements, 22 ft wide with 8-ft bituminous concrete shoulders. Geometric details of the two ramps are shown in Figures 2 and 3. In the following discussion the off-ramp is referred to as Ramp A and the on-ramp as Ramp B.

Collection of Traffic Data

Placement to the nearest 1 ft and travel time to the nearest 0.05 sec were measured at eight segmented metal strips located as shown in Figures 2 and 3. For Ramp A, tapes 1 and 2 detected both through traffic and ramp traffic, whereas the remaining tapes detected ramp traffic only. For Ramp B, tapes 1 through 6 detected ramp traffic only. Tape 7 detected both ramp and through traffic and tape 8 detected through traffic only.

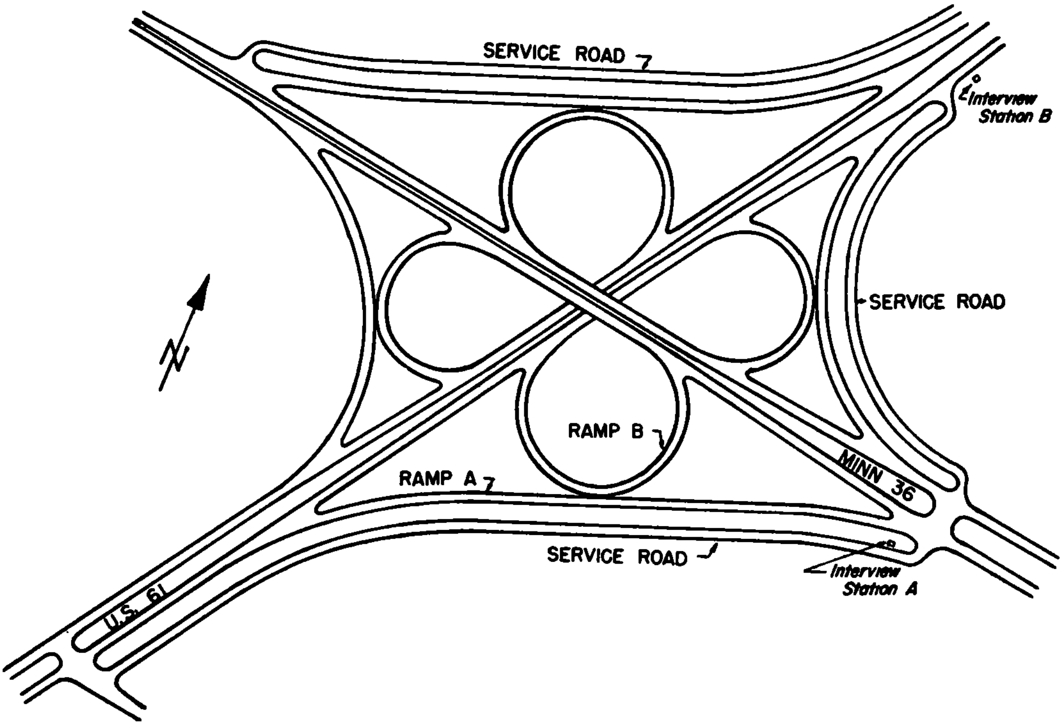

Figure 1. Test site—US 61 and Minn 36.

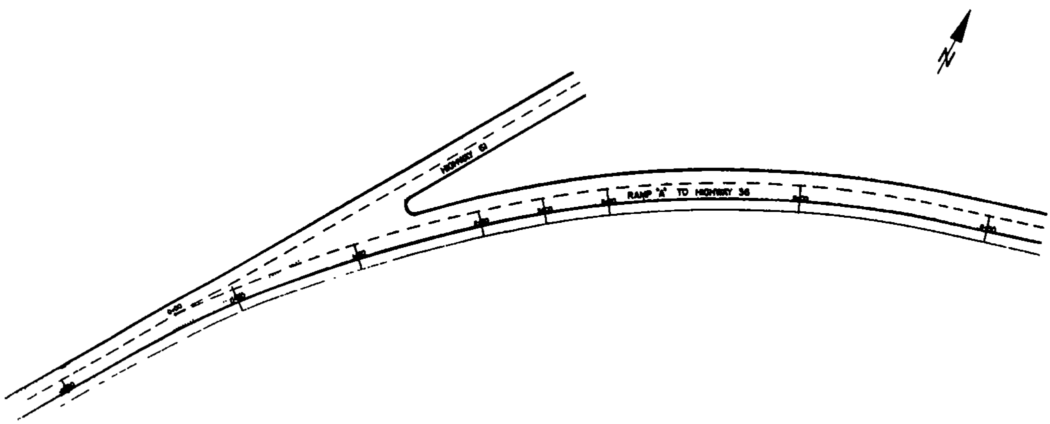

Figure 2. Ramp A.

All night studies were conducted between the hours of 9:30 PM and 12:00 midnight, daytime studies between 3:00 PM and 5:00 PM. All measurements were made on dry pavement with no abnormal weather conditions.

Results of speed and placement observations, at each tape and for each of the test conditions, are given in Table 2 for Ramp A and in Table 3 for Ramp B.

