Technical Report Documentation Page

1. Report No. TX-91+1906-1F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TEXAS MODEL VALIDATION FOR LEFT-TURN PHASING ALTERNATIVES		5. Report Date March 1991
		6. Performing Organization Code
7. Author(s) Randy B. Machemehl and Marc Acampora		8. Performing Organization Report No. Research Report 1906-1F
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Research Study 3-18-90/0-1906
12. Sponsoring Agency Name and Address Texas Department of Transportation Transportation Planning Division P. O. Box 5051 Austin, Texas 78763-5051		13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the Texas Department of Transportation
Research Study Title: "TEXAS Model Validation for Left-Turn Phasing Alternatives"

16. Abstract

The effectiveness of the TEXAS Model for Intersection Traffic in simulating a unique protected-permissive left-turn phasing scheme has been evaluated. Traffic flow and delay data from four Dallas, Texas, area field sites were compared with TEXAS Model simulations.

The field- and original model-generated measures of effectiveness generally compared favorably for traffic flows that were much less than saturation, using default specifications for vehicle and driver mixes within the simulation. However, simulation of flows that were a large fraction of saturation resulted in significant differences between field and simulation data until several "user-level" input specifications, including default driver and vehicle mixes, were modified. A series of changes to code within the model was prompted by the results of the study. These changes were implemented and validated. They resulted in excellent agreement between revised model output and field data using default versions of driver and vehicle distributions.

17. Key Words TEXAS Model, simulation, left-turn, phasing scheme, protected, permissive, traffic flow, intersection, vehicles, drivers, effectiveness, evaluation	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TEXAS MODEL VALIDATION FOR LEFT-TURN PHASING ALTERNATIVES

by

Randy B. Machemehl
Marc Acampora

Research Report Number 1906-1F

Research Project 3-18-90/0-1906

TEXAS Model Validation for Left-Turn Phasing Alternatives

conducted for

Texas Department of Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH

Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

March 1991

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily represent the official views or policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

Research Study Number 3-18-90-1906 was a one-year study executed over approximately seven months. The primary objective was a comparison of traffic delay and flow predicted by the TEXAS traffic simulation model with that measured at four intersections in the Dallas, Texas, area. Traffic signalization employed at each of the four field sites included a unique phasing scheme for protected and permitted left-turn movements. This phasing scheme, often called "ring-based," has been the subject of some discussion regarding its safety and value as a traffic flow enhancement.

Because of the unusual character of the phasing, there was some question regarding whether the TEXAS Model could be configured to simulate its performance. Further, there were questions regarding the relative authenticity of simulated measures of effectiveness. The research study was designed to address these and several other related issues.

ABSTRACT

The effectiveness of the TEXAS Model for Intersection Traffic in simulating a unique protected-permissive left-turn phasing scheme has been evaluated. Traffic flow and delay data from four Dallas, Texas, area field sites were compared with TEXAS Model simulations.

The field- and original model-generated measures of effectiveness generally compared favorably for traffic flows that were much less than saturation, using default specifications for vehicle and driver mixes within the simulation. However, simulation of flows that were a large fraction of saturation resulted in significant differences between field and simulation data until several "user-level" input specifications, including default driver and vehicle mixes, were modified. A series of changes to code within the model was prompted by the results of the study. These changes were implemented and validated. They resulted in excellent agreement between revised model output and field data using default versions of driver and vehicle distributions.

SUMMARY

The TEXAS Model for Intersection Traffic has been evaluated as a tool for studying a unique protected-permitted left-turn phasing scheme. The phasing plan called "ring-based" phasing has been proposed as a means of increasing flow and reducing traffic delay. It is currently being used at a number of intersections in the Dallas, Texas, area.

During the fall of 1989, personnel of the Texas Transportation Institute collected data describing traffic operations at four Dallas area intersections where the phasing scheme was being employed. Data sets developed through manual interpretation of the video imagery were provided by TTI to the CTR research team.

After visiting each of the field sites, observing traffic operations, and collecting geometric data, traffic operations at the four field sites were simulated using the TEXAS Model. Traffic flow and delay data for simulation and field experiences were compared.

All comparisons for low traffic demands were very favorable. High traffic demands, however, produced differences, which were partially overcome through "user-level" changes to simulation parameters. Differences between simulation and field flow and delay data at high traffic volumes prompted code changes to the simulation model which, when implemented and validated, produced excellent agreement between field and simulation statistics.

IMPLEMENTATION STATEMENT

Results of this study have proved that the TEXAS Model can be configured to simulate the unique "ring-based" protected-permitted signal phasing scheme used currently in the Dallas, Texas, area. Additionally, simulation produced traffic measures of effectiveness which compare favorably with those measured in the field. The study prompted development of an improved TEXAS Model code which handles the complete range of low to high traffic demands.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION AND OBJECTIVES

A variety of different traffic signal phasing patterns are currently used at intersections where left-turn movements are allowed during both a protected left-turn phase and the circular green phase. This type of phasing pattern is often called protected-permitted left-turn phasing. A particularly unique scheme of this type, coupled with unusual signal head displays, has been implemented in the Dallas, Texas, area (see Chapter 2). In order to evaluate the value of this phasing scheme as an enhancement to traffic operations, the Texas Transportation Institute (TTI) was commissioned to collect traffic data at four Dallas area field sites where the special phasing scheme was implemented. This study was designed to evaluate the use of the TEXAS traffic simulation Model as a tool for studying the phasing scheme through computer simulation. If the TEXAS Model could be configured to properly simulate the operation of the signal controller under this scheme, and could be proved to produce reliable measures of effectiveness (MOE's), it could be used to further examine this and similar signal phasing patterns.

The TTI data collection for the four field sites occurred during the fall of 1989. Data consisting of phasing patterns and phase durations, as well as traffic flows and delays, were provided by TTI. Following visits to the field sites for observation and measurement of geometric features, the CTR research team simulated the field conditions using the TEXAS Model. MOE's from simulation- and video-based field data were compared through a series of simulation model parameter changes.

The field sites are described in the following chapter, while comparisons of MOE's are described in Chapters 3 and 4. Conclusions and recommendations developed through the effort are presented as Chapter 5.

