Field Evaluation of Traffic Management Strategies for Maintenance Operations in Freeway Middle Lanes

Stephen H. Richards and Conrad L. Dudek, Texas Transportation Institute, Texas A&M University, College Station, Texas

This paper presents results of field studies conducted in Houston, Texas, to evaluate the performance of two innovative approaches for managing traffic during maintenance operations in the middle lane of an urban freeway. The two approaches, traffic shifting with use of the shoulder and traffic splitting, were used by District 12 of the Texas State Department of Highways and Public Transportation during pavement repairs on Interstate 45. The results of the studies indicate that, compared to the multilane closure strategy commonly used at middle-lane work sites (closure of an exterior lane and one or more adjacent middle lanes), both approaches significantly increased work-zone capacity. The studies revealed that (a) traffic shifting could be used to manage traffic at relatively long work sites on freeways with discontinuous shoulders and (b) shoulder use at sites where this strategy was employed was greatly influenced by traffic demand. Traffic splitting around an isolated, middle-lane work site, on the other hand, was used effectively at a relatively short work site on a freeway section that did not have shoulders.

The Texas Transportation Institute is conducting research into traffic management at urban freeway work zones. The research is an attempt to develop more effective traffic-control systems for temporary work zones on urban freeways.

Project field studies have been conducted in Texas to evaluate standard and innovative practices associated with handling traffic through urban freeway work areas. The results of these studies indicate that managing traffic during maintenance activities in the middle lanes (on freeways with three or more lanes in each direction) is a difficult task and that problems often arise related to insufficient work-zone capacity. On the positive side, the studies have revealed innovative management strategies for handling traffic at middle-lane work sites that minimize the reduction in work-zone capacity and thus alleviate many of the inherent problems.

BACKGROUND

Maintenance work in the median lane or shoulder lane of an urban freeway is accommodated by closure of a single lane. Closure of either of these exterior lanes is relatively easy to achieve and, compared to more extensive management strategies (i.e., detours, crossovers, and multilane closures), this approach has minimum negative effects on freeway traffic operation.

The multilane closure strategy illustrated in Figure 1 is commonly used to accommodate work on the middle lane of an urban freeway. The multilane closure strategy involves closing an exterior lane and one or more adjacent middle lanes (1).

The major disadvantage of the multilane closure strategy presented in Figure 1 is the resulting loss of freeway capacity. The extent of the capacity reduction is illustrated by the data in the table below, which are based on studies made by Forbes and others on Los Angeles area freeways (2). The observed capacity data were collected on four-lane sections (in each direction) that were reduced to two lanes to accommodate maintenance work.

Type of Work	Observed Capacity (vehicles/h)
Median barrier or guardrail repair	3200
Pavement repair, mudjacking, or pavement grooving	3000
Resurfacing, slide removal, or striping	2600
Pavement marker installation	2400

From the table, note that capacity flow on four-lane freeway sections reduced to two lanes to accommodate maintenance work ranged between 2400 and 3200 vehicles/h (vph). These flow rates are 30.0-40.0 percent of the theoretical capacity (8000 vph) of a four-lane freeway section. In addition to the work done by Forbes and others, we have evaluated the capacity of three-lane freeway sections reduced to one-lane operation during resurfacing activities. The observed capacity of the one open lane was approximately 25 percent of the theoretical capacity (6000 vph) of a three-lane freeway section. Capacity flow in the open lane ranged between 1550 and 1700 vph.

INNOVATIVE STRATEGIES

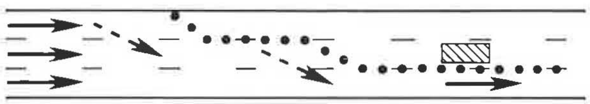
In recent years traffic on urban freeways in Texas has increased rapidly. On many facilities closing more than one lane to perform middle-lane maintenance work results in severe congestion, even during off-peak periods. The Texas State Department of Highways and Public Transportation is considering innovative traffic management strategies that increase capacity at middle-lane work sites, including two approaches used by District 12 during pavement repairs on a 4.0-km (2.5-mile) section of I-45 in Houston.

