Technical Report Documentation Page

1. Report No. TX-94/1953-1F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ANALYSIS OF INTERSTATE 35 DESIGN ALTERNATIVES FOR AUSTIN, TEXAS		5. Report Date November 1994
		6. Performing Organization Code
7. Author(s) Jimmie D. Benson, Timothy J. Lomax, J. Michael Heath, and David L. Schrank		8. Performing Organization Report No. Research Report 1953-1F
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Study No. 7-1953
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Final: September 1990-November 1994
		14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation

Research Study Title: Analysis of Interstate 35 Design Alternatives for District 14

16. Abstract

The Texas Department of Transportation is considering the upgrade and improvement of Interstate 35 (IH-35) in the Austin area. Study 7-1953 was directed toward providing assistance to the Austin District to analyze IH-35 design alternatives. TTI assisted the District in reviewing the designs and integrating HOV lanes in the designs. To support the IH-35 analyses, time-of-day travel models were developed and implemented to support peak-period analyses. The Texas Mezzo-Level HOV Carpool Model was also implemented and applied for the IH-35 analyses. Detailed networks were coded and assigned for the various design alternatives. The purpose of this report is to document the model developed, implemented, and applied in the analyses of the IH-35 design alternatives.

17. Key Words Travel Forecasting, Peak-Hour Assignments, HOV Carpool Model, Detailed Highway Networks	18. Distribution Statement No Restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 90	22. Price

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

ANALYSIS OF INTERSTATE 35
DESIGN ALTERNATIVES FOR AUSTIN, TEXAS

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Research Report 1953-1F
Research Study Number 7-1953
Research Study Title: Analysis of Interstate 35
Design Alternatives for District 14

Sponsored by the
Texas Department of Transportation

November 1994

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IMPLEMENTATION STATEMENT

The focus of this study has been to assist the Austin District in the analysis of alternative designs for Interstate 35. Assistance was provided in incorporating an HOV facility into the alternative designs. The modeled results produced under this study have been used by the District in evaluating the alternative designs. The time-of-day models, the HOV carpool model, and the detailed network coding techniques were developed to interface with the Austin Transportation Study models. These models were implemented and used in this study and will be used in the future Major Investment Studies to be performed for Interstate 35. The FREQ10 application techniques have proven useful in analyzing the operational characteristics of the proposed improvements. The FREQ10 model will continue to be used by the District in their MIS analyses.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. Additionally, this report is not intended for construction, bidding, or permit purposes. Jimmie D. Benson, P.E. Number 45900, was the Principal Investigator for the project.

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SUMMARY

The Texas Department of Transportation is considering the upgrade and improvement of Interstate 35 (IH-35) in the Austin area. For the improvements the Austin District requested assistance in:

- reviewing the conceptual design alternatives delineated by the District;
- assisting in integrating HOV lanes in the design alternatives;
- developing, implementing, and applying time-of-day travel models to facilitate morning and afternoon peak-period analyses of forecast volumes for IH-35 in the Austin area;
- implementing and applying the Texas Mezzo-Level HOV Carpool Model to estimate the forecast carpool usage of the proposed HOV lanes;
- developing detailed 2020 highway networks for various IH-35 design alternatives delineated by the Austin District;
- preparing AM peak hour, PM peak hour, and 24-hour 2020 capacity restrained assignments using the detailed 2020 networks;
- implementing and applying the FREQ10 model for the operational analyses of the various IH-35 design alternatives.

Under this study, TTI provided the needed assistance to the Austin District in the analysis of Interstate design alternatives.

The ATS travel models are the traditional 24-hour travel models. Under this study, time-of-day models were developed and implemented for use in the IH-35 analyses. For the detailed network analyses, both AM and PM peak hour assignments were needed. In addition, peak-period speed estimates were needed for the HOV carpool model applications. A trip table factoring approach was implemented for the peak-period modeling. Time-of-day factors were developed using travel survey data from other cities. Hourly capacity estimates were developed by functional class and area type to be used in the time-of-day highway networks. The Texas Package software provided the framework for implementing the time-of-day models.

The demonstrated ability of HOV lanes (transitways) to move high volumes of peak-period commuters in congested freeway corridors has led to the large commitment to HOV lanes in Texas. Careful consideration is being given to incorporating exclusive HOV lanes in the proposed IH-35 improvements. An important task of this study was to assess the potential carpool usage for these HOV facilities.

The Texas Mezzo-Level HOV Carpool Model was implemented in the Texas Travel Demand Package by TTI for TxDOT to provide for the analysis of HOV facilities in such areas. The model is essentially a post-mode choice model which can be used to estimate the potential home-based work carpool usage for a proposed HOV facility. The home-based work person trip table, mode split information, and auto occupancy information from the ATS regional models are the basic inputs to the HOV carpool model. The HOV carpool model estimates the change in auto occupancy that can be anticipated due to the implementation of the proposed HOV carpool facility. These estimates are based on the differences in peak-period travel times for normal highway trips versus HOV carpool trips. The Texas Mezzo-Level Carpool Model was implemented for use in the Austin analyses.

In the ATS 24-hour networks, freeway sections are coded as a single link. This is common practice in preparing 24-hour networks for system analyses. Using this approach, a single link can be used to represent the main lanes, ramps, and frontage roads (in both directions) for a segment of IH-35. For the operational analysis of the IH-35 alternatives, the ATS networks were revised to include detail coding of the IH-35 design alternative being studied. In the detailed coding of the IH-35 improvements, separate one-way links were coded to represent the main lanes in each direction, the frontage roads in each direction, and entry or exit ramps. These networks were used to prepare morning and afternoon peak-hour assignments as well as detailed 24-hour assignments.

The application of the new modeling techniques implemented for the analyses of the IH-35 design alternatives has proven very successful and useful in reviewing and refining the alternatives. These models can continue to be used as new demographic forecasts are developed for the region to further evaluate the proposed improvements as a part of the Major Investment

Study which will be required under the Intermodal Surface Transportation Efficiency Act (ISTEA).

CHAPTER I. INTRODUCTION

The Texas Department of Transportation (TxDOT) is considering the upgrade and improvement of Interstate 35 (IH-35) in the Austin area. For the improvements the Austin District requested assistance in:

- reviewing the conceptual design alternatives delineated by the District;
- assisting in integrating HOV lanes in the design alternatives;
- developing, implementing, and applying time-of-day travel models to facilitate morning and afternoon peak-period analyses of forecast volumes for IH-35 in the Austin area;
- implementing and applying the Texas Mezzo-Level HOV Carpool Model to estimate the forecast carpool usage of the proposed HOV lanes;
- developing detailed 2020 highway networks for various IH-35 design alternatives delineated by the Austin District;
- preparing AM peak hour, PM peak hour, and 24-hour 2020 capacity restrained assignments using the detailed 2020 networks;
- implementing and applying the FREQ10 model for the operational analyses of the various IH-35 design alternatives.

The objective of Study 7-1953, a three-year study completed in August 1994, was to assist in the analysis of Interstate design alternatives. The following briefly summarizes the work plan tasks:

Task 1: Model Review and Work Plan Refinement

The conceptual alternatives delineated by the District were reviewed and the documentation for the regional travel forecasting models used by the Austin Transportation Study (ATS) were reviewed. Based on these reviews, refinements to the work plan were made.

Task 2: Review of Conceptual Design Alternatives

TTI reviewed and critiqued the conceptual designs developed by the Austin District. These analyses focused on integrating HOV lanes in the design alternatives.

Task 3: Regional Travel Assignment Analyses

The 2020 travel model data (i.e., the trip tables and the highway network) were obtained from the ATS and reviewed. Estimates of peak-period factors and other model parameters were prepared to provide for the application of the Texas Mezzo-level HOV Carpool Model. An HOV carpool network was developed based on the recommended HOV alternative. The Texas Mezzo-Level HOV Carpool Model was applied to estimate potential carpool usage.

Task 4: Operational Analyses for Selected Alternatives

Detailed highway networks were prepared for selected design alternatives for IH-35. Both AM and PM peak-hour assignments were performed for the detailed alternatives. Assistance was provided to the District in the FREQ10 model applications for the operational analyses of selected alternatives. Timing considerations for implementation of HOV alternatives were also examined.

Task 5: Corridor Analysis

The Transportation Planning and Programming Division was responsible for providing the design volumes on schematics. TTI provided the assignments developed under Task 4 for this work and was available to assist in resolving any questions that arose during the corridor analysis.

Task 6: Preparation of Documentation and Assistance in Implementation

This report presents the final report documenting the model applications performed under this study. TTI will also assist in implementing the study results.

ATS MODELS AND FORECASTS

The Austin Transportation Study (ATS) has developed and implemented a traditional four-step travel model set to forecast 24-hour highway and transit volumes. These models were calibrated and validated for 1985 (1). The ATS applied these models to develop the 24-hour 2020 travel forecasts for the region. The ATS model chain uses 635 zones and 25 external stations. The area covered by the models includes all of Travis County and portions of Williamson and Hayes Counties.

The ATS 2020 24-hour networks and trip tables were provided to TTI for use in the IH-35 analyses. The forecast 2020 person trip tables and transit trip tables provided were for the following trip purposes:

Homebased Work

Homebased Non-work - University of Texas

Homebased Non-work - Other

Airport Trips

Non-homebased

In the ATS models, the vehicle trip tables for the above trip purposes are estimated by removing the transit trips and factoring the remaining highway person trips using a single auto-occupancy factor for a given trip purpose. The ATS auto-occupancy was also provided by the ATS to allow TTI to compute the needed vehicle trip tables by purpose. The ATS forecast 2020 vehicle trip tables were provided for the following trip purposes:

Truck-Taxi

External Local

External Through

The trip tables and the 2020 highway network were provided in a TRANPLAN format and had to be converted to the Texas model format for use with the Texas software.

The models implemented under this study were developed to supplement, but not replace, the ATS models. The ATS models do not include time-of-day models or HOV carpool models. In the ATS models, freeways are coded using a single link to represent both the freeway main lanes and frontage roads. The detailed network coding performed under Task 4 of this study required the development of the detailed network coding techniques and parameters.

