or small sample size were not critical for any kind of classification, but that variations in the surface texture of a lane or section sometimes exceed specified classification boundaries. Sometimes outside and inside wheelpath textures fall in two different classes but these were nevertheless recorded as an average in this paper.

The aforementioned classification was carried out with regard to specularity only, and the four classes, either R or N, can be regarded as sufficiently accurate for design purposes. However, the parameter Q0 should be estimated more accurately by considering the surface course composition and aggregate.

Asphalt pavements exposed to traffic become gradually brighter and more specular, which is reflected in increases of Q0 and S1 (and S2), respectively. The physical reasons are that aggregates become more exposed or cleansed of asphalt and more polished or flattened.

More specifically, with regard to the luminance method of design, the data in Table 7 are presented and can be used for the necessary input of reflectance parameters.

Some measurements were carried out with varying viewing angle α. It was found that brightness (Q0) and specularity (S1/S2) decrease somewhat with increasing α toward 1 or 2 degrees.

REFERENCES

1. IES Roadway Lighting Committee, R.N. Schwab and S.H. Young. Proposed American Standard Practice for Roadway Lighting. IES Journal, Vol. 12, No. 3, April 1983, p. 146 ff.
2. CIE Committee TC-4.6. Calculation and Measurement of Luminance and Illuminance in Road Lighting. CIE Technical Report TRI 12/2/75, CIE Publication No. 30 (TC-4.6), Paris 1976.
3. M.G. Bassett, S. Dmitrevski, P.C. Kramer, and F.W. Jung. Measurements of Reflection Properties of Highway Pavement Samples. Journal of the Engineering Society, Sept. 1981.
4. J.B. DeBoer and D.A. Schreuder. Public Lighting. Chapter 3: Theoretical Basis of Road Lighting Design. Philips Technical Library, Eindhoven, The Netherlands, 1967.
5. A. Erbay. Atlas of the Reflection Properties of Road Surfaces. Institut fuer Lichttechnick der Technischen Universitaet Berlin, Federal Republic of Germany, 1974.
6. E. Frederiksen and K. Sorensen. Reflection Classification of Dry and Wet Roadway Surfaces. Danish Illumination Engineering Laboratory, Vol. 8, No. 4, Aug. 1976.

Publication of this paper sponsored by Committee on Visibility.

Influence of Leading Vehicle Turn Signal Use on Following Vehicle Lane Choice at Signalized Intersections

C. S. PAPACOSTAS

ABSTRACT

The findings of a phenomenological study of a rarely addressed subject are discussed: the degree to which turn signals are properly used at signalized intersections and the effect that nonuse has on the lane-choice behavior of subsequent through vehicles. The situation studied involved a lane drop at the far side of the intersection. Three experiments were conducted at two locations to observe the lane preferences of isolated subject vehicles and three cases of car-following. The study revealed that a considerable proportion of left turners failed to properly indicate their movement intentions and this had a significant effect on following through vehicles. Lane choice was also found to be affected by the distance to the lane drop and by the traffic signal display. On the basis of these findings additional study of this subject is recommended.

The driving task involves the response of a driver to numerous stimuli generated by the environment, the traffic control system, and other vehicles on the roadway. Cues from other vehicles are given by their location, their status, and their actions, current or impending. Because of their critical nature in terms of traffic safety, certain leading vehicle actions are accompanied by reinforcing warnings to following drivers. A prime example of this situation is the universal use of brake lights. Concerning these, Rockwell and Treiteter (1) conducted an experiment relating to "both night and day study of car following for no signal display, for the conventional brake light, for the tri-light system denoting brake and accelerator action, and for an acceleration information display of horizontal rows of green and red lights to indicate the magnitude of the leading vehicle's acceleration or deceleration."

It is noteworthy that the preceding study investigated alternative ways by which information about the actions of the leading vehicle are relayed to the follower automatically in the hope that the resulting improvement in intervehicular communication would contribute to the enhancement of traffic safety and efficiency.

Another method of communication between vehicles is the turn signal, which is used to apprise other vehicles of impending lane-changing or turning movements. The study of turn signals appears to have been generally confined to their design aspects emphasizing the ability of other drivers to perceive and discriminate the message conveyed. Thus, a study by Attwood (2) investigated "a driver's ability to detect and interpret rear-signal information... (for) ... two types of signals, one with brake and turn-signal combined under the same lense, the other with brake and turn-signals under separate lenses."

