Developing a Scheduling Tool for Work Zones on Houston Freeways

RICHARD W. DENNEY, JR., and STEVEN Z. LEVINE

ABSTRACT

In Houston the condition of the existing highway network has deteriorated at a far greater rate than can be maintained without affecting traffic severely or endangering the safety of maintenance crews. Consequently, traffic managers have been required to use special techniques, such as real-time traffic control, to maintain an acceptable traffic flow around urban highway maintenance operations during weekday daylight hours. These innovative traffic control strategies require scheduling and planning procedures that have not heretofore been available. The development of just such a scheduling and planning tool is described. The concept of active traffic management in work zones is presented along with a description of a work-zone strategy computer analysis model called Queue and User Cost Evaluation of Work Zones (QUEWZ). A pilot freeway section is used to provide a data base for the development work, and special mapping procedures are used to convey the results of the analysis to traffic managers in Houston.

In Houston, as in many urban areas, freeways are reaching an advanced age, requiring extensive maintenance activity. Unfortunately, many of these same freeways carry such large volumes of daytime traffic that maintenance work zones create formidable traffic control problems. A lane closure on a Houston freeway can create unacceptable queue delays for motorists. Solutions to this problem have ranged from night maintenance activities to weekend activities. However, each of these severely restricts the available hours of maintenance operations and may endanger the highway crew. Therefore, a technique by which maintenance or construction operations can take place during daylight hours must be found. To cope with the situation, a special crew was formed to actively manage traffic on high-volume roadways. This crew supplemented the appropriate traffic control plan as suggested in the Manual on Uniform Traffic Control Devices with the necessary traffic management modifications to maintain an acceptable queue level and ensure worker safety. This active traffic management strategy will be described in greater detail in a subsequent section.

THE PROBLEM

Although the crew using the active traffic management strategy was successful in managing traffic on high-volume roadways, a problem was created as a result. To determine the active traffic management techniques that are needed at a particular location, an extensive analysis of the existing conditions is required. This analysis was handled on a case-by-case basis and was time consuming and inefficient. The existing techniques for performing this type of analysis can be complex and data intensive, which exhausts the limited time for such an analysis.

If the active traffic management concept is to be expanded to better cope with the deterioration of high-volume roadways in Houston, a systematic means of applying it must be developed. In addition, such a method could enable the needed active traffic management strategies for all high-volume roadways to be mapped out and readily available when maintenance is required on a particular highway section. This type of scheduling is more in line with the operation of the maintenance department in a large city such as Houston.

SCOPE

The scope of this paper is to present a possible method of effectively scheduling Houston work-zone activity according to the active strategies that need to be employed. The computer model Queue and User Cost Evaluation of Work Zones (QUEWZ), developed by the Texas Transportation Institute (TTI) in cooperation with the Texas State Department of Highways and Public Transportation (SDHPT), will be used as a development tool in this effort. Initially, the concept of active traffic management will be presented. Second, QUEWZ will be described. Then the use of QUEWZ to determine active traffic management requirements for an existing freeway pilot section will be detailed. Finally, some conclusions will be drawn from the initial application of QUEWZ for scheduling work activity.

ACTIVE TRAFFIC MANAGEMENT

For high-volume roadways in Houston, restricting maintenance activity to nights and weekends, which interferes least with the traveling public, has not allowed sufficient time to accomplish all the required work. Also, weekend activities cause problems in scheduling crews for both supervisors and technicians and thus have not been popular. Night operations have brought up safety and productivity concerns, given their past performance in Houston. On high-volume roadways during off-peak weekday hours, static traffic control plans do not maintain an acceptable queue on the freeway main lanes and in some cases can cause excessive diversion to alternative routes.

Under active traffic management, the demand and the capacity of the freeway main lanes and alternative routes are monitored and, if necessary, modified on a continuous basis. Demand may be adjusted by closing or opening upstream entrance ramps, thereby diverting traffic to an alternative route temporarily. Also, it is possible for an existing ramp-metering system to be adjusted, which could reduce demand through a highway section. Demand can also be reduced by effective use of public information systems, such as changeable message signs and

radio reports before the maintenance work. Capacity may be adjusted by opening or closing the shoulder as a travel lane or by adjusting traffic signal timing on the alternative route.