REPORT ORGANIZATION

This final report for Study 1953 is organized as follows:

- Chapter II describes the time-of-day modeling techniques developed and implemented to estimate peak-period demands and speeds.
- Chapter III describes the HOV carpool model implemented and applied to estimate the forecast HOV carpool demand.
- Chapter IV describes the detailed network coding techniques and parameters used in analyzing the IH-35 alternatives.
- Chapter V provides a brief summary of the study results and future direction for the major investment study (MIS) for the IH-35 improvements.

CHAPTER II. TIME-OF-DAY MODELS

The ATS travel models are traditional 24-hour travel models. Under this study, time-of-day models were developed and implemented for use in the IH-35 analyses. For the detailed network analyses, both AM and PM peak-hour assignments were needed. In addition, peak-period speeds estimates are needed for the HOV carpool model applications.

A variety of techniques may be used to estimate peak-period travel demands. These techniques vary widely in terms of their level of sophistication and in the level of effort required for model development and application. The approaches for estimating peak-period volumes can generally be grouped into four categories: factoring 24-hour volumes, trip table factoring, trip end factoring and direct generation (3). A vehicle trip table factoring approach was selected for implementation and use in this study. The trip table factoring approach has been successfully implemented by TTI for use in the Houston-Galveston region (4). Based on the success of the Houston models, it was considered the desirable approach for implementation in Austin.

The Texas Mezzo-Level HOV Carpool Model (discussed in detail in the next chapter) requires peak-period travel time estimates for its applications. It is important that these travel time estimates reflect the expected congestion on IH-35 so that reasonable potential time savings for HOV carpools can be estimated. These peak-hour travel times are better estimated using a peak-period traffic assignment than a conventional 24-hour non-directional assignment. A post-assignment speed model was implemented to estimated the peak-period speeds based on the peak-period assignment estimates. Again, the speed models implemented were similar to the models implemented by TTI for the Houston-Galveston Region (4, 5, 6).

DEVELOPMENT OF PEAK-PERIOD FACTORS

The forecast peak-period trip tables for the Austin Region are estimated by factoring the forecast 24-hour trip tables. This assures that the peak-period estimates are consistent with the 24-hour trip tables. The trip tables are factored by trip purpose using the PEAKOD routine of the Texas Trip Distribution Package. The PEAKOD routine factors a 24-hour production-to-attraction vehicle trip table and converts it to a peak-period origin-to-destination vehicle trip table.

This process requires estimates of both the percentage of travel expected to occur in the subject time period and the percentage of that travel expected to be in the production-to-attraction direction. A more detailed discussion of time of day models and the PEAKOD routine is available in a report entitled "Development of a Peak-Period Traffic Assignment Capability" (3).

The first step was to estimate peak-period factors for the homebased work, the homebased non-work, and the non-homebased trip tables. Since current travel survey data are not available for Austin area, recent travel survey data from several other Texas cities were obtained and processed for use in estimating the factors for Austin. The three surveys used were the 1990 San Antonio travel survey, the 1990 Amarillo travel survey, and the 1984 Houston travel survey. These travel survey data for San Antonio and Amarillo were made available to TTI by TxDOT's Transportation Planning and Programming Division. The travel survey data for Houston were made available to TTI by the Houston-Galveston Area Council (H-GAC). These data were processed to estimate the percentage of vehicle hours of travel occurring by time period and the portion of the travel in the production-to-attraction direction.

Table 1
Peak-Period Factors Estimates from Recent Travel Surveys in Texas

		Homebased Work		Homebased Non-work		Non-homebased		All 3 Purposes
Time Period	Study Area	% VHT	% P-to-A	% VHT	% P-to-A	% VHT	% P-to-A	% VHT
Morning Peak Hour	Amarillo	18.027	97.814	9.080	81.966	7.881	50.000	10.991
	San Antonio	18.131	98.809	8.553	80.952	7.069	50.000	10.944
	Houston	20.636	97.739	7.192	89.787	4.163	50.000	10.222
Afternoon Peak Hour	Amarillo	15.442	5.677	9.083	31.435	9.229	50.000	10.784
	San Antonio	14.679	6.266	7.722	35.814	9.583	50.000	10.372
	Houston	13.797	2.264	10.152	29.135	9.976	50.000	11.182
Morning Peak 3 Hours	Amarillo	27.582	96.036	19.311	76.851	18.617	50.000	21.220
	San Antonio	34.991	97.847	18.372	76.370	15.435	50.000	22.408
	Houston	44.965	98.374	17.127	88.244	11.877	50.000	23.732
Afternoon Peak 3 Hours	Amarillo	30.974	10.496	24.935	34.797	26.800	50.000	27.144
	San Antonio	32.230	8.230	22.624	34.325	25.340	50.000	26.328
	Houston	30.499	2.395	30.008	32.131	22.988	50.000	27.884

Table 1 summarizes the factors estimated from the three household travel surveys for the morning and afternoon peak-hour and peak 3-hour periods. As may be observed from Table 1 data, 10 to 11 percent of the overall vehicular travel by the residents occurred in the morning peak hour. The percentages of travel by purpose were also reasonably consistent. After reviewing these data and the forecast 2020 population for the Austin study area, it was determined that the factors from the San Antonio survey would be used in the Austin morning peak-hour modeling efforts.

Peak-hour factors are also needed for factoring the 24-hour truck-taxi trip tables and the 24-hour external trip tables. Again there are no recent surveys for the Austin area. The 1984 travel surveys performed in the Houston and Dallas-Fort Worth areas did not include truck, taxi and external traffic surveys. The truck and external surveys performed in 1990 by TxDOT were not structured for this type of analysis. This problem was addressed in the Houston modeling efforts by using factors developed from data collected in urban areas outside of Texas. The five urban areas (from which the Houston factors were estimated) were Boston, Seattle, Louisville, Oklahoma City and Colorado Springs. Since TTI developed these trip table factors to represent a cross-section of urban areas, the factors developed for Houston were also applied in this study. Table 2 summarizes these factors.

Table 2
Truck-Taxi and External Trip Table Factors

	Truck-Taxi		Externals	
Time Period	% VHT	% P-to-A	% VHT	% P-to-A
Morning Peak Hour	7.03	50.00	5.14	55.00
Afternoon Peak Hour	7.40	50.00	8.11	45.00
Morning Peak 3 Hours	19.04	50.00	14.08	55.00
Afternoon Peak 3 Hours	20.19	50.00	22.92	45.00

Source: "Development of Time of Day Factor Estimates for Truck-Taxi and External Travel Using Survey Data from Other Urban Areas", TTI Technical Memorandum, prepared for the Houston-Galveston Area Council, September 20, 1991 (8).

DEVELOPMENT OF HOURLY CAPACITY ESTIMATES

The peak-hour capacity restraint assignments are performed by using the PEAK CAPACITY RESTRAINT routine in the Texas Large Network Package. To perform these peak-hour assignments, hourly capacity estimates were developed for Austin. Table 3 summarizes the 24-hour network capacities used in the ATS. As may be noted, the capacities were developed to represent the typical average daily capacity per lane. To remain consistent with this approach, the hourly capacity estimates were also developed to represent the typical average capacity per hour per lane.

The hourly capacities developed for use in this study are also summarized in Table 3. Tables A-1 through A-6 (of Appendix A), document the formulas and the typical parameter values applied in the formulas to estimate the hourly capacities.

Note that the 24-hour capacity data in Table 3 are used to estimate the 24-hour non-directional capacities on links. Hence, the 24-hour frontage road capacities (i.e., the 18,000 vehicles per day) added to the freeway links represent the sum of the capacities of the two frontage roads (i.e., the frontage road in the A-to-B direction and the frontage road in the B-to-A direction).

In contrast, the peak-hour assignments employ a directional network in which the A-to-B capacity and the B-to-A capacity are estimated separately and entered into different fields in the link data. The hourly capacity data shown in Table 3 are used to estimate the link capacities by direction. Hence, the hourly frontage road capacities added to the freeway directional link capacity represents only the frontage road capacity in one direction. For these frontage road estimates, two-lane frontage roads were assumed. Further, it was assumed that one of the two lanes is generally dedicated to the freeway access/egress; and, therefore, only one lane remains available for through traffic. The typical average capacity per hour per lane for major divided arterials was used to estimate these frontage road capacities.

These hourly capacities have been used to prepare a 2020 Austin peak-hour network for use in the HOV carpool modeling efforts. A peak-hour capacity restraint assignment was performed using this network. The results of the peak-hour assignment were used to apply the post-assignment speed models. These peak-hour congested speeds, in turn, were used to estimate the peak travel times for input to the HOV carpool model.

Table 3
Austin Network Capacities

Functional Class	Area Type	Link Speed kph (mph)	NON-DIRECTIONAL 24-HOUR CAPACITIES * Num. Lanes	x	Capacity/ Lane	+	Front. Rd. Capacity	DIRECTIONAL HOURLY CAPACITIES Num. Lanes	x	Capacity/ Lane	+	Front. Rd. Capacity
Freeway	1	72.5 (45.0)	n	x	19,000	+	18,000	n	x	1,950	+	790
	2	72.5 (45.0)	n	x	22,750	+	18,000	n	x	1,950	+	790
	3	80.5 (50.0)	n	x	22,750	+	18,000	n	x	1,950	+	830
	4	88.6 (55.0)	n	x	20,125	+	18,000	n	x	1,850	+	830
	5	96.6 (60.0)	n	x	12,000	+	18,000	n	x	1,700	+	830
Parkway	3	80.5 (50.0)	n	x	22,750			n	x	1,950		
	4	88.6 (55.0)	n	x	20,125			n	x	1,850		
Expressway	2	56.4 (35.0)	n	x	12,500			n	x	1,100		
	3	64.4 (40.0)	n	x	12,500			n	x	1,050		
	4	72.5 (45.0)	n	x	11,625			n	x	1,050		
	5	80.5 (50.0)	n	x	8,000			n	x	950		
Major Divided Arterial	1	39.4 (24.5)	n	x	8,875			n	x	790		
	2	50.2 (31.2)	n	x	8,250			n	x	790		
	3	51.1 (31.8)	n	x	8,250			n	x	830		
	4	56.1 (34.9)	n	x	7,625			n	x	830		
	5	82.1 (51.0)	n	x	6,125			n	x	830		
Major Undivided Arterial	1	42.1 (26.2)	n	x	8,500			n	x	630		
	2	49.3 (30.6)	n	x	7,875			n	x	630		
	3	49.0 (30.5)	n	x	7,875			n	x	670		
	4	52.3 (32.5)	n	x	7,375			n	x	670		
	5	80.1 (49.8)	n	x	5,875			n	x	670		
Minor Arterial	1	33.6 (20.9)	n	x	7,625			n	x	580		
	2	50.2 (31.2)	n	x	6,875			n	x	580		
	3	48.2 (29.9)	n	x	6,875			n	x	560		
	4	44.1 (27.9)	n	x	6,000			n	x	560		
	5	73.8 (45.9)	n	x	4,750			n	x	540		
Collector	1		n	x	4,875			n	x	430		
	2		n	x	4,375			n	x	430		
	3		n	x	4,375			n	x	430		
	4		n	x	3,875			n	x	430		
	5		n	x	3,000			n	x	400		

* The 24-hour capacities for each functional class (except Collectors) were obtained from the report entitled "Austin Travel Demand Model Calibration and Validation," August 1989(1). The collector capacities were estimated from the network data provided. The collector speeds in the ATS link data were not averaged for entry in this table.