Incidentally, in his randomized-block factorial design, Attwood also examined the effect of four levels of blood alcohol and six levels of stimulus complexity. Another study by Lea and Associates (3) attempted to discover whether the color of turn signals (i.e., red versus amber) had any effect on the accident involvement of vehicles.

It is of interest to note that the differences sought by these studies are conditional on the actual use of turn signals when warranted. But, unlike the case of brake lights when the signal is given automatically, the use of turn signals involves a good deal of driver discretion and, in fact, turn signals are not always used even when required by the traffic codes that typically provide "... whenever the operation of any other vehicle may be affected by this movement (starting, turning, or stopping), the driver shall give a signal plainly visible to the driver of such other vehicle of the intention to make such movement," and, "a signal of the intention to turn right or left when required shall be given continuously during not less than the last 100 feet travelled by the vehicle before turning (4)."

Vehicle inspection programs required by many states invariably include the testing of the operating condition of turn signals. Again, the physical soundness of turn signals would be immaterial in those instances when the driver fails to use them.

The findings of a small-scale study are reported that attempted to quantify the degree and impact of turn signal use in a rather restricted case representing an early step in this direction. Specifically, the study measured the frequency with which certain leaders of vehicular pairs do signal their intention to execute a left turn at signalized intersections and the effect that signaling and the lack of it have on the lane-choice behavior of the following-through vehicle.

THE SITUATION STUDIED

The study addressed the situation where through vehicles approaching a signalized intersection have a choice between using the center lane of the approach in common with left turners and the adjacent lane that is designated for the exclusive use of through vehicles. The choice of the exclusive through lane presents the possibility of a penalty due to the need to merge left on the far side of the intersection because of a lane drop. Thus, the choice of the center lane places a through vehicle under the risk of being delayed by left turners ahead, whereas the choice of the exclusive through lane may cause a through vehicle delays in having to yield to vehicles occupying the center lane within the length of the merging area. The study attempted to quantify the effect that the display versus the failure to display a turn signal has on the lane choice of subsequent through vehicles. The influence of two other factors was also examined. These factors were the traffic signal phase (i.e., red or green) and the length of the merging area on the far side of the intersection.

EXPERIMENTAL SITES

The experiment was originally envisioned to take place at a single site. This plan was subsequently modified to include a second location where the length of the merging area could be controlled. Figure 1 shows the first site, where observations were made on the eastbound Dole Street approach to the T-intersection shown. The approach consists of two 10-ft lanes. No separate left-turn lane and no special turn phasing of the traffic signal was in effect during the periods of data collection. Thus, the center lane of the approach was open to both through vehicles and left turners into the East-West Road. Moreover, the curb lane is dropped at a distance of 250 ft from the intersection because of a narrow bridge.

Subsequent to the collection of data at the first intersection, a second site was selected in order to consider the effect of locational differences (Experiment 2) and the effect of merging area length (Experiment 3). Figure 2 shows the geometric characteristics of the second site, that is, the northbound Keeaumoku Street approach to its intersection with Wilder Avenue. The approach consists of three

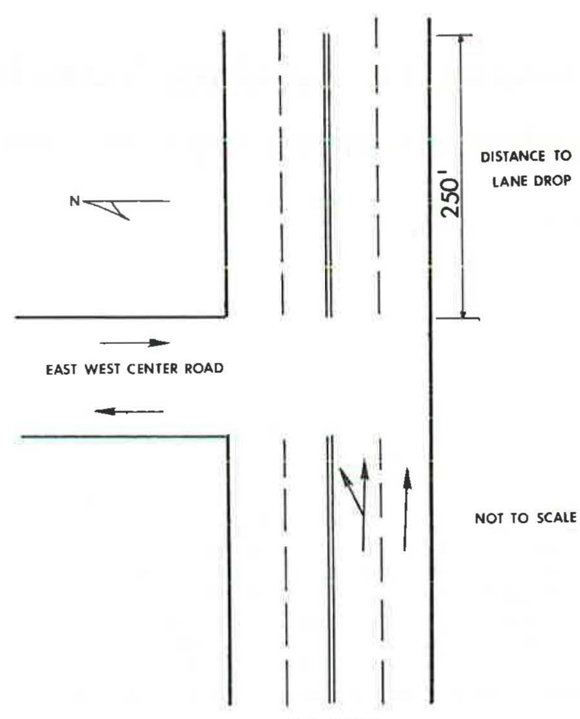

FIGURE 1 The Dole Street site.