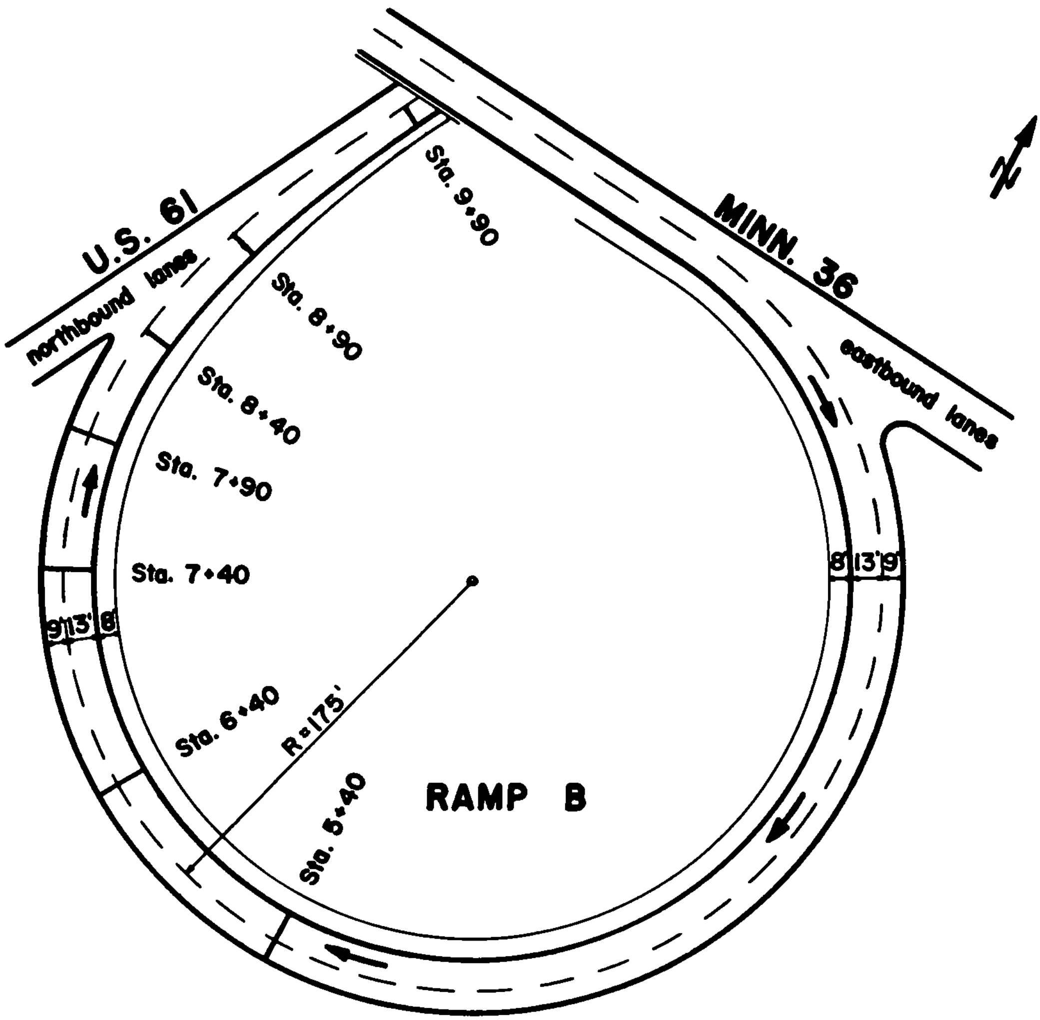

Figure 3. Ramp B.

ANALYSIS OF RESULTS

Ramp A

Velocities of Through Vehicles.—Velocities of through vehicles in the speed trap (1-2) are shown in Figure 4. Mean daytime velocities during the midafternoon hours (48.33 mph) are significantly higher than nighttime velocities (43.38 mph). The difference in speed limit at this site (60 mph daytime, 50 mph nighttime) tends to confuse the effect of visibility on the observed velocities.

The nighttime velocity for through vehicles during Condition I is significantly greater than all other nighttime through velocities. With the exception of Condition I, the type of treatment on the ramp does not appear to have a great effect on the nighttime velocity of through vehicles as they enter the interchange area.

Velocities of Through Vehicles vs Velocity of Ramp Vehicles.—A comparison of velocities of through vehicles against the velocity of ramp vehicles at the same speed trap (tapes 1-2) and of ramp vehicles at the next speed trap (tapes 2-3) is also shown in Figure 4. Vehicles in speed trap 2-3 are partially in the through lane and the dif-

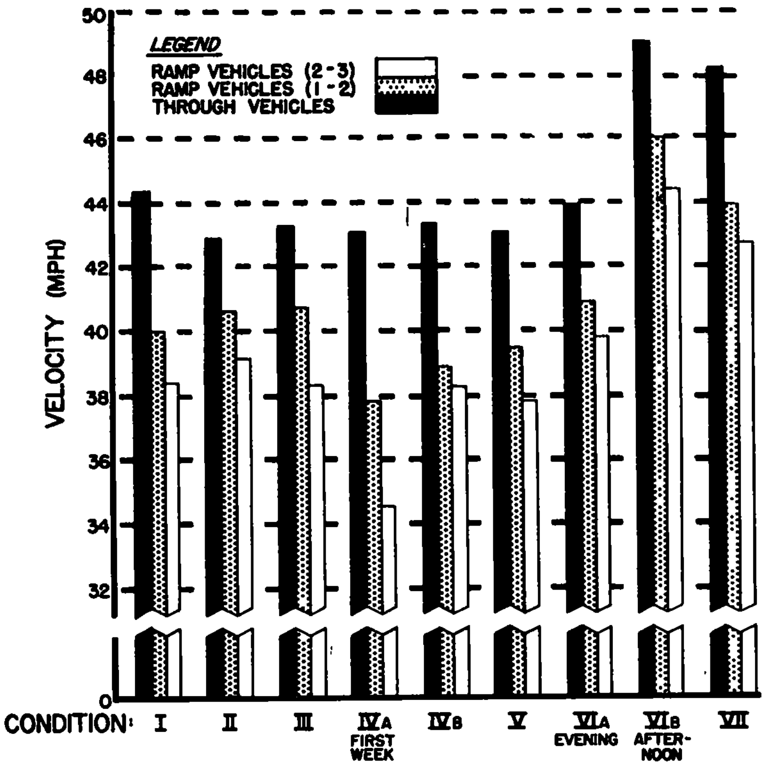

Figure 4. Ramp A velocities.

