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16. Abstract

This report summarizes the improved data base and analysis tools developed as part of Study 1108 for analyzing the travel impacts of freeway maintenance and reconstruction activities. The data base includes the travel impacts of 12 urban freeway reconstruction projects (six in Texas and six outside Texas), the safety impacts of 5 urban freeway reconstruction projects in Texas, the traffic-handling capacities of 33 short-term freeway work zone lane closures, and the diversion characteristics at 11 short-term freeway work zone lane closures. The analysis tools developed include new procedures for estimating short-term freeway work zone lane closure capacity and a new version of the QUEWZ model named QUEWZ-92.

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TRAFFIC PATTERN ASSESSMENT AND ROAD USER DELAY COSTS RESULTING FROM ROADWAY CONSTRUCTION OPTIONS

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METRIC (SI*) CONVERSION FACTORS

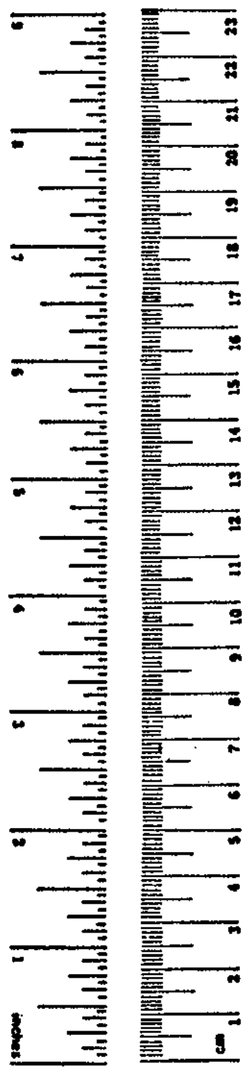
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	Kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectares (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

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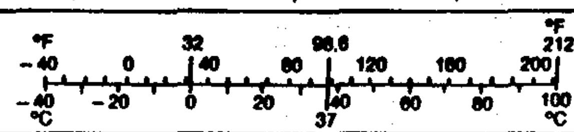

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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SUMMARY OF FINDINGS

This report is the final report for Study No. 2-8-87/1-1108 "Traffic Pattern Assessment and Road User Delay Costs Resulting from Roadway Construction Options." It summarizes the contents of seven previous interim reports:

- o Report 1108-1 "Travel Impacts of Freeway Reconstruction: Synthesis of Previous Experience"
- o Report 1108-2 "Analysis of Accidents at Long-Term Construction Projects in Texas"
- o Report 1108-3 "Travel Impacts of Urban Freeway Reconstruction Projects in Texas"
- o Report 1108-4 "Travel Impacts of the US-59 Southwest Freeway Reconstruction Project in Houston"
- o Report 1108-5 "Updated Short-Term Freeway Work Zone Lane Closure Capacity Values"
- o Report 1108-6 "Natural Diversion at Temporary Work Zone Lane Closures on Urban Freeways in Texas"
- o Report 1108-7 "User's Manual for QUEWZ-92"

Study 2-8-87/1-1108 was coordinated closely with Study 2-18-88-1188 "Corridor Analysis for Reconstruction Activities, Traffic Control Strategies, and Incident Management Techniques." Two reports from Study 1188 are closely related to the topic of Study 1108:

- o Report 1188-1 "Synthesis of Traffic Management Techniques for Major Urban Freeway Reconstruction"
- o Report 1188-4F "Corridor Traffic Management Planning Guidelines for Major Urban Freeway Reconstruction"

Study 1108 evaluated the travel impacts of both long-term freeway reconstruction projects and short-term freeway maintenance operations, whereas Study 1188 focused on major urban freeway reconstruction projects. Study 1188 culminated in procedures for analyzing the travel impacts of alternative corridor traffic management strategies for major urban freeway reconstruction projects (Report 1188-4F). The review of previous experiences outside Texas (Report 1108-1) and data collected and analyzed in Texas (Reports 1108-3 and 1108-4) formed the basis for the guidelines recommended in Report 1188-4F.

Study 1108 culminated in procedures for analyzing the travel impacts of short-term way work zone lane closures (QUEWZ-92). Earlier versions of QUEWZ were anced by incorporating information on the capacity and diversion characteristics ected during Study 1108 at short-term freeway work zone lane closures in Texas. New cedures for estimating work zone traffic-handling capacity were developed to replace the ting procedures in the 1985 *Highway Capacity Manual*; these new procedures have been lemented in QUEWZ-92. The new data on diversion characteristics corroborated the rsion algorithm previously incorporated in QUEWZ and provided better information two parameters of the algorithm: the maximum acceptable (or likely) queue length in es and maximum delay in minutes.

IMPLEMENTATION STATEMENT

It is recommended that the improved analysis tools developed by Study 1108 (or in the companion Study 1188 based upon Study 1108 data) be implemented by TxDOT in its planning and scheduling activities for both long-term freeway reconstruction projects and short-term freeway work zone lane closures. The three analysis tools are:

- Corridor traffic management planning guidelines for major urban freeway reconstruction,
- New procedures for estimating the traffic-handling capacity of short-term freeway work zone lane closures, and
- QUEWZ-92, a computer program with menu-driven user interface for estimating queuing characteristics and additional road user costs at short-term freeway work zone lane closures.

DISCLAIMER

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1. INTRODUCTION

Transportation departments throughout the U.S. devote considerable effort to maintaining and reconstructing our urban freeways. There is growing awareness and concern about the traffic congestion and resulting increases in fuel consumption and mobile source emissions associated with these activities. Study 1108 was undertaken to develop a more comprehensive data base and to improve analysis procedures for estimating the travel impacts of freeway maintenance and reconstruction activities.

The data base development included:

- o Travel impacts of 6 urban freeway reconstruction projects outside Texas (*1*),
- o Travel impacts of 6 urban freeway reconstruction projects in Texas (*3*, *4*)
- o Accident experience at 5 urban freeway reconstruction projects in Texas (*2*),
- o Traffic-handling capacity of 33 short-term freeway work zone lane closures in Texas (*5*), and
- o Traffic diversion characteristic at 11 short-term freeway work zone lane closures in Texas (*6*).

Study 1108, together with its companion Study 1188, involved the development of improved procedures for estimating the traffic impacts of traffic management alternatives for both short-term maintenance operations and long-term freeway reconstruction activities. The procedures include:

- o QUEWZ-92, a computer program for estimating queuing and additional road user costs resulting from short-term freeway work zone lane closures (*7*),
- o New procedures for estimating the traffic-handling capacity of short-term freeway work zone lane closures (*5*), and
- o Corridor traffic management planning guidelines for urban freeway reconstruction projects (*8*).

This final report briefly summarizes the data base and analysis tool development that was detailed in the seven Study 1108 interim reports. Chapter 2 reviews the traffic impacts of major urban freeway reconstruction projects both in Texas and throughout the U.S. Chapter 3 summarizes the accident analyses of 5 freeway reconstruction projects in Texas. Chapter 4 presents recommended procedures for estimating the traffic-handling capacity of short-term freeway work zone lane closures. Chapter 5 discusses the results of traffic diversion studies at short term freeway work zone lane closures in Texas. Chapter 6 reviews the capabilities of QUEWZ-92. Chapter 7 highlights the key findings of Study 1108.