The key element of the active traffic management strategy is that the crew can implement these changes before and during the maintenance operation, depending on existing traffic conditions. For example, a freeway section may not have the extra capacity to absorb the effect of closing one lane for a work activity. Allowing traffic to use the shoulder may relieve the bottleneck, but after a few minutes demand falls off slightly and speeds become too great in the work zone. The crew may decide to close the shoulder, which reduces the capacity slightly, and speeds drop. This procedure may need to be repeated many times during the course of the work. Perhaps some time later the demand increases significantly. The crew may then elect to close an upstream entrance ramp to reduce the demand in the work zone. This may solve the problem on the main lanes, but traffic diverted to a continuous frontage road may cause it to break down, and adjustment of the signals is necessary to maintain an acceptable level of service. Because the crew is on the site and has traffic control as their sole responsibility, changes can be accomplished in a short time, many times within minutes, using a three-person crew.

THE QUEWZ COMPUTER MODEL

QUEWZ is a fast ultramacroscopic model of the work-zone area that is based on easily collected data and evaluates the operational and cost effects of user-specified work-zone strategies (1). The model is based on hourly traffic volumes and a basic geometric description of the freeway subsection. Capacity in the work zone is determined in one of two ways. [The term "capacity" in this paper refers to the volume of passenger vehicles that can be accommodated in an hour of operation at level of service E (impending congestion).] First, the program contains linear regressions of capacity versus the percentage of sites where that capacity is exceeded for each lane closure configuration studied by TTI. Second, the user may specify the work-zone capacity that will be experienced. The first method requires the user to input a greater risk factor to determine that capacity than the average risk factor of the sites studied. The second method requires the user to input the actual capacity per lane in the work zone. Once capacity has been determined, the model compares demand and capacity for the first hour of the analysis period. If speed is reduced but saturation is not reached, the demand equals the volume and the curve of user-supplied speed versus volume-to-capacity ratio is consulted to determine the speed and the user costs due to the effects of the work zone. If the demand exceeds the capacity, vehicles are stored upstream and the capacity equals the volume, whereupon the speeds and costs are determined for that hour. The program then analyzes the next hour: The demand for that hour is added to any preexisting queues and then the capacity and cost analysis is repeated. The model does not consider the effects of traffic diverting to avoid a queue. For long queues users are requested to check alternative routes for possible diversions. For this reason, queue-length estimates may appear unreasonably long.

Output of the model consists of an hour-by-hour breakdown of measures of effectiveness, including average speed, delay, queue length, and cost. The capacity of the work zone and the upstream section, in addition to an echo of the input data, is also included in the output. Input consists of hourly traffic demand, speed versus saturation parameters, work-zone length, number of lanes, upstream capacity, work-zone capacity (or risk factor), cost update factor, and vehicle mix. Most of these variables default to typical values and do not need to be considered.

The techniques that the program uses to determine capacity based on results of the TTI study may be too conservative in some situations. This shortcoming was caused by the lack of availability of work zones that met the conditions of this work. The linear relationships between capacity and cumulative occurrence have been shown in previous research (2) to be easily defended statistically, but the means were determined from a limited supply of data. For this reason, the authors used the user-supplied work-zone capacity option to reflect values that have been indicated by work zones in the immediate vicinity of the pilot section. For example, the risk technique suggested a capacity of 1,550 vehicles per hour per lane (vphpl) in each of three lanes remaining open on a freeway section that normally carries four lanes. This is using a risk factor of 20 percent, which represents the study site that possessed the highest capacity. Actual observations of similar work zones in the immediate vicinity showed saturation flow rates of more than 1,600 vphpl. This difference is minor and may be within the range of adjustments made to calibrate the model. A more serious discrepancy is noted where four lanes of a five-lane section remain open in a work zone. No five-lane freeway sections were studied in the research that forms the basis for QUEWZ. However, an earlier work [NCHRP Report 1-10A (3)] was consulted that based its traffic analysis on research performed in California in the 1960s. The capacity suggested by QUEWZ is 1,550 vphpl. This compares with 1,800 vphpl, which has been observed in sites similar to the pilot section. The values observed in similar sites have been input and override the values generated in QUEWZ in the work reported here. The model was used to determine the queue length resulting from capacity restrictions in the work zone. Then, for those subsections suffering excessive queues, the input was adjusted to reflect active traffic management.

FIELD APPLICATION OF QUEWZ

Description of the Pilot Section

The study section described here was chosen to test the application of QUEWZ to evaluate active traffic management strategies. This particular site was chosen because a recent origin-destination study provided acceptable ramp volume data. Also, this site is scheduled for major maintenance in early 1984, which will allow future field evaluation of the assumptions used in the model.