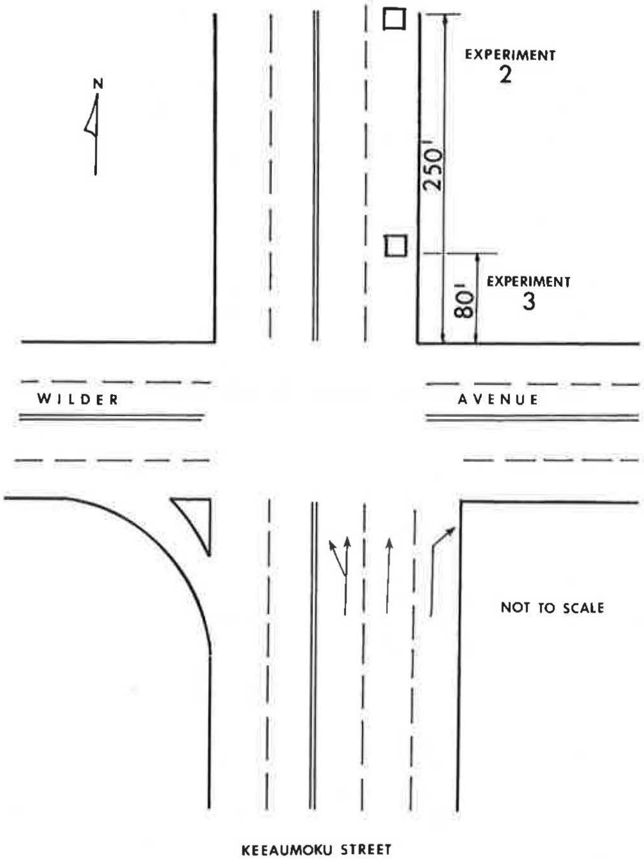

FIGURE 2 The Keeaumoku Street site.

lanes: an exclusive right-turn lane, an exclusive through lane, and a through-and-left center lane. The latter two lanes were relevant to the study.

Parenthetically, because of the light level of traffic examined, any frictional effects between the right-turn lane and the middle lane were considered to be unimportant. The lane drop at this location was due to the presence of a parking lane on the far side of the intersection. Consequently, the distance available for merging could be controlled by the location of the first parked vehicle encountered by through traffic. Two sets of observations were taken at this location. The first corresponded to a merging distance about equal to that of the Dole Street site, the other involved a parked vehicle at a distance of about 80 ft from the intersection (or about one-third the distance in the other two experiments). In all three experiments, the observations were disaggregated according to the traffic signal phase.

EXPERIMENTAL PLAN

The operation of signalized intersections gives rise to a great diversity of vehicular interactions caused by a variety of factors including (but not limited to) the level of demand at the intersection. For example, the lane choice of an approaching through vehicle is affected not only by a turn signal display ahead but also by the number and lane occupancy of vehicles between the subject vehicle and the intersection. Because the main objective of the study was to quantify the effects of turn signals, it became necessary to confine the field observations to cases where the influence of other factors was reasonably reduced. As a result, the test observations were restricted to cases that involved a maximum of two vehicles in a car-following situation, the second vehicle of a pair being a subject vehicle. For purposes of comparison, data relating to the lane choice of isolated through vehicles were also collected. In all three experiments, the response variable consisted of the lane choice of subject (i.e., through) vehicles. Including the case of isolated through vehicles and depending on the action engaged in by the leading (i.e., stimulus-inducing) vehicle in a pair, the following cases were identified for field measurement.

1. Isolated subject vehicle,
2. Subject vehicle subsequent to a left turner that displayed a turn signal,
3. Subject vehicle subsequent to a vehicle in the center lane but displaying no turn signal, and
4. Subject vehicle subsequent to a vehicle in the exclusive through lane.