TABLE 2

SUMMARY OF DATA, RAMP A

Trap	Property	Condition I	Condition II	Condition III	IV 1st Week	IV 2nd Week	V	VI Even-ing	VI After-noon	VII
Through veh (1-2)	Mean velocity (mph)	44 32	42 87	43 30	43 07	43 36	43 05	43 93	49 03	48 18
	Variance (mph)	39 86	42 08	44 18	43 26	44 64	43 48	71 76	55 02	57 80
	Sample size (veh)	433	347	238	111	545	610	240	412	1246
Ramp veh (1-2)	Mean velocity (mph)	39 51	40 62	40 69	37 88	38 90	39 49	40 88	45 91	43 95
	Variance (mph)	39 86	26 86	48 83	48 72	46 78	40 61	54 91	47 49	44 29
	Sample size (veh)	140	127	143	64	157	150	50	173	261
(2-3)	Mean velocity (mph)	38 39	39 17	38 36	34 58	38 33	37 88	39 81	44 41	42 73
	Variance (mph)	40 40	32 99	32 68	39 03	40 54	34 35	38 00	42 63	55 46
	Sample size (veh)	159	131	150	87	158	148	49	175	262
(3-4)	Mean velocity (mph)	39 39	39 49	39 09	37 38	38 39	39 03	40 71	44 56	42 85
	Variance (mph)	34 40	28 38	35 62	40 15	41 56	33 87	27 08	42 44	46 34
	Sample size (veh)	160	131	149	83	157	147	49	177	258
(5-6)	Mean velocity (mph)	40 14	40 67	39 46	37 51	38 52	38 17	41 40	44 63	42 03
	Variance (mph)	46 49	44 06	41 52	62.27	41 01	35 28	44 77	56 15	59 19
	Sample size (veh)	161	134	150	84	152	146	49	176	252
(6-7)	Mean velocity (mph)	39 14	39 80	38 93	36 99	38 80	39 46	40 11	43 30	42 85
	Variance (mph)	34.22	29 01	33 64	43 99	42 89	40 43	28 77	35 25	38 44
	Sample size (veh)	161	132	150	85	151	146	49	175	252
(7-8)	Mean velocity (mph)	39 54	39 86	39 09	35 86	38 09	37 93	40 50	43 73	41 86
	Variance (mph)	32 73	31 92	37 73	42 30	41 85	34 91	34 84	40 11	39 29
	Sample size (veh)	159	129	152	88	153	145	49	173	255
Median placement (ft)										
Tape 1		4.5	4 5	4 5	5 0	4 0	4 5	--	3 5	4 0
Tape 2		2 0	2 0	1 5	2 5	0 0	0 0	--	0 5	-1 0
Tape 3		2 5	3 0	2 0	2 5	2 0	2 0	--	1 0	0 0
Tape 4		2 0	2 5	1 0	2 0	1 5	0 5	--	1 5	-1 0
Tape 5		0 0	1 5	1 0	1 0	1 5	0 5	--	0 0	-1 0
Tape 6		0 0	2 0	1 0	1 5	2 0	1 5	--	1 5	0 5
Tape 7		2 0	4 0	3 0	3 0	2 5	2 0	--	3 5	1 5
Tape 8		2 5	4 5	3 5	4 0	3 0	2 5	--	4.0	2 5

TABLE 3

SUMMARY OF DATA, RAMP B

Trap	Property	Condition I	II	III	IV	V	VI	VII
Through veh	Mean velocity (mph)	41.54	43.27	43.65	42.32	42.13	45.19	46.22
	Variance (mph)	34.72	40.65	40.54	46.18	34.21	43.29	51.97
	Sample size (veh)	305	293	572	538	284	754	514
Ramp veh (1-2)	Mean velocity (mph)	22.96	23.76	23.88	22.99	22.39	22.43	23.49
	Variance (mph)	9.16	8.41	20.68	9.14	11.54	11.93	17.61
	Sample size (veh)	192	167	332	383	241	556	383
(2-3)	Mean velocity (mph)	21.94	23.21	22.73	22.39	21.07	20.94	22.35
	Variance (mph)	10.61	16.87	12.50	11.15	14.71	14.02	20.51
	Sample size (veh)	192	156	329	381	241	557	384
(3-4)	Mean velocity (mph)	20.31	20.04	21.22	20.91	19.29	18.22	19.86
	Variance (mph)	28.32	23.49	22.51	23.41	25.86	31.60	23.86
	Sample size (veh)	192	159	331	390	243	564	378
(4-5)	Mean velocity (mph)	21.21	19.14	20.45	18.44	17.10	16.32	18.17
	Variance (mph)	71.70	61.94	51.69	52.23	60.53	57.73	38.80
	Sample size (veh)	182	152	307	357	230	535	359
(5-6)	Mean velocity (mph)	20.86	19.84	21.75	20.82	19.30	18.96	20.19
	Variance (mph)	33.32	59.04	49.08	54.52	45.14	48.75	45.16
	Sample size (veh)	170	132	281	349	228	528	357
(6-7)	Mean velocity (mph)	24.41	25.41	25.91	26.69	24.75	24.14	25.87
	Variance (mph)	18.92	25.57	34.35	39.40	27.23	28.64	27.66
	Sample size (veh)	169	128	298	354	223	517	352
Median placement (ft):								
Tape 1		2.0	2.5	3.0	0.5	0.5	1.0	-0.5
Tape 2		2.5	3.5	3.0	1.5	0.5	2.5	0.5
Tape 3		3.0	3.5	4.0	1.5	0.5	3.0	1.0
Tape 4		3.0	5.0	4.5	1.5	1.5	3.5	1.0
Tape 5		3.0	4.0	4.0	1.5	1.0	2.5	1.0
Tape 6		4.5	4.5	5.5	3.0	2.5	4.0	2.5

