SAFETY EVALUATION OF FORCED WEAVING AS A TRAFFIC CONTROL MEASURE IN FREEWAY MAINTENANCE OPERATIONS

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Effective traffic speed control during maintenance or reconstruction activity implies not only that the speed will be reduced enough to lower the conflict between work activity and traffic flow but also that no adverse conflicts will be introduced within the traffic stream. Speed control effectiveness and safety were analyzed for 2 examples of a traffic sign-traffic cone-traffic barricade pattern developed by the Iowa State Highway Commission. The pattern forces all through traffic to negotiate a single lane in a weaving pattern. The switchback from 1 lane to another is designed to control speeds. Results indicate that the weaving was highly effective when construction activity was visible; more than 50 percent of all vehicles sampled traveled below the posted temporary speed limit. When no construction activity was evident or when no forced weaving was used, fewer than 20 percent of all vehicles sampled complied with the posted speed limit. Analysis of the lane changing ahead of the weave pattern indicated that no excessive driver confusion was introduced in the approach to this unique speed-control pattern. Only 3 vehicles were observed to perform hazardous or unusual maneuvers in negotiating the advance-warning area.

•PREVIOUS in-depth studies of the anticipated impact of maintaining a completed 42,500-mile Interstate Highway System revealed some startling information (1, 2): (a) By 1975 it is estimated that the annual cost of maintaining shoulders and pavement will be 45 percent of the total Interstate System maintenance cost; and (b) there is little uniformity among the states in the control of freeway traffic when maintenance is performed.

As the Interstate System nears completion, we can reasonably expect the rate of use (extent of travel and traffic volumes) to rise even more rapidly than it has in the past when only parts and segments were completed. When maintenance work crews and freeway traffic interfere with each other, 2 courses of action are possible: (a) Traffic must detour around the work site on an alternate route or special detour roadway; and (b) traffic movement through the work site must be rigidly controlled for safety and efficiency.

It may be feasible to detour traffic onto alternate routes while only portions of the Interstate System are complete. Most of the segments begin and end at tie-in points to the existing primary system. However, when a considerable length of the freeway is completed, the spacing of interchanges limits re-entry points to the freeway. Also, no other type of facility has the traffic capacity that the freeway has or can provide the traffic speed. When the costs of special detour construction, the costs of increased congestion on primary routes, the effects of excessive traffic on alternate route maintenance, and the added costs of increased travel time are accumulated, the advantages of detouring freeway traffic outweigh the disadvantages in only limited situations.

Sponsored by Committee on Maintenance Operations.

Because detouring freeway traffic is desirable only in restricted maintenance situations, the next alternative is to move the freeway traffic through the work zone. This choice eliminates the disadvantages of additional congestion, travel, and delay on alternate routes of the primary system. However, there are disadvantages to carrying traffic through a work site:

1. Delays are experienced by motorists in the vicinity of the work site;
2. Maintenance and reconstruction costs may be higher because traffic interferes with or restricts work crews; and
3. Hazards are added to both through traffic travel and work crew activity.

To minimize the hazards to both traffic and work crews requires that freeway traffic control be effective and efficient. An advance-warning signing system provides 2 characteristics of operation: positive speed control and smooth merging of traffic from closed lanes into open lanes.

Positive speed control brings high-speed freeway traffic down to a speed that does not unduly delay the through traffic yet is sufficiently slow that the work forces are not endangered by high-speed vehicles. No universal guidelines exist defining an appropriate speed for freeway traffic moving through a maintenance area. However, a survey of agencies responsible for freeway maintenance indicated that they attempted to limit traffic to 20 to 45 mph as a general rule. Whether the freeway traffic is limited to 30 or 40 mph is not so important from the workman's view as whether the control is effective. If all vehicles are moving at about 35 mph, workmen could adjust for the hazard of the traffic in their operation; but if some vehicles are traveling at 25 mph and some at 55 mph, the potential for a workman to misjudge the danger of a traffic hazard is greater. Thus, positive speed control is not only getting traffic to conform approximately to a posted speed limit (mandatory or advisory) through the work site but also minimizing the upper extreme speed deviations.