Figure 3 shows the four cases that were observed under green and red traffic signal conditions at each experimental site. The observations that were included in Case 3 were categorized according to whether the leading vehicle traveled straight ahead, whether it turned left without signaling, or whether it displayed the turn signal late. A delayed display was one that occurred after the subject vehicle committed itself to a particular lane. This event was most pronounced during the red phase in instances when the turn signal was displayed after the subject vehicle came to a complete stop or even after the leading vehicle entered the intersection during the subsequent green phase. The effect of turn signal use on the lane choice of subject vehicles could be found by comparing Cases 2 and 3. As far as a subject vehicle is concerned, a leading vehicle in the center lane that displays no turn

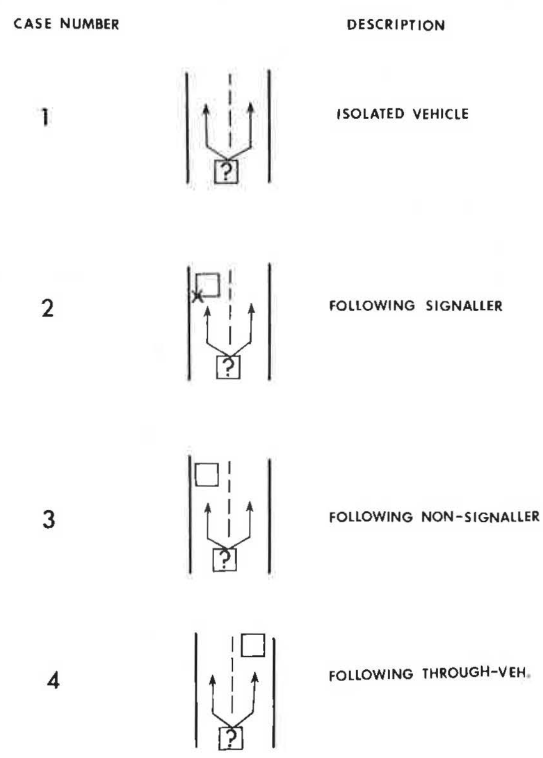

FIGURE 3 The cases studied.

signal may be either a left turner or a through vehicle, a situation that gives rise to the lane-choice predicament described earlier.

DATA COLLECTION

An observer equipped with a special form on which the relevant cases were listed was positioned at a distance of approximately 250 ft upstream from the intersection site. The observer viewed vehicles as they approached the intersection and manually recorded on the forms the lane choice of vehicles qualifying as subject vehicles. All observation sessions were conducted under clear and dry conditions during off-peak periods when excessive queueing was not present. The observer visited the sites on a number of days and continued to collect data until a sufficient sample of about 50 observations became available for the least frequently occurring case. Incidentally, the case in which the leading vehicle of a pair occupied the through lane ahead of a subject vehicle was the rarest of the sought-after cases for all three experiments.

As noted earlier, data corresponding to the four cases were collected for both the red and green displays of the traffic signal. It should be indicated here that the assessment of car-following dynamics that were being observed presented relatively more difficulties of judgment during the green as compared with the red phase. This was true because during the green phase drivers have more freedom to control and adjust their speed, to overtake, and to maneuver their vehicles. In addition, other clues besides the turn signal are available to them regarding impending movements by vehicles ahead. For example, a leading vehicle that is motionless within the intersection, especially in the presence of opposing traffic, is most probably in the process of executing a left turn irrespective of whether it displays a turn signal or not. Moreover, late lane changes and overtaking would be much easier during the green phase under the traffic levels considered because the subject vehicle is not required to come to a stop but can proceed to clear the intersection without severe interruptions. For these and other reasons, it was the opinion of the observer that the data obtained during the red phase are more reliable than those obtained during the green phase.

DATA ANALYSIS

Degree of Turn Signal Use

Table 1 presents the overall counts of the field observation sessions for the three experiments conducted at the two locations described earlier. Experiment 1 corresponds to the Dole Street site, Experiment 2 corresponds to the Keeaumoku Street location when the merging distance was approximately the same as in Experiment 1, and Experiment 3 corresponds to the Keeaumoku site when the merging distance was about 80 ft or one-third of that which existed during the other two experiments. The four cases within each experiment are those shown in Figure 3.

