Capacity of Freeway Work Zone Lane Closures

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INTRODUCTION

The Iowa Department of Transportation (DOT), like many other state transportation agencies, is experiencing growing congestion and traffic delays in work zones on rural interstate highways. The congestion has resulted from unprecedented growth in traffic on rural segments of Iowa interstates. Traffic volumes have reached levels that are unlike those experienced in the past. The congestion on rural interstates is particularly problematic because in rural areas there are few, if any, parallel diversion routes and through traffic, traveling long distances, may be relatively unfamiliar with local conditions and alternative routes. In addition, drivers are generally unaware of the work zone and do not expect heavy congestion in rural Iowa.

The congestion results in unproductive and wasteful delays for both motorists and commercial vehicles. It also results in hazardous conditions where vehicles, stopped in queues on rural interstate highways, are being approached by vehicles upstream at very high speeds. The delay also results in driver frustration, making some drivers willing to take unsafe risks in an effort to bypass delays. To reduce the safety hazards and unproductive delays of congested rural interstate work zones, the Iowa DOT would like to improve its traffic management strategies at these locations in the future.

During the summer of 1998 the Center for Transportation Research and Education (CTRE) at Iowa State University observed a work zone on a rural Iowa interstate highway to measure the volume of vehicles that can pass through a work zone lane closure prior to and during congested operations and to better understand related driver behaviors. One unique aspect of the research we conducted at this lane closure was to observe the rate at which the queue grows (more cars joining the end of the queue than leaving the front of the queue) and the rate at which the queue declines in length. It was found that the queue grows and declines in surges. When it grows, the queue moves backward, and when it shrinks it moves forward. Backward-moving queues grow at rates as high as 30 to 40 miles per hour. This means that as a vehicle approaches the end of the queue at normal highway speeds, for example, 65 miles per hour, a backward-moving queue could be moving toward them, for example, at 35 miles per hour. This results in the end of the queue approaching a vehicle at 100-miles per hour which violates the expectations of the driver and creates a relatively unsafe condition.

This paper reports on part of the research that was done by CTRE for the Iowa DOT to evaluate the capacity of lane closures and driver behavior. A companion paper describes a simulation model that was developed to analyze the driver behavior and emulate the benefits of advanced traffic control at work zone lane closures (*1*).

PRIOR MEASURES OF CAPACITY AT LANE CLOSURES

Most highway agencies simply use the methods described in the *Highway Capacity Manual* to determine the capacity of a lane closure at an interstate work zone (*2*). The capacity estimates in the *Highway Capacity Manual* are based on the work done at the Texas Transportation Institute (TTI) by a variety of investigators over a number of years from the late 1970s and the mid-1980s. This work is based on data collected as part of the Texas Department of Transportation's "Study 292."

Queue and User Cost Evaluation of Work Zones (QUEWZ) is a software package used by many state transportation agencies to determine estimated delays, the length of queues, and user costs due to work zone lane closures. QUEWZ also originated from the same research program conducted at TTI. Later (1987-1991), field data collections were conducted by TTI to update the capacity values and to revise and improve QUEWZ (*3*). One of the more significant impacts of the updates was to change the factor for equating heavy trucks to passenger cars from 1.7 to 1.5. More recently, two studies have been done in North Carolina and in Indiana to try to determine the capacity of lane closures on interstate highways in those states.

Before investigating prior estimates of capacity, it should be recognized that not all estimates of capacity at lane closures are measured using the same criteria. The work done by TTI defined capacity as the hourly traffic volume under congested traffic conditions (*4*). The TTI researchers identified capacity as full-hour volumes counted at lane closures with traffic queued upstream. They considered consecutive hours at the same location as independent studies. A Pennsylvania study defined the hourly traffic volume converted from the maximum-recorded five-minute flow rate as the work zone capacity. A California study measured volumes for three-minute time intervals during congested conditions. Two, three-minute time intervals, separated by one minute, were then averaged and multiplied by 20 to determine the one-hour capacity values (*5*). All of these studies considered the flow passing through a lane closure under congested conditions to be the capacity.