CHAPTER 2. DATA COLLECTION

Personnel of the State Department of Highways (SDHPT), Maintenance and Operations Division, along with pesonnel of TTI, were responsible for choosing the field data collection sites and collecting the data. The intersections chosen are located in the Dallas area and have a unique signal phasing scheme, which will be described later. This signal display varies somewhat from the Manual on Uniform Traffic Control Devices (MUTCD) recommendations and has been the subject of some discussion. Since the phasing pattern was unusual and the signal displays were unique, it was felt that these data would provide an interesting opportunity to observe how well the TEXAS Model would simulate this situation.

DESCRIPTIONS OF INDIVIDUAL INTERSECTIONS

Measured Variables

The four intersections included in this study are the intersections of Garland Road and Buckner Boulevard, Inwood Road and West Mockingbird Lane, Plano Road and Belt Line Road, and Coit Road and Arapaho Road, located in the cities of Dallas and Richardson. All four intersections have four legs and all the streets involved are major arterials. At all intersections, opposing directional flow was separated by a median and each approach had a left-turn bay. In addition, at the intersection of Garland and Buckner, southbound traffic on Buckner was provided with a right-turn-only lane. The intersections of Plano and Belt Line and of Coit and Arapaho are located in commercial areas, while the other two are located in residential areas. The intersection of Coit Road and Arapaho Road was observed to be very spatially constrained. The lanes were narrow and many driveway entrances were located close to the intersection. It was noted that this could have an adverse effect on the volume of traffic the intersection could handle and on the delays incurred at that intersection. Figure 2.1 contains plan views of the intersections' geometrics.

Counts were not made to determine the percentages of various classes of vehicles using the intersections; however, the vehicle mix was observed to contain a very high percentage of passenger cars, with few trucks or buses using the intersections. In running the TEXAS Model, the default vehicle mix (which includes large trucks) was used initially. Later, in a series of specially-noted runs, that mix was modified to more accurately replicate the situation observed in the field.

MEASURED VARIABLES

A number of variables descriptive of traffic generations at the field sites were collected by the TTI research team. These were provided to the CTR team during the spring of 1990. Traffic counts were provided for traffic operations at each intersection during the morning peak and off-peak hours, and again during the afternoon peak and off-peak hours. The counts were broken down by fifteen-minute interval and by movement: through movements, left turns, and right turns. The counts were made for the streets affected by the unique signal timing pattern described in the next section. The TEXAS Model simulations would be performed initially to determine how well the model would perform with this unusual timing pattern. For this study, the cross street volumes were of little significance. In the simulation, a small value of ten vehicles per fifteen minutes was arbitrarily chosen as the cross street traffic volume, since a non-zero value is required for the simulation results and no count data were provided. The field studies apparently did not include cross streets, because no volume or delay or signal timing information was provided to the CTR research team. The intersections of Coit Road and Arapaho Road and of Inwood and West Mockingbird employed more than one signal timing scheme, so traffic counts were made in the aforementioned way for each timing scheme. The signal phase times were measured, including time allowed for permitted and protected left turns.

Stopped delay was interpreted from the video images by TTI personnel for the left-turn traffic affected by the subject phasing scheme. These data were compared to the simulation-based overall average stopped delay.

SIGNAL PHASING PATTERN

The signal timing pattern employed at the four intersections in this study does not adhere to recommendations in the MUTCD. The first phase of the pattern includes a protected left-turn green arrow combined with a circular green — as well as a circular green for through movements — for one direction of travel, while the other direction has only a circular green for permitted left turns. The protected left turn then gets a short clearance interval. In the next phase, both directions' through movements receive a circular green. The previously protected left turn, from its clearance interval, immediately becomes a circular green. After a brief clearance interval for the through traffic in the leading direction, red is observed for that direction, while the opposing through continues with a circular green and the left turn adds a protected green arrow along with a circular green. This is followed by a clearance interval for all presently occurring