CAPACITY RESTRAINT ASSIGNMENT MODEL

The peak-hour assignment performed under this study used the ASSEMBLE PEAK NETWORK and PEAK CAPACITY RESTRAINT routines of the Texas Large Network Package. During the early portion of the study, the Texas capacity restraint procedure was used. The Texas procedure is an iterative technique which requires user specified iteration weights. The peak-hour assignments were performed using six iterations with the following iteration weights: 10, 10, 20, 20, 20, and 20 percent. In November 1992, an equilibrium assignment option was implemented in the PEAK CAPACITY RESTRAINT routine by TTI under another study funded by the TxDOT (9). The equilibrium technique uses an optimization technique to estimate iteration weights. The equilibrium assignment procedure is currently considered the assignment technique of choice. Hence, it was adopted for use in this study as soon as it became available.

SPEED ESTIMATION MODELS

The peak-hour speeds are estimated using the results from the peak-hour capacity restraint assignment. These assignments are used to estimate the directional volume-to-capacity (v/c) ratio for each link. Since this study is focusing on the IH-35 alternatives, the principal focus will be the free-flow travel time estimates and the potential time savings offered to carpools by the HOV facilities being studied.

The speed estimation models employed in the Houston-Galveston region were implemented and calibrated by TTI under studies sponsored by the H-GAC. These models have been adapted for application to the Austin peak-hour network. Separate speed models are used for freeways and for arterial and collector streets. The following describes the two speed estimation models.

Freeway Model

The speed estimation procedures described in a report (prepared by Cambridge Systematics for the EPA in September 1991) entitled "Highway Vehicle Speed Estimation Procedures For Use In Emissions Inventories" were selected for implementation and calibration for the Houston-Galveston Region. The validation results using this technique has displayed very favorable results. This freeway speed estimation procedure has therefore been employed in the study of the IH-35 alternatives under this study.

The freeway speed estimation model relies primarily on the speed estimation techniques described the Highway Capacity Manual (which will be referred to as the HCM). The extensions of the models are similar to those used in Phoenix, but the model coefficients were revised during in the Houston-Galveston Region during the validation process. The methods rely on the estimated v/c ratio as a key measure of congestion for estimating the congested speed based on a link's capacity restrained volume.

The basic freeway model focuses on the decay in speed from a free-flow speed to a Level-of-service E (LOS E) speed as the level of congestion on link increases from a zero-volume condition to a v/c ratio of 1.00. Table 4 lists the speed reduction factors (SRF) currently being used in the model (6). In an earlier version of the model, the speed reduction factors were derived from Figure 3-4 of the HCM (7). The updated speed reduction factors were derived from the Chapter 3 revisions to the HCM recommended by the Freeway Subcommittee of the Highway Capacity and Quality of Service Committee of the Transportation Research Board. For v/c values not included in the Table 4, the speed reduction factors are obtained by interpolating values from Table 4. For example, the speed reduction factor for a v/c ratio of 0.65 would be obtained by interpolating between 0.243 and 0.350 (i.e., the values for v/c ratios of 0.6 and 0.7 respectively).

After obtaining the speed reduction factor for a freeway link based on its v/c ratio from the capacity restrained assignment results, the link's congested speed is computed as follows:

$$\mathbf{S_p = S_{FF} - SRF * (S_{FF} - S_E)}$$

where:

S_P	=	Predicted speed for the link
S_{FF}	=	The free-flow (or zero-volume) speed of the link
S_E	=	The LOS E speed of the link
SRF	=	The speed reduction factor corresponding to the link's v/c ratio.

For the Austin assignments, the freeways are assumed to have a speed limit of 88.5 kph (55 mph). In the rural areas freeways are assumed to have a 104.6 kph (65 mph) speed limit.

The speed limit is used to estimate the link's free-flow speed. Recognizing the tendency of drivers in Texas to speed (particularly under free-flow conditions) the freeway free-flow speed are estimated by adding from 3.2 to 12.1 kph (2 to 7.5 mph) to the freeway link's speed limit, depending on its location. This tendency was clearly reflected in the observed speeds for the Houston region.

Table 4
Freeway Speed Reduction Factors (6)

v/c Ratio	Speed Reduction Factor (SRF)
0.00	0.0000
0.10	0.0001
0.20	0.0004
0.30	0.0015
0.40	0.0035
0.50	0.0061
0.60	0.0086
0.70	0.0100
0.80	0.1250
0.90	0.4200
0.95	0.6000
1.00	1.0000

As may be noted, the preceding technique can be used only for volume to capacity ratios up to 1.0. Because traffic assignments occasionally exceed these limits, a model extension is needed. In the current version of the model, an extension based on the BPR model (currently used in the Houston models) was implemented in the Austin model (6). The model extension for freeways and expressways with a volume to capacity ratio over 1.0 is:

$$S_P = S_{P1} * [1.15/(1.0 + (0.15*(V/C)^4)]$$

where:

S_P = predicted speed for the link

S_{P1} = the speed estimated on the link for a v/c ratio of 1.0 using the freeway model

V/C = the capacity restraint directional v/c ratio constrained to a maximum value of 1.5.

Arterial and Collector Street Model

Since the primary focus of this study is the IH-35 alternatives, a simpler model was selected for application to the arterial and collector streets. The model selected was the traditional BPR impedance adjustment model. The BPR model has also been employed in earlier versions of the Houston model and found to provide good estimates of peak-hour travel times. The results of the BPR model applications in Houston are described in a report entitled "Development, Update and Calibration of 1985 Travel Models for the Houston-Galveston Region" (4).

A constrained version of the traditional BPR impedance adjustment function was used the estimate these peak-hour directional speeds. The BPR function is applied as follows:

$$S_p = S_0 / [1.0 + 0.15(V/C)^4]$$

where:

S_p = estimated peak-hour speed based on the directional v/c ratio

S_0 = estimated zero-volume speed

V/C = capacity restraint directional v/c ratio constrained to a maximum value of 1.5.

Since the network data contain only the 24-hour speeds on arterials and collectors, the zero-volume speeds must be estimated for application of the BPR function. The zero-volume speeds for the non-freeway facilities were simply estimated by dividing the 24-hour speed by 0.92 and rounded to the nearest integer speed.

PEAK-HOUR TRAVEL TIME ESTIMATES

The peak-hour network used to perform the peak-hour capacity restraint assignment is coded without the HOV links represented in order to get an estimate of the peak travel times without HOV facilities. The normal 24-hour speeds are used as input to the capacity restraint assignment. The post-assignment directional peak-hour speeds (estimated by the speed models using the capacity restrained peak-hour assignment results) are then inserted into the link data for the alternative being studied. These speeds represent the best available estimate of the expected operational peak-hour speeds on the system. The ASSEMBLE PEAK NETWORK and BUILD TREES routines of the Texas Large Network Package are used to develop the peak-hour zone-to-zone peak-hour travel time estimates using the normal highway facilities (i.e., without the HOV carpool facilities).

The proposed HOV carpool links are then inserted into the link data containing the estimated peak-hour speeds. The ASSEMBLE PEAK NETWORK and BUILD TREES routines are then applied using the HOV network to develop the peak-hour zone-to-zone travel time estimates for carpools using the HOV facilities. The differences in these travel time estimates provide the HOV model with an estimate of the potential time savings for HOV carpools.

CHAPTER III. HOV CARPOOL MODEL

Historically, the emphasis of highway planning has been to assess the capability of a proposed system of highway improvements to serve the forecast travel demands. Freeway system expansion is often necessary to serve the projected demand. However, the planned addition of more traffic lanes by itself is often not sufficient to provide the capacity needed to prevent severe peak-period congestion and travel time delays.

In such situations, consideration is often given to providing special lanes designated for the exclusive use of high-occupancy vehicles (HOVs) such as buses and carpools. Experience has shown that these special lanes can be an effective means of moving large volumes of persons during highly congested peak periods. During the peak hour it is estimated that HOV facilities can move the person trip equivalent of three normal traffic lanes. Obviously, the magnitude of the person movement capability of HOV lanes can significantly enhance the peak-period person movement capability of a severely congested freeway corridor. This demonstrated ability of HOV lanes (transitways) to move high volumes of peak-period commuters in congested freeway corridors has led to the large commitment to HOV lanes in Texas. Careful consideration is being given to incorporating exclusive HOV lanes in the proposed IH-35 improvements. An important task of this study was to assess the potential carpool usage for these HOV facilities.

TEXAS MEZZO-LEVEL HOV CARPOOL MODEL

From a travel demand modeling perspective, HOV carpool demand modeling is a new and evolving area with a relatively limited experience base. In some of the recently developed mode choice models, an HOV carpool component has been included in the model. However, the mode choice models for most urban areas do not include an HOV carpool component. The Texas Mezzo-Level HOV Carpool Model was implemented in the Texas Travel Demand Package by TTI for TxDOT to provide for the analysis of HOV facilities in such areas (10). The model is essentially a post-mode choice model which can be used to estimate the potential homebased work carpool usage for a proposed HOV facility.