Smooth merging is fundamental to safe and efficient operations on a freeway any time 2 or more traffic streams are joined into one (3). Closing a through lane denies drivers the visual guidance of the gradually changing geometry of the pavement surfaces available at entrance ramps and main-lane drops. The configuration of signs, barricades, and traffic cones must provide sufficient guidance so that drivers can decide in which lanes they should be and carry out their decisions without abnormal or hazardous movements. Some highway agencies responsible for freeway maintenance have developed standard layouts for signs, barricades, and traffic cones that indicate rates of taper for merging traffic as a function of traffic speed or roadway geometry (2, 4, 5).

STUDY OBJECTIVE

The Iowa State Highway Commission (ISHC) uses a unique pattern of traffic cones and barricades to control traffic speeds on freeways when traffic is carried through a work site. The standard configuration is shown in Figure 1. This pattern is modified as required by roadway conditions at the work site. Usual modifications include changes in the spacing between consecutive signs, altering rates of taper, or spacing of the "lane switchback" because an entrance ramp or exit ramp is adjacent to the work site (or a similar constraint exists). The ISHC weaving section is a unique feature to slow freeway traffic and is, therefore, frequently an unfamiliar experience to drivers passing through Iowa on the Interstate Highway System. Potentially, this nonuniform traffic control pattern (with respect to states other than Iowa) could represent a special driving problem on the Iowa Interstate routes during the maintenance season. The National Science Foundation, therefore, funded a research initiation grant with the following objectives: (a) to estimate speed characteristics of vehicles traversing the weave section to indicate conformance with posted speed limits and to evaluate general safety of speeds; and (b) to evaluate merging and weaving of vehicles in advance of the weaving section.

DATA COLLECTION METHODOLOGY

Two classes of data were collected by 2 separate methods. Data on the weaving and merging behavior of vehicles as the traffic stream entered the advance-warning sign

Figure 1. Lane-closure pattern used in Iowa to slow traffic.