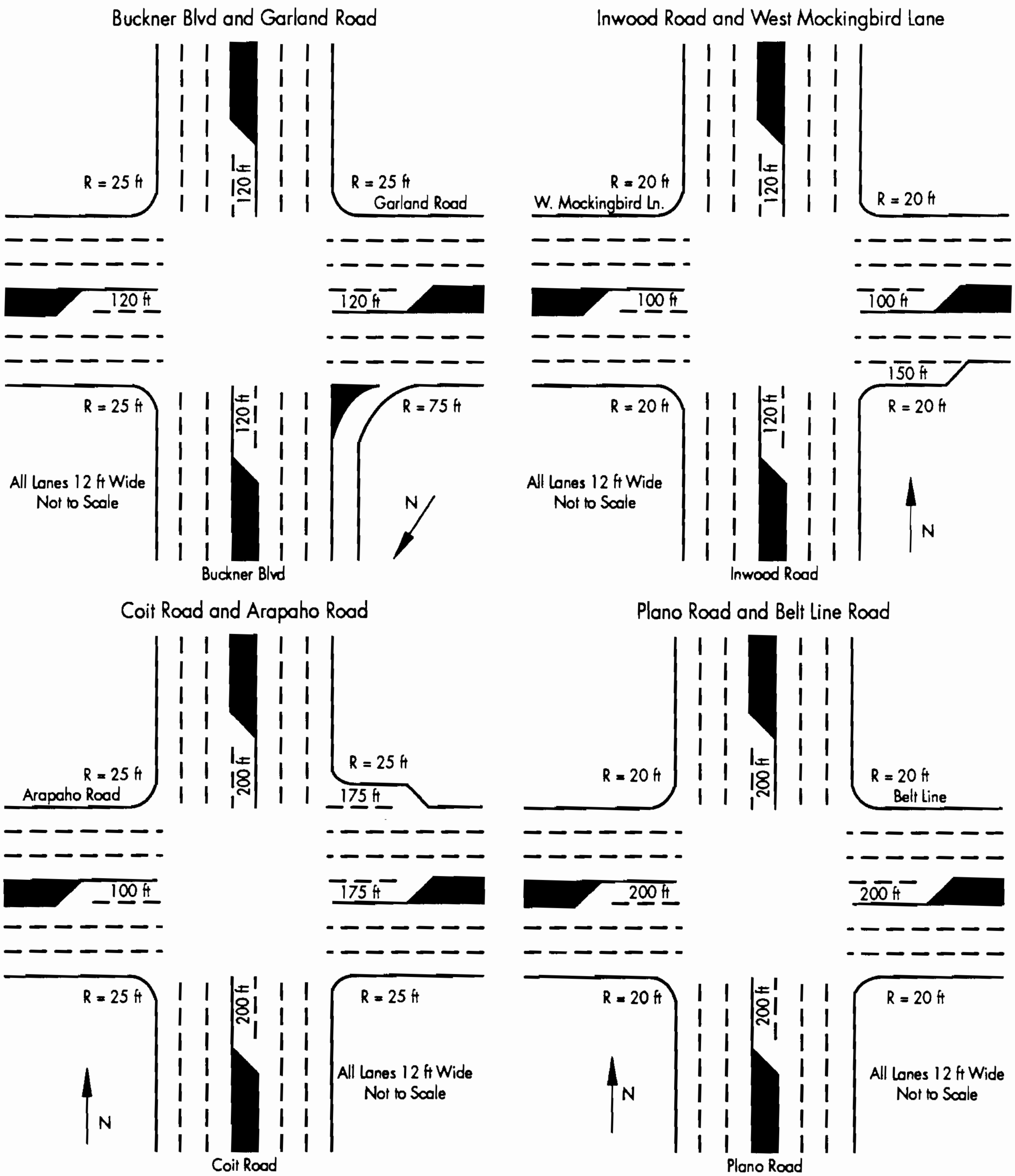

Figure 2.1 Field site geometrics

Coit and Arapaho - Case 1

Phase	Movements	Time (sec)
A	protected	7.5
		3.0
B		21.0
		3.0
C	protected	7.0
		5.0
D		38.5
		5.0

← N

N - prot = 7.5
S - prot = 7.0
N - per = 36.0
S - per = 34.5
Cycle = 90
N leads
Solid Line: Through
Dashed Line: Clearance

Coit and Arapaho - Case 2

Phase	Movements	Time (sec)
A	protected	24.5
		3.0
B		49.0
		3.0
C	protected	15.0
		5.0
D		75.5
		5.0

← N

N - prot = 24.5
S - prot = 15.0
N - per = 72.0
S - per = 79.5
Cycle = 180
N leads
Solid Line: Through
Dashed Line: Clearance

Figure 2.2 Signal timing and phasing for the Coit and Arapaho intersection

Inwood and West Mockingbird Lane - Case 1

Phase	Movements	Time (sec)
A	protected	16.0
		3.0
B		24.0
		3.0
C	protected	12.0
		4.0
D		83.0
		5.0

N ↓

W - prot = 12.0
E - prot = 16.0
W - per = 46.0
E - per = 43.0
Cycle = 150
E leads
Solid Line: Through
Dashed Line: Clearance

Inwood and West Mockingbird Lane - Case 2

Phase	Movements	Time (sec)
A	protected	22.0
		3.0
B		24.0
		3.0
C	protected	12.0
		4.0
D		77.0
		5.0

N ↓

W - prot = 12.0
E - prot = 22.0
W - per = 52.0
E - per = 43.0
Cycle = 150
N leads
Solid Line: Through
Dashed Line: Clearance

Figure 2.3 Signal timing and phasing for the Inwood and West Mockingbird intersection

Buckner Blvd and Garland Road

Phase	Movements	Time (sec)
A	protected	11.5
		3.0
B		16.0
		3.0
C	protected	15.5
		5.0
D		41.0
		5.0

↑ N

W - prot = 11.5
E - prot = 15.5
W - per = 39.5
E - per = 33.5
Cycle = 100
N leads
Solid Line: Through
Dashed Line: Clearance

Figure 2.4 Signal timing and phasing for the Garland and Buckner intersection

Plano Road and Belt Line Road

Phase	Movements	Time (sec)
A	protected	10.1
		3.0
B		11.1
		3.0
C	protected	9.8
		5.0
D		43.0
		5.0

N →

N - prot = 9.8
S - prot = 10.1
N - per = 27.2
S - per = 28.9
Cycle = 90
S leads
Solid Line: Through
Dashed Line: Clearance

Figure 2.5 Signal timing and phasing for the Plano and Beltline intersection

movements. Finally, cross-street traffic receives the circular green. Figures 2.2 through 2.5 depict this phase pattern, along with the timing for each intersection. The two different timing schemes, for Coit and Arapaho and for Inwood and West Mockingbird, are each represented separately.

SUMMARY

Information for characterizing the test intersections, either provided to or developed by the research team, included intersection geometrics as well as signal timing and phasing patterns. MOE's provided for characterizing traffic operations included traffic flows as well as stopped time left-turn delays.

Procedures implemented in developing complementary simulation data are presented in the following chapter.

CHAPTER 3. PERFORMING THE TEXAS MODEL SIMULATIONS

The various forms of field data collected for this study, as well as descriptions of the geometric features of the intersections, were given in Chapter 2. Traffic volumes, counted at various times of day and broken into straight, left-turn, and right-turn movements, were summarized in tabular form. Measured stopped delays and the timing schemes for the traffic signals at the intersections were also given. Finally, a description of the unique signal phasing scheme was provided.

SIMULATION SPECIFICATIONS

This chapter will briefly discuss how the data were used in running the TEXAS Model simulations. The discussion is presented assuming that the reader is familiar with the TEXAS Model. Additional information on the TEXAS Model can be found in Refs 1, 2, and 3.

A simulation was performed for each fifteen-minute time interval represented in the field data. Thus a variety of conditions were represented in the simulation, as data were collected during AM off-peak, AM peak, PM off-peak, and PM peak time periods. In addition, the intersections of Coit and Arapaho and of Inwood and West Mockingbird had more than one signal timing scheme. Each of these schemes was also represented by simulations for the same time periods noted above.

To set up a simulation run, first the geometry of the intersection in question would be entered, based on the data provided, through the GDVDATA preprocessor. Also entered at this time were the traffic volumes counted in the field for that fifteen-minute interval being simulated and the turning movement percentages. As was mentioned previously, the cross street volume was arbitrarily entered as ten vehicles per fifteen minutes. Initially, all other simulation values were defaults except that the headway distribution was changed from shifted negative exponential to uniform distribution in the cases where the computer was unable to process the large numbers of vehicles due to the minimum gap requirements of the default distribution. This occurred in only five runs on the intersection of Coit and Arapaho, and this modification would have no significant bearing on the overall results. The geometry processor was run at this point so that all movement paths through the intersection could be described mathematically.

The next step was to enter the simulation data in the part of the program called SIMDATA. This included specifying the length of simulation time, which was fifteen minutes throughout this study. Also input at this time were the signal phasing pattern and the specific signal timing scheme desired for the simulation. The simulation was finally run by executing the simulation processor, SIMPRO.