Dixon and Hummer define work zone capacity as the flow rate at which traffic behavior quickly changes from uncongested conditions to queued conditions (*6*). Jiang defines capacity as the flow just

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before a sharp speed drop followed by a sustained period of low vehicle speeds and fluctuating traffic flow which defines the formation of a queue. It is Jiang's contention that what TTI was measuring was not capacity of the bottleneck but rather the queue discharge rate (*7*).

TTI work zone capacity research published in 1982 was used as a basis for the methods for determining work zone capacity as described in the 1985 *Highway Capacity Manual* (as well as the 1994 manual). This work was based on hour-long data collected on urban Texas freeways with lane closures. The applications of these data may be difficult to extrapolate to other locales due to the differences in driver behavior and differences in design of urban Texas interstate highways. Texas makes extensive use of frontage roads, making it much easier for motorists to bypass congested segments of highway.

The work conducted by TTI as part of Study 292 and work by other institutions and other individuals have resulted in a wealth of literature reporting on the measurement of queue discharge rates at work zones under a variety of factors which impact capacity. For example, one study investigated the sensitivity of capacities to the use of shoulders during lane closures and to splitting traffic when a center lane is closed (*8,9*). Some have looked at the type of traffic control devices and their placement and how they impact capacity and delay. Others have investigated pavement conditions, night versus day, traffic volumes and traffic composition, merge discipline and speed control strategies, and the duration of work zones (short-term versus long-term) (*8,10,11*). Still others have investigated the relationship of the location of construction work to the traffic lane (*6,8,12*).

The work Dixon and Hummer completed on capacities and delays at work zones conducted for the North Carolina Department of Transportation in 1996 probably provides the most significant inference for Iowa. The North Carolina study included field data collected under conditions similar to those of interest to Iowa: lane closures on two-lane rural interstate highways. The North Carolina study used a more relevant measure of capacity for a lane closure than the TTI researchers. The North Carolina researchers defined capacity as the traffic volume immediately before queuing begins.

An important and unique finding of the North Carolina study is the identification of the location within a work zone that governs maximum traffic flow through the work zone. The location tends to vary with traffic conditions and with construction work activities. The work done by TTI has assumed that the feature governing the maximum traffic flow is the point at the end of the taper. Dixon and Hummer report that the maximum flow is governed by three locations. The segment of the work zone travel path adjacent to the work area controls the maximum flow where the construction work activity is heavy, meaning large equipment and workers adjacent to the travel path. Under conditions where the work activity is low, then the maximum flow (prior to queue formation) is governed by the end of the merge taper. However, when the work activity is heavy, the maximum traffic flow was found to be about seven percent less than the maximum flow at the taper end for work zones on two-lane rural interstate highways. When a queue has formed, the maximum flow is governed by the merging activity upstream from the work zone. In other words, once a queue has been formed, the maximum flow of the entire work zone is governed by the rate at which traffic can be discharged from the queue, which is generally at a lower rate than the capacity of the taper end, accounting for capacity drop when a queue is formed.

Shown in Figure 1 is the traditional flow-speed relationship where the maximum flow (Q_m) is roughly half the free flow speed. This symmetrical relationship was reflected in flow-speed relationships identified in the *Highway Capacity Manual* until the 1990 interim edition. Starting with the 1990 interim manual, the top half of the curve was shown to be more flat, and the maximum flow is reached when speed declines by 14 percent rather than 50 percent.

Figure 2 shows a more realistic representation of the flow-speed relationship with three distinct portions of the relationship. The top half of the curve represents flow under uncongested conditions. The bottom portion of the curve represents flow during congestion. The reduction in maximum flow when traffic operation drops from uncongested to congested is the capacity drop. In other words, immediately before flow breakdown occurs, the flow rate is greater than after a flow breakdown. Therefore, when the queuing condition is reached, a capacity reduction (or drop) occurs (*13,14*). The capacity drop is due to turbulence in the traffic flow that results after a breakdown.