2. TRAVEL IMPACTS OF URBAN FREEWAY RECONSTRUCTION PROJECTS

This chapter summarizes the travel impacts of six urban freeway reconstruction projects outside Texas and six projects in Texas. The impacts of the projects outside Texas were determined from a review of published literature; whereas the impacts of the Texas projects were determined from data collected and/or analyzed as part of Study 1108. First, the projects outside Texas are discussed. Then, the analysis methodology and observed impacts of the Texas projects are documented.

TRAVEL IMPACTS OF SIX PROJECTS OUTSIDE TEXAS

Six projects outside Texas were reviewed prior to data collection and analysis in Texas. The projects, listed in chronological order, are as follows:

- o I-94 Edens Expressway in Chicago,
- o I-376 Penn-Lincoln Parkway East in Pittsburgh,
- o I-93 Southeast Expressway in Boston,
- o I-5 Ship Canal Bridge in Seattle,
- o US-10 John C. Lodge Freeway in Detroit, and
- o I-94 Menomonee Valley Bridge in Milwaukee.

Table 1 summarizes the key characteristics of these projects and their reported travel impacts. (Table 1 also includes three Texas projects for which corresponding data were available.) These projects represent the full range of possible capacity reductions through the reconstruction zone (from no long-term lane closures to the total closure of one direction of the freeway). During the Lodge Freeway project, one directional roadway at a time was reconstructed and all traffic in that direction was diverted to alternative routes. At the Edens Expressway, Parkway East, Ship Canal Bridge, and Menomonee Valley Bridge projects, long-term lane closures were implemented. At the Southeast Expressway project, lane and shoulder widths were reduced, but the same number of travel lanes were maintained as before reconstruction. More detailed descriptions of the projects and their reported travel impacts are presented in Reports 1108-1 (*1*), 1108-3 (*3*), and 1188-1 (*9*).

TABLE 1. Summary of Urban Freeway Reconstruction Project Travel Impacts

Project	Dates	Number of Lanes in Each Direction (Peak/Off-Peak)		Freeway ADT Before Reconstruction (1000 vpd)	% Change in Freeway AADT
		Before	During		
I-94 Chicago	1978-80	3/3	2/2	135	-30
I-394 Pittsburgh	1981-82	2/2	1/1	84	-56
I-93 Boston	1984 1985	4/3 4/3	4/2 4/2	160	-8 0
I-5 Seattle	1984 1985	4/4 4/4	4/2 2/2	210	-38 -40
US-10 Detroit*	1986 1987	3/3 3/3	3/2 0/0	150	-19 -100
I-94 Milwaukee	1987	4/4	2/2	120	-45
I-35 Austin	1986-88	2/2	2/2	93	+7
US-75 Plano	1987 1988	2/2 2/2	2/2 2/2	98	-15 -12
US-59 Houston	1990 1991 1992	3/3 3/3 3/3	3/3 3/3 3/3	143	-12 -2 +6

* In 1987, one directional roadway at a time was closed.

The major findings of the review of the six projects outside Texas are as below:

o The percentage reduction in average daily traffic volumes was approximately equal to the percentage reduction in capacity. In Chicago, the number of lanes on the Edens Expressway was reduced by 33 percent, and there was a 30 percent reduction in average daily traffic. In Pittsburgh, Seattle, and Milwaukee, where the number of lanes through the reconstruction zone was reduced by 50 percent, the reduction in average daily traffic ranged from 38 to 56 percent. In Boston, where the same number of lanes as before reconstruction were maintained during peak periods, but one of three lanes was closed during off-peak periods, the reduction in average daily traffic was 8 percent during the first year and 0 percent during the second year.

- Considerable fluctuations have been reported in traffic volumes through the reconstruction zone during the first several weeks of projects. A common pattern (in Chicago, Pittsburgh, and Boston, for example) was for traffic volumes to be low enough during the first week of a project (as a result of extensive media attention) that traffic conditions were reasonably good. When motorists learned that conditions were not as bad as expected, they migrated back to the freeway. It took several weeks for motorists to experiment with alternative routes and adjust their travel patterns before a new equilibrium was established.

- Among those motorists who changed travel patterns during reconstruction, diversion to an alternative route in the corridor was much more common than diversion to an alternative mode. Only small amounts of diversion to alternative modes were reported in Chicago, Pittsburgh, Boston, Detroit, and Milwaukee. Seattle, however, reported a 10 percent increase in bus ridership and 33-56 percent increase ridesharing requests.

- In Pittsburgh and Boston, where fairly complete screen lines through the corridor were monitored, little change in total corridor-wide traffic volumes were reported. However, in Chicago, Seattle, and Milwaukee, where less complete screen lines were monitored, not all of the decreases in traffic volumes in the reconstruction zone could be explained by increases elsewhere in the corridor.

- Evidence of the cancellation of discretionary trips during off-peak periods was reported at most of the projects.

- Changes in traffic conditions were reportedly fairly minor in Boston and Milwaukee. In Pittsburgh, increases in corridor-wide average travel times ranged from 1 to 13 min (4 to 57 percent). In Detroit, decreases in average speed on the three suggested alternative routes ranged from 0 to 13 mph (0 to 31 percent).

TRAVEL IMPACTS OF SIX PROJECTS IN TEXAS

The following urban freeway reconstruction projects in Texas were studied:

- I-35 in Austin,
- US-75 in Plano,
- US-59 Southwest Freeway in Houston,
- I-45 North Freeway in Houston,
- I-35W in Fort Worth, and
- I-10 in El Paso.

The first three projects began during the course of Study 1108 and, therefore, it was possible to collect traffic data before and during those projects. The last three projects were either underway or completed at the start of Study 1108; therefore, for these projects traffic data that had been previously collected by others were analyzed. First, the analysis methodologies are presented for the two categories of projects. Then, the observed travel impacts are summarized.

Data Collection and Statistical Analysis Methodology

The plan for developing a data base on the travel impacts of urban freeway reconstruction projects in Texas involved the collection and analysis of data from both "new and "existing" projects. "New" refers to projects that started after Study 1108 had started, and "existing" refers to projects that were underway when Study 1108 began.

New Projects

Traffic conditions were monitored before and during reconstruction projects on I-35 in Austin, US-75 in Plano, and US-59 Southwest Freeway in Houston. The same basic data collection plan was implemented at the three projects. Traffic volume, travel time, and speed data were collected before and during reconstruction. Every effort was made to make each data collection effort identical.

Traffic Volume Data. The traffic volume data included screen line, automatic traffic recorder (ATR) station, and vehicle classification counts. Partial screen lines were aligned perpendicular to the freeway and were positioned at locations where changes in travel patterns were most likely to be observed. In locating the screen lines, consideration was given to the characteristics of the reconstruction zone, the origins and destinations of freeway users, and the location of major cross streets. As a minimum, counts were taken on the freeway, frontage roads, and one parallel arterial street. Directional volumes were collected using machine counters. Data were collected during the midweek (Tuesday through Thursday). ATR stations in the urban area that were not affected by the reconstruction project were selected as comparison locations. The ATR station data were used to seasonally adjust the screen line counts, so that the changes attributable to the reconstruction project could be isolated from normal seasonal and daily variations. Vehicle classification counts were taken during peak and off-peak periods.