Initially, simulations were performed for each fifteen-minute field data interval, with the only exceptions to the pre-programmed default values noted above. Six conditions were simulated for the intersection of Inwood and West Mockingbird, nine for the intersection of Plano and Belt Line, fourteen for Garland and Buckner, and seventeen for Coit and Arapaho, for a total of forty-six initial simulations. Ten additional simulations were performed later with some of the default values modified. These additional simulations will be described in the next chapter.

SUMMARY

All conditions represented in the field data were simulated using all available field information to characterize the intersections, signalization, and traffic. Initially, all parameters required for simulation not measured in the field were specified as default values. Additional repetitions of the simulation were performed later using modifications to default specifications. Results of the comparisons of field and simulation MOE's are presented in Chapter 4.

CHAPTER 4. SIMULATION RESULTS

In Chapter 2 the raw data collected in the field were described, and in Chapter 3 the use of these data in the running of TEXAS model simulations was outlined. This chapter will provide the results obtained from the simulations and appropriate comments. Also described are the modifications made to default simulation parameters, the reasons why these modifications were tried and why the fifteen-minute intervals were chosen to be re-simulated. Finally, the results of these simulations are given.

From simulation, the Overall Average Stopped Delay, the Number of Left-Turn Vehicles Processed for Left Turns, and the Total Number of Vehicles Processed from each subject approach were obtained. These values would be compared with the measured field values for delay, left-turn volume, and total volume, respectively.

Table 4.1 Comparison of counted and simulated traffic volumes — Coit and Arapaho

		Coit Northbound						Coit Southbound					
RUN	t	COL LT	SIM LT	Δ	COL TV	SIM TV	Δ	COL LT	SIM LT	Δ	COL TV	SIM TV	Δ
1	2	41	38	-3	249	243	-6	25	20	-5	238	223	-15
2	3	38	35	-3	244	233	-11	27	27	0	242	233	-9
3	4	43	43	0	243	237	-6	28	28	0	270	266	-4
4	5	51	43	-8	281	283	2	22	22	0	295	301	6
5	6	44	39	-5	268	255	-13	22	24	2	261	263	2
6	7	44	36	-8	283	276	-7	40	39	-1	302	306	4
7	2	54	41	-13	362	337	-25	34	35	1	297	298	1
8	3	49	38	-11	316	297	-19	39	43	4	334	334	0
9	4	55	50	-5	314	309	-5	33	34	1	285	287	2
10	5	54	47	-7	306	308	2	37	38	1	287	293	6
11	6	47	39	-8	296	282	-14	38	36	-2	289	288	-1
12	7	40	32	-8	317	305	-12	31	32	1	303	302	-1
Avg		47	40	-7	290	280	-10	31	32	0	284	283	-1
13	3	51	48	-3	482	442	-40	33	33	0	319	322	3
14	4	55	50	-5	497	431	-66	36	32	-4	294	287	-7
15	5	63	45	-18	571	420	-151	36	31	-5	311	305	-6
16	6	61	44	-17	553	429	-124	40	37	-3	350	334	-16
17	7	56	41	-15	609	437	-172	42	34	-8	351	323	-28
Avg		57	46	-12	542	432	-111	37	33	-4	325	314	-11
15.2(1)	5	63	49	-14	571	498	-73	36	39	3	311	318	7
16.2(1)	6	61	51	-10	553	467	-86	40	44	4	350	361	11
17.2(1)	7	56	43	-13	609	500	-109	42	37	-5	351	347	-4
Avg		60	48	-12	578	488	-89	39	40	1	337	342	5
15.3(2)	5	63	51	-12	571	501	-70	36	39	3	311	324	1
16.3(2)	6	61	46	-15	553	470	-83	40	40	0	350	359	9
17.3(2)	7	56	53	-3	609	517	-92	42	39	-3	351	346	-5
Avg		60	50	-10	578	496	-82	39	39	0	337	343	6

Abbreviations: COL = field data
SIM = simulation data
LT = left turn volume/15 min
TV = total approach volume/15 min
Δ = difference between previous two columns
t = serial number for replicate 15-minute field observation periods on different days
(1) Simulation using 100% fast passenger cars
(2) Simulation with 100% fast passenger cars and 100% aggressive drivers

Field-counted and simulation-produced left-turn and total approach volumes are presented in Tables 4.1 through 4.4. All volumes are for fifteen-minute analysis intervals. Overall differences between simulated and field left-turn volumes ranged from a maximum of -33 percent at Mockingbird to 0 in several cases. The overall unweighted average indicated that simulation produced about five fewer left-turn vehicles per fifteen minutes than the field counts. At Garland and Buckner, the average field and simulated left-turn flows across fourteen different conditions were exactly equal. The comparison of

Table 4.2 Comparison of counted and simulated traffic volumes — Garland and Buckner

		Garland Eastbound						Garland Westbound					
RUN	t	COL LT	SIM LT	Δ	COL TV	SIM TV	Δ	COL LT	SIM LT	Δ	COL TV	SIM TV	Δ
1	1	65	66	1	204	206	2	30	36	6	218	241	23
2	2	66	64	-2	242	250	8	32	32	0	244	266	2
3	3	71	80	9	223	238	15	33	35	2	238	254	16
4	4	72	71	-1	225	226	1	34	26	-8	232	241	9
5	5	66	67	1	266	265	-1	38	37	-1	228	229	1
6	6	62	55	-7	245	251	6	38	35	-3	194	207	1
7	7	66	63	-3	230	229	-1	36	38	2	215	235	20
8	1	65	65	0	286	282	-4	37	37	0	205	213	8
9	2	61	58	-3	277	279	2	43	48	5	194	208	14
10	3	73	74	1	272	271	-1	47	46	-1	220	237	1
11	4	75	72	-3	277	278	1	42	42	0	178	190	1
12	5	83	78	-5	269	282	13	41	40	-1	232	239	7
13	6	61	65	4	239	243	4	36	41	5	214	242	28
14	7	67	67	0	279	283	4	39	42	3	219	244	25
Avg		68	68	0	252	256	4	38	38	0	217	232	15

Abbreviations: COL = field data
SIM = simulation data
LT = left turn volume/15 min
TV = total approach volume/15 min
Δ = difference between previous two columns
t = serial number for replicate 15-minute field observation periods on different days