In April of 1978, state forces repaired potholes with asphaltic concrete in the northbound and southbound middle lane of a six-lane section of I-45 (three lanes in each direction). A work crew of approximately 10, along with several maintenance vehicles (i.e., asphalt trucks and a steel-wheeled roller), occupied the middle lane during work activities. As the work progressed, the location of the activity within the work zone moved slowly downstream at approximately 2 km/h (1 mph). The work took several days to complete.

Site Characteristics

The area of the repair work was a six-lane urban freeway facility with three 3.7-m (12-ft) lanes in each direction. It has 3.0-m (10-ft) outside shoulders and 2.4-m (8-ft) inside shoulders; however, the shoulders are discontinued at overpasses and bridge structures. Access

Figure 1. Multilane closure strategy used for middle-lane maintenance operations.



to and from the freeway is provided by right-hand slip ramps, which connect to parallel continuous frontage roads. In the study area, I-45 has an approximate average daily traffic (ADT) of 120 000.

Traffic Management Plan

The primary feature of the traffic management plan was the use of innovative approaches to increase work-zone capacity. To accommodate work on sections with shoulders, traffic was shifted out of the median and middle lanes and encouraged to use the shoulder lane and outside shoulder as travel lanes. To accommodate work on bridges and overpasses without shoulders, the middle lane was closed. Traffic was split around the middle-lane work area and motorists were permitted to travel in the median and shoulder lanes. The two strategies (traffic shifting with use of the shoulder and traffic splitting) were not used at the same time.

To reduce demand on the main traffic lane, entrance ramps were closed in the 4.0-km (2.5-mile) work area. Generally, two to four ramps were involved. Motorists who normally use these ramps had to remain on the frontage road and enter the freeway downstream of the work area. Frontage road signalization was not modified.

Traffic Control at Locations with Shoulders

Figure 2 shows the traffic-control devices used to manage traffic in the main lane during work on sections that have shoulders. All signs shown in the figure were temporary work-zone signs and had a black legend on an orange background.

The approach illustrated in Figure 2 made use of a typical multilane closure (presented in Figure 1) to remove traffic from the work-occupied middle lane. Motorists, however, were encouraged, by the use of special signs and cones, to use the outside shoulder as an additional travel lane. This management approach was fashioned after a similar approach developed by the California Division of Highways (2). Experience in California indicated that the strategy increased work-zone capacity significantly on a four-lane freeway section that has continuous shoulders, and motorists tended to use the shoulder only when congestion existed.

Comparison of the situation in the Houston studies to that studied in California reveals a major difference: The shoulders at the Houston sites were not continuous. Motorists on the shoulder were moved off the shoulder in the vicinity of bridge and overpass structures, then encouraged to use the shoulder again immediately downstream of the structures.

Traffic Control at Locations Without Shoulders

Figure 3 shows the traffic-control scheme used to manage traffic during work on sections of I-45 that do not have shoulders. All signs shown in the figure were temporary work-zone signs. They had a black legend on an orange background, except for the flashing arrow board and specially fabricated symbolic signs, which warned motorists of the traffic split. The symbolic traffic split signs had a black legend on a yellow background.

The management approach illustrated in Figure 3 is not a new concept, but it does have an innovative feature. Note in the site layout that cones were placed on the lane line between the middle and shoulder lanes to discourage lane weaving. These cones extended 150 m (492 ft) upstream of the taper closing the middle lane. Sight distance to the actual closure was approximately 400 m (1312 ft).

FIELD EVALUATION

Methods for evaluation of the innovative traffic management approaches used by District 12 were developed in response to the actual work performed. No attempt was made to control site variables or alter the work activities; therefore, the type and amount of data collected are somewhat limited. Nevertheless, sufficient data were collected to report significant findings.

Data were collected at work sites in the northbound and southbound middle lanes of I-45, where the shifting strategy was used. Manual traffic counts were made at several locations, and traffic operation was documented on videotape and 8-mm movies. Approximately 4 h of data were collected during a two-day study period.