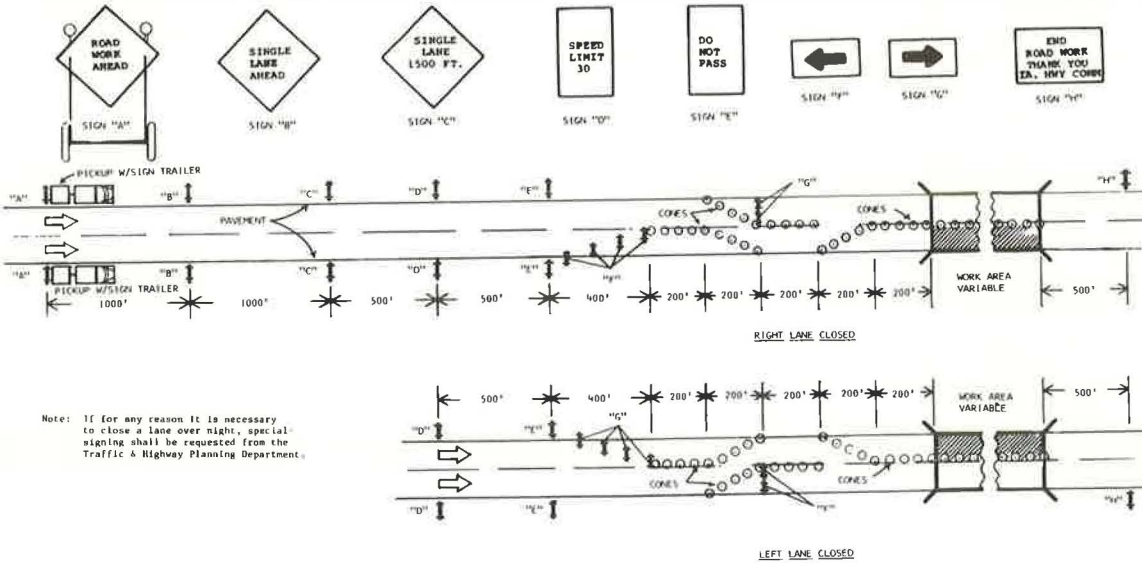
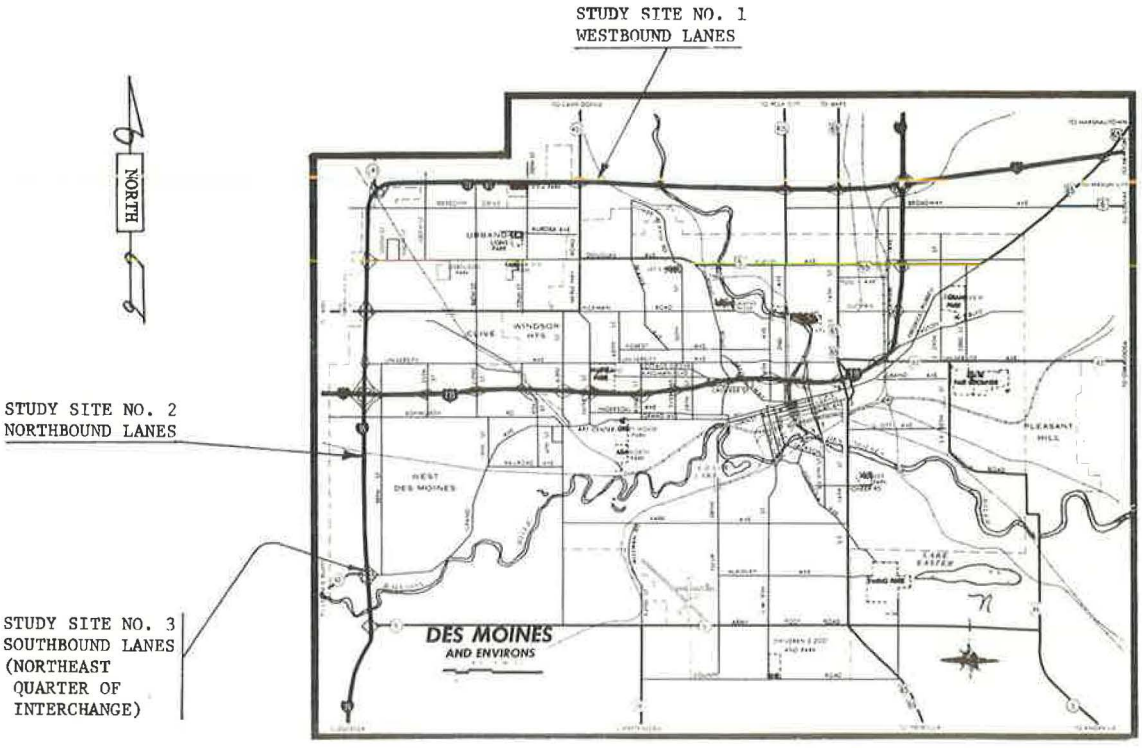


Figure 2. Site locations on I-35 and I-80.



area and maneuvered into the speed control weave section were collected with a 16-mm Beaulieu R-16 camera. The weaving data were collected on black and white film at 2 frames/sec. The Beaulieu R-16 holds a 100-ft roll of film so that each loading of the camera provided about 35 min of data. Camera observation positions were selected to look down on the traffic passing through the sign-barricade system, so the signs and barricades themselves were used as reference marks in retrieving data from the film. While the camera was operating, observers recorded the lane distribution of vehicles before the drivers were close enough to the signing system to react to sign information. This established a null condition reference from which to evaluate the weaving and merging as drivers progressed down the roadway. In addition, while the film was being exposed, a sample of vehicle license plates was recorded to classify the drivers as local (same county as study site), Iowa-other-than-local (vehicle registered in some Iowa county not containing the study site), or out-of-state. All trucks with multiple-state registration were classified as out-of-state. All government vehicles with an Iowa license plate not identifying a county were considered as Iowa-other-than-local vehicles. This classification may be a bit arbitrary and can possibly lead to some bias, but we felt those classes were as logical as could be devised to estimate the proportion of the drivers who might be unfamiliar with the traffic control scheme (out-of-state), those who might be unfamiliar with the control configuration at the study site (Iowa-other-than-local), and those who may be repeat drivers (local). In the early phases of the study methodology experimentation, we hoped that each vehicle observed on film could be positively identified by license plate; that proved to be impossible, so the gross sample identification was accepted.