Table 4.3 Comparison of counted and simulated traffic volumes — Inwood and W. Mockingbird

		West Mockingbird Lane Eastbound						West Mockingbird Lane Westbound					
RUN	t	COL LT	SIM LT	Δ	COL TV	SIM TV	Δ	COL LT	SIM LT	Δ	COL TV	SIM TV	Δ
1	1	55	53	-2	249	216	-33	35	30	-5	177	160	-17
2	2	49	48	-1	196	188	-8	28	24	-4	161	143	-18
Avg		52	51	-1.5	223	202	-21	32	27	-5	169	152	-17.5
3	4	69	65	-4	309	273	-36	44	30	-14	186	158	-28
4	5	81	66	-15	330	247	-83	41	31	-10	193	157	-36
5	6	77	66	-11	321	245	-76	44	23	-21	199	151	-48
6	7	71	64	-7	285	238	-47	41	32	-9	194	172	-22
Avg		75	65	-9.25	311	251	-61	43	29	14	193	160	-33.5
4.2(1)	5	81	66	-15	330	269	-61	41	36	-5	193	179	-14
5.2(1)	6	77	71	-6	321	285	-36	44	38	-6	199	185	-14
Avg		79	69	-11	326	277	-49	43	37	-6	196	182	-14
4.3(2)	5	81	70	-11	330	280	-50	41	43	2	193	196	3
5.3(2)	6	77	62	-15	321	282	-39	44	46	2	199	205	6
Avg		79	66	-13	326	281	-45	43	45	2	196	201	5

Abbreviations: COL = field data
SIM = simulation data
LT = left turn volume/15 min
TV = total approach volume/15 min
Δ = difference between previous two columns
t = serial number for replicate 15-minute field observation periods on different days
(1) Simulation using 100% fast passenger cars
(2) Simulation with 100% fast passenger cars and 100% aggressive drivers

total approach values yielded similar results, ranging from -20 percent (simulation less than field) to 0 for two different cases at the Coit and Arapaho intersection. Overall, the simulated and field-counted left-turn and total approach volumes tend to agree quite well. Data for different signal timing schemes are separated on the tables by a solid line, and the average values for each set of data for a single timing scheme are provided in italics. Also calculated is the difference, Δ, between the field and the simulated values.

Comparative stopped time delay data for the test sites are presented in Tables 4.5 through 4.8. The tables present the raw field stopped delay data with column heading "DM" and the final adjusted value as "dM2." The DM values were reduced by the TTI analysts by approximately 8 percent as recommended in the FHWA guide for the delay collection procedure which was employed (Ref 6). The most comparable simulation and field delay statistics are those designated OASD (overall average stopped delay) and dM2 (modified field delay). Comparisons of the simulation and field left-turn delays were favorable for the Garland and Buckner and the Plano and Belt Line sites. At these locations, where traffic volumes were generally light, average simulation and field delays varied from each other by -3 and +8 seconds per vehicle, respectively. At the other two field sites, traffic volumes were high for some or most observation periods. For these high-volume conditions, simulation produced left-turn stopped delays that were much higher than field values. These

Table 4.4 Comparison of counted and simulated traffic volumes — Plano and Belt Line

		Plano Northbound						Plano Southbound					
RUN	t	COL LT	SIM LT	Δ	COL TV	SIM TV	Δ	COL LT	SIM LT	Δ	COL TV	SIM TV	Δ
1	2	46	42	-4	189	196	7	43	40	-3	169	168	-1
2	3	50	46	-4	206	196	-10	32	34	2	157	157	0
3	4	60	56	-4	222	233	11	28	24	-4	134	124	-10
4	2	58	53	-5	281	289	8	52	50	-2	242	237	-5
5	3	64	58	-6	306	309	3	33	39	6	215	218	3
6	4	70	64	-6	264	265	1	49	48	-1	202	192	-10
7	5	64	64	0	266	263	-3	40	41	1	212	211	-1
8	6	49	44	-5	214	220	6	33	33	0	179	183	4
9	7	51	49	-2	234	233	-1	38	43	5	201	200	-1
Avg		57	53	-4	242	245	2	39	39	0	190	188	-2

Abbreviations: COL = field data
SIM = simulation data
LT = left turn volume/15 min
TV = total approach volume/15 min
Δ = difference between previous two columns
t = serial number for replicate 15-minute field observation periods on different days

Table 4.5 Comparative delay data — Plano and Belt Line

		Plano Northbound					Plano Southbound				
RUN	t	DM	dM2	ASD	OASD	Δ	DM	dM2	ASD	OASD	Δ
1	2	16.1	14.8	26.8	21.7	6.9	19.2	17.7	21.9	18.6	0.9
2	3	11.5	10.6	31.5	23.3	12.7	26.7	24.6	25.8	22.0	2.6
3	4			27.1	18.9	—			27.4	21.7	—
4	2	19.8	18.2	35.2	29.2	11.0	25.3	23.3	48.8	47.8	24.5
5	3	25.3	23.3	43.0	40.7	17.4	18.2	16.8	29.8	27.6	10.8
6	4	50.2	46.2	37.8	33.1	-13.1	35.7	32.9	49.4	47.4	14.5
7	5	21.9	20.1	39.4	35.1	15.0	38.9	35.7	40.3	37.4	1.7
8	6	24.9	22.9	31.8	22.4	-0.5	14.9	13.7	26.8	23.6	9.9
9	7	26.9	24.7	44.4	39.9	15.2	26.5	24.4	33.1	29.2	4.8
Avg		24.6	22.6	35.2	29.4	8.1	25.7	23.6	33.7	30.6	8.7

Abbreviations: DM = raw field stopped delay
dM2 = modified field stopped delay
ASD = simulated average stopped delay
OASD = simulation overall average stopped delay
(total stopped delay/volume processed)
Δ = OASD - dM2
t = serial number for replicate 15-minute field observation periods on different days

conditions were the topic of several sets of additional simulation runs. Data for the additional simulation runs, described below, appear in Tables 4.5 through 4.8 designated by the original run number being re-simulated, and following the decimal, a serial number.

The simulation results were problematic for several conditions at the intersections of Inwood and West Mockingbird and of Coit and Arapaho. Volume and delay data for these conditions are presented in Table 4.9. In particular, it was noted that the TEXAS Model had a difficult time processing the large numbers of vehicles required in several of the runs. This led to low simulated values for total volume and left-turn volume and to extremely high delay values.