In Table 2a the data in Case 2 (i.e., late or no signal) are disaggregated according to whether the leading vehicle eventually proceeded through the intersection straight ahead or whether it executed a left turn. These findings reveal the degree to which leaders of vehicular pairs in the center lane who did not display the turn signal were, in fact, turning left (Column 5). Also shown in the table are the observed numbers of left-turning leaders who probably used the turn signal (Column 1). Using these values, it is possible to compute the percentage of left-turning leaders of vehicular pairs who failed to properly give an indication of their intended maneuver (Column 4). It is clear that both categories constituted considerable proportions of their respective totals. That is, based on frequency alone, the proportion of drivers who neglected to use the turn signal cannot be ignored.

The data in Table 2a indicate that there exist differences in turn signal use apparently related to the traffic control phase. The data in Table 2b aid the examination of this possibility by presenting the results of chi-square tests that compared the use of turn signals between the green and red phases for each of the three experiments. Adapting the terminology of <u>same</u> for failing to reject the hypothesis of equality of proportions at the 0.05 level of significance, <u>different</u> for rejecting the hypothesis at the 0.5 level but failing to do so at the 0.01 level, and <u>very different</u> for rejecting the hypothesis at both levels, the data in Table 2b indicate that the percentage of nonsignaling left turners (irrespective of how computed) was affected by the traffic signal control at the short-merging-distance Keeaumoku Street site. For the other Keeaumoku experiment, the computed chi-square value approaches the theoretical 0.05-level value. In all other instances, the hypothesis of equality could not be rejected. Combined, these findings may portend other differences besides the length of the merging area. To examine this possibility further, the chi-square test was employed to compare the proportions of nonsignalers between experiments.

The data in Table 2c indicate the results of pairwise comparisons between experiments when non-

TABLE 1 Lane-Choice Data

	Green Phase				Red Phase			
Case	Center Lane	Through Lane	Center (%)	Through (%)	Center Lane	Through Lane	Center (%)	Through (%)
1	162	84	66	34	104	46	69	31
	129	57	69	31	112	39	74	26
	163	72	69	31	157	34	82	18
2	27	123	18	82	9	70	11	89
	20	75	21	79	15	80	16	84
	30	84	26	74	22	56	28	72
3	97	42	70	30	57	33	63	37
	43	23	65	35	65	40	62	38
	53	24	69	31	89	62	59	41
4	49	23	68	38	58	11	84	16
	31	20	61	39	47	8	85	15
	34	17	67	33	43	7	86	14

Note: The three rows associated with each case correspond to Experiments 1, 2, and 3, respectively.

TABLE 2 Degree of Turn Signal Use

(a) Raw Data

EXPERIMENT	GREEN PHASE					RED PHASE				
	(1) CASE #2 TOTAL	(2) CASE #3 LEFT	(3) CASE #3 THROUGH	(4) (2) AS % OF (1)+(2)	(5) (2) AS % OF (2)+(3)	(1) CASE #2	(2) CASE #3 LEFT	(3) CASE #3 THROUGH	(4) (2) AS % OF (1)+(2)	(5) (2) AS % OF (2)+(3)
1. Dole	150	81	58	35	58	79	50	40	39	56
2. Keeaumoku	95	31	35	25	47	95	34	71	26	32
3. Keeaumoku	114	37	40	25	48	78	51	100	40	34

(b) Green versus red

EXPERIMENT	(2) AS % OF (2)+(3)	(2) AS % OF (1)+(2)
1. Dole	0.165* (same)**	0.488 (same)
2. Keeaumoku (long)	3.661 (same)	0.103 (same)
3. Keeaumoku (short)	4.386 (diff.)	7.294 (very diff.)

(*) computed chi-square

(**) see text

(c)

EXPERIMENT	GREEN 1	GREEN 2	RED 1	RED 2
2	2.307 (same)	—	6.574 (very diff)	—
3	2.089 (same)	0.017 (same)	10.988 (very diff)	0.054 (same)

(d)

EXPERIMENT	GREEN 1	GREEN 2	RED 1	RED 2
2	4.145 (diff)	—	4.519 (diff)	—
3	4.771 (diff)	0.000 (same)	0.016 (same)	5.701 (diff)

signalers are taken as the proportion of all nonsignaling leaders of vehicular pairs traveling in the center lane (i.e., Case 3). With respect to the observations taken during the green phase, the three experiments indicate no differences at the 0.05 level of significance. During the red phase, on the other hand, the two Keeaumoku Street experiments were found to be the same but were either different or very different when compared with the Dole Street experiment: a lower percentage of nonsignalers were found in the former as compared to the latter (i.e., combined 33 percent versus 56 percent). In this instance, then, a locational difference emerged. Parenthetically, the major differences between the two locations include the existence of an exclusive right-turn lane at Keeaumoku, the potential conflicts between subject vehicles with opposing traffic turning left at the same site, and possibly some uncertainty on the part of drivers approaching the Keeaumoku intersection about the length of the merging zone on the far side of the intersection.