Applications Perspective

The model is implemented as the HOVMODEL routine in the Texas Trip Distribution Package (11). The application of the model requires the following inputs:

- the homebased work (HBW) person trip table for the region
- the morning peak zone-to-zone travel times for normal highway trips
- the morning peak zone-to-zone travel times for carpools eligible to use HOV facilities
- the sector-to-sector base mode split for HBW trips
- the base auto occupancy estimates for HBW trips

Based on the differences in travel times for normal highway trips versus HOV carpool trips, the model estimates the change in auto occupancy that can be anticipated due to the implementation of the proposed HOV carpool facility. Using this information, the model estimates and outputs two HBW vehicle trip tables:

- the HBW carpool trips expected to use the HOV facility
- the HBW vehicle trips expected to use only the normal highway facilities

The model looks at each zone pair in the region. If the use of the HOV carpool facility offers more than a minimum travel time savings, then the HBW person trips for that zone pair are considered "candidate" trips for possible carpooling. The regional model data are used to prove base information on the transit mode share and auto occupancy assuming that the facility is not open to carpools. Based on comparison of the peak travel times on normal highway versus the time for HOV carpool users, the carpool model estimates the shift in auto occupancy expected. The Texas auto occupancy models are applied to the non-transit candidate trips to estimate the vehicle trips by integer occupancies (i.e., 1 person, 2 persons, 3 persons and 4+ person vehicles). The vehicle trips are separated into the two output trip tables.

Three Model Approach

Based on the review of the available HOV lane carpool demand models, a model developed by Barton Aschman and Associates, Inc. (BAA) for the Atlanta Regional Commission was selected for "mezzo-level" adaptation in the Texas Package (10). The Atlanta model provided for the analysis of either 3+ or 4+ person carpools. For Texas applications and based on the Houston experience, TTI modified and extended the models to accommodate a 2+ person carpool definition.

One of the very salient features of the Atlanta Model was its use of three models. The three models, originally developed for use in the Washington, D.C. region, are: (1) the travel time ratio model developed by JHK & Associates for use in estimating carpools in the Shirley Highway and IH-66 corridor inside the Beltway; (2) the logit model developed by BAA for use in estimating carpools in the Bolling/Anacostia Corridor; and (3) the time savings model developed by the Metropolitan Washington Council of Governments for estimating carpools for long-range planning. These three models are described in detail in Appendix B of this report.

In their review and analyses of the three models, BAA concluded that it was impossible to judge with any degree of assurance which of the three models is more accurate for all conditions and, indeed, for any specific condition. All three models have been accepted and used for planning HOV facilities in the Washington, D.C. region. Based on their analyses, it was recommended that an HOV carpool model make use of all three models. Hence, each of the three models is applied to each zonal interchange to estimate the HOV carpools. A weighted average of their estimate is computed to the final "best estimate."

The three models do not require information on the characteristics of the trip maker such as income or automobiles available. This is certainly a salient feature both from a "mezzo-level" adaptation perspective and from a "portability" perspective.

The three models are used as "shift" models with the region's travel demand model data used as the basis for the shift. This methodology not only reduces the potential errors in the models but allows the HOV model's estimates to be compatible with other estimates and forecasts being made for the area without the use of carpool facilities, another very desirable feature from a "portability" perspective.

Texas Auto Occupancy Models

A set of average auto occupancy models (which are referred to as the base auto occupancy models) is needed for a post-mode choice implementation of the HOV model. These auto occupancy models are used to estimate the percentage of vehicles by integer occupancy groups (i.e., 1, 2, 3 and 4+ person autos) for a specified average auto occupancy group. In the Atlanta version of the model, the base auto occupancy models were developed using data from the Washington, D.C., area and only allow consideration of average auto occupancies as low as 1.15. This minimum limit of 1.15 for the specified average auto occupancy for HBW trips was considered a serious constraint for Texas applications. While 1.15 may be considered as a relatively low average auto occupancy for HBW trips in the Washington, D.C. area, it is probably very close to the regional average for the HBW trips in the larger urban areas in Texas. Indeed, the 1984 travel survey for Houston indicated a regional average auto occupancy of 1.13 for HBW trips.

A new set of auto occupancy models were, therefore, calibrated which are felt to be more representative of urban areas of Texas. The new models allow the estimation of integer car probabilities in cases where average auto occupancy is less than 1.15. The new Texas Base Auto Occupancy Model, like the Atlanta model, is a set of regression models. The new model was developed through the use of vehicle classification data from the Houston area. The new model allows for consideration of average auto occupancies as low as 1.06. Appendix B contains a detailed description of the new base auto occupancy model.

Texas HOV Model Test Results

The test and evaluation of the Texas Mezzo-Level HOV Carpool Model focused on the ability of the model to reasonably replicate observed levels of carpool usage on the HOV facilities in Texas. Two sites were selected for testing the model: (1) the Katy Transitway in Houston and (2) Phase I of the Gulf Transitway in Houston.

The Katy Transitway, which began operation in 1984, is an 18.5 km (11.5 mile) limited access facility which exists in the median section of the Katy Freeway (IH-10W) between SH-6 and the West Loop (IH-610). Intermediate access points are provided from a park-and-ride lot at SH-6 and from the freeway median near Gessner Road. Extensive data exist regarding carpool operation on the Katy Transitway, as it is one of the most studied facilities of its kind in the country. The availability of these data made it the primary focus for the testing and evaluation of the Texas model.

The Phase I portion of the Gulf Transitway is a 9.5 km (5.9-mile) facility which operates in the median section of the Gulf Freeway (IH-45S) and runs from just south of the South Loop (IH-610) to Dowling Street in downtown Houston, with intermediate access points located at the South Loop and at a transit center. Although it was felt that the Phase I portion of the Gulf Transitway was a marginal facility in terms of length of operation (relative to the Katy Transitway), the facility was used as a secondary site for model testing and evaluation. The primary reason for choosing the Phase I Gulf Transitway as a test site was that it was the only other operating HOV facility in the state on which carpools were allowed and for which data existed at the time of the study.

The test results from the two applications of the Texas mezzo-level HOV carpool model were judged to be "good" (i.e., within $\pm$12.5 percent of observed volumes). Since the models are applied as "shift" models using the regional model results, it was felt that the model could be expected to generally produce reasonable carpool estimates which are consistent with the regional forecast. Based on the test results, it was recommended that the Texas Mezzo-Level HOV Carpool Model be incorporated in the Texas Trip Distribution Package software for application in Texas cities. Based on these results, the model has been used in the Houston-Galveston area for the past four years.

AUSTIN APPLICATIONS

The Texas Mezzo-Level Carpool Model forecast the HOV carpools which would be expected to use the HOV facilities being considered for implementation in the IH-35 improvements. These analyses were performed under Task 3 of this study. The following briefly describes the data used as input to the HOV model and briefly summarizes the model results.

Data Inputs and Parameters

The first major input to the HOV model is the forecast HBW person trip table for the region. The ATS 2020 HBW person trip table (provided to TTI by the City of Austin in May

1992) was used in this modeling effort. This 24-hour trip table (in production-to-attraction format) is the official HBW person travel forecast for the region.

The next key inputs to the HOV model are zone-to-zone peak-hour travel time estimates based on the forecast travel for the region. The time-of-day models (discussed in Chapter II) were applied to estimate the 2020 morning peak-hour volumes and congested speeds. The congested directional speed estimates were inserted into a peak-hour network for use in estimating the zone-to-zone travel times using only the normal highway facilities. This network is generally referred to as the "normal highway network." A second peak-hour highway network was then developed by inserting links to represent the HOV carpool facilities proposed for the IH-35 improvements. The second network was used to estimate the zone-to-zone peak-hour travel times for trips eligible to use the HOV carpool facilities. This second network is generally referred to as the HOV carpool network.

The sector-to-sector HBW mode split estimates for 2020 are also a key input to the HOV model. The ATS 2020 HBW transit person trip table was also provided to TTI in May 1992 for use in these analyses. Using the transit trip table and the person trip table, the sector-to-sector mode shares were computed. The ATS uses a very detailed sector structure consisting of 90 sectors in model applications. The ATS sector structure was used to complete the sector interchange mode shares for input to the HOV model.

The ATS uses an average auto occupancy of 1.13 for converting non-transit HBW person trips to vehicle trips. The Austin CBD, the State Capitol Complex, and the University of Texas at Austin areas (i.e. Sectors 64 and 58) are already intensely developed and experience parking limitations. It is certainly reasonable to expect that the 2020 HBW trips attracted to these areas will have a somewhat higher auto occupancy than the remainder of the region. A conservative auto occupancy rate of 1.20 was assumed for HBW trips attracted to these areas in the HOV analyses. The remainder of the sector interchanges used the ATS regional auto occupancy estimate of 1.13.

In applying the HOV model, it is desirable to estimate terminal times. The default production and attraction terminal times were set to 1.0 and 2.0 minutes, respectively, in the HOV model runs. The default terminal times were used for all areas except the CBD, Capitol Complex, and UT areas (i.e., Sectors 64 and 58). For these areas, production and attraction terminal times of 2.0 and 5.0 minutes, respectively, were used.

The Austin HOV model applications used a carpool definition of 2+ persons/vehicle (i.e., carpools with 2 or more persons in the vehicle are allowed to use the HOV carpool facilities). Only HBW trips which could save 2.5 minutes or more in the peak period were considered potential candidates for HOV usage.

HOV Results

The final HOV model applications were performed in the fall of 1992. The following briefly summarized the HOV model results.

The ATS 2020 forecast for the region estimates 1,580,122 HBW person trips for the region. An estimated 10.44 percent of these trips will use the planned transit system for the region. The HOV carpool model found that approximately 94,147 of the 1,580,122 HBW person trips could save 2.5 minutes or more using the proposed IH-35 carpool facilities. Approximately 10,283 HBW carpools would be expected to use the proposed facilities each day. These carpools would be expected to carry about 22,211 persons representing an average occupancy on the carpool lane of 2.16 persons/vehicle. Of the 94,147 candidate HBW person trips, 29.6 percent would be expected to remain on transit and 44,056 (or 46.8 percent) would be expected to travel in single occupant vehicles. The 22,211 person trips expected to travel by carpool on the HOV facility represents 23.6 percent of the 94,147 candidate HBW trips. The carpool model indicates that an estimated additional 3,142 carpools would be formed to take advantage of the HOV carpool facilities.