As a possible solution, the default values for the traffic mix were modified. It was observed that the field traffic was comprised of nearly all passenger cars and that the default traffic mix incorporates both large and small trucks. To test this assumption, simulations (runs 15.2-17.2 of Table 4.6 and 4.2-5.2 of Table 4.8) were performed with the traffic mix modified to include 100 percent small, fast cars. Additionally the parameters which affect gap acceptance by left turners (*t*lead and *t*lag) were set to the minimum currently allowed. The results were noticeably improved.

Since the high volumes which gave the TEXAS Model difficulty were occurring during peak traffic conditions, drivers would, for the most part, be commuters who were familiar with the route, and so probably would drive fast and aggressively. To test this assumption, additional simulations (runs 15.3-17.3 of Table 4.6 and 4.2-5.2 of Table 4.8) were performed in which the driver characteristics were modified to reflect 100 percent of the most aggressive drivers allowed by the simulation. This modification involved

Table 4.6 Comparative delay data — Coit and Arapaho

		Coit Northbound					Coit Southbound				
RUN	t	DM	dM2	ASD	OASD	Δ	DM	dM2	ASD	OASD	Δ
1	2	13.0	11.9	37.1	34.1	22.2	21.3	19.6	30.0	22.5	2.9
2	3	11.1	10.2	30.3	25.1	14.9	27.0	24.8	32.3	22.7	-2.1
3	4	19.5	18.0	43.5	42.5	24.5	16.0	14.7	34.5	25.9	11.2
4	5	37.3	34.3	95.6	95.6	61.3	19.1	17.6	34.4	25.0	7.4
5	6	21.0	19.3	44.1	40.7	21.4	20.4	18.7	41.6	31.2	12.5
6	7	33.7	31.0	53.5	50.5	19.5	48.7	44.8	40.5	31.1	-13.7
7	2	23.6	21.7	60.2	58.8	37.1	30.5	28.0	55.7	54.1	26.1
8	3	25.7	23.7	122.5	122.5	98.8	48.5	44.6	50.5	48.2	3.6
9	4	23.9	22.0	90.0	90.0	68.0	30.1	27.7	30.7	27.1	-0.6
10	5	17.9	16.5	48.3	48.3	31.8	25.7	23.7	38.9	32.8	9.1
11	6	11.3	10.4	58.8	52.8	42.4	27.3	25.1	42.3	35.3	10.2
12	7	16.8	15.5	29.6	26.8	11.3	16.3	15.0	46.8	39.5	24.5
Avg		21.2	19.5	59.5	57.3	37.8	27.6	25.4	39.9	33.0	7.6
13	3	31.3	28.8	85.2	85.2	56.4	57.7	53.1	95.4	95.4	42.3
14	4	29.3	26.9	129.2	129.2	102.3	46.3	42.6	302.2	302.2	259.6
15	5	26.9	24.7	153.3	153.3	128.6	52.9	48.7	211.6	211.6	162.9
16	6	27.8	25.5	106.8	104.4	78.9	64.8	59.6	206.0	206.0	146.4
17	7	69.5	63.9	145.2	145.2	81.3	116.3	107.0	194.9	194.9	87.9
Avg		37.0	34.0	123.9	123.5	89.5	67.6	62.2	202.0	202.0	139.8
15.2(1)	5		24.7		68.0	43.3		48.7		52.7	4.0
16.2(1)	6		25.5		37.4	11.9		59.6		66.1	6.5
17.2(1)	7		63.9		62.3	-1.6		107.0		137.6	30.6
Avg			38.0		55.9	17.9		71.8		85.5	13.7
15.3(2)	5		24.7		38.2	13.5		48.7		78.7	30.0
16.3(2)	6		25.5		42.9	17.4		59.6		44.0	-15.6
17.3(2)	7		63.9		52.4	-11.5		107.0		90.7	-16.3
Avg			38.0		44.5	6.5		71.8		71.1	-0.6

Abbreviations: DM = raw field stopped delay
dM2 = modified field stopped delay
ASD = simulated average stopped delay
OASD = simulation overall average stopped delay (total stopped delay/volume processed)
Δ = OASD - dM2
t = serial number for replicate 15-minute field observation periods on different days
(1) Simulation using 100% fast passenger cars
(2) Simulation with 100% fast passenger cars and 100% aggressive drivers

modifying the actual data file created by GDVDATA, since no user-friendly interface is provided to allow for the direct modification of driver characteristics.

The results of these experiments are presented in Figures 4.1 and 4.2, depicting information for the Coit and Inwood intersections, respectively. The figures indicate that modifications to vehicle mix and driver type generally produced acceptable delay predictions for the Coit site but did not really succeed for the Inwood site.

Based upon these and other field evaluations, a number of modifications to TEXAS Model code were developed. These include the following:

(1) An input option was added to allow left-turning vehicles on signalized lanes to advance into the intersection on the green signal indication to within 10 feet of the first potential intersection conflict point.
The signal-response algorithm was modified to allow vehicles which have moved more than 4 feet beyond the stop line to react as if they have an unprotected-green signal indication when under the yellow-change interval, and to react as if they have a protected-green signal indication after the signal becomes red. These additions potentially allow more left-turn traffic to be processed.

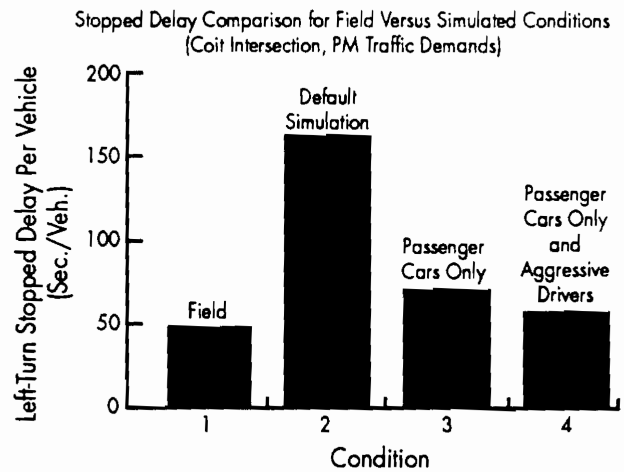

Figure 4.1 **Effects of changes to driver and vehicle mix for the Coit intersection**