The speed of vehicles after they had passed through the slow-down weave of traffic cones and barricades could not be obtained from the time-lapse photography. The close spacing of signs and cones in this area obscured the reference mark pattern, and the smaller vehicles were sometimes hidden from view. Enoscopes (flash boxes) were set up to measure the speeds of vehicles after the drivers had been slowed down by the weave section. The flash boxes were placed behind barricades and were hidden from the drivers' view. This limited the "gawker" effect of drivers' watching the collection of traffic data.

Maintenance work and reconstruction on Interstates 80 and 35 in the Des Moines area provided an opportunity to sample the traffic characteristics approaching this weave traffic control scheme. Figure 2 shows the location of 3 study sites.

1. At the Merle Hay Road on the north edge of Des Moines, the westbound traffic approaching the diamond interchange was observed. Figure 3 shows the location of signs, the camera location, and the roadway profile.
2. At the Minnesota and St. Louis Railroad on the southwest edge of the Des Moines area, northbound traffic was observed. No interchanges were near to provide disruptive influences. Figure 4 shows the layout of this site and the profile of the approach.
3. At the Iowa-90 interchange southwest of Des Moines, a temporary traffic control scheme was set up to direct traffic around a bridge joint-sealing operation. Instead of the full weave, only signs and a merge-left cone pattern were used to control through traffic. Speed data were collected here to compare to the speed control of the weave pattern. Figure 5 shows the layout at this site.

DATA ANALYSIS AND INTERPRETATION

Speed Control Data

The effectiveness of a speed control can be evaluated in several ways. One measure against which the method control can be evaluated is to calculate the proportion of the vehicles moving at or below the posted speed limit. At all 3 study sites, the speed limit was posted at 30 mph. At sites 1 and 3 vehicles were in rather poor compliance with the 30-mph speed limit, while at site 2 the majority of the vehicles (58.3 percent) were traveling at or below the speed limit after negotiating the weave section designed to

Figure 3. Plan and profile of site 1.

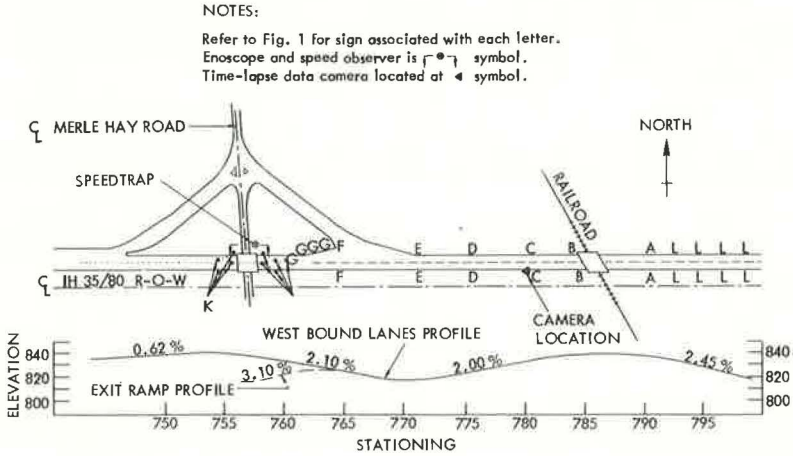


Figure 4. Plan and profile of site 2.