It should be noted that the 22,211 HBW person trips expected to travel by carpool on the HOV facility is by no means all of the person trips expected to use the facility. A significant portion of the 27,880 candidate HBW person trips traveling by transit will likely be on buses on the HOV facility. Also, while work trip carpools would generally be expected to account for most of the carpool trips on the facility, there will be a significant number of carpools on the facility which are not HBW trips. For example, it is reasonable to expect a significant number of non-work carpools traveling on the HOV facility to the University of Texas. These trips are not accounted for in the HOV carpool model.

AIR QUALITY ANALYSES

As a part of the regional travel analyses performed under Task 3, an analysis of the mobile source emissions impacts of the proposed IH-35 improvements was performed. The following briefly summarizes the results of these analyses.

The No-Build Alternative

To assess the impact of the proposed IH-35 improvements on mobile source emissions, a no-build alternative was defined. To create the no-build alternative network, the capacities for the IH-35 links in the 2020 network were reduced to the current 1993 levels. All other planned improvements in the 2020 network remained unchanged. Since the no-build alternative will not have an HOV lane, the original ATS vehicle trip tables developed prior to the application of the HOV model were used for the assignment. A capacity restraint assignment was performed for the no-build alternative.

For the build alternative, the assignments developed in the HOV analyses were used. This allowed the air quality analyses to reflect the impact of both the added HOV lanes and the added capacity for the normal highway travel.

Emissions Estimation Methodology

The air quality analyses were performed using the Texas Mobile Source Emissions Software. The Texas Mobile Source Emissions Software is a series of programs developed by the Texas Transportation Institute to facilitate the estimation of mobile source emissions. The methods used in applying this software have been successfully used in developing the mobile source emissions estimates for air quality analyses in the El Paso, Beaumont-Port Arthur and Victoria regions. This methodology is also similar the procedures used for the Dallas-Fort Worth mobile source emissions estimates. Portions of this software are also employed in the Houston-Galveston region for their emissions estimates.

The following briefly summarize the program and procedures used in developing the emissions estimates for both the build and no-build alternatives. The three programs in the Texas Mobile Source Emissions Software for the Austin analyses were:

PREPIN — The PREPIN program was developed to facilitate the estimation of time-of-day VMT and speeds for air quality analyses. The program inputs a 24-hour assignment and applies the needed time-of-day factors to estimate the directional time-of-day travel. The Dallas-Fort Worth speed models are used to estimate the operational time-of-day speeds by direction on the links. Special intrazonal links are defined, and the VMT and speeds for intrazonal trips are estimated. These VMT and speeds by link are subsequently input to the IMPSUM program for the application of MOBILE5a emission factors.

POLFAC5A — The POLFAC5A program is used to apply the MOBILE5a program to obtain the emission FACTORS (rates). The MOBILE5a emission factors are obtained for eight vehicle types and 63 speeds (i.e., 3 mph through 65 mph) for each vehicle type. Hence, there are 504 factors (i.e., 8 x 63 = 504) for each pollution type. Three pollution types are computed: VOC, CO and NOx. Hence, for a given application there are 1512 emission factors. These emission factors are output to an ASCII file for subsequent input to the IMPSUM program. The POLFAC5A program is applied for each time-of-day time period being used. These time-of-day emission factors are applied using the IMPSUM program to time-of-day VMT estimates by link.

IMPSUM — The IMPSUM program applies the emission rates (obtained from POLFAC5A) and VMT mixes to the time-of-day VMT and speed estimates to estimate the emissions. The basic input to IMPSUM include:

1. VMT mix by county and roadway type.
2. MOBILE5a emission factors developed using POLFAC5A by county.

3. Abbreviated assignment results by link input for the subject time period. The PREPIN program allows the user to estimate the VMT and speed on each link by time period. For each link, the following information is input to IMPSUM: roadway type number, VMT on link, operational speed estimate, and the link distance.

Using these input data, the VMT for each link is stratified by the eight vehicle types, and the MOBILE5a emissions factors are applied to estimate the mobile source emissions for that link.

The PREPIN software was applied to both the build and the no-build alternatives to produce the time-of-day VMT and speed estimates for each alternative. The four time-of-day periods used in these analyses were:

Morning Peak Hour:	7:15 a.m. - 8:15 a.m.
Midday:	8:15 a.m. - 4:45 p.m.
Afternoon Peak Hour:	4:45 p.m. - 5:45 p.m.
Overnight:	5:45 p.m. - 7:15 a.m.

The POLFAC5A program was applied to develop the summer emissions factors for each time-of-day period for target 2020 application year. The average temperature for the subject season and subject time-of-day period was an input to the POLFAC5A application of the MOBILE5a model. The appropriate parameters for input to the MOBILE5a model (via the POLFAC5A routine) were developed by TxDOT in consultation with the Texas Natural Resources Commission.

Finally, the IMPSUM program was applied to estimate the emissions for each of the four time-of-day periods. The emissions estimates for each of the four time-of-day periods were summed to develop the final emissions estimates.

Air Quality Impacts

The Texas Mobile Source Emissions Software was applied to develop mobile source emissions estimates for both the build and no-build alternatives. The air quality impacts of the proposed IH-35 improvements were estimated by comparing the emissions differences between the alternatives for three types of emissions: VOC , CO and NOx. These analyses indicated that the VOC emissions for the build alternative were 2,145 pounds per day lower (i.e., 2.1 percent lower) than the no-build. Similarly, the CO emissions for the build alternative were 19,848 pounds per day lower (i.e., 2.3 percent lower). Conversely, the NOx emissions for the build alternative were slightly higher than the no-build alternative (i.e., 94 pounds per day higher or 0.05 percent higher).

CHAPTER IV. DETAILED NETWORK MODELS

In the ATS 24-hour networks, freeway sections are coded as a single link. This is common practice in preparing 24-hour networks for system analyses. Using this approach a single link can be used to represent the main lanes, ramps, and frontage roads (in both directions) for a segment of IH-35. For the operational analysis of the IH-35 alternatives, the ATS networks were revised to include detailed coding of the IH-35 design alternative being studied. In the detailed coding of the IH-35 improvements, separate one-way links were coded to represent the main lanes in each direction, the frontage roads in each direction, and entry or exit ramps. These networks were used to prepare morning and afternoon peak-hour assignments as well as detailed 24-hour assignments.

Assistance was also provided in the implementing and applying of the FREQ10 program for the operational analyses of the design alternatives. The detailed assignment results were used in estimating the ramp volumes for the FREQ10 applications performed by the Austin District.

DETAILED NETWORK CAPACITIES

In developing the detailed network coding for the IH-35 design alternatives, a separate and more detailed set of functional classifications was used for the detailed links. The hourly capacities developed for use in the detailed coding are summarized in Table 5. Tables A-7 through A-14 (of Appendix A) document the formulas and the typical parameter values applied in the formulas to estimate the hourly capacities. The Transportation Planning and Programming Division requested that 24-hour detailed networks also be developed and assigned for use in the corridor analysis performed by the division. The 24-hour capacities for the detailed coding are also summarized in Table 5. The capacities for the non-detailed portions of the network are the same as those listed in Table 3 of this report. The detailed networks for each of the IH-35 design alternatives prepared under this study were provided to TxDOT.

Table 5
Austin Detailed Network Capacities

Functional Class	Area Type	Link Speeds kph (mph)	24-HOUR CAPACITIES Num. Lanes	x	Capacity/ Lane	+ Front. Rd. Capacity	HOURLY CAPACITIES Num. Lanes	x	Capacity/ Lane	+ Front. Rd. Capacity
Normal Freeway Main Lanes	1	72.5 (45.0)	n	x	19000		n	x	1,950	
	2	72.5 (45.0)	n	x	22750		n	x	1,950	
	3	80.5 (50.0)	n	x	22750		n	x	1,950	
	4	88.6 (55.0)	n	x	20125		n	x	1,850	
	5	96.6 (60.0)	n	x	12000		n	x	1,700	
Elevated & Depressed Freeway Main Lanes	1	77.3 (48.0)	n	x	19975		n	x	2,050	
	2	77.3 (48.0)	n	x	23925		n	x	2,050	
	3	85.3 (53.0)	n	x	23925		n	x	2,050	
	4	93.4 (63.0)	n	x	21225		n	x	1,950	
	5	101.0 (63.0)	n	x	12700		n	x	1,800	
Freeway to Freeway Ramps	1	64.4 (40.0)	n	x	17050		n	x	1,750	
	2	64.4 (40.0)	n	x	20425		n	x	1,750	
	3	72.5 (45.0)	n	x	20425		n	x	1,750	
	4	72.5 (45.0)	n	x	17950		n	x	1,650	
	5	72.5 (45.0)	n	x	11650		n	x	1,650	
Collector/ Distributor (CD) Lanes	1	56.4 (35.0)	n	x	17050		n	x	1,750	
	2	56.4 (35.0)	n	x	20425		n	x	1,750	
	3	64.4 (40.0)	n	x	20425		n	x	1,750	
	4	64.4 (40.0)	n	x	17950		n	x	1,650	
	5	64.4 (40.0)	n	x	11650		n	x	1,650	
HOV Lanes	1	96.6 (60.0)	Not Applicable				n	x	2,050	
	2	96.6 (60.0)	Not Applicable				n	x	2,050	
	3	96.6 (60.0)	Not Applicable				n	x	2,050	
	4	96.6 (60.0)	Not Applicable				n	x	2,050	
	5	105.0 (65.0)	Not Applicable				n	x	2,050	
Normal Ramps	1	48.3 (30.0)	n	x	15725		n	x	1,500	
	2	48.3 (30.0)	n	x	16575		n	x	1,500	
	3	56.4 (35.0)	n	x	16200		n	x	1,500	
	4	64.4 (40.0)	n	x	15050		n	x	1,500	
	5	72.5 (45.0)	n	x	10825		n	x	1,500	
Collector/ Distributor Lanes to Surface Streets	1	48.3 (30.0)	n	x	16525		n	x	1,575	
	2	48.3 (30.0)	n	x	17400		n	x	1,575	
	3	56.4 (35.0)	n	x	17025		n	x	1,575	
	4	56.4 (35.0)	n	x	15800		n	x	1,575	
	5	56.4 (35.0)	n	x	11375		n	x	1,575	
HOV Ramps	1	48.3 (30.0)	Not Applicable				n	x	1,575	
	2	48.3 (30.0)	Not Applicable				n	x	1,575	
	3	56.4 (35.0)	Not Applicable				n	x	1,575	
	4	56.4 (35.0)	Not Applicable				n	x	1,575	
	5	56.4 (35.0)	Not Applicable				n	x	1,575	
Frontage Roads	1	40.3 (25.0)	n	x	7975		n	x	710	
	2	48.3 (30.0)	n	x	7425		n	x	710	
	3	56.4 (35.0)	n	x	7450		n	x	750	
	4	64.4 (40.0)	n	x	6900		n	x	750	
	5	80.5 (50.0)	n	x	5525		n	x	750	

