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Traffic Capacity Through Urban Freeway Work Zones in Texas

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Findings of capacity studies conducted at urban freeway maintenance and construction work zones in Houston and Dallas are summarized. Studies were conducted on five-, four-, and three-lane freeway sections. The results indicate that the per-lane capacities are affected by the number of lanes open during the roadwork. For example, the average capacity on a three-lane section with two lanes open was 1500 vehicles per hour per lane (vphpl), whereas the average capacity with one lane open was only 1130 vphpl. Also illustrated is how the data can be used to estimate the effects of the lane closure. The results of the study can be used in scheduling work that involves lane closures on freeways.

Findings of capacity studies conducted at 28 maintenance and construction work zones on freeways in Houston and Dallas are summarized. All these studies were made at sites where one or more traffic lanes were closed. A total of 37 studies were conducted at work zones while the work crew was at the site; 4 studies were conducted while the work crew was either not at the site or not occupying a closed lane directly adjacent to one of the open lanes.

FREEWAY WORK-ZONE CAPACITY

Capacity with Work Crew at Site

Figure 1 illustrates the range of volumes measured at several work sites while the work crew was at the site. All volumes were measured while queues were formed upstream from the lane closures and thus essentially represent either the capacities of the bottlenecks created by the lane closures or the effects of drivers staring because of the work crew and machinery. Each point in Figure 1 represents the volume observed during one study; therefore, it is easy to view how the data cluster for each lane-closure situation.

The formula (A,B) is used in this paper to identify the various lane-closure situations evaluated: A represents the number of lanes in one direction during normal operations; B is the number of lanes open in one direction through the work zone.

The average capacity for each closure situation studied is shown in the table below. The data show that the average lane capacity for the (3,2) and (4,2) combinations was approximately 1500 vehicles per hour per lane (vphpl).

No. of Lanes		No. of	Avg Capacity	
Normal	Open	Studies	Vehicles per Hour	Vehicles per Hour per Lane
3	1	5	1130	1130
2	1	8	1340	1340
5	2	8	2740	1370
4	2	4	2960	1480
3	2	8	3000	1500
4	3	4	4560	1520

The studies conducted at work sites with (5,2) and (2,1) closure situations indicate significant reductions in capacity (compared with 1500 vphpl). The average capacity for these two situations was approximately 1350 vphpl.

Studies at (3,1) sites revealed an even greater reduction in capacity. The average capacity was found to be only 1130 vphpl.

Figure 2 shows the cumulative distribution of the observed work-zone capacities. The function of Figure 2 is to assist the users in identifying risks in using certain capacity values for a given lane-closure situation to estimate the effects of the lane closures (e.g., queue lengths).

For example, the 85th percentile for the (3,1) situation is 1020 vphpl. This means that 85 percent of the studies conducted on three-lane freeway sections with one lane open through the work zone resulted in capacity flows equal to or greater than 1020 vphpl. The capacity flow was equal to or greater than 1330 vphpl in only 20 percent of the cases studied. Thus, to assume a capacity of 1500 vphpl for (3,1) work zones would tend to underestimate the length of queues caused by the lane reduction at the vast majority of these work zones.

Because of the limited amount of data, no attempt was made to statistically correlate capacity to the type of road work. There are characteristics at each work site that affect the flow through the work zone. Presence of on ramps and off ramps, grades, alignment, percentage of trucks, etc., also affect the flow. These factors were not evaluated in the studies performed as part of this research.

It is also interesting to note that, even at the same site, there were variations in maximum flow rate. Work activities (e.g., personnel adjacent to an open traffic lane and trucks moving into and out of the closed lanes) caused these variations.

Table 1 is an attempt to summarize typical capacities observed in California by Kermode and Myra (1) and those observed in Texas by the Texas Transportation Institute. The California data represent expanded hourly flow rates, whereas most of the Texas data are full-hour counts. The reader is cautioned that the typical capacities by type of work zone shown in Table 1 for Texas freeways are based