The analysis procedure used to test the statistical significance of the changes in traffic volumes along the screen lines before versus during reconstruction involved the use of a comparison section. Analyses were performed separately by route, direction, and time period. The analysis time periods included the entire day (i.e. 24-hour period), as well as the A.M. peak, midday off-peak, and P.M. peak. The procedure was used to test the statistical significance of the observed change in volumes at the routes along the screen lines relative to the comparison location. One or more ATR stations in the urban area were used as the comparison location. The changes in volumes at the screen line relative to the comparison location (i.e., seasonally adjusted percentage change in volumes attributable to the reconstruction project) were computed. This procedure provided an objective basis for isolating the volume changes attributable to the reconstruction project and for testing whether the changes were statistically significant. Details of the statistical analysis methodology are provided elsewhere (*3*).

Travel Time and Speed Data. Travel times were measured on the freeway, frontage roads, and at least one parallel alternative route. The floating-car technique was used in which the driver of a test vehicle attempts to operate at the median speed on the route by passing as many vehicles as pass the test vehicle. Travel time runs were performed inbound in the morning (during both peak and off-peak periods) and outbound in the afternoon (both peak and off-peak). Runs were made only during the midweek (Tuesday through Thursday). The same schedule of start times was used before and during reconstruction. Times were recorded at the beginning and end of the routes, as well as at intermediate cross streets common to all of the routes. The total length of the route and the distance between cross streets were measured using vehicle-installed distance-measuring instruments. Average travel speeds were estimated by dividing the length of the route by the travel time.

Travel times before and during reconstruction were compared on the mainlanes, frontage roads, and alternative routes. Data were analyzed separately by time period (A.M. peak, off-peak, and P.M. peak). Since the same schedule was used for the travel time runs before and during reconstruction, it was possible to use a paired t-test to analyze the statistical significance of the differences between travel times on each route before and during reconstruction. The travel times before and during reconstruction were paired according to the start time of the runs. Pairing the travel times by start time helped control for the effect of hourly volume patterns on travel times and, thereby, isolate the changes in travel time attributable to the reconstruction project.

Existing Projects

Data were obtained for three existing projects on I-45 North Freeway in Houston, I-35W in Fort Worth, and I-10 in El Paso. At these projects, traffic volume and/or travel time data had been collected previously either by or for the Department. These data were obtained and analyzed. No original data collection, was performed by the Study 1108 research team at these projects.

Observed Travel Impacts

During all of the Texas projects that were analyzed, the same number of freeway lanes as existed before reconstruction were maintained. There were minor freeway capacity reductions associated with off-peak lane closures, reductions in lane and shoulder widths, and detours within the right-of-way. In addition, on US-75 in Plano and US-59 in Houston there were long-term frontage road lane closures, and on I-35W in Fort Worth there were long-term ramp closures which restricted access to the freeway.

The key characteristics and travel impacts of the three "new" projects (I-35 in Austin, US-75 in Plano, and US-59 in Houston) were included in Table 1 for comparison purposes. Unfortunately, corresponding data were not available for the three "existing" projects.

The observed travel impacts at the six Texas projects can be summarized as follows:

- The I-35 project in Austin had little impact on traffic patterns or travel times. Traffic volumes were actually higher than expected (given normal seasonal volume patterns) on the freeway and throughout the corridor as a whole. Travel times on freeway, frontage roads, and alternative arterial routes before and during reconstruction were not significantly different.

- The US-75 project in Plano affected traffic volumes but caused little change in travel times. Traffic volumes on the freeway and throughout the corridor generally decreased during reconstruction. Freeway volumes were 15,000 vpd (15 percent) lower than normal during reconstruction, and total corridor volumes were 23,000 vpd (12 percent) lower. Travel times through the corridor before and during reconstruction were not significantly different.

- The US-59 Southwest Freeway project in Houston also affected traffic volumes but caused little changes in travel times throughout the corridor. Traffic volumes on the freeway and throughout the corridor generally decreased during reconstruction; the impacts were greatest during the first phase of the project and decreased during subsequent phases. Freeway volumes were 19,000 vpd (12 percent) lower than expected during the first phase of reconstruction, 3,500 vpd (2 percent) lower during the second phase, and 9,000 vpd (6 percent) higher than expected during the third phase. Corridor-wide volumes were 16 percent lower than expected during the first phase, 14 percent lower during the second phase, and 9 percent lower during the third phase. Travel times through the corridor were not significantly different during versus before reconstruction.

- The I-45 North Freeway project (Phase II) in Houston had little impact on traffic patterns or travel times. There were only minor changes in peak period traffic volumes on the freeway and frontage roads, although some shifting of traffic between the freeway and frontage roads was observed early in the project. Travel times on the freeway, frontage roads, and two alternative arterial routes before and during the project were about the same.

- The I-35W project in Fort Worth affected the volume and pattern of traffic entering and exiting the freeway, but had little effect on total corridor-wide volumes. Ramp volumes in the reconstruction zone decreased 11 percent during Phase I (when 12 of the original 30 ramps were closed) and 31 percent during Phase II (when 20 of the original 30 ramps were closed).

- The I-10 project (Phases II and III) in El Paso had little effect on travel times in the corridor. Travel times on I-10 were generally lower during reconstruction, which may be attributable to the effects of demand management programs that were implemented. The fact that only small changes in travel times were observed on the alternative routes in the corridor suggests that there was little diversion to these routes from the reconstruction zone.

SUMMARY

Projects on heavily traveled urban freeways outside Texas at which long-term lane closures were implemented experienced percentage reductions in freeway volumes approximately equal to the percentage reduction in the number of lanes during reconstruction. Most of the diversion was to alternative routes in the corridor; little reduction in corridor-wide traffic volumes was observed. Diversion to alternative modes was generally small, but at one project where alternative modes were strongly promoted, a 10 percent increase in bus ridership was observed.

The traffic control plans typically used by the Department effectively minimize the adverse travel impacts resulting from the projects. The minor capacity reductions associated with narrowing lane and shoulder widths and detouring traffic within the right-of-way (maintaining the same number of freeway lanes as before reconstruction), have little effect on traffic volumes and travel times in the freeway corridor. However, when access to the freeway is restricted due to ramp closures and/or frontage road lane closures, some diversion of traffic away from the freeway is likely to occur. The Department should analyze the availability of excess capacity on other routes in the corridor when considering traffic control options that would significantly reduce freeway, frontage road, or ramp capacity. The procedures presented in Report 1188-4F may be used to conduct these analyses.