DETAILED NETWORK ASSIGNMENTS

Both morning and afternoon peak-hour capacity restraint assignments and a 24-hour capacity restraint assignment were performed using the detailed networks developed for each design alternative studied. These 2020 assignments were performed using the ASSIGN SELF-BALANCING Routine in the Texas Large Network Package. The new equilibrium assignment option (9) was used for these assignments. Six iterations were performed for each assignment. The results for the three assignments performed for each design alternative studied were provided to TxDOT.

PREPARATION OF POSTED ASSIGNMENT VOLUMES

The link data used for each assignment were converted from Texas Package format to TRANPLAN format. The equilibrium assignment results were inserted in the TRANPLAN link data in the fields normally used for the counted volumes. The TRANPLAN software was then used to plot the networks with the assigned volumes posted. The posted network plots along with the TRANPLAN data were transmitted to TxDOT.

FREQ10 APPLICATIONS

This section documents the use of FREAK in the analysis of improvements to the IH-35 freeway corridor. An explanation of the FREQ10 model is included as well as a discussion of how models were developed for IH-35 and the measures of effectiveness (MOEs) which were used. This section also discusses the methodology used to convert the output from the TRANPLAN model into input data for the FREQ10 program.

FREQ10 Program

FREQ10 is the tenth in a series of computer freeway simulation models that were developed at the Institute of Transportation Studies (ITS), University of California, Berkeley. The program allows simulation of traffic operations given a set of input parameters. Several different measures of effectiveness (MOEs) are produced which provide the user with quantitative data to compare various alternative freeway configurations.

Input Requirements

There are two types of input required for the FREQ10 model -- demand characteristics and freeway characteristics. In general, these characteristics require the following data:

Demand characteristics	O-D patterns, vehicle occupancy levels, distribution of vehicle occupancies
Freeway characteristics	Mainlane capacities, mainlane geometrics

Demand Characteristics

Entrance and exit ramp volume counts and freeway mainlane volume counts are used as input information to build a synthetic O-D trip matrix. Total entry volumes are apportioned to downstream exit ramps in proportion to the volumes on those exit ramps.

Vehicle mix and vehicle occupancy are also required for freeway mainlane modeling. Proportions of single occupant, double occupant, three or more occupant cars and buses in the traffic stream are required for each entrance ramp.

Freeway Characteristics

Freeway characteristics quantify the supply side of the freeway system. The modeled length of mainlane freeway is governed by: 1) a maximum of 40 freeway subsections; or 2) a maximum of 20 input or 20 output locations. A subsection is defined as a point of demand change (entrance or exit ramp) or a geometric change (e.g., lane drop/addition, large gradient change, etc.) The user must also supply (for each subsection) the number of lanes, the mainlane capacity, gradient, curvature, speed versus flow relationship, ramp characteristics, and percentage of trucks. Another limitation of FREQ10 is the maximum of 24 time periods, which, when used in 15-minute increments, limits the model length to 6 hours. This is sufficient to encompass freeway operations during a single peak period in the peak direction.

These data needs have been satisfied utilizing recording traffic counters, manual mainlane traffic counts, and travel time and speed studies. The traffic counts are recorded at 15-minute increments, and the travel time runs are started at 15-minute intervals. Some of the data are generally available from area planning agencies, but the detailed count and travel speed information is usually too expensive for those agencies to collect on a regular basis.

Modeling Assumptions

The FREQ10 program makes certain assumptions in order to operate effectively and efficiently. It assumes that freeway operations can be simulated by ignoring any randomness in traffic behavior and the behavior of individual vehicles. The program operating procedure transfers demand downstream instantly at the beginning of each time period unless demand exceeds capacity. This process greatly reduces computing time and is sufficiently accurate for almost all situations. It does not provide the detailed accounting of individual vehicle movements provided by more microscopic models and required in some traffic engineering analyses.

If demand exceeds capacity in a particular time period/subsection combination, traffic is stored on upstream entrance ramps or upstream freeway subsections. These vehicles become part of the demand for the following time period and are counted in the travel time delay estimate. The model, however, does not shift the mode of trips or the entry location, and it assumes that traffic demand and roadway capacity remain constant over a time period.

Freeway HOV Lane Analysis with FREQ10

The input data are used to calibrate the model to existing freeway conditions using the speed and congestion contours derived from the travel time runs. The model information is adjusted to match the observed information by changing subsection capacity in the congested areas. The level of precision is well within that of the input data and is consistent with the ultimate use of the FREQ10 model in this study.

The FREQ10 model provides considerable data that permit quantitative comparison of alternatives. The measures of effectiveness (MOEs) included in the output are: 1) vehicle-hours and passenger hours of travel on the freeway; 2) vehicle hours and passenger hours of ramp delay; 3) total vehicle hours and passenger hours; 4) total vehicle miles and passenger miles; 5) average vehicle speed; and 6) total fuel consumption.

Developing Current Models

In order to look at future roadway conditions along IH-35 it was necessary to first establish models which reflected the current situation on the freeway. This was done using 1992 demand and freeway characteristics. These necessary input data such as freeway geometrics and capacities, occupancy levels, and origin-destination patterns were all collected for the section of IH-35 from Braker Lane in the north to William Cannon in the south. Four models were prepared for IH-35 within these limits:

- Southbound A.M.
- Southbound P.M.
- Northbound A.M.
- Northbound P.M.

These models were calibrated by reviewing average vehicular speed as well as comparing the queuing diagrams generated by the FREQ10 models to the queuing diagrams which accompanied actual travel time studies from the sections being modeled.

The FREQ10 models were used to review future roadway conditions on IH-35 after they were calibrated. Future travel demands were generated by the model TRANPLAN. This modeling program generates peak-hour demands on each of the ramps and mainlane sections of IH-35. These peak-hour volumes were converted into 15-minute time periods by creating peak-hour ramp factors (a process which will be discussed in the next section). The current models and the peak-hour ramp factors along with any geometric changes scheduled for the roadway, the FREQ10 models were used to show future conditions on IH-35.

Developing Ramp Factors

This section documents the methodology used to convert future IH-35 peak-hour ramp volumes into 15-minute volume estimates (for the time periods of 6:00 a.m. to noon and 3:00 p.m. to 9:00 p.m.) to be used in the FREQ10 freeway simulation model. The general approach was to develop 15-minute ramp factors for each ramp that, when multiplied by the "system peak hour" ramp volume, will produce volume estimates for every 15-minute interval from 6:00 a.m. to noon and from 3:00 p.m. to 9:00 p.m. According to the travel demand model being developed for the year 2020, the morning and evening peak hours of travel for the Austin area will occur from 7:00 a.m. to 8:00 a.m and from 5:00 p.m. to 6:00 p.m.; peak hours varied on the ramps on IH-35.

Preliminary Ramp Grouping

The study limits for the IH-35 FREQ10 analyses were determined to be from north of the Braker exit to south of the Riverside exit in the southbound direction and from south of William Cannon entrance to north of the US 290 exit in the northbound direction for the morning analyses. The 57 ramps within the IH-35 study limits were divided into groups according to the direction (northbound or southbound), the type of ramp (entrance or exit), and the capacity of the ramp. This preliminary sorting process resulted in the 10 ramp groups shown in Table 6.

Data Reduction

After the ramps were divided into the 10 groups listed in Table 6, they had to be divided further in order to group ramps with similar 15-minute ramp factors. This was done by utilizing the historic ramp counts for each of the 57 ramps in the study to calculate the ratio of the 15-minute volume to the system's peak-hour volume (PHV) for each of the 24 15-minute intervals. First, a statistical analysis was performed on each ramp data set. This procedure consisted of examining the minimum value, maximum value, average, median, range, standard deviation, and correlation coefficient in order to identify ramps with similar ratios within the same group for each of the 6-hour periods (morning and evening). Once the ramps were reduced to smaller groups, their ratios were plotted for each 15-minute period. From these plots, it could be further determined which ramps could be grouped together for the ramp factor calculations. Example calculations for 12th Street, 8th Street, 1st Street, and Riverside ramps from 6:00 a.m. to noon (which are part of the southbound exit ramp group with 1,800 vph) are included in Table 7. It should be noted that the values included in Table 7 reflect the 15-minute ramp factors in percentage form. Note that the averages, standard deviations (σ), and correlation coefficients (r) (which were some of the statistics used to reduce the groups) do not vary greatly. The general relationship between these four ramps is illustrated in Figure 1. The remaining plots developed in this analysis are included in Appendix A (6:00 a.m. to noon) and Appendix B (3:00 p.m. to 9:00 p.m.).