The pilot section consists of 4.2 miles of the Southwest Freeway (US-59) from the West Loop Freeway (I-610) to a major split just south of downtown Houston. The freeway carries approximately 210,000 vehicles per day and its corridor serves four of the six major business districts in the Houston area. The freeway section is divided into 10 subsections ranging from 600 ft to 1.2 miles that are each bounded by geometric changes causing a change in either demand or capacity. The terminal subsections are five lanes and the sections connecting them have a base of four lanes (Table 1). For all but the terminal subsections, a continuous frontage road is available as an alternative route. Other parallel routes in the region do not contribute significantly

TABLE 1 Freeway Description of Pilot Section (Before Work Zone)

Section No.	No. of Lanes	Length (miles)	Capacity[a] (vph)	Peak Midday Volume (vph)
1	5	1.05	10,250	6,170
2	4	0.39	8,200	5,628
2A	4[b]	0.11	8,720	6,293
3	4	0.26	8,200	5,738
3A	4[b]	0.31	8,800	6,697
4	4	0.34	8,200	6,144
5	4	0.50	8,200	5,215
6	5	0.57	10,250	6,605
7	5	0.23	10,250	6,237
8	5	0.26	10,250	6,280

[a]Defined as the total volume of passenger cars that can be accommodated in 1 hr of level-of-service E operation (impending congestion).

[b]Capacity increased slightly to account for an additional auxilliary lane (weaving considered).

to excess corridor capacity that can be used for diversion because they already experience heavy daytime traffic and their capacity is extremely limited.

Assumptions Used in QUEWZ

QUEWZ was used first to measure the effects of closing one lane in each subsection. In this paper each subsection is treated independently, as if the work zone occupied only that subsection. Combinations of subsections were not tested, but individual results may be combined, which will be discussed later. Active traffic management strategies were not applied unless the initial run showed queues with a length in excess of 2 miles. This queue length roughly corresponds to a 20-min delay to motorists, which has been shown in recent unpublished research to be the threshold at which motorists seek an alternative route. The assumption of 2 miles as a boundary of acceptability reflects an assumption that speed is constant in a queue for all conditions. This assumption is not realistic for many conditions resulting in freeway queuing but is reasonable when considering capacity restraints like those found in work zones. Also, this assumption is in keeping with the capabilities of the model and the quantity of required input data. As was previously mentioned, the alternative routes are not capable of handling this diverted traffic, and general corridor congestion could be expected.

The capacity was determined from field observation in which short saturation flows as high as 2,500 vphpl were noted. The average capacity was first assumed to be approximately 2,000 vphpl, but morning peak-hour volumes in some four-lane sections reached 8,300 vehicles. It can be assumed that off-peak traffic will not be as aggressive as peak traffic, and a capacity of 2,050 vphpl was used throughout the work. This capacity was used as the base value for each through lane upstream of the work zone. In several sections capacity was added to the section because of the presence of an auxilliary lane; consideration was given to weaving in these places.

The available data for determining ramp volumes consisted of ramp counts by peak period only, and consequently these volumes were expanded to all the hours in that peak period. The volumes used were those of the highest-volume hour in that particular peak period, and the other hours were assumed to have equally high volumes; consequently, the average hourly volume in that peak period is somewhat lower than that used in the model. This is not expected to cause a serious error because daily volume profiles in the Houston area show relatively minor differences from the peak hour to the lowest-volume daytime hour. Based on discussions with maintenance personnel, a 6-hr period of work-zone activity was determined to be the minimum required time to perform maintenance work on a particular freeway subsection. More desirable was 7 hr, if this could be obtained.

Results of the Model

The results of closing one lane with no active traffic management are shown in Table 2. These results indicate that the four-lane sections of freeway become significantly oversaturated and cannot maintain shorter than 2-mile queues throughout the 7-hr work-zone period. These and later results indicated that the assumption of a 7-hr work period from 9:00 a.m. to 4:00 p.m. extended into the afternoon peak flow, even though only the inbound side of the freeway was studied. Therefore, the work-zone time was limited to 9:00 a.m. to 3:00 p.m. Results shown in Table 2 are for work periods extending to 4:00 p.m. and consequently show large queues.