TABLE 4

VELOCITY DIFFERENCES FOR THROUGH VS RAMP VEHICLES

Through vs Ramp Vehicle Trap	Velocity Difference (mph) for Conditions: I	II	III	IV 1st Week	IV 2nd Week	V	VI Evening	VI Afternoon	VII
(2-3)	5.93	3.70	4.94	8.49	5.03	5.17	4.62	4.12	5.45
(1-2)	4.40	2.25	2.61	5.19	4.46	3.56	3.05	3.12	4.23

ference in average speed between through vehicles and ramp vehicles at this point ranges from 8.49 to 3.70 mph. A summary of differences is given in Table 4.

During daylight hours, when visibility is presumably ideal, the speed differential between through vehicles and ramp vehicles ranges from 4.12 to 5.45 mph. These speed differentials, day and night, indicate that the geometry of the exit ramp permits ramp vehicles to operate at a speed that minimizes interference with through vehicles.

The difference in velocities between through vehicles and ramp vehicles at the first speed trap on US 61 may give some measure of the advance warning given ramp vehicles by the intersection treatment. The differences are also given in Table 4. Daytime differences before treatment (Condition IV) are consistent at about 3 mph. Drivers are aware of the ramp and make only slight adjustments for the change in speed.

At night, with a minimum of lighting or guides (Conditions II and III) existing traffic did not slow down in anticipation of the ramp. It is not possible to say whether this reflects greater confidence on the part of the driver or less advance knowledge of the point of exit. But inasmuch as these differences are even less than those found under the best conditions of visibility (Conditions VI and VII), the evidence indicates that with no lights, or with Interstate delineation only, drivers are not anticipating the ramp exit.

The maximum speed difference occurs during the first week of full treatment (Condition IV). Drivers approaching the ramp are well aware of the all-blue surface treatment. This effect is also present in the daytime as evidenced by the speed difference of 4.23 mph after full treatment as compared to a difference of 3.12 mph before treatment.

With one week of familiarization the speed difference for night, full treated (Condition IV), changed from 5.19 to 4.46 mph, indicating that drivers were going through a learning process. Further familiarization plus the lights (Condition V) resulted in a further decrease in speed differences.

Although the velocity differences between through and ramp vehicles at the first speed trap do not give clear-cut patterns, it appears that two conclusions may be made:

1. Minimum night visibility guides (Conditions II and III) give less advance knowledge of the precise location of the ramp exit, as evidenced by a minimum velocity difference between ramp and through vehicles.
2. Drivers require a learning period and change their method of operation as time goes on after the introduction of a new and different night guidance system.

Velocity Profiles of Ramp Vehicles.—When velocities at each of the speed traps are shown in Figure 5, daytime velocities are greater than nighttime velocities at all points. All conditions show a pattern of deceleration in passing from trap (1-2) to trap (2-3).

The influence of the treatment on mean velocities is again evident. The lowest observed mean velocities at all stations occurred during the first week of full reflective treatment (Condition IV). Maximum nighttime velocities at all stations occurred with the lights off. During the second week of full treatment, drivers had made adjustments and tended to drive at velocities that approached those under the other conditions. The decrease in velocity with reflective treatment is also evident in the daytime studies.

Before paint was applied, drivers tended to maintain or slightly increase their velocity between the final two speed traps. In all instances, after reflective treatment had been applied, vehicles decelerated when leaving the painted section. Speed trap (6-7) was at the end of the treated section, speed trap (7-8) was beyond the treated section. Drivers faced with an abrupt change in surface treatment reacted by slowing down. (The delineation was continuous over the length of the ramp.)

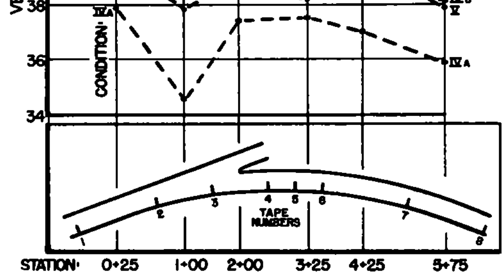

Figure 5. Ramp A velocity profile.

Analysis of Variance of Velocity Data. —An analysis of variance was made to evaluate the differences in velocity and to furnish more information on the reasons for these differences.

Separate analyses were made for the day and night studies. The first week of full treatment (Condition IV) was not included in the analysis inasmuch as it was apparent by inspection that the observed velocities were of different character than the remaining velocities. The daylight evening velocities were not analyzed with the midafternoon velocities for the same reason.

The design for the nighttime analysis of variance is given in Table 5.