Table 6
Ramp Groupings for I-35 Study Limits

Category	Ramp Name/Location
NB entrance ramps with 1,800 vph capacity	William Cannon, Stassney, Ben White, Woodward, Oltorf, Riverside, 8th Street, 12th Street, Airport, and 51st Street
NB exit ramps with 1,800 vph capacity	Ben White, Woodward, Oltorf, Woodward, Oltorf, Woodland, Riverside, Holly, 1st Street, MLK, 51st Street, Reinli, and US 290
NB entrance ramps with 1,200 vph capacity	1st Street
NB exit ramps with 1,200 vph capacity	8th Street
NB entrance ramps with 900 vph capacity	19th Street and 32nd Street
NB exit ramps with 900 vph capacity	Manor, 26th Street, 38½ Street and Airport
SB entrance ramps with 1,800 vph capacity	Braker, Diamondback Trail, Rundberg, US 183, St. John, US 290, Cameron Road, 51st Street, MLK, 6th Street, and 1st Street
SB exit ramps with 1,800 vph capacity	Braker, Rundberg, US 183, US 290, 51st Street, Airport, 12th Street, 8th Street, 1st Street, and Riverside
SB entrance ramps with 900 vph capacity	Airport, 38½ Street, and 26th Street
SB exit ramps with 900 vph capacity	38½ Street, 32nd Street, 26th Street, and MLK

Table 7
Statistical Analysis of a Sample Group of Southbound Exit Ramps
Morning Evaluation Period

Southbound Exit Ramp	Minimum	Maximum	Average	Median	Standard Deviation[1]	Correlation Coefficient[2]
12^{th} Street	3.06	43.18	18.23	15.17	9.710	+0.1076
8^{th} Street	5.42	33.67	17.48	16.13	6.572	+0.0676
1^{st} Street	4.42	34.32	19.18	17.47	7.956	+0.2009
Riverside	5.29	31.88	20.10	20.94	6.941	+0.3292

Note: All values included above reflect the ramp factors in percentage form (i.e., ramp factor x 100).
[1]The standard deviation (σ) is a measure of dispersion. It gives a numerical value representing the clustering tendency of the data.
[2]The correlation coefficient (r) is a measure of the strength of the linear relationship between two quantitative variables.

Ramp Factor Determination

Once the groups from Table 6 were reduced, the average ramp factors were determined. Table 8 indicates the 15-minute volumes for each ramp and the weighted average (or ramp factor [PHF]) for the 12th, 8th, 1st, and Riverside Streets southbound exit ramp grouping. These ramp factors were calculated by using the 15-minute to system peak-hour volume (PMV) ratios (in parentheses in the equations below) and the peak-hour volumes for each of the ramps in the group. The average ramp factor was weighted according to the peak-hour volume ratios for each ramp. The following example illustrates the determination of the ramp factor for the 7:45 to 8:00 a.m. 15-minute interval for the ramps shown in Table 8.

$$Avg\ Ramp\ Factor\ =\ \frac{\frac{12th\,St}{PHV}(PHF)+\frac{8th\,St}{PHV}(PHF)+\frac{1st\,St}{PHV}(PHF)+\frac{Riverside}{PHV}(PHF)}{12th\,St\,PHV+8th\,St\,PHV+1st\,St\,PHV+Riverside\,PHV}$$

$$Avg\ Ramp\ Factor\ =\ \frac{804(.3235)+1{,}140(.2775)+440(.3074)+840(.3047)}{3{,}224}$$

$$Avg\ Ramp\ Factor\ =\ 0.308$$

Results

The 15-minute ramp factors were calculated for each of the reduced groups and are shown in Tables 9 through 12. The ramp factors shown in the tables represent the approximate ratio of 15-minute volume to system volume for each time interval on the ramp in question. To determine the 15-minute volume in the year 2020 for a given ramp, one would multiply the peak-hour volumes given by the year 2020 travel demand model by the corresponding 15-minute ramp factor. For example, the volume on the northbound entrance ramp at William Cannon during the interval from 7:15 to 7:30 a.m. assuming a PHV of 1,350 in the year 2020 would be:

$$Volume_{\ 7:15-7:30} = Ramp\ Factor\ *\ PHV = 0.271\ *\ 1350 = 366\ vehicles$$

where: 0.271 = ramp factor for NB William Cannon entrance ramp for 7:15-7:30 a.m. (Table 10).

As with any automated calculation, a reasonableness check should always be made to ensure that the 15-minute volumes are plausible. A good rule of thumb is no more than 500 vehicles per 15-minute interval for ramps with 1,800 vph capacity, no more than 330 vehicles per interval for ramps with 1,200 vph capacity, and no more than 250 vehicles per interval for ramps with 900 vph capacity. An example of a potential problem ramp is the SB Braker Exit where, due to its relatively low historic volumes, an extremely high 15-minute ramp factor is obtained at time period 8:15 to 8:30 a.m.

It should be noted that the peak hour of the system and the peak hour of the individual ramp will not always exactly coincide. The morning and evening peak hours of travel for the system are from 7:00 a.m. to 8:00 a.m and 5:00 p.m. to 6:00 p.m. An individual ramp, however, may have a peak-hour volume from 7:30 a.m. to 8:30 a.m or from 4:45 p.m. to 5:45 p.m. This results in the sum of four consecutive 15-minute ramp factors potentially exceeding 1.0 outside the 7:00 to 8:00 a.m. or 5:00 to 6:00 p.m. time periods. Nevertheless, the 15-minute Ramp Factors should always be approximately 1.0 from 7:00 to 8:00 a.m. and from 5:00 to 6:00 p.m.

Table 8
Example Ramp Factors for Southbound Exit Ramps
Morning Evaluation Period

	Historical Ramp Factors[1]				Weighted Average[2]
15-minute interval (a.m.)	12th Street	8th Street	1st Street	Riverside	
6:00	0.031	0.054	0.044	0.053	0.047
6:15	0.040	0.063	0.057	0.062	0.056
6:30	0.059	0.082	0.076	0.061	0.070
6:45	0.099	0.119	0.112	0.133	0.117
7:00	0.137	0.194	0.156	0.205	0.180
7:15	0.200	0.215	0.206	0.211	0.212
7:30	0.286	0.263	0.257	0.268	0.280
7:45	0.324	0.278	0.307	0.305	0.308
8:00	0.432	0.337	0.343	0.300	0.351
8:15	0.380	0.266	0.331	0.319	0.318
8:30	0.221	0.224	0.272	0.247	0.237
8:45	0.238	0.185	0.272	0.220	0.220
9:00	0.217	0.198	0.246	0.227	0.217
9:15	0.146	0.138	0.158	0.211	0.163
9:30	0.122	0.148	0.164	0.180	0.153
9:45	0.133	0.153	0.162	0.186	0.158
10:00	0.153	0.148	0.175	0.208	0.169
10:15	0.119	0.137	0.158	0.213	0.156
10:30	0.131	0.162	0.175	0.183	0.162
10:45	0.147	0.181	0.118	0.191	0.166
11:00	0.150	0.154	0.171	0.168	0.159
11:15	0.179	0.145	0.177	0.182	0.168
11:30	0.194	0.160	0.213	0.221	0.193
11:45	0.240	0.193	0.255	0.271	0.235

[1]The ratio of historical 15-minute volumes to the peak-hour volume (7-8 a.m.); these ratios were calculated for data obtained from 1988 to 1991.

[2]The average (weighted by volume) ramp factor for the group of similar ramps, in this case, southbound exit ramps at 1st Street, 8th Street, 12th Street and Riverside. This value represents the factor by which to multiply the future (2020) peak-hour volume to obtain 15-minute ramp volume estimates for the year 2020 to be used in the FREQ model.

Table 9
15-Minute Ramp Factors for Southbound IH-35, Morning Evaluation Period

TIME (am)	Entrance Ramps						Exit Ramps							
	Braker Rundberg	DBT[1] Cameron[2] 51st	US 183 St John US 290 1st	Airport 38.5	26th	MLK 6th	Braker	Rundberg	US 183 US 290 51st	Airport	38.5	32nd 26th	MLK	12th 8th 1st River
6:00	.074	.063	.065	.077	.038	.070	.038	.060	.060	.156	.039	.044	.009	.047
6:15	.072	.075	.069	.082	.071	.077	.086	.063	.063	.124	.048	.059	.020	.056
6:30	.103	.078	.099	.113	.062	.099	.143	.097	.087	.115	.059	.075	.035	.070
6:45	.167	.110	.141	.107	.091	.116	.143	.124	.152	.184	.135	.154	.080	.117
7:00	.205	.162	.177	.183	.105	.199	.286	.274	.226	.250	.167	.174	.156	.180
7:15	.270	.218	.240	.224	.262	.235	.229	.310	.248	.252	.200	.222	.170	.212
7:30	.277	.248	.257	.255	.305	.230	.229	.232	.286	.255	.252	.268	.322	.280
7:45	.247	.365	.309	.376	.324	.328	.238	.184	.232	.238	.383	.331	.352	.308
8:00	.185	.355	.282	.592	.381	.322	.556	.213	.300	.262	.415	.316	.261	.351
8:15	.186	.248	.247	.543	.362	.336	.815[3]	.198	.221	.251	.281	.286	.185	.318
8:30	.204	.227	.227	.476	.229	.283	.400	.189	.215	.236	.232	.249	.187	.237
8:45	.206	.195	.243	.460	.281	.346	.333	.138	.177	.267	.239	.333	.141	.220
9:00	.171	.170	.216	.389	.271	.340	.381	.149	.174	.224	.223	.225	.120	.217
9:15	.144	.138	.196	.366	.290	.306	.229	.110	.135	.203	.194	.195	.061	.163
9:30	.152	.138	.199	.323	.309	.315	.257	.114	.157	.216	.265	.185	.091	.153
9:45	.135	.136	.194	.378	.262	.262	.276	.106	.149	.200	.199	.188	.094	.158
10:00	.122	.146	.154	.377	.262	.377	.276	.068	.141	.216	.171	.167	.100	.169
10:15	.128	.120	.171	.499	.313	.346	.238	.090	.144	.170	.174	.149	.056	.156
10:30	.114	.124	.174	.439	.390	.343	.305	.095	.139	.229	.220	.148	.098	.162
10:45	.137	.134	.179	.411	.295	.345	.343	.097	.185	.219	.227	.150	.091	.166
11:00	.118	.135	.166	.454	.469	.462	.229	.103	.151	.227	.272	.119	.054	.159
11:15	.143	.154	.169	.489	.400	.400	.362	.062	.160	.223	.214	.128	.065	.168
11:30	.131	.142	.197	.489	.448	.487	.248	.089	.182	.212	.214	.125	.077	.193
11:45	.130	.148	.223	.535	.457	.493	.371	.052	.188	.194	.272	.143	.101	.235

[1]Diamondback Trail Entrance Ramp. This ramp is designated as the Braker entrance in the FREQ model.
[2]Cameron Road Turnaround Entrance Ramp. This ramp is designated as US 290 entrance in the FREQ model.
[3]Check calculated 15-minute volume for reasonableness.