Shoulder Use

Lane distribution data were collected during work activities. Figure 4 shows the location of the lane distribution count stations relative to the lane closures and shoulder-use signing. Station 1 was located downstream of the median-lane closure, near the first shoulder-use sign (CARS MAY USE SHOULDER 500 FT AHD). Station 2 was located approximately 150 m (492 ft) downstream of the point where use of the shoulder was first encouraged. The middle lane was still open to traffic at this point. Station 3 was located near the work activity and downstream of the start of the middle-lane closure.

Table 1 summarizes the lane distribution data. From the table, note that no drivers were observed traveling on the shoulder at station 1. Only a few drivers were observed using the shoulder (1.2-2.9 percent) at station 2. By the time drivers reached station 3, however, a significant number were using the shoulder. For example, during studies conducted when the flow rate through the work site was approximately 2400 vph, 38.1 percent of the traffic in the main lane was observed using the shoulder at station 3.

The increased shoulder use at station 3 is probably due to two factors: (a) The middle lane was closed at station 3, resulting in greater lane volumes and more congestion at this location compared to station 2; and (b) drivers had more time to read the signs and observe the action of other drivers by the time they reached station 3.

Influence of Shoulder Use on Capacity

Traffic counts of the main lane were made in the vicinity of the work activity to assess the ability of the strategy to increase work-zone capacity. Table 2 presents data on counts made during the period of heaviest observed flow. The data represent demand flows rather than capacity flows; demand never exceeded work-zone capacity. Nevertheless, the data in the table indicate that driver use of the shoulder as a travel lane increased work-site capacity well above capacities observed at similar sites where the multilane closure strategy (Figure 1) was used.

Note in the table that flow rates based on 5-min counts ranged from 2160-2616 vph. These flow rates represent a substantial increase over observed capacities (1550-1700 vph) at sites where the multilane closure strategy was used.

As reported in the California studies, the shifting strategy successfully increased work-zone capacity. In California the strategy permitted average hourly lane flows up to 1333 vph (total flow averaged over two available lanes and the shoulder). Lane flows up to 1308 vph were observed in the Houston studies (total flow averaged over one available lane and the shoulder).

Figure 5 illustrates the influence of traffic demand on shoulder use. Note from the figure that more drivers

Figure 2. Traffic-control strategy used during work on sections with shoulders.