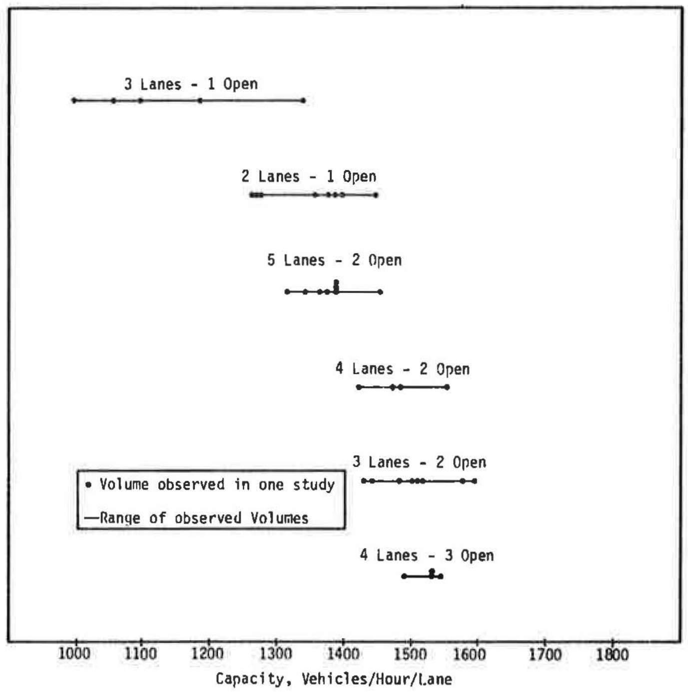


Figure 1. Range of observed work-zone capacities for each lane-closure situation studied (work crew at site).

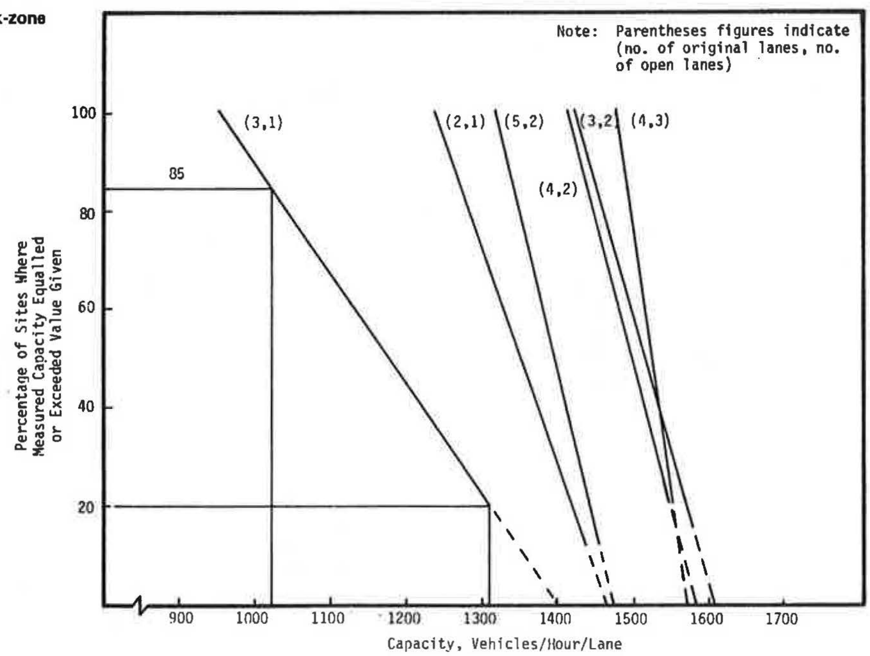


Figure 2. Cumulative distribution of observed work-zone capacities.

on limited data. The amount of data used to develop capacity rates for California was not indicated (1).

Capacity with No Work Activity at Site

Three studies were conducted at construction sites during the peak period while the work crew was not at the site. These studies were conducted in Houston on a three-lane section of southbound I-45. Two lanes were open during the studies. The average capacity for this (3,2) lane-closure situation was 1800 vphpl.

One study was conducted on the north I-610 loop in Houston. The right two lanes of a four-lane section were closed. There was no work activity in the closed lane immediately adjacent to traffic. A work crew and their machinery did occupy the shoulder lane, however, which was one lane removed from moving traffic. The volumes measured on the two open lanes over a period of 30 min were as follows: 926 vehicles in the lane adjacent to the closure and 730 vehicles in the median lane. These 30-min volumes are equivalent to flow rates of 1850 and 1475 vph. It was apparent from field observations that the demand volumes were lower than the capacity of the two open lanes. Queues did not form upstream from the work activity or the cone taper. There was available capacity in the median lane. The work crew (one lane away from an open traffic lane) did not affect flow through the work zone. It is estimated

Table 1. Summary of capacity for some typical operations.

Type of Work	Capacity (vph) Lane-Closure Situation 3,1	2,1	5,2	3 or 4,2	4,3
Median barrier or guard-rail repair or installation	N/A	1500[a]	N/A	3200[a] 2940	4800[a] 4570
Pavement repair	1050	1400[a]	N/A	3000[a] 2900	4500[a]
Resurfacing, asphalt removal	1050	1200[a] 1300	2750	2600[a] 2900	4000[a]
Striping, slide removal	N/A	1200[a]	N/A	2600[a]	4000[a]
Pavement markers	N/A	1100[a]	N/A	2400[a]	3600[a]
Bridge repair	1350	1350	N/A	2200[a]	3400[a]

Note: N/A = not available.