We did not observe a capacity drop in the data we collected at an Iowa work zone. However, in similar studies in North Carolina and Indiana, a significant capacity drop was observed (*7,15*). The capacity drop illustrates the importance of not allowing the traffic operations at a work zone lane closure to decline from uncongested to congested.

FIELD DATA COLLECTION

The site selected for data collection during the summer of 1998 is located on Interstate Highway 80 between U.S. 61 and Interstate Highway 74. Data were collected to determine the following:

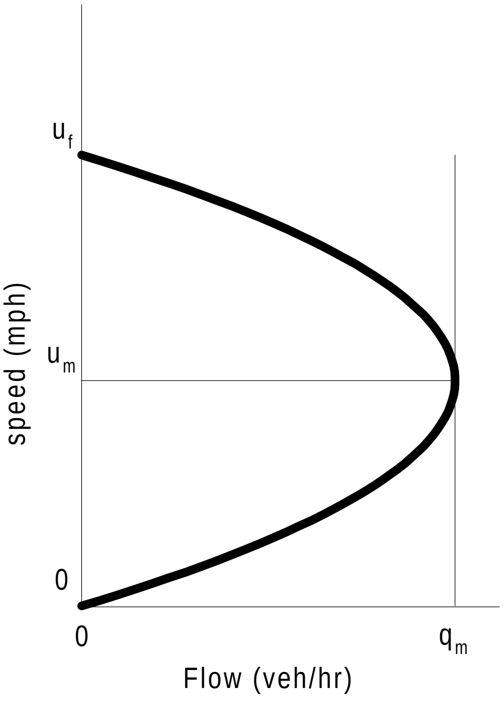

FIGURE 1 Traditional speed-flow relationship

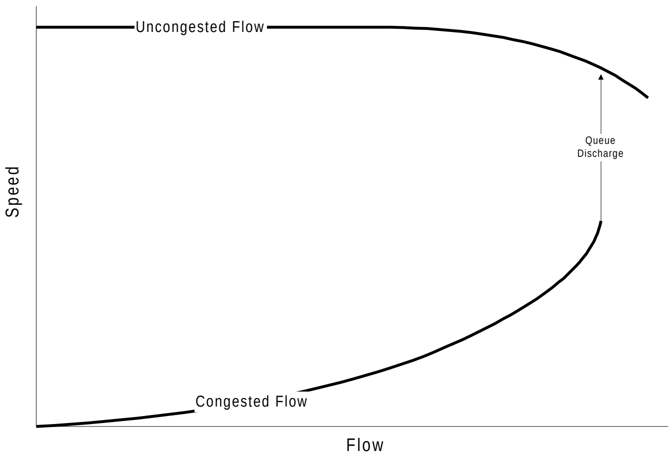

FIGURE 2 Revised speed-flow relationship

1. Traffic flow characteristics (speed, density, and volume) at the end of the lane closure taper.
2. Traffic flow characteristics upstream from the lane closure (500 feet or 152 meters upstream of the taper).
3. The length of the queue when congestion occurs. This is a measure of storage and the difference in queue length from one time to the next is the speed that the queue growths or is discharged.

Two trailers with 30-foot (9.14 meters) booms and two cameras on top of the booms were used to collect video. The video images were processed to derive the traffic flow data. A picture of one of the trailers is shown in Figure 3. A schematic of a typical data collection layout is shown in Figure 4.