3. ACCIDENT ANALYSES FOR FREEWAY RECONSTRUCTION PROJECTS IN TEXAS

This chapter presents an analysis of the safety impacts of five major freeway reconstruction projects in Texas during the period 1984 through 1988:

- o I-35 in Austin,
- o US-75 in Plano,
- o I-45 North Freeway in Houston,
- o I-10 in El Paso, and
- o I-35W in Fort Worth.

None of the projects required permanent lane closures on the freeway during reconstruction. Instead, work areas were created in the median and between the freeway mainlanes and frontage road, and were separated from mainlane traffic with portable concrete barriers. Shoulders were narrowed or eliminated, lanes at some locations were narrowed, and lanes were shifted laterally within the right-of-way as the project progressed through the complex reconstruction sequence. Temporary freeway lane closures were generally allowed during off-peak conditions (daylight and nighttime), although the frequency with which lanes were actually closed varied from project to project. In addition to the mainlane reconstruction work, the projects also included work on the frontage roads, whose intensity varied among projects. More detailed descriptions of the projects are presented in Report 1108-2 (*2*).

DATA COLLECTION AND ANALYSIS METHODOLOGY

Accident data for each project were obtained from the Texas Department of Public Safety's Master Accident Files. Information about each reported accident occurring on the state highway system is maintained in the file. The limits of each reconstruction project were located by control number, section number, and milepoint as designated by the TxDOT Roadway Inventory system; and all accidents in both directions of travel on the freeway and frontage roads within those project limits were extracted from the Master Accident File.

A before versus during analysis of accidents was performed for each project, utilizing a comparison section and a check for comparability between the reconstruction project and comparison section. For most of the projects, the comparison section was located immediately upstream or downstream of the reconstruction section. At projects where traffic and other conditions varied from one end to the other, however, sections on both ends of the reconstruction section were used together to provide a composite comparison section. The use of comparison sections helps to factor out many of the extraneous factors (including year-to-year changes in traffic conditions, weather, and accident reporting procedures) that may influence the number of reported accidents at a location. It is assumed that the changes observed in year-to-year accident trends at the comparison section would also have occurred at the reconstruction section if reconstruction had not been ongoing at the site. The differences in year-to-year trends between the reconstruction project and the comparison section are then assumed to be due to the presence of reconstruction.

Two or three years of before data at each reconstruction project location (and corresponding comparison sections) were collected. The similarity of accident trends between the reconstruction sections and comparison sections before reconstruction were tested using a maximum-likelihood goodness-of-fit test to insure that the comparison sections selected for each site were comparable to the reconstruction sections in terms of year-to-year accident trends. Data during reconstruction at both the reconstruction project location and the comparison sections were also obtained, and the comparability of year-to-year accident trends during reconstruction was also checked.

Analyses were first performed separately for each project. The results from each project were also combined into a multiple before-during analysis with paired comparison ratios. The results of the combined analysis provide a proper overall estimate of the percentage change in accidents across all projects, along with a test of the statistical significance of the change. Details of the statistical procedures used in the accident analyses are presented elsewhere (*2*).

The change in the total number of accidents at each site was of particular interest in this study. The effect of reconstruction was also determined for accidents in each of the following categories:

1. Severity (property damage only, injuries plus fatalities),

2. Time of day (daytime, nighttime (including dusk and dawn)), and

3. Type (single-vehicle, multi-vehicle rear-end, other multi-vehicle).

Separate analyses were conducted for the freeway mainlanes and for the adjacent frontage roads because of the differences in their geometry and traffic characteristics.

OBSERVED SAFETY IMPACTS

Table 2 summarizes the effects of reconstruction upon both mainlane and frontage road accidents. At the five projects, the average increase in total accidents on the mainlanes was 28.7 percent and on the frontage roads was 2.4 percent. All of the reported increases in mainlane accidents were statistically significant at a 0.05 significance level, whereas none of the increases in frontage road accidents were statistically significant.

TABLE 2. Average Accident Experience at Five Freeway Reconstruction Projects in Texas

Accident Category	Average Change in Accidents During Reconstruction (%)	
	Mainlanes	Frontage Roads
All Accidents	+28.7*	+2.4
Accident Severity:		
PDO Accidents	+24.9*	+2.4
Severe Accidents	+38.8*	+3.8
Time-of-Day Distribution:		
Daytime Accidents	+24.4*	+2.7
Nighttime Accidents	+37.4*	+2.8
Accident Type:		
Single Vehicle	+13.9*	+4.6
Rear-End Multi-Vehicle	+45.7*	-6.1
Other Multi-Vehicle	+14.7*	+8.9

* Change is statistically significant at 0.05 significance level.

The averages in Table 2 must be interpreted carefully, however, due to the variability among the five projects. To illustrate this variability, Table 3 summarizes the change in total mainlane and total frontage road accidents during each of the five reconstruction projects. Similar variability among the projects was observed in each accident category.

TABLE 3. Change in Total Mainlane and Frontage Road Accidents by Project

Project	Change in Accidents During Reconstruction (%)	
	Mainlanes	Frontage Roads
I-35 in Austin	+38.8*	-4.4
US-75 in Plano	+13.3	+6.4
I-45 in Houston	+21.2*	-6.3
I-35W in Fort Worth	+22.9*	+27.7*
I-10 in El Paso	+37.7	+3.9

* Change is statistically significant at 0.05 significance level.

The change in total mainlane accidents ranged from a 13.3 percent increase during the US-75 project in Plano to 38.8 percent increase during the I-35 project in Austin. Total mainlane accidents at the five projects were found to be statistically homogeneous. Therefore, the overall average increase of 28.7 percent provides a reasonable estimate of the expected increase in total mainlane accidents during reconstruction projects with similar characteristics.

With respect to total frontage road accidents, however, the five projects were not statistically homogeneous. The 27.7 percent increase in total frontage road accidents during the I-35W project in Fort Worth is clearly different from the other projects. The reason for the much larger increase in frontage road accidents cannot be determined conclusively from the data in the Master Accident File. TxDOT personnel suggested three possible reasons: (1) the large number of ramp closures during reconstruction increased traffic volumes (and therefore conflicts) on the frontage road, (2) the geometry of the acceleration lanes on the ramps left open was restricted due to space limitations, which made merging onto the freeway difficult and sometimes caused traffic to back up the ramp onto the frontage road, thereby creating additional conflicts, and (3) some accidents at the freeway-ramp junction may have been coded in the Master Accident File as frontage road accidents. A more detailed statistical analyses was conducted to evaluate the effect of the restricted entrance ramp geometrics. The results indicated a significantly (0.05 level) larger increase in total mainlane accidents in the vicinity of the entrance ramp junctions than away from the ramp junctions (*10*).

SUMMARY

At the five freeway reconstruction projects studied, total mainlane accident experience was reasonably consistent, averaging a 28.7 percent increase. The change in total frontage road accidents was small at four of the five projects. The statistically significant 27.7 percent increase at one project may be attributable to ramp closures that increased traffic conflicts on the frontage road.