[a]These volumes represent capacity rates observed in California (1). Other volumes are average capacities observed in Texas.

that the capacity of the two open lanes under the above-cited conditions was about 1800 vphpl. This volume could probably be sustained as long as queues did not form.

Shoulder Use and Traffic Splitting on Three-Lane Section

Generally, when maintenance work is required on the middle lane of a three-lane section, both the middle lane and one of the exterior lanes are closed. Table 1 indicates that the average capacity on the open lane may be between 1050 and 1350 vph depending on the type of road work. Results summarized in earlier research (2) indicate that the capacity could be increased to 3000 vph by using a traffic-control approach called "shifting" whereby drivers are encouraged to use the shoulder as an additional travel lane. In effect, two lanes are open to traffic.

The research also indicates that the capacity could be increased to approximately 3000 vph by using a traffic-splitting approach. In this approach the middle lane is closed and traffic is allowed to travel on both sides of the work activity. It is important, however, that the lane-closure technique recommended by Richards and Dudek (2) be used to implement the splitting approach. Otherwise, considerable driver confusion could take place. The technique involves closing the left lane far upstream from the work area so that only two lanes of traffic enter the split area. Traffic is then funneled and split by using cones--one lane to the left and the other to the right.

APPLICATION TO WORK SCHEDULING AND TRAFFIC CONTROL

Maintenance work on urban freeways. even if performed during off-peak periods, can result in serious congestion and motorist delay. Because of increasing pressures from the motoring public to maintain acceptable levels of service on urban freeways, it is important to analyze the potential impacts of a lane closure in order to schedule the work during periods when the congestion would be minimized and/or to select the most effective alternative traffic-control techniques.

This portion of the paper illustrates how the capacity-study findings can be applied to assist the users in making decisions about scheduling freeway maintenance. It discusses the requirements and procedures for making estimates of traffic volumes and capacities.

Estimating Traffic Volumes

Work-zone volumes are usually estimated from data routinely supplied by automatic traffic counters installed at permanent locations. It is important that current hourly volumes be used to estimate the potential impacts of a lane closure. Volume maps showing average daily traffic are not adequate for this purpose. Hourly traffic volumes recorded by the automatic counters during the previous two weeks on the same day of the week as the scheduled work will provide reasonable estimates of traffic demands.

Anticipated demand volumes at a work zone can also be estimated with good accuracy by making an on-site traffic count (manned or machine) one or two days prior to the work activity. The cost and time involved in conducting this type of special count, however, restrict the use of this approach to special cases.

Hourly traffic-volume data from permanent counters are readily available to most users; however, there are some limitations in using the data. One limitation is that the permanent count data may not provide an accurate estimate of work-zone traffic volumes. Many freeway maintenance sites are a considerable distance from a permanent counter. The volumes recorded at the count stations can differ greatly from those at the work site, especially when there are several ramps between the count station and the work zone. Traffic volumes on a radial freeway, for example, may be much higher near the central business district (CBD) compared with those on the outskirts of the city. If the permanent counter is located near the city limits, then the traffic volumes at a work zone near the CBD may be underestimated. In this case, the congestion may be somewhat more severe than estimated.

It should be apparent from this discussion that there may be significant problems and inaccuracies in using existing permanent counter data to estimate work-zone volumes. However, until new urban freeway counting programs are developed and implemented, permanent counter data are probably the most practical.

The problem of estimating traffic demands at work zones is compounded by the phenomenon of natural diversion. When encountering unusual congestion on an urban freeway during the off-peak periods, many drivers will leave the freeway and travel on the frontage road to bypass the congestion or seek alternative routes to their destinations (3,4). The extent of this natural diversion is difficult to predict.

Estimating Capacity

Previously, 1500 vphpl was a common value used by many traffic-control planning analysts to estimate the flow through work zones. The capacity data presented earlier, however, provide better insight into typical capacities at work zones on Texas freeways. For example, a review of Figure 2 suggests that using a work-zone capacity of 1500 vphpl for (4,3), (4,2), and (3,2) lane-closure situations may not be too critical. However, this value seems too high for estimating the impacts of the (3,1), (2,1), and (5,2) closure situations.

As previously discussed, the cumulative distributions of observed work-zone capacities shown in Figure 2 can be used to identify risks associated with using certain capacity values for a given lane-closure situation to estimate the effects of the lane closures (e.g., queue lengths).