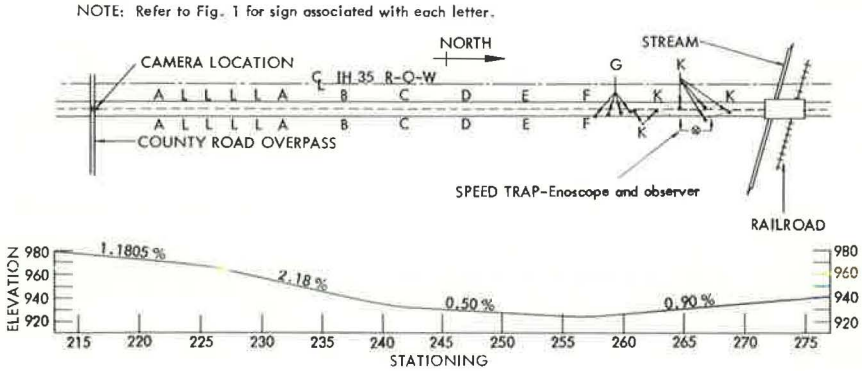
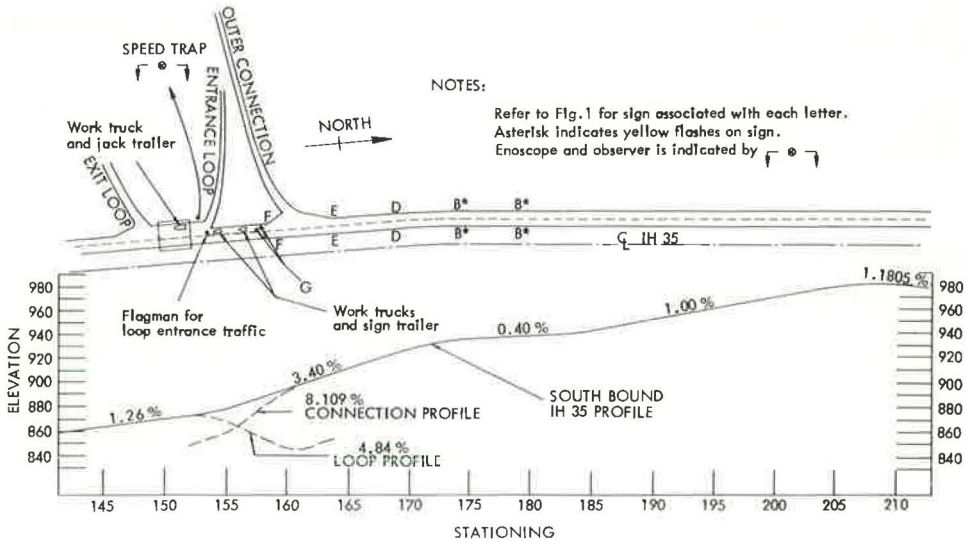


Figure 5. Plan and profile of site 3.



control speeds (Table 1). We assumed that the 30-mph speed was in fact the desirable speed to which vehicles should be limited. No attempt was made to establish what was the upper limit of a "safe" speed for traffic moving through the work site. Based on the percentage of vehicles obeying the posted speed limit, the conditions at site 2 produced a much safer operation.

If a spot speed sample is arrayed in order of increasing speed, frequently the dispersion pattern about the mean speed is very close to a normal distribution. Two published works have directed some effort to relating this "normality" of speeds to the general safety of travel (6, 7). The essence of both of these reports is that, if driving environment, traffic conditions, and driver desires combine to produce a normal distribution pattern of speeds, then speed has a minimal effect in traffic hazard (accident rate should be low). Further, if any condition causes the speeds to be non-normal in distribution, the skewness of the distribution is important in determining whether the speed characteristics are leading to unsafe operations. If most drivers are driving slower than the mean and a few drivers are traveling a great deal faster than the mean, a distribution would have a negative (left) skew. If most drivers are traveling faster and a few cautious persons are driving slower than the mean, the distribution would have a positive (right) skew. Skewness is shown in Figure 6. A study by the Ohio Department of Highways indicated that signing for safe speed limits reduced accidents and improved safety only when the speeds were skewed negatively or to the left (8). Further, Taylor found that the safest traffic operation was produced when speeds were normally distributed (6).