Additional research will be needed to better understand how site-specific conditions influence accident experience during reconstruction projects. The Master Accident File does not include many important details about accidents occurring in a work zone. In particular, the details of the traffic control plan--including lane and shoulder widths, ramp geometry, advance signing, lighting, type and location of channelizing devices, and the nature of the work activity--are not included. More detailed studies will be needed in order to determine the effects of these specific traffic control and geometric design features on accidents in reconstruction zones and, therefore, provide information that can be used to make more cost-effective decisions about those design features that affect safety.

4. FREEWAY WORK ZONE LANE CLOSURE TRAFFIC-HANDLING CAPACITY

This chapter summarizes the new data on short-term freeway work zone lane closure capacity that were collected as part of Study 1108 to update the values reported in the 1985 *Highway Capacity Manual* (*11*). First, the data collection methodology is described. Next, the new data are presented and compared with the older values in the *Highway Capacity Manual*. Finally, a procedure for estimating work zone capacity is outlined.

DATA COLLECTION METHODOLOGY

More than 45 hours of capacity count data were collected at 33 different freeway work zones with short-term lane closures. Data were collected for 5 different lane closure configurations: [3,1], [2,1], [4,2], [5,3], and [4,3]. (The first number in brackets is the total number of lanes in the direction of travel, and the second number is the number of lanes open during the work zone.) All sites at which data were collected were short-term lane closures. Most were maintenance work zones, although several were short-term, off-peak lane closures at long-term reconstruction projects. All of the work zones were in general compliance with the Texas *Manual on Uniform Traffic Control Devices* (*12*). Standard channelizing devices were used at the lane closures (i.e., traffic cones, drums, or vertical panels).

All capacity counts were taken where vehicles entered the beginning of the lane closure through the channelizing taper. Data were used only for time periods during which traffic was queued upstream of the lane closure. Therefore, the capacity counts represent the rate at which vehicles discharge from the upstream queue, merge into the reduced number of lanes through the taper, and enter the lane closure. Sites at which ramps were located within the taper were not analyzed.

OBSERVED CAPACITIES

Table 4 summarizes the new capacity data for short-term freeway work zone lane closures. A comparison of these new data with the corresponding older values in the 1985 *Highway Capacity Manual* indicates that, for the [3,1] and [2,1] lane closure configurations, the averages for the new data are significantly higher than for the old data (based upon a t-test at a 0.05 significance level). For the other configurations, the averages of the old and new data are not significantly different. The higher observed capacities might be attributable to better and more consistent work zone traffic control and a driving population more experienced with work zone lane closures.

TABLE 4. New Data on the Capacity of Short-Term Lane Closures at Freeway Work Zones

Lane Closure Configuration (Normal, Open)	Number of Studies	Average Capacity (vphpl)	Average Percentage of Heavy Vehicles	Average Capacity (pcphpl)*	Average Peak Hour Factor
[3,1]	11	1460	12.6	1588	0.92
[2,1]	11	1575	4.9	1629	0.94
[4,2]	5	1515	9.8	1616	0.92
[5,3]	2	1580	2.0	1601	0.93
[4,3]	4	1552	4.3	1597	0.96
All	33	1536	8.0	1606	0.93

* Calculated using a passenger car equivalent for heavy vehicles of 1.7.

The average capacities for the five lane closure configurations range only from 1,588 to 1,629 pcphpl--a difference of only 41 pcphpl. When analysis-of-variance was performed on the data summarized in Table 4, the results indicated that there were no statistically significant differences among the average capacities in pcphpl for the five lane closure configurations (at a 0.05 significance level).

The overall average capacity (for all lane closure configurations combined) is approximately 1,600 pcphpl. This value compares logically to the capacities of 2,000 pcphpl for freeways and multilane highways and 1,800 pcphgpl for signalized intersections, which represent the queue discharge rates under ideal conditions for the corresponding facility type (*11*).

The peak hour factor is the ratio of the hourly capacity divided by the highest 15-min flow rate during the hour. The relatively high average peak hour factors (ranging from 0.92 to 0.96) suggest that, although some variability exists at a site over time, the average capacities are reasonably stable when queues are present.

The capacities observed at individual work zones, combining all lane closure configurations, ranged between 1,414 and 1,741 pcphpl (except for one value of 1,913 pcphpl). The data collected as part of Study 1108, together with observations from previous studies, suggest that factors contributing to below-average capacities include unusual or unusually intense work activities and the presence of ramps within the taper area or immediately downstream of the beginning of the lane closure. These factors distract the driver and complicate the driving task more than the "average" work zone and, as a result, reduce the efficiency of traffic flow. Unfortunately, there are not sufficient data to quantify the magnitude of these factors' capacity-reducing effect.

ESTIMATING FREEWAY WORK ZONE LANE CLOSURE CAPACITY

Recommended Base Work Zone Capacity Value

The capacity data collected during Study 1108 suggest that it would be appropriate to use the overall average capacity of 1,600 pcphpl as the base capacity value for short-term freeway work zone lane closures, regardless of the lane closure configurations. This value is based upon work zones whose traffic control is in compliance with the *Manual on Uniform Traffic Control Devices*.

The recommendation of a single base capacity value departs from the 1985 *Highway Capacity Manual* which recommended a different base value in vph for each lane closure configuration. The new data summarized in Table 4, however, indicate that after adjusting for the percentage of heavy vehicles, there were no statistically significant differences among the average capacities of the five lane closure configurations observed. The use of a single base value is also consistent with the other procedures in the 1985 *Highway Capacity Manual*. Furthermore, the value of 1,600 pcphpl relates logically to the base capacity values in those procedures.

Adjustments to the Base Work Zone Capacity Value

The recommended base value of 1,600 pcphpl represents the average of all recently observed work zone capacities. The capacities of individual work zones fell within a range of approximately $\pm$ 10 percent of 1,600 pcphpl. Therefore, when certain conditions are present, the base capacity value should be adjusted for better predictions. Recommendations are made on adjustments for the intensity of work activity, effect of heavy vehicles, and presence of entrance ramps.

Adjustment for the Intensity of Work Activity

Both current and previous research results suggest that work zone capacity decreases as the intensity of work activity increases. The intensity of work activity increases with the number and size of work vehicles, the number of workers, the magnitude of noise and dust, and the proximity of work to the open travel lanes. Work zone capacity also may be decreased when the type of work activity is unusual and causes more rubbernecking than a more common activity. Observed capacities tend to be lower than average for work that occurs close to the open travel lanes and that involves more and larger equipment and workers; whereas, capacities tend to be higher than average for work that occurs further from the open travel lanes and that requires less and smaller equipment.

Unfortunately, the available data are not sufficient to quantify the relationship between the intensity of work activity and the adjustment to the base capacity value. Therefore, the only guidance that can be provided is to adjust the base capacity value up or down within a $\pm$ 10 percent (160 pcphpl) range for work activities whose intensities are significantly different than average.