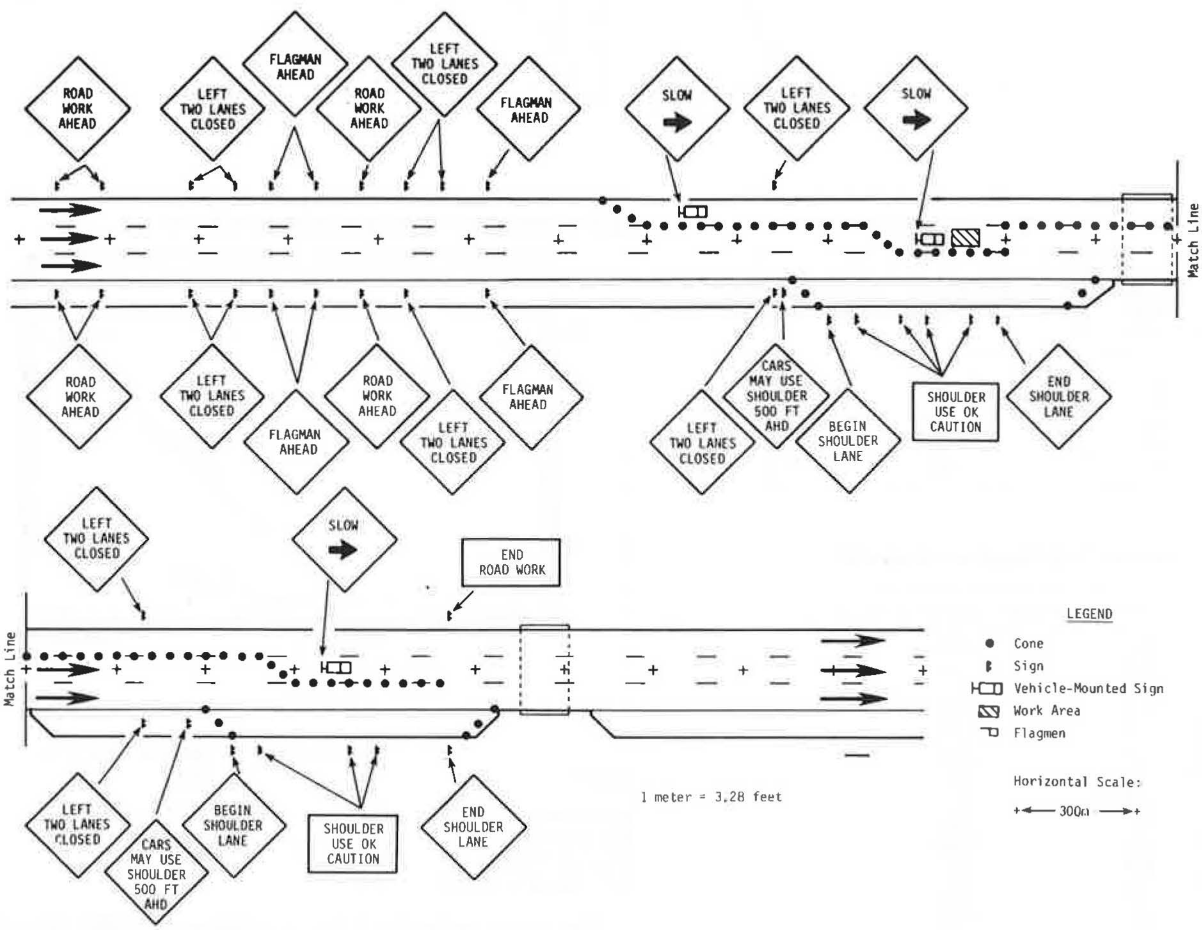


Figure 3. Traffic-control strategy used during work on sections without shoulders.

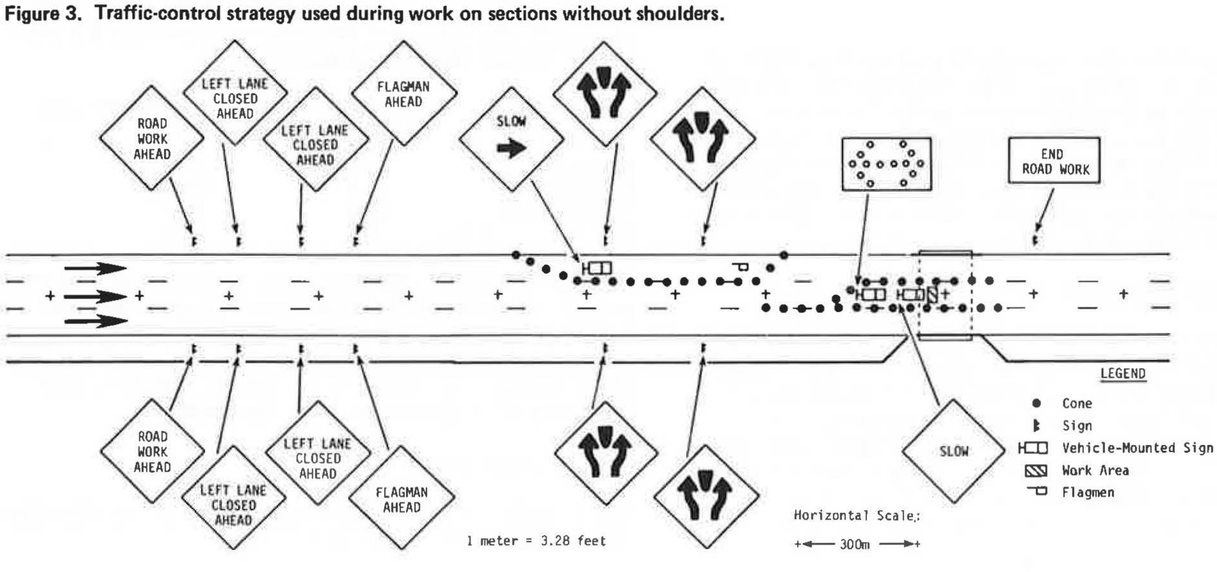


Figure 4. Lane distribution count stations—traffic shifting with use of the shoulder.