Data analysis results given in Table 1 indicate that speeds at all study sites were approximately normally distributed. The Kolmogorov-Smirnov goodness-of-fit test was applied to the speed samples, and the highest significance level was 0.10 for one of the speed samples at site 1. Common practice would not reject the hypothesis that the sample came from a normal distribution unless the significance level was 0.05 or 0.01. We would generally interpret this result to mean that all 4 samples were probably from normal distributions but that the data at site 1 are approaching non-normality. This test still is no basis for concluding that traffic operations at any of the sites were hazardous.

When the spot speed data were examined for skewness, however, one sample was significantly skewed. The skew test t-value was positive for all 4 samples, so at least no dangerous negative skew was observed (Table 1). Sample 1 taken at site 1 is significantly skewed, and the probability of a greater skewness test statistic, if the speeds were in fact not skewed, was 0.004. The results of this test indicate that, although the speeds contained in sample 1 have an undesirable skew, none of the samples has a potentially hazardous negative skew.

One other possible measure of safety is the maximum speed. Because all sites had the same posted speed limit of 30 mph, a lower maximum observed speed would potentially indicate a safer operation. Table 1 gives maximum speeds of 55, 42, and 61 mph for sites 1, 2, and 3 respectively.

The data analysis results suggest that a difference exists among the spot speed samples. The samples were compared on a pair-wise basis to test 2 hypotheses:

1. Were the variances (variability) of the 2 compared samples equal? and
2. Were the mean speeds of the 2 compared samples equal?

Table 2 gives the results of the pair-wise tests. Using the 0.05 level of significance as the rejection limit revealed that the variance for sample 4 was significantly different from those for samples 1, 2, and 3. The mean speeds of samples 1 and 2 were the only ones for which the hypothesis of equality could be accepted.

If the results of the speed data analysis are all combined in a qualitative judgment, the operation at site 2 was superior to the traffic operation at sites 1 and 3. The superiority of traffic operations through site 2 over site 3 could be explained as the superiority of the ISHC weave traffic control pattern over simply merging traffic out of a closed lane and relying on signs to control speeds. Any attempt to explain the superiority of the traffic operation at site 2 over site 1 is more complex. At site 1 the off-ramp may have been an influence contributing to some delay or abnormal operation.

Table 1. Spot speed data analysis.

Sample	Site	Sample Size	Mean Speed	Standard Deviation	Vehicles Traveling ≤30 mph (percent)	Test for Skewness: Calculated t	Test for Skewness: Significance Level	Test for Normality: Largest Deviation	Test for Normality: Significance	Speed Range (mph): Maximum	Speed Range (mph): Minimum
1	1	103	35.7	6.28	13.6	2.86	0.004	0.123	0.10	55.2	20.3
2	1	106	34.7	6.34	18.9	1.15	0.25	0.106	0.20	55.2	20.6
3	2	108	29.6	5.92	58.3	1.41	0.15	0.055	>0.20	42.8	18.6
4	3	107	39.1	8.14	13.1	1.18	0.25	0.069	>0.20	61.0	21.9

Figure 6. Relation of skew to sample mean value.

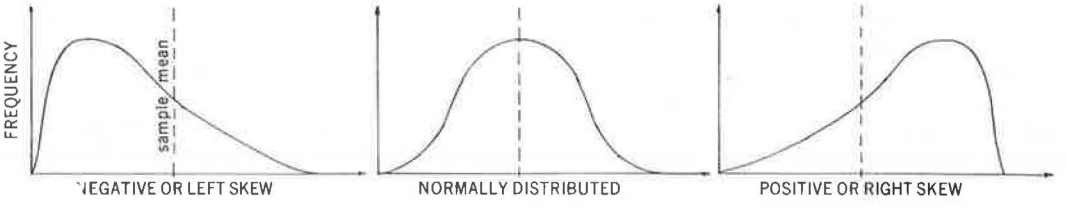


Table 2. Comparison of spot speed samples for equal variances and equal means.