FIGURE 3 Data collection trailer

DATA AND DATA ANALYSIS

The data collection trailers were positioned at the site for 19 days during the summer of 1998. Congestion was observed on only four days. Shown in Figure 5 is a plot of the data collected on July 2, 1998. The upper plot line shows the flow values in passenger car equivalents, summarized in 15-minute intervals. The lower line is the average speed over the same 15-minute interval. When queuing conditions exist (starting at 15:00) the average speed drops precipitously while the volume stays nearly constant before and after queuing. In other words, we did not observe a capacity drop.

To determine the maximum capacity of the lane closure, we took the average volume of the ten highest volumes immediately before and after queuing conditions. The lane closure capacities observed are listed in Table 1. Shown are both the highest and an average of the ten highest volumes to pass through the lane closure during an uncongested 15-minute period. Also, separate columns are shown for flows in vehicles and in passenger car equivalents.

TABLE 1 Volumes During Free Flow Conditions

		Unconverted Free-Flow Volumes		Converted Free-Flow Volumes	
Date	**Traffic Conditions**	**Highest Volume (veh/hr)**	**Mean of 10 Highest Volumes (veh/hr)**	**Highest Volume (pcph)**	**Mean of 10 Highest Volumes (pcph)**
6/19/98	Free Flow	1284	1216	1542	1374
7/2/98	Free Flow	1392	1302	1542	1442
7/10/98	Free Flow	1524	1438	1680	1630
8/7/98	Free Flow	1572	1375	1752	1493

The length of the queues for these dates was monitored, with the length to the nearest 0.05 miles recorded every minute. To accomplish this, the project team drove a vehicle on the opposite shoulder of the interstate in the direction of the westbound traffic. The team kept the vehicle even with the upstream end of the eastbound queue, and recorded the milepost readings from the delineator posts in the ditch. The lengths of the queues over time are shown for one day in Figure 6 for data collected on August 6, 1998. In Figure 6, the change in the length of the queue over the one-minute data collection interval was an indication of the speed with which the queue grows or dissipates. The speed of change in queue length is shown in Figure 7. Even averaged over an entire minute, speeds were recorded in excess of 30-miles per hour.

CONCLUSION

We found, through limited data collection, that capacities in rural Iowa work zone lane closures varied from roughly 1,400 passenger car equivalents to 1,600. We also found that through queues can move backward and forward at very swift rates, meaning that queuing vehicles at lane closures presents a very serious safety condition. However, the data collected by automated traffic recording devices along the I-80 corridor also show very consistent day of the