Estimating Queue Length and Delay

The delays associated with stop-and-go driving that occur at work zones where there is a lane closure are the result of a lack of capacity. These work zones, which have insufficient capacity to handle demand, are analogous to an hourglass. The neck of the hourglass can handle only so much sand, and there is nothing the excess sand on top can do but wait. When traffic demand at a work zone exceeds the capacity of the work zone, vehicles begin to stack up at the lane-closure taper to wait their turn to pass through the work area.

Figure 3 is a simple graphical procedure that can be used to obtain a rough estimate of queue length and delays at work zones. These estimates are obtained by plotting the cumulative demand volumes and the cumulative service volumes (capacity) versus time. As illustrated, the number of vehicles stored (or queued) and individual vehicle delay at any given time can be estimated.

The length of traffic backup or queue length can be roughly estimated by using the following relationship:

$$L_t = Q_t \ell / N \quad (1)$$

where

- L_t = estimated length of backup (queue length, ft) at time t,
- Q_t = estimated number of vehicles in queue at time t,
- N = number of open lanes upstream from lane closure, and
- ℓ = average space occupied by vehicle in queue (use ℓ = 40 ft).

Sample Problem

Figures 2 and 3 and the tables in this paper present information to assist the user in making decisions related to scheduling maintenance. The following example demonstrates how the information may be used.

Assume that maintenance work must occupy a three-lane freeway section. The work will require that the median lane be closed as shown in Figure 4. The work will require approximately 4 h to complete. This includes the time required to install and remove traffic-control devices. Data obtained from a nearby permanent counter during the previous two weeks were used to estimate the following demand volumes:

Time	Volume Anticipated (vph)
9:00-10:00 a.m.	2920
10:00-11:00 a.m.	3120
11:00-12:00 a.m.	3200
12:00-1:00 p.m.	3500
1:00-2:00 p.m.	3830
2:00-3:00 p.m.	3940
3:00-4:00 p.m.	4620
4:00-5:00 p.m.	5520

It should be noted at this point that any estimates of the queue length and vehicle delays by using the procedure shown in Figure 3 will be influenced by the accuracy of the demand-volume data. The estimates are also greatly influenced by assumed work-zone capacity. The consequences of using different capacity estimates are explored in this sample problem.

Referring back to the table in the first section and Figure 2, it is seen that the average capacity for the (3,2) lane-closure situations studied was 1500 vphpl or 3000 vph. The 85th percentile was 1450 vphpl or 2900 vph, and the 100th percentile was 1420 vphpl or 2840 vph. If these capacities (3000, 2900, and 2840 vph) are assumed, the graphical technique discussed earlier has been used to estimate the resulting queue lengths and delays (see Figure 5).

In Figure 5, the work is assumed to begin at 9:00 a.m. The estimated queue length at 1:00 p.m., after 4 h of maintenance work and assuming a capacity of 3000 vph, is 2.1 miles. The estimate by using 2900 vph is 2.9 miles, almost 1 mile longer; and the estimate by using 2840 vph is 3.5 miles, about 1.5 miles longer. Therefore, the capacity value is a very sensitive parameter when queue length is estimated.

Figure 2 shows that the average capacity value of 3000 vph (1500 vphpl) is at the 60th percentile. This means that based on the data collected to date, there is a 40 percent chance that the actual capacity may be lower than 3000 vph and thus that the queue length will be longer than 2.1 miles. Likewise, there is only a 15 percent chance that the traffic will back up farther than 2.9 miles, if we assume that the maintenance work took 4 h to complete. These estimates should be helpful in deciding where to place the advance signs for the work zone.

It should be apparent that stop-and-go traffic extending for 2.9 miles would be very undesirable. Thus, other options should be explored, for example, the following:

1. Perform the work on a Saturday or Sunday when the volumes are lower,
2. Perform the work at night,
3. Reduce the work time or split the work into two shifts, or
4. Implement additional traffic-control strategies.

Curves similar to those shown in Figure 5 can be developed for weekend or night work. It is not the intent of this paper to discuss the merits or prob-

Figure 3. Graphical procedure for estimating queue length and delays at work zones.