Samples Compared	Calculated F	Significance Level	Equal Variances Hypothesis	Calculated t	Table t	Equal Means Hypothesis[a]
4-1	1.676	0.05	Rejected	3.4	1.984	Rejected
4-2	1.648	0.05	Rejected	4.4	1.984	Rejected
4-3	1.889	0.01	Rejected	9.78	1.984	Rejected
3-2	1.145	—[b]	Accepted	6.06	1.972	Rejected
3-1	1.127	—[b]	Accepted	7.26	1.972	Rejected
2-1	1.017	—[b]	Accepted	1.146	1.972	Accepted

[a]0.05 significance level. [b]Not significant.

Table 3. Percentage of vehicles in lanes at each distance reference point.

Site	Sample	DRP1 L1	DRP1 L2	DRP2 L1	DRP2 L2	DRP3 L1	DRP3 L2	DRP4 L1	DRP4 L2	DRP5 L1	DRP5 L2	DRP6 L1	DRP6 L2	DRP7 L1	DRP7 L2
1	1	0	100	09	91	53	47	63	37	70	30				
1	2	0	100	18	82	60	40	71	29	79	21				
1	3	0	100	19	81	56	44	64	36	71	29				
1	4	0	100	22	78	54	45	69	31	74	26				
1	—[a]	0	100	27	73	56	44	67	33	73	27				
2	1	0	100	08	92	40	60	60	40	68	32	75	25	84	16

Note: DRP = distance reference point; and L = lane.

[a]Combined.

Table 4. Lane volume at site 2 based on lane distribution at site 1.

Distance Reference Point	Light Volume Lane	Expected Limit: Lower	Expected Limit: Upper	Observed	Distance Reference Point	Light Volume Lane	Expected Limit: Lower	Expected Limit: Upper	Observed
1	1	0	0	0	4	2	37	61	58
2	1	28	51	12[a]	5	2	28	51	46
3	2	51	77	88[a]					

[a]Observed value at site 2 falls outside the range of values expected 95 percent of the time based on the traffic pattern of lane placement at site 1.

If the off-ramp was an influence, it would seem to have delayed the traffic and slowed speeds rather than to have increased speeds. In the author's opinion, the main factor was the presence, in full view of the driver, of heavy equipment and construction activity on the roadway at site 2. At site 1 no construction or maintenance activity was visible on the through roadway to stimulate the drivers' desire for safety. This is a topical area of freeway maintenance research for further study.

Weaving and Merging During Advance Warning

Time-lapse photography data on the weaving between traffic streams and merging-diverging manuevers of traffic streams were analyzed in order to gain further insight into the differences in traffic operations between site 1 and site 2. The camera was positioned as far away from the point where 1 of the 2 lanes was closed as was physically possible. The constraint on camera location at both site 1 and site 2 was the farthest vantage point from which a full view of both the vehicles and the roadway could be maintained (Figs. 3 and 4). At site 1 the camera was about 2,000 ft from the point where lane 1 (outside lane) was closed completely. The camera at site 2 was about 1.1 miles from the point of closure on lane 1.

The lane distribution of vehicles approaching the weave speed control section is given in Table 3. Distance reference point 1 is the point where the traffic cones completely blocked the curb lane, reference point 2 is at the beginning of the traffic cone taper, and reference points 3, 4, and so on are at the locations of the major signs successively more distant from the beginning of the taper. Four film samples were available from site 1, and 1 sample was available from site 2. Data sampling is not so unbalanced as it might seem superficially. Site 1, which has an exit ramp, sharp changes in vertical alignment, and a limited distance over which unfamiliar drivers had full view of the temporary traffic control system, could have been expected to produce large variations in lane placement. The data collected and analyzed, however, yielded quite consistent lane-distribution percentages as given in Table 3.