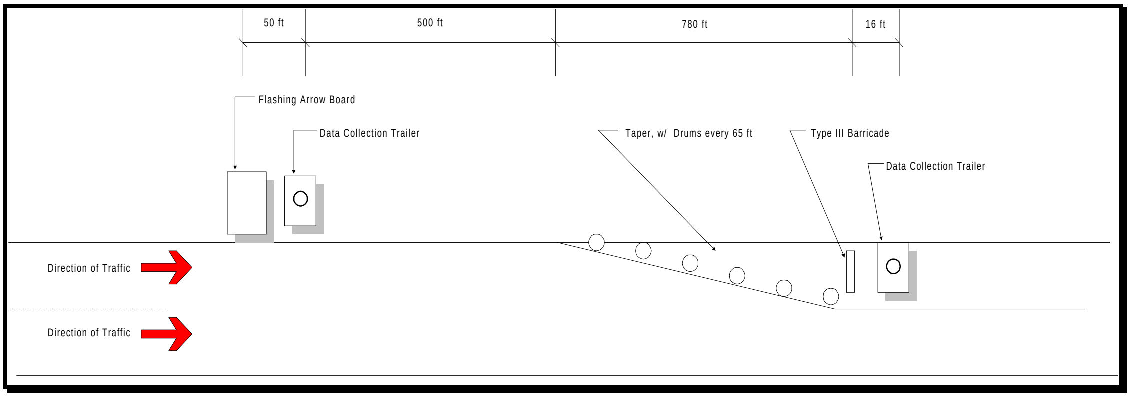

FIGURE 4 Typical data collection layout

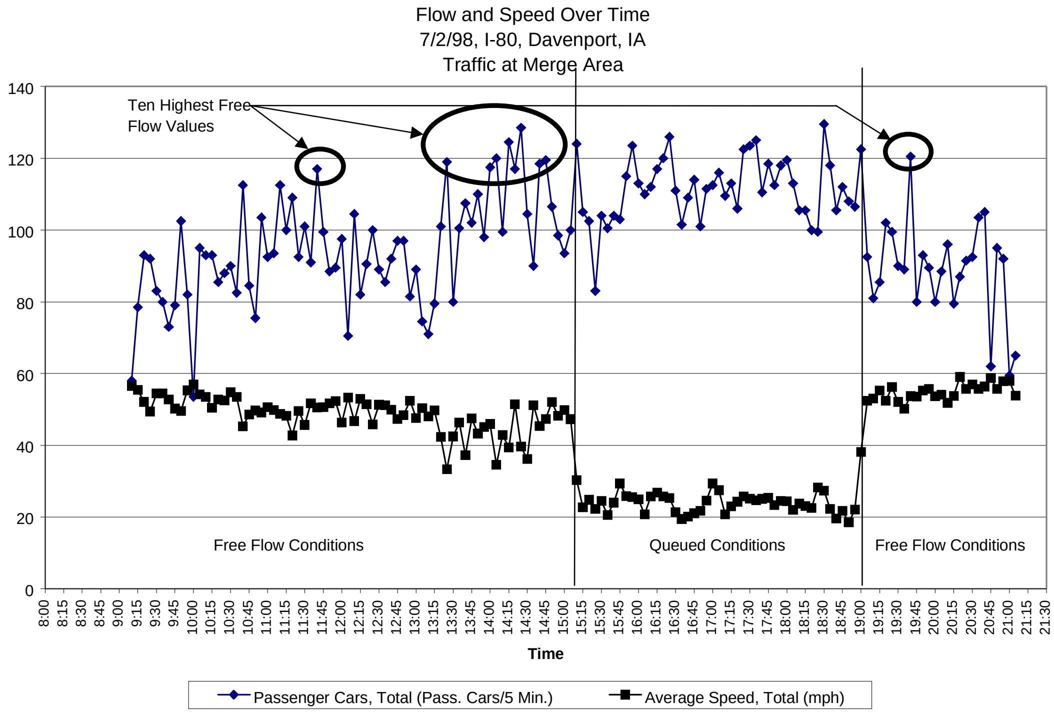

FIGURE 5 Volume and speed data collected atlane closure

week and time of day repeating patterns in traffic volumes. This means that given the likely traffic volume and measure of capacity, we can begin to contrast the historical volumes and begin to predict when congestion is going to occur and apply traffic management strategies to mitigate congestion. Possible strategies might include identifying diversion routes and informing drivers well in advance so they may select alternative routes or alternative times to travel. This information may be provided to drivers through a variety of possible traveler information systems.

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REFERENCES

1. Kamyab, A., T. Maze, M. Nelson, and S. Schrock. Using Simulation to Evaluate the Performance of Smart Workzone Technologies and Other Strategies to Reduce Congestion, *Proceedings for the 6th World Congress on Intelligent Transport Systems*, Toronto, Canada, November 1999.
2. Highway Capacity Manual, *Transportation Research Board Special Report 209*, Washington, D.C., 1994.
3. Krammes, R.A. and G.O. Lopex. *Updated Short-Term Freeway Work Zone Lane Closures Capacity Values.* Prepared by the Texas Transportation Institute for the Federal Highway Administration and for the Texas Department of Transportation, Austin, TX, Report No. FHWA/TX-92-/1108-5, 1992.