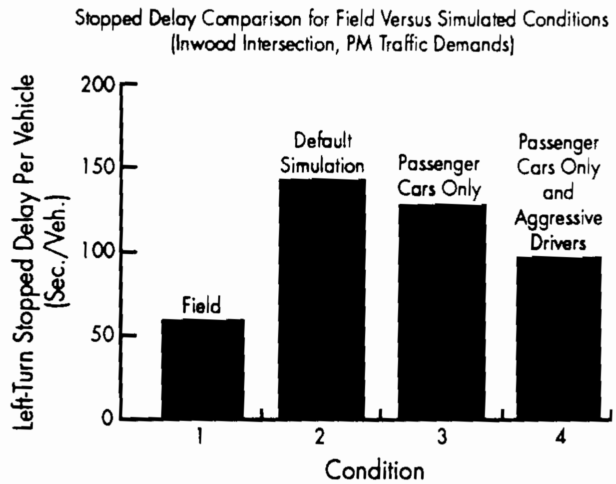

Figure 4.2 **Effects of changes to driver and vehicle mix for the Inwood intersection**

Table 4.7 **Comparative delay data — Garland and Buckner**

		Garland Eastbound					Garland Westbound				
RUN	**t**	**DM**	**dM2**	**ASD**	**OASD**	**Δ**	**DM**	**dM2**	**ASD**	**OASD**	**Δ**
1	1	37.9	34.8	45.2	28.8	-6.0	8.1	7.4	26.9	20.2	12.8
2	2			45.7	30.0	—	15.2	14.0	21.2	17.2	3.2
3	3	26.4	24.3	41.1	24.7	0.4	14.0	12.9	19.4	15.0	2.1
4	4	43.8	40.3	38.8	23.5	-16.8			23.6	18.2	—
5	5	32.8	30.1	50.6	32.5	2.4			18.7	15.7	—
6	6	35.1	32.3	28.0	19.3	-13.0			17.0	14.6	—
7	7			39.2	22.4	—			17.3	10.4	—
8	1	33.0	30.4	42.6	22.3	-8.1	32.0	29.4	22.0	17.8	-11.6
9	2	26.9	24.8	31.1	22.0	-2.8	24.4	22.5	26.8	22.9	0.4
10	3	27.9	25.6	40.7	24.8	-0.8	24.3	22.5	25.0	20.7	-1.8
11	4			35.9	23.4	—	32.6	30.0	22.2	16.4	-13.6
12	5			44.5	27.4	—	21.4	19.7	25.0	20.6	0.9
13	6			38.0	25.1	—	20.8	19.2	22.5	17.6	-1.6
14	7			45.7	25.9	—	20.4	18.7	21.7	19.6	0.9
Avg		33.0	30.3	40.5	25.2	-5.6	21.3	19.6	22.1	17.6	-0.8

Abbreviations: DM = raw field stopped delay
dM2 = modified field stopped delay
ASD = simulated average stopped delay
OASD = simulation overall average stopped delay (total stopped delay/volume processed)
Δ = OASD - dM2
t = serial number for replicate 15-minute field observation periods on different days

(2) An intersection conflict-avoidance routine was added so that vehicles that have gained the right to enter the intersection will adjust their velocity to avoid conflicts with other vehicles that have previously gained the right to enter the intersection. This addition was necessitated by the left-turn pull-out option. It allows the use of lower time values than previously suggested for the lead and lag safety zones for intersection conflict-checking, thus potentially processing more left-turn traffic.

(3) The maximum jerk rate (rate of change of acceleration) for a vehicle was changed from a constant to a variable, and the value was changed from 4 to 6 feet/sec/sec/sec.

(4) The minimum distance between vehicles when stopped in a queue was changed from a constant to a variable, and the programmed value was changed from 4 to 3 feet.

(5) A variable was added for each vehicle to define whether the vehicle had been updated for the current time increment and whether the vehicle

Table 4.8 Comparative delay data — Inwood and W. Mockingbird

		W. Mockingbird Lane Eastbound					W. Mockingbird Lane Westbound				
RUN	t	DM	dM2	ASD	OASD	Δ	DM	dM2	ASD	OASD	Δ
1	1	21.4	19.7	123.4	123.4	103.7	39.2	36.1	124.0	124.0	87.9
2	2	12.6	11.6	47.7	40.7	29.1	42.5	39.1	115.1	115.1	76.0
Avg		17.0	15.7	85.6	82.1	66.4	40.9	37.6	119.6	119.6	82.0
3	4	32.5	29.9	82.0	82.0	52.1	71.6	65.9	149.9	149.9	84.0
4	5	74.7	68.7	118.0	118.0	49.3	48.5	44.6	207.3	207.3	162.7
5	6	74.4	68.4	110.9	110.9	42.5	79.6	73.2	202.3	202.3	129.1
6	7	60.9	56.1	104.7	104.7	48.6	70.0	64.4	180.6	180.6	116.2
Avg		60.6	55.8	103.9	103.9	48.1	67.4	62.0	185.0	185.0	123.0
4.2(1)	4		68.7		98.9	30.2		44.6		163.4	118.8
5.2(1)	5		68.4		88.3	19.9		73.2		169.1	95.9
Avg			68.6		93.6	25.1		58.9		166.3	107.4
4.3(2)	4		68.7		94.0	25.3		44.6		107.9	63.3
5.3(2)	5		68.4		83.0	14.6		73.2		114.4	41.2
Avg			68.6		88.5	19.9		58.9		111.2	52.3

Abbreviations: DM = raw field stopped delay
dM2 = modified field stopped delay
ASD = simulated average stopped delay
OASD = simulation overall average stopped delay
(total stopped delay/volume processed)
Δ = OASD - dM2
t = serial number for replicate 15-minute field observation periods on different days
(1) Simulation using 100% fast passenger cars
(2) Simulation with 100% fast passenger cars and 100% aggressive drivers

Table 4.9 Problematic simulation conditions

				LT Delay		LT Volume		Total Volume	
Intersection	Condition	Dir	Tim	COL	SIM	COL	SIM	COL	SIM
Coit	1	N	1	19.5	57.3	47	40	290	280
	2	S	1	25.4	33.0	31	32	284	283
	3	N	2	34.0	123.5	57	46	542	432
	4	S	2	62.2	202.0	37	33	325	314
	3.5	N	2	34.0	55.9	57	48	542	488
	4.6	S	2	62.2	85.5	37	40	325	337
	3.7	N	2	34.0	44.5	57	50	542	496
	4.8	S	2	62.2	71.1	37	39	325	337
Inwood	1	E	1	15.7	82.1	52	51	223	202
	2	W	1	37.6	119.6	32	27	169	152
	3	E	2	55.8	103.9	75	65	311	251
	4	W	2	62.0	185.0	43	29	193	160
	3.5	E	2	55.8	93.6	75	69	311	277
	4.6	W	2	62.0	166.3	43	37	193	182
	3.7	E	2	55.8	88.5	75	66	311	281
	4.8	W	2	62.0	111.2	43	45	193	201

Additional conditions: Conditions x.5 & x.6 = all sports cars
Conditions x.7 & x.8 = sports cars/aggressive drivers

doubled its desired speed while on an intersection path.