TABLE 5

DESIGN FOR NIGHTTIME ANALYSIS OF VARIANCE

Hour	Condition									
	I		II		III		IV		V	
	1st Night	2nd Night	1st Night	2nd Night	1st Night	2nd Night	1st Night	2nd Night	1st Night	2nd Night
1st	X	X	X	X	X	X	X	X	X	X
2nd	X	X	X	X	X	X	X	X	X	X

Five different conditions were observed. Each condition was observed on two different weekday nights, generally not on consecutive evenings. Two hours of data were collected for each night. The following questions were asked and tested:

1. Are the speeds significantly different for each of the five treatment conditions?
2. Is there any difference in speeds between the early part of the week and the latter part of the week? (1st day vs 2nd day)
3. Are the speeds in the early night hours (approximately 9:45 to 11:00 PM) significantly different from speeds observed at a later hour of the night? (1st hour vs 2nd hour)
4. Are the speeds for the ten different days significantly different? (days) This item, difference between the ten nights, would presumably be significant if the treatment differences were significant. On the other hand, the night-to-night differences may or may not be different if the treatment differences are not significant.

The analysis of variance test given in Table 5 was applied to the following speed observations:

Through vehicles

Trap 1 - 4 (ramp)
Trap 5 - 8 (ramp)
Trap 1 - 2 (ramp)
Trap 2 - 3 (ramp)
Trap 3 - 4 (ramp)
Trap 5 - 6 (ramp)
Trap 6 - 7 (ramp)
Trap 7 - 8 (ramp)

The same analysis of variance design was used for the daytime speeds, except that no comparison was made between the first and second days. The first day vs second day comparison was not made because the elimination of the daytime-evening observations reduced the before daytime study (Condition V) to only one day of observation.

The results of the analysis of variance are given in Table 6.

TABLE 6

RESULTS OF ANALYSIS OF VARIANCE[a]

Source of Difference	Night: Treatment Conditions	Night: 1st Hr vs 2nd Hr c	Night: Days	Night: 1st Day vs 2nd Day	Day: Treatment Conditions	Day: 1st Hr vs 2nd Hr	Day: Days
Through vehicles	0.025[b]	0.001[c]	0.001[c]	0.05[b]	0.040[b]	0.500	0.150
Trap 1-4	0.200	0.150	0.50[b]	0.02[b]	0.003[b]	0.800	0.001[c]
Trap 5-8	0.450	0.180	0.020[b]	0.15	0.020[b]	0.800	0.040[b]
Trap 1-2	0.080	0.120	0.030[b]	0.02[b]	0.003[b]	0.900	0.002[c]
Trap 2-3	0.500	0.650	0.200	0.20	0.20[b]	0.800	0.002[c]
Trap 3-4	0.500[c]	0.250	0.080	0.07	0.010[c]	0.400	0.004[c]
Trap 5-6	0.004[c]	0.600	0.003[c]	0.08	0.001[c]	0.600	0.003[c]
Trap 6-7	0.600	0.800	0.090	0.02[b]	0.450	0.800	0.080
Trap 7-8	0.020[b]	0.100	0.022[c]	0.15	0.004[b]	0.600	0.004[c]

[a]Numerical entries give probability of getting velocity differences under any condition by chance alone.
[b]Velocity differences that might occur by chance alone less than 1 time in 20.
[c]Velocity differences that might occur by chance alone less than 1 time in 100.

During the daytime studies there was no real difference between the first and second hour observations. The difference between treatments and days are significant at nearly all points.

The nighttime velocity analysis is less consistent. There appears to be no justification for assuming that velocities during the two study hours at night were not the same on any given night (except for through vehicles). There is no logical explanation for this significant difference by hours for the through vehicles when a like difference does not occur for ramp vehicles.

The analysis of variance indicates that the different treatments have a significant effect on speeds only for through vehicles, and ramp vehicles between tapes 5 - 6 and 7 - 8. The significance of the speed differences between 7 - 8 is explained by the driver reaction to the end of the color pavement. There is no logical explanation to the speed difference between 5 and 6. The significant difference in speed between through vehicles for the treatment conditions is brought about by the higher speeds of the vehicles during Condition I. This may be a function of the chronology of the experiment as well as the visibility conditions, inasmuch as during Condition I drivers were unaware of a testing program, though in subsequent tests drivers were aware of some program.

Although the analysis of variance does not indicate a statistically significant difference in treatments, there are several factors that influence the test for analysis of variance. Figure 5 shows that velocities for Condition II (no lights) are consistently higher at all stations during nighttime observations. Although the analysis of variance test did not establish a statistically significant difference, it is most improbable that the speeds during the Condition II study (lights off) could exceed speeds during all other conditions at all six speed traps simply by chance. (The actual probability is $1/5^6$ = 1/15, 625.)

The extreme variation in observed speeds between drivers also influences the results of the analysis of variance. The observed standard deviation at night is about 6. 5 mph, which means that the range of speed between the 15 percentile and 85 percentile is approximately 13. 0 mph. This rather large difference between drivers tends to obscure any real difference between the other factors being tested; i. e., days, first hour vs 2nd hour, treatments, etc. If differences do exist, this difficulty of extreme variation can be overcome by increasing the sample size. The necessity of limiting the over-all study period and the relatively low volumes at night made it extremely difficult to obtain a larger sample than observed in this study. The higher daytime volumes permitted larger sample sizes to be taken without increasing the sampling rate or time.

The speed differences between the first day and second day of the test were not anticipated. However, at three of the nighttime speed traps there is an indication that such a difference may exist. The first day-second day difference has little influence on the results of the test for differences between treatments but does give some indication that in an experiment of this type the time of the week should be a control factor.