According to Table 2c, the same "locational" effect between Dole Street and Keeaumoku Street is observed with respect to the percentage among all observed left turners that failed to properly signal during the green phase. However, the percentage corresponding to the red phase indicated mixed results: a higher proportion of nonsignalers was found at the short-merging distance site vis-a-vis the other Keeaumoku experiment. Moreover, this higher percentage was statistically the same as that corresponding to the Dole Street experiment. Without this anomaly, the pattern of locational differences would be the same as before, although more pronounced.

Behavior of Subject Vehicles

The lane-choice behavior of through vehicles admissible within the cases identified for the purposes of the study were analyzed next. The overall results of the observation sessions that are given in Table 1 were subjected to three groups of analysis as follows:

1. Case by case comparisons between pairwise combinations of experiments (Table 3);
2. For each experiment, case by case comparisons between the red and green phases of the traffic signal (Table 4); and
3. For each experiment, comparisons between cases by traffic control phase (Table 5).

All analyses applied the chi-square test. The results are discussed using the terminology of same, different, and very different as defined previously.

Table 3 presents the experimental chi-square values that resulted from the case by case comparisons by traffic control phase between pairs of experiments. The data in Table 3a indicate that the lane-choice behavior of subject vehicles for the two long-merging-distance experiments at Dole and Keeaumoku Streets was the same. On the other hand, the short-merging-distance experiment showed some differences from both long-merging-distance experiments: the results were found to be the same for all cases under green and for Cases 3 and 4 under red, but differences were detected in Cases 1 and 2 under red.

The lane-choice proportions in the case of isolated subject vehicles (Case 1) and in the case of

TABLE 3 Case by Case Comparisons for Pairs of Experiments

(a) Experiments 1 vs. 2

CASE	GREEN	RED
1	0.591 (same)	0.869 (same)
2	0.350 (same)	0.701 (same)
3	0.444 (same)	0.042 (same)
4	0.694 (same)	0.046 (same)

(b) Experiments 1 vs. 3

CASE	GREEN	RED
1	0.675 (same)	7.745 (very diff)
2	2.646 (same)	7.001 (very diff)
3	0.021 (same)	0.456 (same)
4	0.026 (same)	0.085 (same)

(c) Experiments 2 vs. 3

CASE	GREEN	RED
1	0.000 (same)	3.236 (same)
2	0.789 (same)	3.927 (diff)
3	0.218 (same)	0.227 (same)
4	0.382 (same)	0.006 (same)

TABLE 4 Case by Case Comparisons by Signal Phase

CASE NO.	EXPERIMENT 1	EXPERIMENT 2	EXPERIMENT 3
1	0.512 (same)	0.949 (same)	9.290 (very diff)
2	1.705 (same)	0.876 (same)	0.084 (same)
3	1.032 (same)	0.184 (same)	2.124 (same)
4	4.931 (diff)	8.286 (very diff)	5.209 (diff)

subject vehicles behind signaling left turners (Case 2), were found to be very different between the short-merging-distance experiment at Keeaumoku Street vis-a-vis the Dole Street experiment (Table 3b). This difference emerges in a milder form (apparently due to locational similarities) from the comparison of the two Keeaumoku Street experiments (Table 3c). The general conclusion that may be drawn here is that the length of the merging zone affects the lane choice of isolated vehicles and through vehicles that are behind a signaling left turner. The raw data in Table 1 quantify the reasonable expectation that a larger proportion of subject vehicles would choose the center lane when the merging distance is shortened. The contribution of the traffic control on this tendency is examined next.