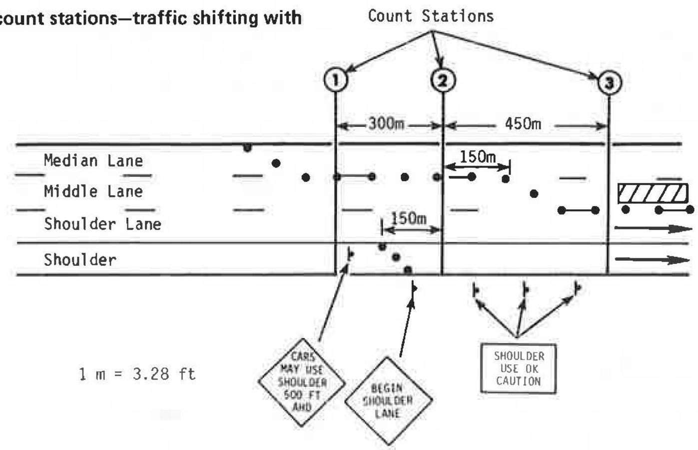


Table 1. Lane distribution data—traffic shifting to use the shoulder.

Flow Rate (vph)	Station	Study Time (min)	Total Traffic: Middle Lane (%)	Total Traffic: Shoulder Lane (%)	Total Traffic: Shoulder (%)
1600	1	-	N/A	N/A	N/A
	2	10	20.6	78.2	1.2
	3	15	-	91.6	8.4
2400	1	70	42.1	57.9	0
	2	30	34.7	62.4	2.9
	3	75	-	61.9	38.1

Table 2. Volume data—traffic shifting to use the shoulder.

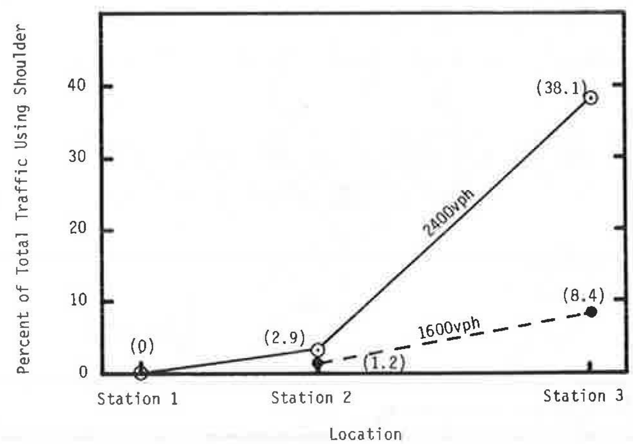
Time Period	Observed Volume	Hourly Flow Rate
11:00-11:05 a.m.	192	2304
11:05-11:10 a.m.	184	2208
11:10-11:15 a.m.	188	2256
11:15-11:20 a.m.	200	2400
11:20-11:25 a.m.	212	2544
11:25-11:30 a.m.	211	2532
12:15-12:20 p.m.	209	2508
12:20-12:25 p.m.	186	2232
12:25-12:30 p.m.	218	2616
12:30-12:35 p.m.	195	2340
12:35-12:40 p.m.	196	2352
12:40-12:45 p.m.	215	2580
12:45-12:50 p.m.	200	2400
12:50-12:55 p.m.	193	2316
12:55- 1:00 p.m.	180	2160
Average	199	2388

used the shoulder when the traffic demand was 2400 vph than when it was 1600 vph. This supports the finding of the California study that little or no traffic will use the shoulder until some degree of congestion develops. The difference in the shoulder-use rates at the two levels of volume (1600 vph and 2400 vph) was most pronounced at station 3, where the middle lane was closed. There was more congestion associated with this location.

Shoulder Use by Vehicle

The advance sign installed to encourage use of the shoulder read CARS MAY USE SHOULDER 500 FT AHEAD, which implied that only automobiles should use the shoulder. This message was selected to discourage truck traffic from using the narrow and structurally inadequate shoulder. The data presented in the tables below indicate that the subtle message did influence driver action; however, many trucks were observed on the shoulder.