Adjustment for the Effect of Heavy Vehicles

It is recommended that the heavy vehicle adjustment factors in the 1985 *Highway Capacity Manual* be used to account for the effect of heavy vehicles upon work zone capacity. The heavy vehicle adjustment factor H is calculated as follows:

$$H = \frac{100}{[100 + P \times (E - 1)]} \tag{1}$$

where,

H = heavy vehicle adjustment factor (vehicle/passenger car)
P = percentage of heavy vehicles (%)
E = passenger car equivalent (passenger cars/heavy vehicle)

A passenger car equivalent of 1.7, which is recommended in the 1985 *Highway Capacity Manual* for trucks on freeway segments in level terrain, was used convert the observed work zone capacity counts and percentage of heavy vehicles to capacities in pcphpl. Reference should be made to the *Highway Capacity Manual* for passenger car equivalent values for rolling or mountainous terrain and for extended individual grades.

Adjustment for the Presence of Ramps

In demand-capacity analysis, care must be taken to appropriately adjust either demand or capacity for the presence of ramps. The upstream end of the channelizing taper should be used as the reference point for estimating both demand and capacity. That is, the demand used for analysis purposes should be the hourly volume of vehicles that attempt to enter at the beginning of the lane closure, and capacity is the hourly rate at which vehicles actually can enter.

Typically, historical mainlane volume data are used to estimate the approach demand volume. If there are ramps between the mainlane count location and the beginning of the lane closure, then the mainlane counts should be adjusted by the exit and entrance ramp volumes to estimate the mainlane volume at the beginning of the lane closure.

Another issue that must be addressed in estimating demand is the percentage of normal traffic volumes that diverts from the freeway in response to work-zone-induced delays. QUEWZ has an algorithm for estimating diversion and adjusting demand accordingly. If the analysis is performed manually, then demand volumes should be adjusted based upon local experience.

The work zone capacity (i.e., the rate at which the mainlane queue upstream of the lane closure discharges into the work zone) appears to be affected by entrance ramps within the taper area or immediately downstream of the beginning of the full lane closure. It has

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In review, the recommended values for the base capacity and the various adjustments are as follows:

I = range {-160 to +160 pcphpl} depending on the type, intensity and location of work activity

R = minimum of {average entrance ramp volume in pcphpl during the lane closure period for ramps located within the channelizing taper or within 500 ft downstream of the beginning of the full lane closure, or one half of the capacity of one lane open through the work zone (i.e., 1600 pcphpl/2N)}

H = based on Equation 1 for various percentages of heavy vehicles and passenger car equivalents

SUMMARY

The new data collected as part of Study 1108 differ from the older values reported in the *1985 Highway Capacity Manual* in two ways. First, the new average capacities for [3,1] and [2,1] freeway work zone lane closures are significantly larger than the older values. Second, the new data indicate that average capacities in pcphpl do not differ significantly among lane closure configurations, whereas the 1985 *Highway Capacity Manual* reported different average capacities in vphpl for each configuration. It is recommended that the new base capacity value and adjustments be used in lieu of the current procedures in the *1985 Highway Capacity Manual* for estimating the capacity of short-term freeway work zone lane closures. Accordingly, these values have been incorporated into the revised version of QUEWZ that was developed as part of Study 1108 and will be discussed in Chapter 6.

5. DIVERSION AT SHORT-TERM FREEWAY WORK ZONE LANE CLOSURES

This chapter summarizes the analysis of diversion characteristics at eleven short-term freeway work zone lane closures in Texas. First, the data collection methodology and sites are described. Then, observed diversion characteristics are summarized.

DATA COLLECTION METHODOLOGY AND SITES

The data collection effort for the diversion studies consisted of travel time measurements performed at hour or one-half hour intervals on both the freeway and the adjacent frontage road; measurements of the queue length on the freeway due to the lane closure during each travel time run; and traffic volume counts made on the freeway mainlanes, frontage road, and entrance and exit ramps in the vicinity of the lane closure.

Travel time data were collected using the floating-car technique, whereby the driver attempts to travel at the median speed of the traffic stream. At each site, a study section was identified beginning 3 or 4 miles upstream of the anticipated location of the lane closure and extending beyond the point where the work zone was expected to end. Travel time runs were initiated at the same time on the freeway and frontage road so as to provide a consistent basis for comparison. Times were recorded at the start of each run, at several intermediate points (usually cross-street centerlines), and at the end of the study section.

Traffic queue data were collected during the travel time runs conducted on the day of the lane closure at each site, using an in-vehicle distance measuring instrument. The instrument was used to record the instantaneous speed, time, and cumulative distance from the start of the run to selected locations at each site. These locations included the centerline of major cross-streets, advance warning signs for the work zone, the beginning and ending points of each lane closure cone taper, and the beginning of the traffic queue. The beginning of the traffic queue was defined as the location where the instantaneous speed dropped to below 30 mph.

Traffic volume data were collected continuously on the freeway mainlanes, frontage roads, and all entrance and exit ramps (to the extent possible) in the study section. The frontage road and ramp counts were collected using machine counters connected to pneumatic tubes placed across the ramp or travel lanes. Because of the high traffic volumes and wide cross-sections on the freeway mainlanes, counts were recorded either by loop detectors already imbedded in the pavement or by manual counts made by data collection personnel. Freeway mainlane counts were made upstream of the work zone close to the beginning of the study section.

An attempt was made to select study sites that encompassed a range of demand volumes and work zone lane closure configurations in order to observe sites with different diversion characteristics. However, the nature of maintenance operations with short-term lane closures made it impossible to control these characteristics of the sites studied.

Table 5 summarizes the characteristics of the eleven study sites. Sites 1 through 8 were part of a seal-coat operation on the I-410 North Loop in San Antonio. Site 9 was located on the I-10 Katy Freeway and Site 10 on the I-45 Gulf Freeway, both in Houston. Site 11 was located on the I-35E East R.L. Thornton Freeway. At the eight sites in San Antonio, the normal-volume-to-work-zone-capacity ratio was between 2.1 and 4.0, whereas the ratios at the other three sites did not exceed 1.2.

OBSERVED DIVERSION CHARACTERISTICS

Table 5 also summarizes the results of the observed diversion characteristics at the study sites. Report 1108-6 (*6*) provides a more detailed discussion.

At sites 1 through 8, where normal freeway volumes were 2-4 times larger than the work zone capacity, the maximum queue length ranged between 1.1 and 2.3 miles (with an average of 1.7 mi), encompassed between 3 and 6 ramps (with an average of 4.5 ramps), and produced maximum delays ranging between 9.9 and 25.7 min (with an average of 20.3 min). The volumes and percentages of diverting traffic varied among the sites, but the extent of queuing was reasonably consistent. Queuing tended to reach a threshold level at most sites and remain at approximately those levels for the remainder of the closure. Although the point at which this threshold was reached (in terms of the actual queue length) varied by site, it was fairly consistent in the number of ramps engulfed in the queue prior to attaining that threshold. Two forms of diversion were observed. Some motorists with advance warning of the work zone and associated delays completely avoided the affected freeway section. Other motorists diverted after reaching the affected freeway segment either by exiting upstream of their normal off-ramp or by not entering the freeway at their normal on-ramp.

At sites 9 through 11, where normal freeway volumes were no more than 1.2 times the work zone capacity, queuing occurred for only very short periods of time. Volumes at these sites appeared to decrease enough that little or no queuing occurred. It appears that advance traffic information (e.g., newspaper reports, television and radio reports, word of mouth, or seeing the lane closure from the opposite direction of travel) led enough motorists to divert from the freeway before reaching the work zone that traffic conditions remained near normal.