The data in Table 4 indicate the results of an analysis that compared separately for each experiment the lane-choice behavior of subject vehicles for each of the four cases when the traffic control phase is varied. In all three experiments the traffic signal was found to affect the lane choice of through vehicles subsequent to a leader who occupied the through lane (Case 4): proportionately more subject vehicles chose the center lane during the red phase than during the green phase. Additionally, the short-merging-distance experiment showed a peculiarity vis-a-vis the two long-merging-distance experiments: more isolated subject vehicles chose the center lane on red as compared to green in the instance of the short-merging-distance experiment. This finding, of course, is both reasonable and consistent with the findings of earlier analyses (Table 3), which, when taken together with the present findings, reveal a strong interaction between the merging distance and the traffic signal in the case of isolated vehicles (Case 1), but, in the case of vehicles subsequent to a signaling left turner (Case 2), the merging distance alone appears to be the predominant factor.

Finally, the question of the effect of turn signal use or non-use on the lane choice of subject vehicles was examined by comparing their lane-choice proportions between the various cases for each experiment. The data in Table 5 indicate overwhelming preference for the through lane when comparing proportions in the case of signaling leaders (Case 2) and all other cases irrespective of the traffic signal display. Of interest is that, during the green phase, no difference was detected in lane choice in the presence of nonsignaling leaders traveling in the center lane (including eventual left turners) vis-a-vis cases not involving a signaling left turner. This finding was not consistently true during the red phase. The comparison of vehicles following a leader in the through lane (Case 4) versus the case of vehicles following nonsignaling leaders in the center lane (Case 3) indicated a consistent difference attributable to a higher proportion of center-lane users among the former in agreement with earlier findings (Table 4). The two locations were reversed with respect to the remaining two comparisons in Table 5b, both involving the case of isolated vehicles. At Dole Street, no difference is observed between isolated vehicles and vehicles following a nonsignaling leader in the center lane. Additionally, at the same location, more center lane users were found among vehicles subsequent to leaders in the through lane than among isolated vehicles. In the last two comparisons, the reverse was found to be true at the Keeaumoku site. The cause of this reversal appears, more than anything else, to be a higher preference for the center lane on the part of isolated vehicles on Keeaumoku Street, a situation that may be explainable by the locational differences discussed earlier.

TABLE 5 Between-Case Comparisons by Signal Phase

Experiment No. 1

(a) Green

	Case #1	Case #2	Case #3
Case #2	85.530 (very diff)		
Case #3	0.623 (same)	78.975 (very diff)	
Case #4	0.121 (same)	54.140 (very diff)	0.066 (same)

(b) Red

	Case #1	Case #2	Case #3
Case #2	69.501 (very diff)		
Case #3	0.917 (same)	47.686 (very diff)	
Case #4	5.322 (diff)	78.494 (very diff)	8.381 (very diff)

Experiment No. 1

Experiment No. 2

(a) Green

	Case #1	Case #2	Case #3
Case #2	58.900 (very diff)		
Case #3	0.397 (same)	31.797 (very diff)	
Case #4	1.340 (same)	23.048 (very diff)	0.236 (same)

(b) Red

	Case #1	Case #2	Case #3
Case #2	79.589 (very diff)		
Case #3	4.368 (diff)	44.194 (very diff)	
Case #4	2.914 (same)	69.716 (very diff)	18.186 (very diff)

Experiment No. 2

Experiment No. 3

(a) Green

	Case #1	Case #2	Case #3
Case #2	57.541 (very diff)		
Case #3	0.008 (same)	33.808 (very diff)	
Case #4	0.142 (same)	24.164 (very diff)	0.066 (same)

(b) Red

	Case #1	Case #2	Case #3
Case #2	72.523 (very diff)		
Case #3	22.594 (very diff)	19.453 (very diff)	
Case #4	0.406 (same)	40.719 (very diff)	12.200 (very diff)

Experiment No. 3

SUMMARY AND CONCLUSIONS

The results of a small-scale exploratory phenomenological study of a rarely addressed subject have been discussed: the degree of use of turn signals by left turners at signalized intersections and the effect of their use and non-use on the lane-choice behavior of subsequently approaching through vehicles. The specific situation studied involved a lane drop at the far side of the intersection, which gave rise to a predicament on the part of subject vehicles relating to the choice of lane between a common left/through center lane and a through lane adjacent to it. For comparative purposes, data on the lane choice of isolated subject vehicles and of subject vehicles subsequent to a leader in the exclusive through lane were also collected. Three experiments were conducted in an attempt to determine the effect of turn signal use as distinguished from the effect of other factors such as the traffic signal display and the merging distance to the lane drop.