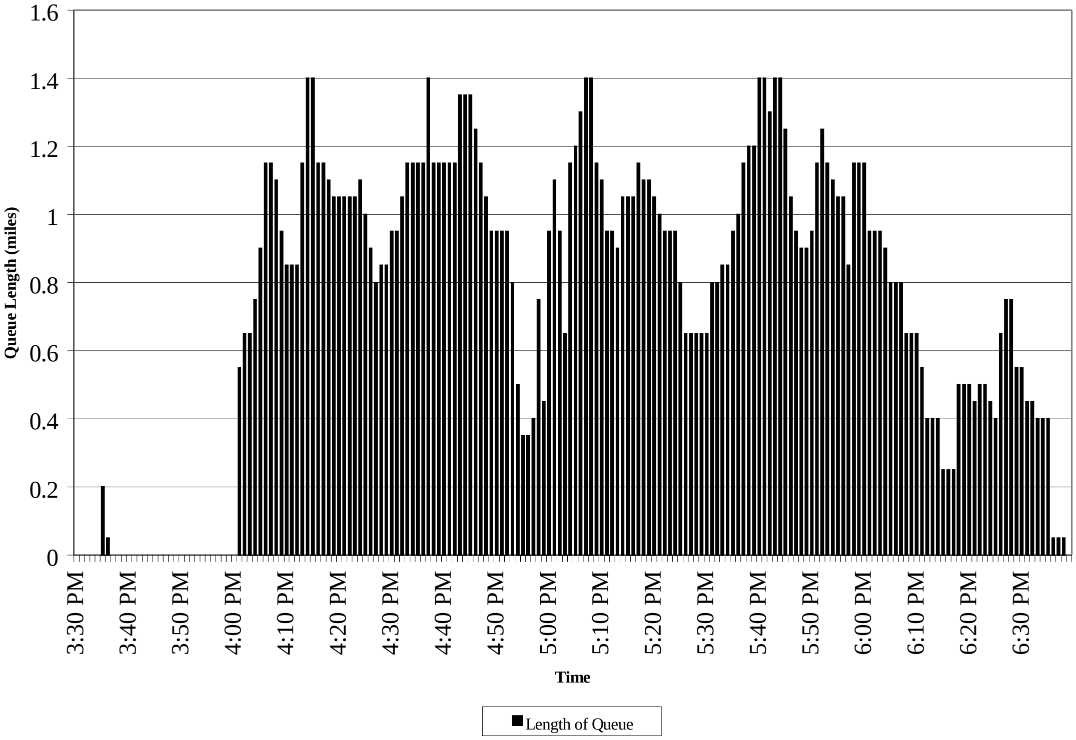

FIGURE 6 Queue length data

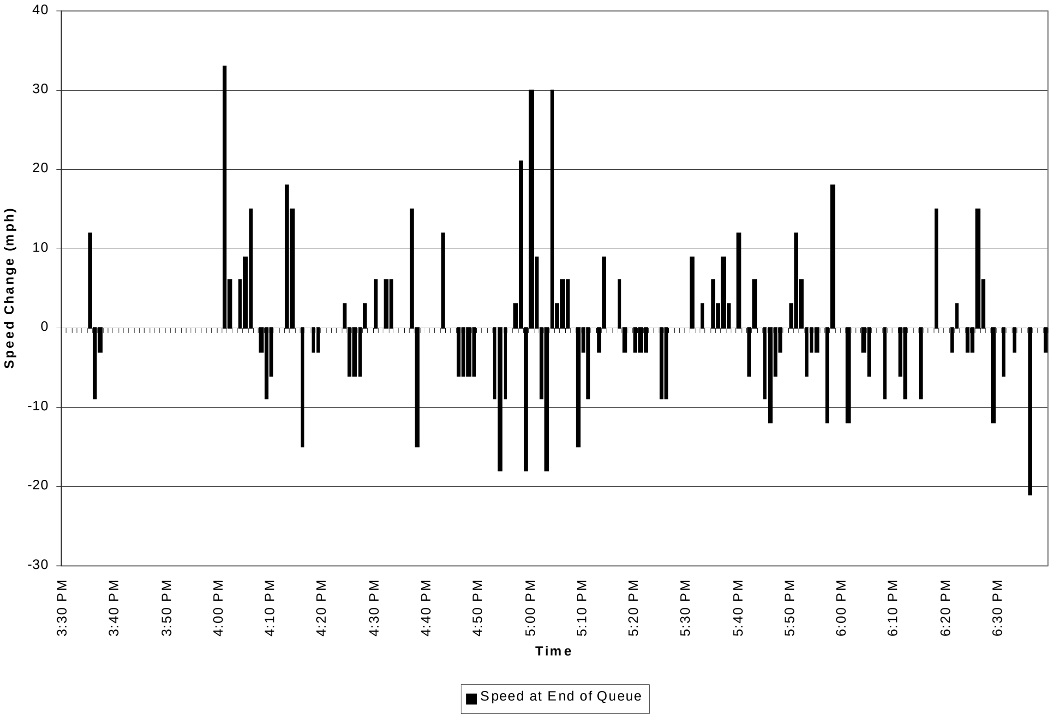

FIGURE 7 Speed changes at the end queue

4. Dudek, C.L. and S.H. Richards. Traffic Capacity Through Urban Freeway Work Zones in Texas, *Transportation Research Record 869*, 1982, pp. 14-18.
5. Kermode, R.H. and W.A. Myra. Freeway Lane Closures, *Traffic Engineering*, Vol. 40, No. 5, 1970, pp. 14-18.
6. Dixon, K.K. and J.E. Hummer. *Capacity and Delay in Major Freeway Construction*. Prepared for the North Carolina Department of Transportation by the Center for Transportation Engineering Studies, North Carolina State University, Report No.23241-94-8, 1995.
7. Jiang, Y. *Traffic Capacity, Speed, and Queue-Discharge Rate of Indiana's Four-Lane Freeway Work Zones*, presented at the Annual Meeting of the Transportation Research Board, Washington, D.C., 1999.
8. Richards, S.H., and Dudek, C.L. Field Evaluation of Traffic Management Strategies for Maintenance Operations in Freeway Middle Lanes,

Transportation Research Record 703, 1979, pp. 31-36.

9. Dudek, C.L. and Richards, S.H. *Traffic Management for Middle Lane Maintenance on Urban Freeways.* Prepared by the Texas Transportation Institute for the Federal Highway Administration and the Texas Department of Transportation, Austin, TX, Report No. FHWA/TX-80/3+228-1, 1980.