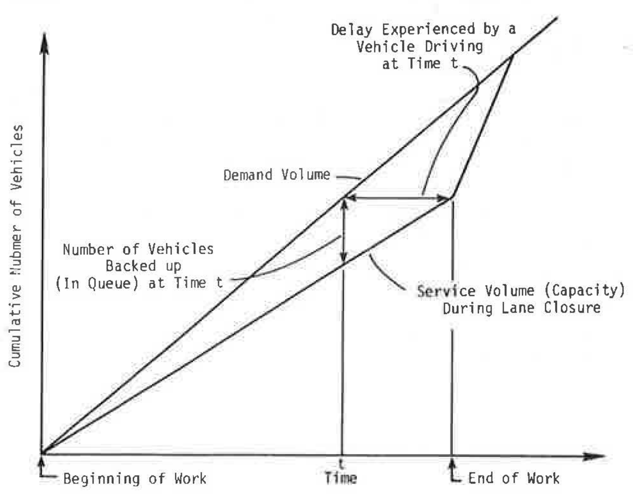


Figure 4. Sample lane-closure problem.

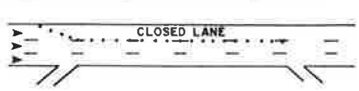
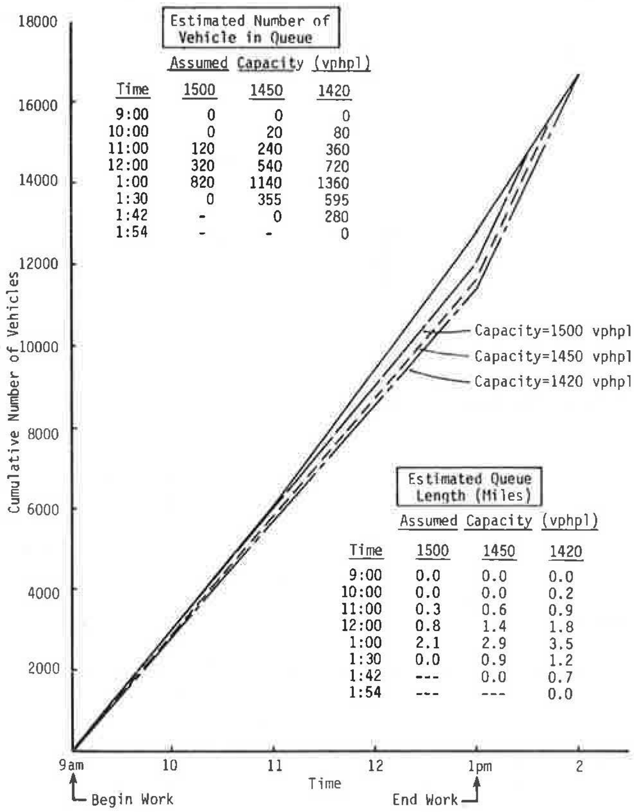


Figure 5. Sample problem solution.



lems of performing road work during these times. However, it suffices to say that the lower volumes associated with these time periods will result in reduced congestion.

A review of Figure 5 indicates that if the work could be completed within 3 h or less, the amount of congestion would be greatly reduced. If a capacity of 3000 vph is assumed, the queue would extend an estimated 0.8 mile upstream from the lane closure, and with a capacity of 2900 vph (85th percentile), the queue would not extend more than 1.4 miles. If the work could be divided into two 2-h periods from 9:00 to 11:00 a.m. on two separate days, the expected queue length would be greatly reduced to approximately 0.5 mile (if comparable volumes are assumed for both days).

Another option would be to implement additional traffic-control strategies. These might include entrance-ramp closure and shoulder use. Each of these strategies should be evaluated for its merits before implementation.

Closing entrance ramps at and upstream from a work zone may possibly reduce the traffic demands and greatly reduce queues so that work could be performed for four continuous hours. Decisions concerning entrance-ramp closures, including the time of closures, should be based on the anticipated freeway and entrance-ramp traffic demands and the available capacity on the alternative route (e.g., frontage roads and arterial streets). Ramps should be closed when the combination of the freeway and the ramp volumes exceeds the work-zone capacity and there is available capacity on the alternative route. The ramps should remain open when the traffic demands are less than the work-zone capacity. In the sample problem, for example, the entrance ramps should not be closed until approximately 10:00 a.m. even though the maintenance begins at 9:00 a.m. Closing ramps when available capacity still exists on the freeway promotes driver discontent and may create unnecessary operational problems on other facilities (e.g., frontage roads and arterial streets). Ramp-closure techniques are discussed in a report by Richards and Dudek (5). Provisions should be made to achieve improved signal coordination on the frontage road whenever ramps are closed.

Allowing traffic to use the shoulder is another way to increase work-zone capacity. Up to 1500 vph additional vehicles can be accommodated by using the shoulder. Traffic-control details for shoulder use have been presented by Richards and Dudek (2).

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