TABLE 2 Output from QUEWZ: One-Lane Closure with No Active Traffic Management

Section No.	Queue Length (miles) by Time of Day						
	9:00-10:00 a.m.	10:00-11:00 a.m.	11:00 a.m.-12:00 noon	12:00-1:00 p.m.	1:00-2:00 p.m.	2:00-3:00 p.m.	3:00-4:00 p.m.
1[a]	0	0	0	0	0	0	0
2	0.8	2.4	3.9	5.5	7.1	8.6	10.7
2A	1.4	4.2	7.1	9.9	12.7	15.6	19.2
3	0.9	2.7	4.4	6.2	8.0	9.8	11.9
3A	1.8	5.4	9.0	12.6	16.2	19.8	23.6
4	1.3	3.8	6.4	8.9	11.5	14.0	16.6
5	0.4	1.2	2.0	2.8	3.5	4.3	5.3
6[a]	0.2	0.5	0.8	1.1	1.4	1.4	1.0
7[a]	0	0	0	0	0	0	0
8[a]	0	0	0	0	0	0	0

[a]Sections where queue is acceptably short.

The five-lane sections do not experience long delays and therefore do not require active traffic management. Of the 10 sections, 6 will require active traffic management of some kind. Recent unpublished research by TTI shows that volumes of up to 1,000 vph were observed when the shoulder was used as a travel lane managed by a flagger. Based on this knowledge, the six critical subsections were modified to show the effects of an added shoulder lane of a capacity of 750 vph (because the shoulder lane will only be used as conditions warrant). The results of this run are shown in Table 3. The shoulder lane was added to sections 2 through 5, which cleared up the unacceptable queues in sections 2, 3, and 5. For sections 2A, 3A, and 4, long queues still resulted, so upstream ramps must be managed to reduce demand in the work zone.

In section 2A, the entrance ramp immediately upstream from the work zone carries approximately 550 vph, which could be diverted to the frontage road by closing the ramp. In section 3A, the same treatment can be used to divert 550 vph. The entrance ramp immediately upstream from section 4 carries 930 vph and if closed would remove too much traffic from the main lanes. Consequently, this ramp should be actively managed to close it approximately half of the time, removing about 450 vph from the main lanes. This partial closure could be accomplished with a

TABLE 3 Output from QUEWZ: One-Lane Closure with Actively Managed Shoulder

	Queue Length (miles) by Time of Day						
Section No.	9:00-10:00 a.m.	10:00-11:00 a.m.	11:00 a.m.-12:00 noon	12:00-1:00 p.m.	1:00-2:00 p.m.	2:00-3:00 p.m.	3:00-4:00 p.m.
1[a]	0	0	0	0	0	0	0
2[a,b]	0.1	0.3	0.5	0.6	0.8	1.0	1.6
2A[b]	0.7	2.2	3.6	5.0	6.5	7.9	10.2
3[a,b]	0.2	0.6	1.0	1.4	1.8	2.0	2.9
3A[b]	1.1	3.3	5.5	7.7	9.9	12.1	14.6
4[b]	0.6	1.7	2.9	4.1	5.2	6.4	7.6
5[a,b]	0	0	0	0	0	0	0
6[a]	0	0	0	0	0	0	0
7[a]	0	0	0	0	0	0	0
8[a]	0	0	0	0	0	0	0

[a]Sections where queue is acceptably short.
[b]Sections where shoulder is actively managed.

portable ramp meter or by physically closing the ramp for blocks of time. These strategies were modeled and the results are shown in Table 4.

In Table 4 only section 3A is still at an unacceptable level. Managing two ramps upstream from this section yields acceptable operation on the main lanes, diverting just more than 1,000 vph to the frontage road. Based on field experience in Houston, this large diversion will require modification of the frontage road traffic signals to favor the increased demand. This can be accomplished by switching the signal controller to the appropriate peak dial. Diversion can also be accomplished with other techniques, such as signs warning the motorist of the closure placed upstream from the section for a period of time before the work.

TABLE 4 Output from QUEWZ: One-Lane Closure with Actively Managed Shoulder and Ramps

	Queue Length (miles) by Time of Day						
Section No.	9:00-10:00 a.m.	10:00-11:00 a.m.	11:00 a.m.-12:00 noon	12:00-1:00 p.m.	1:00-2:00 p.m.	2:00-3:00 p.m.	3:00-4:00 p.m.
1[a]	0	0	0	0	0	0	0
2[a,b]	0.1	0.3	0.5	0.6	0.8	1.0	1.6
2A[a,c]	0.2	0.6	1.0	1.4	1.8	2.1	3.9
3[a,b]	0.2	0.6	1.0	1.4	1.8	2.0	2.9
3A[c]	0.1	0.4	0.7	1.0	1.3	1.5	3.1
4[a,c]	0.1	0.4	0.7	1.0	1.3	1.5	2.3
5[a,b]	0	0	0	0	0	0	0
6[a]	0	0	0	0	0	0	0
7[a]	0	0	0	0	0	0	0
8[d]	0	0	0	0	0	0	0

[a]Sections where queue is acceptably short.
[b]Sections where shoulder is actively managed.
[c]Sections where shoulder and ramps are actively managed.