In almost all speed traps, the night-to-night speed differences are significant. These speed differences are a function of two principal causes: (a) any differences caused by the type of treatment on drivers' speeds at night, and (b) differences in the way drivers behave from day to day. Drivers do not react in the same way on different days even when all apparent differences in the highway, weather, etc., have been eliminated. It appears that this variation is even greater than the effect of the treatment used on the highway and does mask some of the observed differences.

Vehicle Placement. —Figure 6 shows the median placement of the right rear wheel of vehicles relative to the right-hand edge of the pavement, shown to the nearest ½ ft. Placement stations 1 and 2 are located on the through pavement, the right-hand edge being the edge of the concrete. Positions 3 through 8 are on the off-ramp with the edge of the traveled portion being separated from the paved shoulder by a white reflectorized shoulder stripe. The nighttime situation with lights is taken as the standard of comparison.

Vehicle placements for daytime before-and-after reflectorized treatment and for nighttime with the lights on (Condition I) are shown in the upper section of Figure 6.

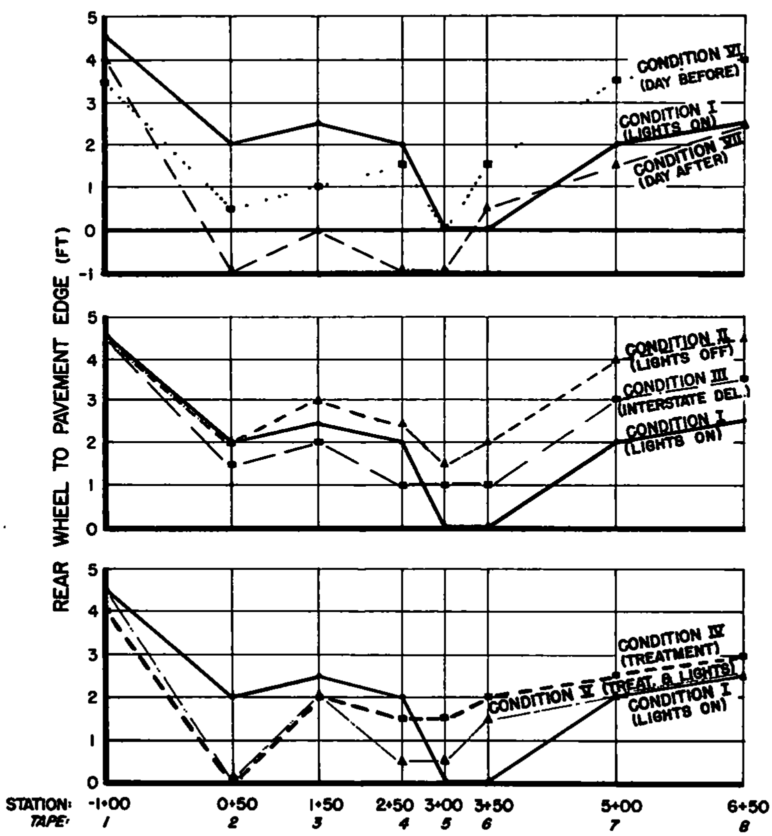

Figure 6. Ramp A vehicle placement.

The most notable difference between the three conditions occurs at stations 2, 3 and 4, when the effect of the treatment in daylight is to cause the vehicles to use the shoulder as a transition lane to the ramp. (The geometry of Ramp A is such that the most gradual approach to the ramp is one that approaches the shoulder of the pavement at stations 2 and 3.) At night with lights, vehicles remained 2 ft away from the shoulder, following a more abrupt path to the ramp; in daytime before treatment, the path is midway between the other paths shown.

At nighttime with minimum guides (Conditions II and III), vehicles used nearly the same path as with the lights on as shown in the second section of Figure 6. Drivers took a median position at least 1 ft away from the shoulder at all stations.

Finally the effect of the addition of the reflectorized treatment both with and without lights is shown in the lower section of Figure 6. In moving from the through lane to the ramp at station 2, the vehicles again use more of the shoulder as a transition lane, as was the case for daytime with pavement treatment. Beyond the nose of the ramp the paths cross and are then parallel to the vehicular paths observed with lights only.

In all instances in which reflectorized treatment was used (Conditions IV, V, and VII), vehicles tended to use more of the shoulder lane parallel to US 61 in decelerating and approaching the off-ramp. This is consistent with the observations for speed, in which instances, reflectorized treatment conditions apparently caused ramp drivers to approach with a lesser velocity than for other conditions. During the daytime with reflectorized treatment, when drivers were aware of the material on the edge of the shoulder, they did use portions of the shoulder in preference to driving on the brightly colored pavement. In no other instance was the median placement position beyond the edge of the pavement.