SUMMARY

Based on the results from these studies, the diversion algorithm previously implemented in QUEWZ, which estimates the volume of traffic that must divert so that queuing does not exceed a maximum length in miles or delay in minutes, was retained. Although not directly programmed into the QUEWZ model, the data also indicate that traffic volumes at lane closure sites will be slightly lower than normal historical counts would indicate, and reducing historical demand volumes by 5 percent may improve the accuracy of the analysis results.

TABLE 5. Summary of Work Zone Geometry, Traffic, and Diversion Characteristics at Eleven Study Sites

Site	Lane Closure Configuration [Total, Open]	Normal Freeway Volumes (vph)	Estimated Work Zone Capacity (vph)	Volume-to-Work-Zone-Capacity Ratio	Maximum Queue Length (mi)	# of Ramps in Maximum Queue	Maximum Delay (min)
1	3,1	4150-4900	1600	2.6-3.1	2.3	6	25.7
2	3,1	3600-4500	1600	2.3-2.8	1.1	3	9.9
3	3,1	3750-4500	1600	2.3-2.8	1.2	3	15.1
4	3,1	4150-4900	1600	2.6-3.1	1.8	5	21.3
5	3,1	5100-6250	1600	3.2-3.9	1.9	5	18.4
6	3,1	4950-6200	1600	3.1-3.9	2.1	6	34.4
7	3,1	5300-6450	1600	3.3-4.0	1.6	4	15.1
8	3,1	3300-4000	1600	2.1-2.5	1.6	4	22.8
9	4,3	5300-5600	4800	1.1-1.2	NS	NS	NS
10	3,2	3300-3800	3200	1.0-1.2	NS	NS	NS
11	4,2	2000-3650	3200	0.6-1.1	NS	NS	NS

NS = not significant.

6. QUEWZ-92

QUEWZ, which stands for Queue and User Cost Evaluation of Work Zones, is a tool for evaluating freeway work zone lane closures that has been developed and revised under several research studies during the last 12 years. QUEWZ-92 is the most recent microcomputer version of the QUEWZ program that was developed as part of Study No. 2-8-87/8-1108. This chapter provides a brief description of QUEWZ-92 and highlights the enhancements that were made as part of Study 1108.

CAPABILITIES OF QUEWZ-92

QUEWZ-92 is a computerized version of commonly used manual techniques for estimating the queue lengths and additional road user costs resulting from work zone lane closures. It simulates traffic flows through freeway segments both with and without a work zone lane closure in place and estimates the changes in traffic flow characteristics and additional road user costs resulting from a lane closure whose time schedule and lane configuration are described by the model user. QUEWZ-92 can also apply the same traffic flow simulations to identify time schedules for lane closures that will not produce excessive queue lengths and delays. The model can be applied to freeway facilities, or other multilane highways, with as many as six lanes in each direction and can analyze work zones with any number of lanes closed in either one or both directions. The model can analyze 24 consecutive hours. QUEWZ-92 operates on IBM-compatible, DOS-based microcomputers. A user's manual for QUEWZ-92 has been published as Report No. 1108-7 (7).

Output Options

QUEWZ-92 has two output options:

- o The road user cost option, and
- o The lane closure schedule option.

The road user cost output option analyzes a user-specified lane closure configuration and schedule of work activities. The output consists of estimates of traffic volumes, capacities, speeds, queue lengths, and additional road user costs for each hour affected by the lane closure. A diversion algorithm may be used with this option to estimate the volume of traffic that might divert from the freeway in response to work-zone-related delays.

The lane closure schedule option summarizes the hours of the day when a given number of lanes can be closed without causing excessive queuing. The user may define what constitutes excessive queuing. This option evaluates each possible number of closed lanes. For example, when analyzing a work activity in the outbound direction of a freeway which has 3 lanes, QUEWZ-92 would evaluate schedules for closing both 1 and 2 lanes. QUEWZ-92 considers each hour as a possible starting hour for the lane closure and for each starting hour determines the number of hours that lanes could remain closed before queuing becomes excessive.

Speed and Queue Estimation

Both output options use the same speed and queue estimation procedures. QUEWZ-92 estimates speed and queuing using procedures presented in the 1985 *Highway Capacity Manual* (*10*). Average speeds are estimated based on the typical speed-volume relationship for freeway facilities presented in Chapter 3 of the *Manual*.

When demand volumes exceed the capacity of the work zone, queuing characteristics are estimated using input-output analysis. The procedures presented in Chapter 6 of the *Manual* are used to perform input-output analysis.

Road User Cost Estimation

The additional road user costs associated with a freeway work zone lane closure are estimated as the difference between the road user costs with versus without the lane closure. Two components of road user costs are included: vehicle operating costs and delay costs.

Diversion Algorithm

The diversion algorithm is used in conjunction with the road user cost output option to provide more realistic estimates of the additional road user costs resulting from freeway work zone lane closures. The algorithm estimates the volume of traffic diverting from the freeway in response to work-zone-related delays. Additional road user costs for diverting traffic are also estimated.

The algorithm is based upon observations of work zone lane closures on urban freeways with continuous parallel frontage roads in Texas. It was observed that queue lengths and delays tended to reach threshold levels soon after the lane closure was implemented and then remained near those threshold levels throughout the duration of the lane closure. Therefore, the diversion algorithm calculates the traffic volume that must divert from the freeway so that delays do not exceed either a maximum queue length in miles or delay to motorists in minutes. On average, the maximum queue engulfed 5 ramps, and the queue length varied according to the average ramp spacing. The maximum observed delay averaged approximately 20 minutes across the study sites.

Input Data Requirements

The input data requirements of QUEWZ-92 depend upon the output option that is desired. Some or all of the following data may be required to provide the desired output:

- o The lane closure configuration,
- o The schedule of work activity,
- o The traffic volumes approaching the freeway segment, and
- o Alternative values to the defaults provided for various model constants.

Lane Closure Configuration

The lane closure configuration is described by:

- o The number of directions in which lanes are closed (1 or 2),
- o The total number of lanes in each direction,
- o The number of open lanes through the work zone in each direction,
- o The length of the lane closure, and
- o The capacity of the work zone.

The total number of lanes, number of open lanes, and per-lane capacities may be different in each direction. The length of the lane closure, however, must be the same when both directions are evaluated in the same run of the model. If necessary, a separate data set may be created and run for each direction.

Schedule of Work Activity

The schedule of work activity is defined by:

- o The hours the lane closure begins and ends, and
- o The hours that work activity begins and ends.

The hours the lane closure begins and ends define the time period during which the lane closure is in place. Work activity may be specified during all or part of the time period when lanes are closed.

Traffic Volumes

QUEWZ-92 analyzes traffic flows on an hourly basis and, therefore, requires directional hourly traffic volumes. This requirement can be satisfied by providing either:

- o Directional hourly volumes for the period of interest, or
- o The AADT of the roadway, the day of the week when the lane closure will be in effect, and the general location of the freeway (urban or rural).