(6) The minimum relative distance between stopped vehicles that causes a following vehicle to initiate a move-up maneuver was changed from a constant to a variable, but the programmed value remained at 10 feet. A vehicle will normally use the 10-foot value, except that this value is decreased to 3 feet when the vehicle ahead is accelerating. This change allows vehicles to respond more aggressively when a signal turns green.

(7) When the vehicle under examination was being required to accelerate according to the current speed of the vehicle ahead, and this requirement was removed, the distance used to transition the desired speed of the vehicle under examination from the current speed of the lead vehicle to the input desired speed of the vehicle under examination, was decreased from 100 to 50 feet. This change allowed vehicles to respond more aggressively when the vehicle ahead was pulling away from the vehicle being processed.

Additionally, a number of other changes to output reporting and vehicle/driver response to sign control were made. These are being documented with the next version of the TEXAS Model.

Comparisons of the TEXAS original and revised statistics, as well as field left-turn volume and delay statistics, are presented in Tables 4.10(A) and 4.10(B). The comparisons of Table 4.10(A) indicate much-improved agreement between field and revised TEXAS Model statistics. The differences between revised TEXAS and field data of Table 4.10(B) indicate two very encouraging things. First, the differences are both plus and minus, indicating no consistent bias: that is, the model does not consistently over- or underestimate field conditions. Second, the magnitudes of the differences are quite small. All simulation data generated with the revised model used the default vehicle and driver distributions.

These and other validation efforts of the revised TEXAS Model indicate that the modifications have solved the problems described earlier. The revised model is able to replicate the field conditions described within this study.

SUMMARY

The previous sections have presented discussions of comparisons of field and simulation traffic volume and stopped time delays. For the two test sites having moderate or lighter traffic demands, the volume and delay statistics for field and simulation conditions compare favorably. For the other two sites, conditions of high traffic demand resulted in large differences between the field and simulated data. User-level changes to vehicle and driver mix specifications produced improved simulation results for the problematic conditions at the Coit intersection. However, a series of significant changes to TEXAS Model code have been implemented and have essentially solved the problems. Comparisons of the revised Model predictions to field data indicate excellent agreement.

Table 4.10A. Revised TEXAS Model and field data

			LT Delay			LT Volume		
Intersection	Run	Dir	COL	SIM OLD	SIM REV	COL	SIM OLD	SIM REV
Coit	15	NB	24.7	153.3	37.8[1]	63	45	541
		SB	48.7	211.6	55.4[1]	36	31	391
	17	NB	63.9	145.2	41.0[1]	56	41	441
		SB	107.0	194.9	66.9[1]	42	34	421

[1] Mean for six replicate runs.
Default Driver and Vehicle Specifications

Table 4.10B. Differences between revised TEXAS and field data

Intersection	Run	Dir	LT Delay Difference	LT Volume Difference
Coit	15	NB	-6.7	+9
		SB	-40.1	-3
	17	NB	+22.9	+8
		SB	+40.1	0
	Total Difference		+16.2	+14

CHAPTER 5. RECOMMENDATIONS AND CONCLUSIONS

Traffic operations of four intersections with unique signal phasing plans were simulated with the TEXAS Model. Traffic volumes and stopped time delays predicted by the model were compared with field-measured values. Four different traffic demand conditions and several timing plans were simulated for each field site. For almost two-thirds of the simulated conditions, field and simulated volume and stopped delay varied by less than 10 percent.

High traffic demands at two field sites produced significant differences between field and simulated MOE's. User-level changes to simulation model specifications (changes that could be made by typical users) produced acceptable simulation results in all but approximately 10 percent of the simulated conditions (all at the Mockingbird Lane site). Changes to codes within the TEXAS Model designed to solve these remaining difficulties were not ready for testing at the time of submission of this preliminary report.

Experience gained through this effort has prompted the following recommendations:

(1) The unique protected-permitted left-turn phasing plan currently used in the Dallas area can be simulated using the TEXAS Model.

(2) When using TEXAS to simulate peak-period traffic operations in congested intersections, users should at least qualitatively characterize the vehicle mix at their field site. This characterization will allow proper modification of the default vehicle mix. If simulating an intersection condition that does not yet exist, users should modify the default vehicle mix to reflect only passenger cars.

(3) Simulation of peak-period traffic under heavy congestion should usually be performed only with aggressive drivers (Type 1 as characterized in the current TEXAS Model).

REFERENCES

1. Lee, Clyde E., Glenn E. Grayson, Charlie R. Copeland, Jeff W. Miller, Thomas W. Rioux, and Vivek S. Savur, "The TEXAS Model for Intersection Traffic — User's Guide," Research Report 184-3, Center for Highway Research, The University of Texas at Austin, July 1977.

2. Lee, Clyde E., Randy B. Machemehl, and Wiley M. Sanders, "TEXAS Model Version 3.0 (Diamond Interchanges)," Research Report 443-1F, Center for Transportation Research, The University of Texas at Austin, January 1989.

3. Lee, Clyde E., Randy B. Machemehl, Robert F. Inman, Charlie R. Copeland, Jr., and Wiley M. Sanders, "User-Friendly Texas Model — Guide to Data Entry," Research Report 361-1F, Center for Transportation Research, The University of Texas at Austin, August 1986.

4. *Highway Capacity Manual — 1985*, Transportation Research Board Special Report 209, 1985.

5. Lin, Han-Jei, Randy B. Machemehl, Clyde E. Lee, and Robert Herman, "Guidelines for Use of Left-Turn Lanes and Signal Phases," Research Report 258-1, Center for Transportation Research, The University of Texas at Austin, January 1984.

6. *Texas Transportation Institute Research Report 0989*, Texas Transportation Institute, Texas A&M University, College Station, Texas, 1991.