Figure 5. Influence of traffic demand on shoulder use.



Vehicle	Shoulder Used (%)	Shoulder Not Used (%)
Automobile	9.3	90.7
Pickup and van	8.1	91.9
Truck and bus	2.6	97.4
All vehicles combined	8.4	91.6

The above table gives the percentage of traffic by vehicle type that used the shoulder when main-lane demand was approximately 1600 vph. From the table, 9.3 percent of all automobiles used the shoulder, 8.1 percent of pickup trucks and vans used the shoulder, but only 2.6 percent of trucks used the shoulder.

Vehicle	Shoulder Used (%)	Shoulder Not Used (%)
Automobile	40.2	59.8
Pickup and van	41.6	58.4
Truck and bus	25.3	74.7
All vehicles combined	39.1	60.9

This table presents the same information collected during periods when the demand increased to approximately 2400 vph. Under these higher-volume conditions, 40.2 percent of the automobiles used the shoulder, 41.6 percent of the pickup trucks and vans used the shoulder, and 25.3 percent of the trucks used the shoulder.

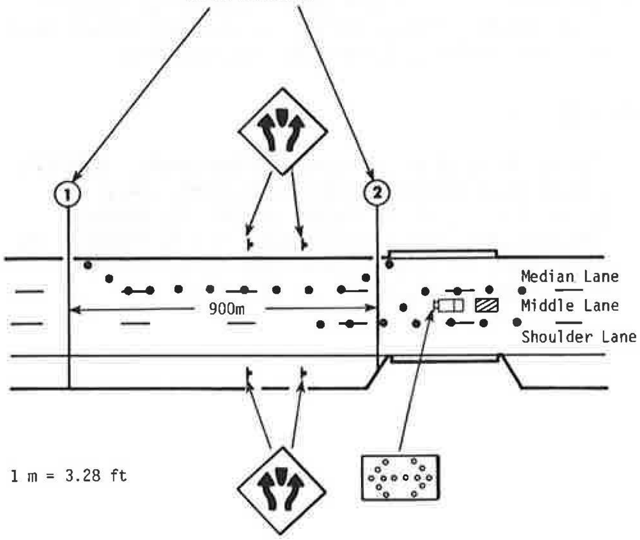
Other Observations

The following special observations were made about the performance of the strategy:

Table 3. Volume data—traffic splitting.

Time Period	Observed Volume	Hourly Flow Rate
10:35-10:40 a.m.	206	2472
10:40-10:45 a.m.	192	2304
10:45-10:50 a.m.	214	2568
10:50-10:55 a.m.	218	2616
10:55-11:00 a.m.	180	2160
11:00-11:05 a.m.	244	2928
Average	209	2508

Figure 6. Lane distribution count stations—traffic splitting.



1. Shoulder-use signing was not erected until after the median and middle lanes had been closed for 15 min. Therefore, for a brief time, all freeway traffic was funneled into the shoulder lane. Some queueing resulted, but the queue quickly dissipated after the shoulder-use signing was erected.

2. On the first day of operation, freeway demand was greatly reduced by closing several entrance ramps in the vicinity of the work. The result was extremely light flow on the freeway and severe congestion on the parallel frontage road. During this period, use of the shoulder was minimal and several vehicles drove across the outer separation to gain access to the freeway and avoid lengthy delays at signalized frontage-road intersections. State forces later took corrective action and reopened a high-volume entrance ramp.

3. The freeway cross-section included acceleration-deceleration lanes in the vicinity of ramps. Motorists attempted to form an additional travel lane at these locations, even though the added pavement width eventually was discontinued.

Traffic Splitting

The work schedule permitted data collection for a one-day period at a middle-lane work site on I-45 where the splitting strategy was employed. Manual traffic counts were made at two locations and traffic operation was documented on videotape and 8-mm movies during the one-day study.