The most accurate form of input would be directional hourly volumes obtained from traffic counts taken at the site of the work zone. The AADT volume option uses two sets of adjustment factors (one for urban freeways and the other for rural freeways) to estimate directional hourly volumes from the AADT input. These factors represent the average daily, hourly, and directional variations in traffic volumes on Interstate highways in Texas.

Default Values for Model Constants

The user may supply alternative values to the default values provided for the following model constants:

- o Cost update factor,
- o Percentage of trucks,
- o Speeds and volumes at various points on a speed-volume curve,
- o Capacity of a lane in work zone, and
- o Excessive queuing.

QUEWZ-92 estimates road user costs in 1990 dollars. The cost update factor, which is calculated using the Consumer Price Index, may be used to update costs to current-year dollars. The speed-volume relationship used in QUEWZ-92 may be revised by changing the parameters of the relationship. The default percentage of trucks, per-lane work zone capacity, and definition of excessive queuing, are averages based upon the capacity and diversion studies conducted as part of Study 1108, but may be revised to reflect site-specific conditions.

REVISIONS TO QUEWZ AS PART OF STUDY 1108

The Texas Transportation Institute (TTI) developed the original version of QUEWZ in 1982 as part of TxDOT Study No. 2-18-81-292. QUEWZ operated on a mainframe computer and provided estimates of traffic speeds, queue lengths, and additional road user costs resulting from a work zone lane closure with user-specified time schedule and lane configuration.

TTI incorporated two enhancements into QUEWZ under Interagency Contract 84-85-0413 with the (then) Houston Urban Office of TxDOT. First, an input option was added that allowed the traffic volume data requirements of the model to be satisfied by providing an Annual Average Daily Traffic (AADT) volume rather than directional hourly volumes; adjustment factors were computed for freeways in Houston and were included in the model to estimate directional hourly volumes for a specified day of the week and month from the AADT. Second, an output option was added that provides a schedule of the times of day during which a particular number of lanes may be closed without causing excessive queuing and delay.

As part of TxDOT Study 2-6-85-412, TTI incorporated into QUEWZ the algorithm that accounted for the diversion of traffic away from the freeway in response to queues and delays caused by the work zone lane closure. In addition, the adjustment factors for estimating directional hourly volumes from AADT were changed to represent the average hourly distribution of traffic at automatic traffic recorder stations on urban and rural Interstates in Texas.

A microcomputer version of QUEWZ was developed by TTI under contract to the Florida Department of Transportation. A menu-driven procedure for entering data, running QUEWZ, and printing output was added. Graphical output for the lane closure schedule was also created.

As part of Study 1108, the microcomputer version developed for the Florida Department of Transportation was enhanced. The principal new features are (1) new work zone capacity estimating procedures, and (2) new default values for the diversion algorithm. These features are based upon the results summarized in Chapters 4 and 5 and detailed in Reports 1108-5 (*5*) and 1108-6 (*6*). In addition, the previously developed menu-driven user interface was refined. This new version is called QUEWZ-92.

SUMMARY

QUEWZ-92 is the latest microcomputer version of QUEWZ. This microcomputer version includes a menu-driven user interface Q92MENU which simplifies the process of entering data and running QUEWZ-92. QUEWZ-92 incorporates all of the relevant data collected as part of Study 1108. In particular, QUEWZ-92 contains the work zone lane closure capacity estimation procedure documented in Report 1108-5 (*5*) and the diversion results documented in Report 1108-6 (*6*). It is recommended that QUEWZ-92 be made available for use by those TxDOT personnel responsible for evaluating the traffic impacts of short-term freeway lane closures as part of their work zone planning and scheduling activities.

7. CONTRIBUTIONS OF STUDY 1108

The results of Study 1108 make significant contributions to the data base and analysis tools available for analyzing traffic patterns and road user costs at freeway work zones. The major contributions are the following:

- Recommended *Corridor Traffic Management Planning Guidelines for Major Urban Freeway Reconstruction* were developed using the Study 1108 data base on the travel impacts of urban freeway reconstruction projects.

- New procedures for estimating the traffic-handling capacity of short-term freeway work zone lane closures were developed to replace existing procedures in the 1985 *Highway Capacity Manual.*

- QUEWZ-92, an enhanced version of the original QUEWZ model that incorporates the capacity and diversion data collected during Study 1108, was developed for use in planning and scheduling short-term freeway work zone lane closures.

REFERENCES

1. R. A. Krammes and G. L. Ullman. *Travel Impacts of Freeway Reconstruction: Synthesis of Previous Experience*. Report No. 1108-1. College Station, TX: Texas Transportation Institute, 1987.

2. G. L. Ullman and R. A. Krammes. *Analysis of Accidents at Long-Term Construction Projects in Texas*. Report No. FHWA/TX-90/1108-2. College Station, TX: Texas Transportation Institute, 1991.

3. R. A. Krammes, K. D. Tyer, G. L. Ullman, J. J. Dale, and T. R. Hammons. *Travel Impacts of Urban Freeway Reconstruction Projects in Texas*. Report No. FHWA/TX-91/1108-3. College Station, TX: Texas Transportation Institute, 1991.

4. M. A. Shafer, K. D. Tyer, and R. A. Krammes. *Travel Impacts of the US-59 Southwest Freeway Reconstruction Project in Houston*. Report No. FHWA/TX-92/1108-4. College Station, TX: Texas Transportation Institute, 1992.

5. R. A. Krammes and G. O. Lopez. *Updated Short-Term Freeway Work Zone Lane Closure Capacity Values*. Report No. FHWA/TX-92/1108-5. College Station, TX: Texas Transportation Institute, 1992.

6. G. L. Ullman. *Natural Diversion at Temporary Work Zone Lane Closures on Urban Freeways in Texas*. Report No. FHWA/TX-92/1108-6. College Station, TX: Texas Transportation Institute, 1992.

7. R. A. Krammes, G. L. Ullman, J. L. Memmott, and C. L. Dudek. *User's Manual for QUEWZ-92*. Report No. FHWA/TX-92/1108-7. College Station, TX: Texas Transportation Institute, 1993.

8. R. A. Krammes, G. L. Ullman, and C. L. Dudek. *Corridor Traffic Management Planning Guidelines for Major Urban Freeway Reconstruction*. Report No. FHWA/TX-91/1188-4F. College Station, TX: Texas Transportation Institute, 1991.

9. G. L. Ullman, R. A. Krammes and C. L. Dudek. *Synthesis of Traffic Management Techniques for Major Freeway Construction*. Report No. FHWA/TX-91/1188-1. College Station, TX: Texas Transportation Institute, 1989.

10. D. B. Casteel and G. L. Ullman. "Accidents at Entrance Ramps in Long-Term Construction Work Zones." *Transportation Research Record* 1352, 1992, pp. 46-55.

11. *Highway Capacity Manual*. Special Report 209. Washington, DC: Transportation Research Board, 1985.

12. *Manual on Uniform Traffic Control Devices*. Part VI. Austin, TX: Texas Transportation Institute, 1988.