10. Rouphail, N.M. and Z.A. Nemeth. Human Factors Considerations as Freeway Construction Lane Closures, *ITE Journal*, Vol. 52, 1982, pp. 37-44.
11. Byrd, P.S., P. Geza, D.S. Jessen, and P.T. McCoy. *Driver Survey of the Late-Merge Work Zone Traffic Control Strategy*, presented to the 78th Annual Meeting of the Transportation Research Board, Washington, D.C., 1999.
12. Rouphail, N.M. and G. Tiwari. Flow Characteristics at Freeway Lane Closures, *Transportation Research Record 1035*, 1985, pp. 50-58.
13. Hall, F.L. and K. Agyemang-Duah. Freeway Capacity Drop and Definition of Capacity, *Transportation Research Board 1320*, National Research Council, Washington, D.C., 1991.
14. Persaud B., S. Yager, and R. Brownlee. *Exploration of the Breakdown Phenomena in Freeway Traffic*, presented at the Transportation Research Board Annual Meeting, Washington, D.C., January 1998.
15. Dixon, K.K., J.E. Hummer, and N.M. Rouphail. *Comparison of Rural Freeway Work Zones Queue Length Estimation Techniques: A Case Study*, presented at the Transportation Research Board Annual Meeting, Washington, D.C., January 1998.