Counts were made in the main traffic lane in the vicinity of the work activity to determine flow rates through the work site. A summary of the count data is presented in Table 3. The volume data in the table represent demand flows rather than capacity flows; however, field observations suggest that the work site was operating just below capacity. From the table, flow rates based on 5-min volume counts ranged from 2160 to 2928 vph. These flow rates represent a substantial increase over observed capacities (1550-1700 vph) at similar sites where the multilane closure strategy (Figure 1) was used. The average flow rate during a 30-min study period in which demand was highest was 2508 vph.

Figure 6 shows the location of the two-lane distribution count stations. Station 1 was approximately 150 m (492 ft) upstream of the median lane closure. Station 2 was at the beginning of the middle lane closure. The table below summarizes the lane distribution data. It shows that 59.8 percent (7.7 + 52.1 percent) of the traffic was in the median and middle lanes at station 1 and 40.2 percent was in the shoulder lane. The distribution did not change greatly at station 2, where 56.5 percent of the observed traffic was in the middle lane (the median lane was closed) and 43.5 percent of traffic was in the shoulder lane.

		Total Traffic		
Station	Study Time (min)	Median Lane (%)	Middle Lane (%)	Shoulder Lane (%)
1	30	7.7	52.1	40.2
2	30	-	56.5	43.5

The number and direction of lane changes that occurred in a section 300 m (984 ft) immediately upstream of the middle-lane closure were recorded. During the study period, only seven vehicles, or 1.5 percent of the total vehicles, changed lanes within this critical zone. Three of the seven lane changes were from the middle lane to the shoulder lane and four of the lane changes were from the shoulder lane to the middle lane.

Based on observed lane-change maneuvers and flow past the work site, the strategy appeared to provide an adequate level of safety to both motorists and work crew. This fact, combined with the increased work-zone capacity achieved, indicates that traffic splitting is a useful strategy for managing traffic at relatively short, middle-lane work sites where no shoulders exist.

During the installation and removal of middle-lane-closure devices (i.e., cones and arrow board), the three-lane freeway section was reduced to one-lane operation. Some congestion and motorist confusion resulted.

SUMMARY OF FINDINGS

Results of the field studies indicate that both approaches, traffic shifting with use of the shoulder and traffic splitting, increased work-zone capacity significantly. Specific findings associated with the approaches are enumerated below.

Traffic Shifting with Use of the Shoulder

1. Demand flows up to 2616 vph were accommodated without traffic queueing by use of this strategy on the three-lane study section. This flow rate represents a substantial increase over observed capacities (1550-1700 vph) at sites where the multilane closure strategy (Figure 1) was used. It also indicates that the strategy can be effective on freeway sections that have discontinuous shoulders.

2. More traffic used the shoulder at locations where only the shoulder lane and shoulder were open to traffic than at locations where the middle lane was also open.

3. During study periods when the demand flow was approximately 2400 vph, up to 38.1 percent of the amount of traffic in the main lane used the shoulder. At flow rates of 1600 vph, however, the percentage dropped to 8.4 percent.

4. The shoulder-use signing implied that only automobiles could use the shoulder. This implication may have caused drivers of trucks and buses to be more hesitant in the use of the shoulder than drivers of automobiles, pickups, and vans. Despite the reference only to automobiles, however, up to 25.3 percent of the trucks and buses used the shoulder.

Traffic Splitting

1. This strategy accommodated demand flow rates at the study site ranging from 2160-2928 vph. As flow rates approached the upper value (2928 vph), some queueing was observed, which indicates that capacity flow was approximately 3000 vph. This flow rate represents a substantial increase over observed capacities (1550-1700 vph) at sites where the multilane closure strategy (Figure 1) was used.

2. Lane distribution did not change significantly in the vicinity of the work site. Only 1.5 percent of the vehicles approaching the work zone changed lanes in a 300-m (984-ft) section immediately upstream of the taper that closed the middle lane.

3. Traffic cones were placed on the lane line between the middle lane and shoulder lane for a distance of 150 m (492 ft) upstream of the taper closing the middle lane. These cones appeared to be effective in reducing the number of sudden lane changes and other erratic maneuvers within this critical area.

ACKNOWLEDGMENT

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