The study revealed that a considerable proportion of left turners failed to properly indicate their movement intentions. Between 30 and 60 percent of the nonsignaling leaders observed eventually turned left, and between 25 and 40 percent of the left-turning leaders observed failed to properly use the turn signal.

The study also quantified the following reasonable phenomena:

1. A shorter merging distance was found to increase the percentage of followers of signaling left turners who chose the common lane;
2. An interaction effect was found between traffic signal control and merging distance on the lane-choice behavior of isolated subject vehicles; and
3. The traffic signal control was found to affect the lane choice of vehicles subsequent to leaders occupying the through lane.

As would be expected, subject vehicles following signaling left turners indicated an overwhelming preference for the through lane vis-a-vis the common left-and-through approach lane. It is of interest, however, that in certain instances subject vehicles behaved similarly when isolated from other vehicles as compared to cases in which they followed nonsignaling leaders, even though the latter could be eventually executing a left turn. In other words, a number of subject vehicles would have selected a different approach lane had they been apprised of the turning intention of the vehicle ahead. The ultimate implication of this discrepancy on traffic safety and efficiency must await further examination. With respect to traffic safety, a study of the correlation between certain types of conflicts on the one hand and the pattern of turn signal use on the other within the general framework of conflict analysis (5) may prove fruitful. In addition, based on the findings of the current study, it appears that the investigation of other situations involving the use of turn signals (for example, lane changing) and the study of more complex cases in the vicinity of signalized intersections are warranted.

REFERENCES

1. T.H. Rockwell and J. Treiteter. Sensing and Communication Between Vehicles. NCHRP Report 51. TRB, National Research Council, Washington, D.C., 1968.
2. D.A. Attwood. Effects of Moderate Levels of Blood Alcohol on Responses to Information from Simulated Automobile Rear-Signal Systems. Accident Analysis and Prevention. Vol. 10, No. 1, March 1978.
3. Lea and Associates Limited. An Evaluation of Automotive Lighting Systems and Accident Involvement Phase II. Final Report HS-032-790. Transport Canada Research and Development Center. Vancouver, Aug. 1979.
4. Traffic Code. City and County of Honolulu. 1975.
5. W.D. Glauz and D.J. Migletz. Application of Traffic Conflict Analysis at Intersections. NCHRP Report 219. TRB, National Research Council, Washington, D.C., 1980.

Publication of this paper sponsored by Committee on Visibility.

Cost-Effectiveness Evaluation of Rural Intersection Levels of Illumination

KYLE A. ANDERSON, WELDON J. HOPPE, PATRICK T. McCOY, and RAMON E. PRICE

ABSTRACT

Lighting is often installed at rural intersections to improve the safety of night traffic operations at these locations. However, there are no generally accepted design criteria that define the levels of illumination required at rural intersections. The objective of this research was to evaluate the cost-effectiveness of rural intersection levels of illumination. Six lighting systems were installed at a rural, unchannelized intersection of two two-lane highways. Speed-profile and traffic-conflict studies were conducted on an uncontrolled approach to the intersection. The studies were conducted at night at each level of illumination as well as with no lighting. The data were analyzed to determine the safety- and cost-effectiveness of each level of illumination. The results of the research indicated that, for a given luminaire wattage, two-luminaire systems provided safer traffic operations than did one-luminaire systems; and the safest operations were observed under a two 200-watt high-pressure-sodium (HPS) luminaire system. The results of the cost-effectiveness analysis revealed that lighting was not warranted at rural intersections with main highway average daily traffic less than 3,250 vehicles per day. At higher volume intersections a two 200-watt HPS luminaire system was the most cost-effective.

Lighting is installed at rural intersections to improve the safety of night traffic operations at these locations. But although several studies (1) have found improvements in highway safety as a result of intersection lighting, generally accepted warrants that define the circumstances under which the costs of installing and maintaining rural intersection lighting are justified do not exist. In addition, current guidelines for fixed roadway illumination (2-4) do not deal directly with rural in-