The foregoing analysis applies only to single-lane closures on the median lane. Closures on the right side disallow the use of the shoulder as a travel lane and require extensive ramp closures. As before, QUEWZ was used to determine the effects of single-shoulder-lane closure strategies. Multiple-lane closures could be considered only on the five-lane sections, but the proximity of high-volume connection roadways at interchanges prohibits multiple-lane closures even at those locations.

It is important to note that these procedures do not directly address center-lane closures where traffic is routed around the work zone on both sides. This technique has been used for certain short-term emergency roadway repairs, such as a pavement blowup or severe potholes; but for planned long-term maintenance where many repairs will be performed, center-lane closures have not been popular for either the drivers or the maintenance crews. The results of the analysis for median-lane closures are applicable, within expected variation in traffic, to center-lane closures.

If the work zone covers more than one section, all the strategies recommended for each section should be applied, unless they conflict. The control strategies must be examined to determine which ones will not be appropriate for the longer work zone.

Of the 10 sections, previous policy allowed no weekday lane closures on any of them. After analysis with QUEWZ four of those sections became available for use. Active traffic management allowed single left-lane closures on all the sections and single right-lane closures on all but two of them (with the possibility of significant frontage road delays on two more of the sections). Multiple-lane closures must still be reserved for the weekend.

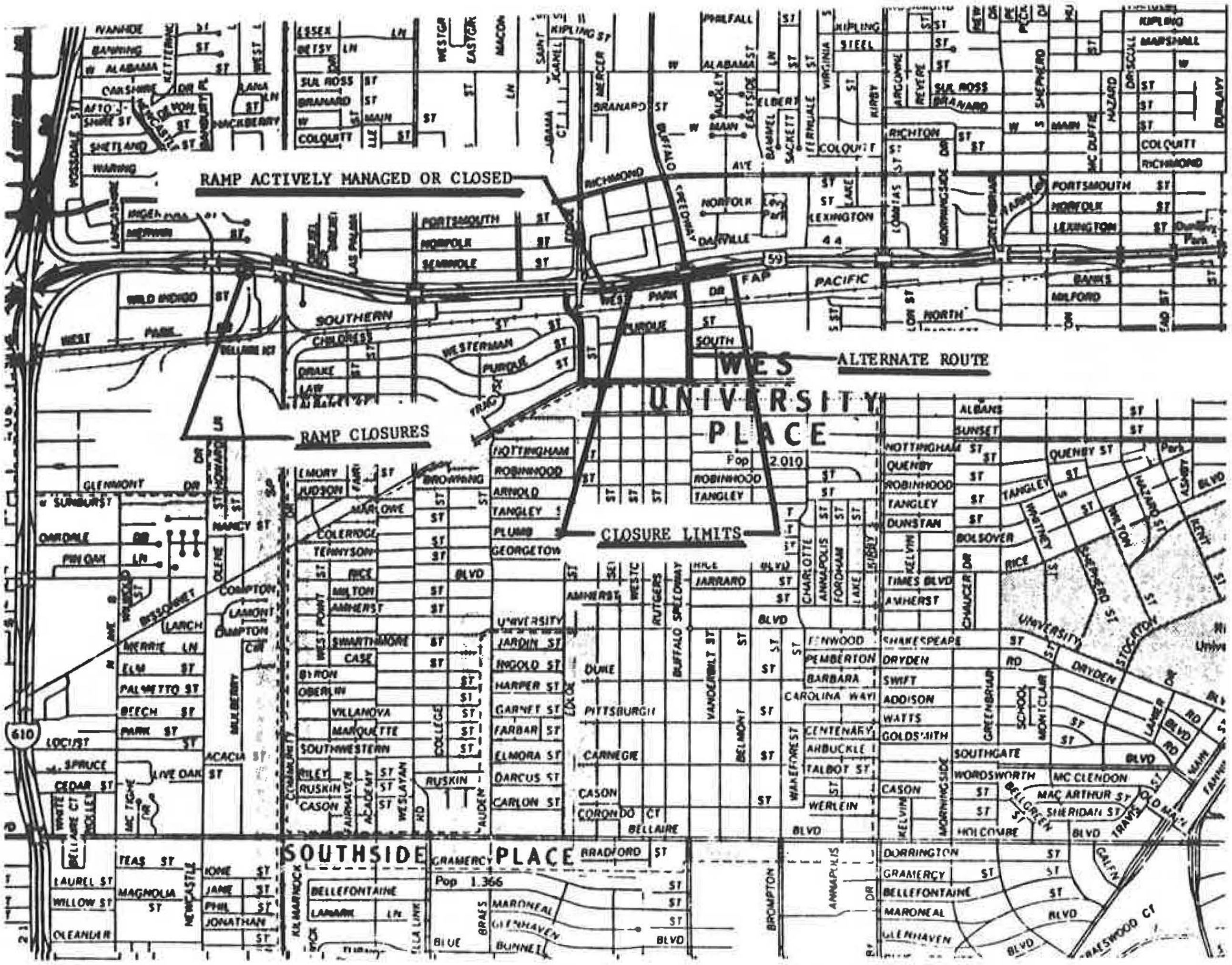
The foregoing analyses can be displayed on a series of maps showing the limits of the work zone and the required traffic management activities. These maps greatly aid in scheduling maintenance activity by forecasting traffic management needs. Figure 1 gives an example of this map, showing section 4 of the pilot study. (Note that this is a summary map showing overall strategy. Detailed maps are being developed to show ramp and main-lane volumes, lane configuration, and pavement marking details that can provide a base for developing traffic control plans.)