Ramp B

Velocity Analysis.—The purpose and geometry of Ramp B precludes a complete analysis of velocities as made for Ramp A. The absence of an acceleration lane, the

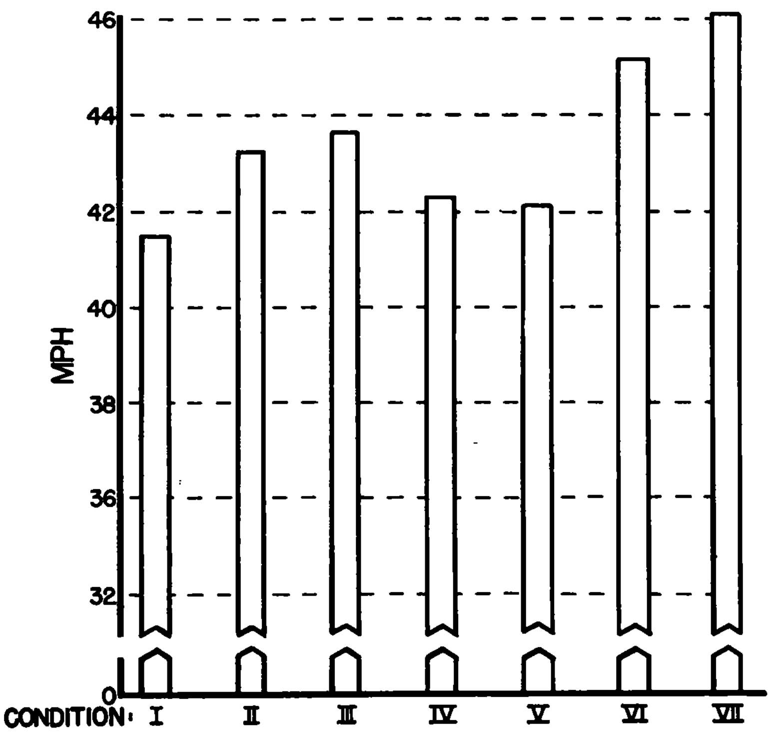

Figure 7. Ramp B over-all velocity.

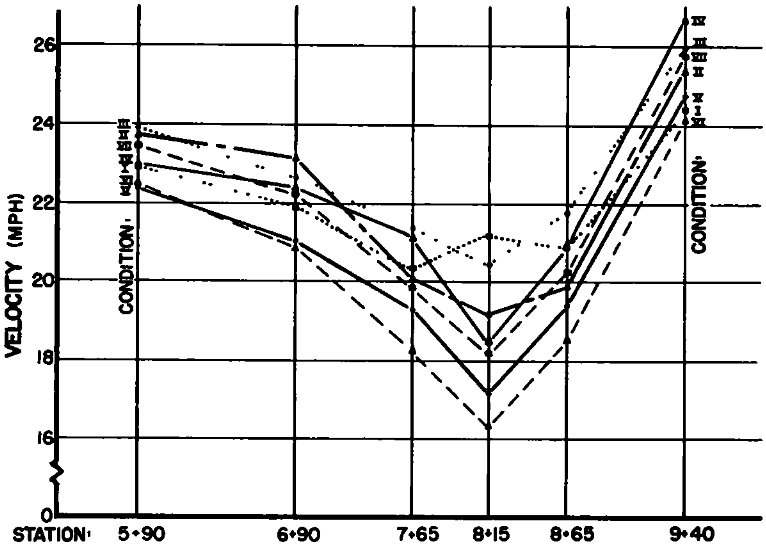

Figure 8. Ramp B velocity profile.

presence or absence of vehicles on US 61, a greater volume on Ramp B, and the restrictive geometry of the ramp limited the free choice of speed by the majority of vehicle drivers, so that visibility conditions are considered to have a lesser effect than that in the analysis of Ramp A. The following data are presented to give an indication of the type and nature of operation at Ramp B.

Velocities of Through Vehicles. —Velocities of through vehicles on US 61 in the lane immediately adjacent to Ramp B are shown in Figure 7. The average of all nighttime velocities was 42.70 mph and for daytime the average was 45.61 mph; in both instances less than the equivalent measurement made before the entrance to Ramp A. Through vehicles at this point were influenced by the presence of ramp vehicles and by deceleration of some through vehicles preparing to turn at the next exit ramp immediately beyond the end of the speed trap.

Maximum nighttime velocities occurred during the condition of poor visibility (i.e., no light) and with Interstate delineation only. During the daytime the maximum through speed occurred after treatment.

Velocity Profiles of Ramp Vehicles. —Velocity profiles for Ramp B are shown in Figure 8. Daytime velocities are no greater than those observed at nighttime, again reflecting the influence of the volume on velocity patterns at this ramp.

Vehicles enter the test area at a speed of about 23 mph and decelerate to about 18.5 mph at a point 100 ft before entering the through lane. From this point onward, the average vehicles accelerate quickly, entering the through lane at a grand average velocity of 25.5 mph; about 15 to 20 mph slower than the through vehicles in the same lane.

Vehicle Placements. —Median vehicle placements for Ramp B are shown in Figure 9. Placements again refer to the right rear wheel and are referenced to the paved shoulder edge which is differentiated from the true pavement edge on the ramp by means of a reflectorized shoulder edge marking. Station 7 is on the highway and the vehicle positions at this point are influenced by traffic on US 61. Station 8 is beyond the point at which ramp vehicles would cross it and is applicable to through vehicles only. The discussion applies only to placement stations 1 through 6 which are on the circular portion of the ramp.

The condition for daytime before, daytime after, and lights on is shown in the upper section of Figure 9. For lights on and daytime before treatment, the paths are very nearly parallel. After the painted treatment in the daylight, when the paved shoulder is visible to the driver, the driver path is shifted 2 ft towards the inside the circle, the average driver using only the first 7 ft of a 22-ft wide pavement.

Vehicle placements for Conditions I, II, and III are compared in the middle section of Figure 9. The effect of turning the lights off is to cause the drivers to move from ½ to 1 ft or more further on to the pavement and stay away from the shoulder to a greater degree than with the light on. There is little difference between the light-off condition and the addition of Interstate delineator.

The effect of reflectorized treatment during Conditions IV and V is shown in the lower portion of Figure 9. Again, the effect of treatment only (Condition IV) and treatment plus light (Condition V) is to move the vehicles closer to the shoulder, much as existed for the daytime, after reflectorized treatment.