It was of interest to estimate what the effect of the exit ramp is on traffic. At site 1 the exit ramp traffic was 34 percent of the total volume, so it could have been a major influence causing the differences in lane placement. The lane distribution at each reference point at site 1 was taken as the reference basis for a binomial probability expectation of the number of vehicles to be found in the light volume lane at site 2. If the traffic were similar in behavior (that is, the exit ramp has no effect on lane distribution), the expected range of vehicles predicted at site 2 based on site 1 data should include the actual observed vehicle count. To calculate the expected range, we used the normal distribution approximation to the binomial and chose a 0.05 significance level. The results are given in Table 4. At reference points 2 and 3 the lane distribution at site 1 fails to predict the number of vehicles at the corresponding point at site 2. Reference point 3 is at the beginning of the exit ramp deceleration lane taper, and reference point 2 is 650 ft farther (just beyond the exit ramp gore for site 2). Reference point 4 is 500 ft upstream from reference point 3. These results can be interpreted to mean that the effect of the percentage of the exiting traffic only extended for about 500 ft each side of the exit ramp itself.

At each site the proportion of traffic that was local in nature might be a factor in the degree to which the exit ramp traffic influenced lane placement. At site 1 samples of license plates indicated that during the studies 27 percent of the vehicles were registered in the local county, 15 percent were registered in other Iowa counties, and 58 percent were out-of-state vehicles. At site 2 the same categories were 28, 42, and 30 percent respectively. Although the relative proportion of vehicles that were out of state and Iowa but not local were quite different at the 2 sites, the percentage of local vehicles was nearly identical. It does not appear that vehicles representing repeat drivers through the site are significant enough to bias the findings. If no temporary traffic controls were in effect, the high percentage of exiting traffic should encourage the through traffic to move left into lane 2 in the vicinity of the exit ramp. However, far more traffic stayed in the outside lane and merged left as it approached the traffic cone taper than did so at site 2 where no exit ramp influenced the traffic (Table 4).

If the exit ramp traffic at site 1 confused the through drivers, or if the through drivers in lane 1 constrained the exiting traffic, then some hazardous or unusual traffic maneuvers in the vicinity of the exit ramp should be observed. A total of 1,636 consecutive vehicles were analyzed in detail for lane changing and shifting of positions within the traffic stream as it moved through the exit ramp area. Of these, 2 vehicles exited from the median lane in front of a platoon in the right lane and 1 vehicle stopped in the curb lane at the start of the traffic cone taper. This indicates that the communication with the driver is at least adequate. Drivers apparently can perceive what is required of them to negotiate the speed control weave without unduly interfering with the traffic, which is more concerned with the permanent road signs for exits and so on.

GENERAL CONCLUSIONS

Based on the somewhat limited data provided by a research initiation project, the control of freeway traffic through a maintenance or reconstruction area by the use of the Iowa State Highway Commission weave pattern is a safe and effective operation. Speeds through the areas where work is in progress are controlled significantly better with the use of the ISHC pattern than with the use of signs alone. Driver communication is adequate for safe lane changing under the present light-to-moderate volumes experienced on Iowa Interstate routes.

FURTHER QUESTIONS

As in any new research, more questions were raised in this study than were answered. The following are some of these.

1. How far back from the lane closure do drivers react to the warning signs?
2. Are there more effective communication means that can reduce the amount of signing and thereby reduce the cost of control?
3. What is the capacity of the weave speed control section for various rates of taper within the weave section?
4. What are the ranges of traffic volumes over which this weave section is effective? How is its volume-capacity ratio related to its effectiveness?
5. How significant is platoon behavior in communicating the proper movement through the control section to following drivers?

Perhaps some of these questions can be answered in the future. Before general application of this unique control scheme is attempted, it would be helpful to be able to predict its usefulness, effectiveness, and relative safety.

ACKNOWLEDGMENTS

This work was supported by the Engineering Research Institute at Iowa State University through funds provided by the National Science Foundation. The cooperation of personnel of the Iowa State Highway Commission is acknowledged, especially that of Robert Shelquist and Harold Dowden. The assistance of my sons, Michael and Jebel, who donated their services in data collection, is also acknowledged.

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