CONCLUSIONS

In Houston, some maintenance that was previously restricted to night and weekend activity can now be performed on weekdays using active traffic management strategies. New tools were required for scheduling the crews employing these strategies so that they can be applied effectively. The QUEWZ computer model has been shown to provide reasonable evaluations of the effectiveness of these strategies. The results of the analysis using QUEWZ can be presented in map format, which greatly aids in scheduling active traffic management resources.

RECOMMENDATIONS FOR FUTURE WORK

The development of this tool is part of an ongoing project to provide traffic and analysis data in a format that provides quick reference. Other aspects of this project will be concerned with establishing a representation for data reliability that can be shown graphically so that the engineer will know what level of confidence can be placed on his interpretation of the data. This will allow the engineer to supplement the data base as required when work is performed in a sensitive area requiring improved data. These new data may be obtained by making selective ramp volume counts, for example. Another aspect of this project is to explore ways to use these data to predict the consequences of major freeway incidents. Because the tool developed here provides a useful way to analyze original and subsequent data, it is recommended that it be included as part of the final comprehensive techniques resulting from this parent project.



MEDIAN LAND(S) CLOSURE	SHOULDER LANE(S) CLOSURE
Actively manage shoulder as a travel lane and actively manage Edloe St. entrance ramp. **If shoulder not available close Edloe St. entrance ramp and close Newcastle St. entrance ramp. See Note.** **ALTERNATE ROUTE: Frontage Road. If shoulder not used, frontage road will incur significant delays, and some traffic should be diverted to Edloe south to Bissonet east to Buffalo Speedway and north to Frontage Road.** **TOTAL DIVERSION: 460 vph if shoulder used. 1300 vph (930 + 370) if shoulder not used** **Multiple lane closures not recommended.**	**Close Edloe St. entrance ramp and Newcastle St. entrance ramp.** **ALTERNATE ROUTE: Frontage Road and Edloe south to Bissonnet east to Buffalo Speedway and north to Frontage Road. Significant delays may be incurred.** **TOTAL DIVERSION: 1300 vph (930 + 370)** **Multiple lane closures not recommended** **NOTE: ramp closure equipment existing at Newcastle entrance ramp.**

FIGURE 1 Work-zone plan, summary map 4: District 12, Southwest Freeway (limits: Edloe Street entrance ramp to Buffalo Speedway entrance ramp).

REFERENCES

1. J.L. Memmott and C.L. Dudek. A Model to Calculate the Road User Costs at Work Zones. Research Report 292-1. Texas Transportation Institute, Texas A&M University, College Station, Sept. 1982.
2. C.L. Dudek and S.H. Richards. Traffic Capacity Through Work Zones on Urban Freeways. Research Report 228-6. Texas Transportation Institute, Texas A&M University, College Station, April 1981.
3. R.L. Lytton and W.F. McFarland. Systems Approach to Pavement Design: Implementation Phase. NCHRP Report 1-10A. HRB, National Research Council, Washington, D.C., March 1974.

Publication of this paper sponsored by Committee on Traffic Safety in Maintenance and Construction Operations.