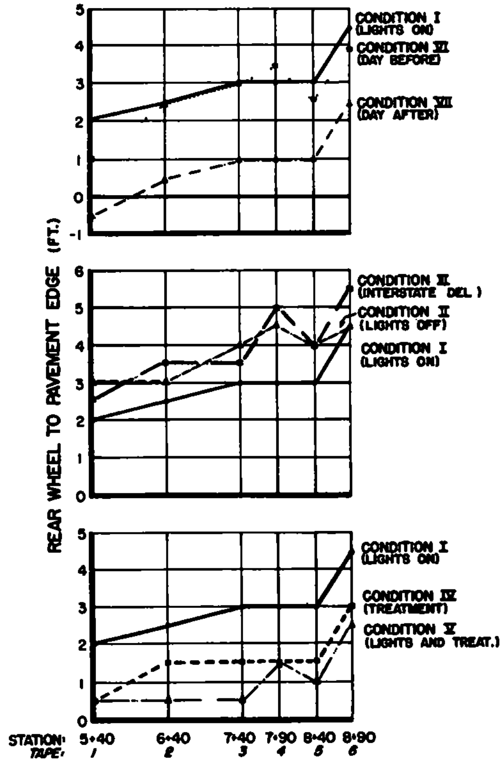

Figure 9. Ramp B vehicle placement.

SUMMARY

The summary of results is as follows:

1. Except for lights on, the type of treatment used at the intersection had relatively little effect on nighttime velocities of through vehicles as they approached the interchange at a point 300 ft before the nose of the first exit ramp. Absolute volume levels of through and merging vehicles influenced the velocities between Ramps A and B. Daytime through velocities were less after treatment than before.
2. Greatest differences in nighttime velocities between through vehicles and off-ramp vehicles before their exit (taken as indicative of early recognition of the exit situation) occurred with lights only, reflective treatment only, and reflective treatment plus lights. Minimum speed differences at the off-ramp occurred with lights off and Interstate delineation treatment.
3. Daytime velocity differences between through vehicles and off-ramp vehicles were greater than at nighttime with no lights and with Interstate delineation only.
4. Minimum off-ramp velocities occurred during the first week of reflective treatment. Maximum nighttime off-ramp velocities occurred with minimum treatment—no lights. Daytime off-ramp velocities were consistently greater than nighttime velocities; daytime before reflective treatment greater than after reflective treatment. Off-ramp velocities tended to increase with time as drivers adjusted to the reflectorized treatment.
5. Off-ramp vehicles tended to decelerate when passing from reflectorized pavement to nonreflectorized pavement. This pattern occurred during daylight, with reflective treatment at night, and with reflective treatment plus lights. The deceleration took place even though the blue and yellow reflectorized delineators were extended over the length of the ramp.
6. Velocities at Ramp B are influenced by volumes of ramp traffic and through traffic, the higher velocities on the ramp occurring at night with low volume. Daytime Ramp B velocities are lower, largely because of the influence of the greater volume rates during the day.
7. In all conditions of reflectorized treatment, daytime, nighttime treatment only, and treatment plus lights, drivers used more of the shoulder lane parallel to US 61 in

decelerating and entering the off-ramp. Minimum use of the shoulder for transition to the off-ramp occurred with lights on, lights off, and Interstate delineation. During daytime after treatment, drivers tended to use the shoulder of the ramp proper for a greater distance than any other treatment condition.

8. At Ramp B, vehicle placements for lights on and daylight are nearly identical. With poorer levels of visibility, lights off and Interstate delineation, drivers move closer to the center of the ramp away from the shoulder. With treatment, day, night, and treatment plus lights, drivers tend to move away from the center of the ramp, using the extreme right-hand edge of the pavement.

CONCLUSIONS

The conclusions drawn from the analysis of the data are based on studies made with minimum periods for driver familiarization between phases of the study. Although further time for adjustment by the drivers to the different treatments may have influenced the results, the basic measurements are taken to be typical of the influence of the different treatments on driver patterns.

The most evident influence of the integrated reflectorized treatment occurred at the exit ramp. Both velocity differences and use of the paved shoulder as a transition to the off-ramp indicated that the system gave drivers knowledge of the exit location which was equal to that in daytime or with the lights on. The combined use of lights and reflective treatment did not show a substantial change in the use of the exit ramp when compared with lights only or reflective treatment only.

There is evidence that full width painting of the on-ramp in particular caused drivers to encroach on the shoulder. Whether drivers would follow this pattern with less substantial shoulders than are present at this site is not evident from the data. Also, the abrupt ending of the blue pavement at the off-ramp caused drivers to slow down when leaving the blue pavement. More gradual transitions for the start of the yellow on-ramp paint and the end of the blue off-ramp paint will probably diminish these last two effects. It is also possible that broad stripes of reflectorized pavement will accomplish the same results as obtained with full width reflectorized pavement.

Finally, further test installations at different interchanges will be required to substantiate the findings of this particular study and its applicability to other conditions of design and traffic. Even more important is the need for improved measures of driver performance and evaluation of highway improvements. This study has compared stream flow characteristics, day and night, for different treatment conditions one against the other. No absolute figure of merit is available. There is a real need to develop better measures than those used here, many of which only indirectly get at the needed answers.

REFERENCES

1. Fitzpatrick, J. T., "Unified Reflective Sign, Pavement and Delineation Treatment for Night Traffic Guidance." HRB Bull. 255, 138-145 (1960).
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