Table 10
15-Minute Ramp Factors for Northbound IH-35, Morning Evaluation Period

TIME (am)	Entrance Ramps						Exit Ramps								
	W Cannon Stassney	B White 8th 12th Airport	Woodward 51st	Oltorf River	1st	19th 32nd	B White	Woodwar d Holly	Oltorf Woodland MLK	1st River	8th	Manor Airport	26th 38.5	51st Reinli	US 290
6:00	.072	.081	.053	.044	.088	.055	.110	.064	.058	.061	.067	.085	.056	.050	.073
6:15	.078	.083	.060	.058	.062	.079	.135	.057	.048	.073	.058	.043	.058	.077	.062
6:30	.124	.117	.079	.081	.131	.086	.244	.103	.096	.128	.099	.056	.105	.107	.082
6:45	.198	.171	.119	.133	.196	.121	.293	.141	.141	.171	.166	.096	.152	.172	.102
7:00	.237	.188	.177	.154	.193	.132	.329	.192	.187	.276	.215	.185	.173	.211	.196
7:15	.271	.233	.208	.209	.206	.211	.247	.274	.221	.265	.272	.257	.226	.260	.189
7:30	.248	.282	.274	.280	.271	.297	.203	.309	.277	.270	.251	.281	.248	.258	.302
7:45	.244	.296	.339	.351	.333	.337	.216	.244	.298	.190	.257	.255	.343	.258	.309
8:00	.182	.246	.313	.316	.310	.344	.360	.345	.312	.161	.303	.185	.313	.254	.378
8:15	.194	.236	.174	.240	.208	.298	.276	.230	.226	.241	.230	.222	.298	.273	.367
8:30	.194	.262	.197	.222	.196	.258	.247	.124	.224	.247	.267	.173	.238	.245	.320
8:45	.175	.235	.208	.225	.224	.280	.235	.097	.209	.213	.203	.180	.246	.221	.362
9:00	.151	.241	.175	.279	.226	.308	.184	.110	.231	.208	.205	.198	.303	.192	.356
9:15	.117	.229	.187	.237	.202	.281	.173	.097	.178	.177	.172	.201	.297	.212	.309
9:30	.104	.233	.154	.200	.159	.318	.172	.081	.137	.135	.162	.137	.228	.216	.300
9:45	.112	.245	.166	.171	.191	.365	.200	.072	.116	.162	.189	.113	.196	.212	.402
10:00	.104	.243	.139	.174	.211	.318	.170	.071	.126	.133	.211	.109	.167	.217	.367
10:15	.093	.269	.191	.171	.183	.413	.142	.069	.112	.137	.214	.166	.208	.201	.351
10:30	.101	.281	.171	.202	.181	.382	.178	.067	.121	.170	.195	.139	.162	.200	.353
10:45	.097	.297	.182	.225	.165	.392	.148	.082	.157	.141	.163	.142	.241	.227	.324
11:00	.106	.289	.172	.196	.206	.567	.125	.070	.119	.159	.219	.161	.200	.216	.367
11:15	.125	.318	.198	.187	.165	.513	.140	.057	.121	.161	.177	.187	.213	.239	.427
11:30	.103	.340	.202	.178	.247	.429	.160	.079	.138	.160	.150	.168	.219	.270	.427
11:45	.103	.370	.210	.228	.213	.461	.149	.086	.148	.170	.198	.202	.235	.326	.547

Table 11
15-Minute Ramp Factors for Southbound IH-35, Evening Evaluation Period

Time (p.m.)	Entrance Ramps				Exit Ramps					
	Airport 26th 38.5	Woodland 6th	Oltorf 1st B. White	51st US 290 US 183 MLK	MLK 26th	32nd 38.5	Woodward Woodland	8th 1st	12th St. Elmo	Airport US 290 Riverside B. White Stassney
4:00	.239	.149	.167	.205	.188	.233	.183	.345	.122	.232
4:15	.259	.172	.165	.216	.212	.266	.203	.349	.130	.222
4:30	.274	.165	.179	.219	.189	.245	.210	.341	.113	.227
4:45	.252	.175	.205	.231	.155	.235	.232	.325	.127	.236
5:00	.251	.164	.201	.240	.186	.223	.211	.315	.119	.250
5:15	.255	.276	.228	.247	.173	.244	.226	.353	.132	.271
5:30	.267	.201	.226	.246	.224	.221	.229	.344	.117	.290
5:45	.253	.281	.234	.272	.174	.243	.265	.355	.136	.280
6:00	.277	.225	.243	.257	.232	.236	.243	.271	.223	.262
6:15	.237	.323	.272	.267	.242	.259	.281	.209	.267	.243
6:30	.236	.235	.267	.230	.231	.247	.262	.206	.285	.233
6:45	.228	.199	.228	.216	.233	.263	.219	.225	.226	.255
7:00	.224	.167	.235	.204	.246	.246	.170	.230	.257	.239
7:15	.231	.139	.234	.206	.200	.183	.182	.285	.214	.240
7:30	.197	.122	.195	.196	.183	.221	.199	.243	.149	.234
7:45	.175	.134	.167	.179	.211	.217	.211	.201	.097	.228
8:00	.196	.153	.175	.185	.220	.193	.181	.286	.100	.234
8:15	.137	.112	.151	.192	.156	.179	.149	.238	.071	.211
8:30	.133	.094	.133	.162	.120	.163	.124	.191	.063	.199
8:45	.146	.090	.132	.160	.120	.127	.119	.200	.061	.184
9:00	.104	.096	.126	.159	.109	.110	.163	.186	.058	.184
9:15	.128	.0876	.110	.152	.105	.094	.156	.184	.056	.163
9:30	.161	.086	.106	.133	.079	.097	.109	.148	.054	.149
9:45	.160	.087	.120	.136	.068	.103	.115	.148	.055	.135

Table 12
15-Minute Ramp Factors for Northbound IH-35, Evening Evaluation Period

Time (p.m.)	Entrance Ramps					Exit Ramps						
	26th/32nd 19th	Rundberg 51st US 290	US 183 6th 12th	1st	Riverside Airport	Manor 26th/32nd 38th	Holly 1st	Reinli/Clayton Yager-51st Braker	15th	6th	Airport	Rundberg US 290-US 183 St. Johns
4:00	.179	.132	.125	.176	.175	.271	.222	.091	.214	.325	.161	.190
4:15	.214	.127	.141	.197	.173	.248	.191	.079	.223	.221	.174	.195
4:30	.177	.137	.132	.202	.188	.269	.206	.094	.218	.229	.161	.209
4:45	.193	.151	.162	.255	.205	.258	.242	.098	.233	.284	.148	.224
5:00	.190	.200	.171	.236	.209	.269	.182	.149	.240	.243	.181	.236
5:15	.266	.233	.192	.272	.219	.251	.193	.157	.251	.297	.216	.256
5:30	.209	.226	.198	.213	.221	.248	.236	.192	.250	.243	.258	.258
5:45	.236	.254	.217	.236	.241	.267	.224	.183	.278	.250	.226	.241
6:00	.245	.254	.232	.275	.237	.271	.236	.233	.310	.267	.210	.247
6:15	.281	.264	.300	.260	.261	.233	.281	.242	.188	.207	.274	.238
6:30	.236	.243	.243	.224	.255	.194	.278	.242	.228	.253	.268	.254
6:45	.233	.233	.225	.219	.247	.248	.178	.229	.268	.232	.239	.246
7:00	.196	.205	.190	.203	.198	.232	.218	.218	.226	.176	.203	.254
7:15	.193	.206	.159	.233	.208	.195	.173	.238	.203	.170	.126	.210
7:30	.140	.165	.139	.182	.211	.233	.179	.197	.239	.178	.129	.200
7:45	.154	.161	.116	.188	.198	.209	.178	.163	.311	.162	.100	.194
8:00	.139	.160	.107	.173	.185	.221	.163	.152	.263	.161	.100	.192
8:15	.155	.150	.094	.152	.172	.178	.152	.165	.201	.146	.103	.190
8:30	.152	.137	.077	.152	.150	.171	.139	.136	.195	.183	.123	.190
8:45	.128	.149	.075	.155	.163	.186	.134	.113	.151	.153	.087	.173
9:00	.144	.137	.072	.142	.159	.147	.127	.130	.1700	.146	.090	.170
9:15	.138	.150	.079	.149	.145	.136	.081	.129	.1163	.101	.081	.162
9:30	.144	.151	.064	.211	.154	.130	.094	.120	.0975	.047	.097	.152
9:45	.138	.144	.057	.230	.142	.132	.073	.095	.0988	.083	.094	.138

Express Ramps

The 15-minute ramp factors for the express exits and entrances on IH-35 were analyzed separately due to the potential for very different volume patterns. The same methodology, however, was employed; and the resulting factors are shown in Tables 13 and 14.

Mainlane Entry Points

Tables 15 and 16 contain the 15-minute factors for the mainlane entry and destination points respectively. These factors were calculated in the southbound and northbound directions for both the morning and evening peak periods.

Table 13
15-Minute Ramp Factors for the Express Ramps
Morning Evaluation Period

Time (a.m.)	NB Express Exit NB Express Entrance	SB Express Exit SB Express Entrance
6:00	.076	.058
6:15	.080	.075
6:30	.111	.098
6:45	.165	.140
7:00	.201	.190
7:15	.235	.231
7:30	.262	.287
7:45	.285	.278
8:00	.274	.300
8:15	.261	.272
8:30	.257	.274
8:45	.222	.220
9:00	.243	.218
9:15	.212	.177
9:30	.183	.188
9:45	.194	.167
10:00	.222	.165
10:15	.208	.155
10:30	.212	.145
10:45	.216	.158
11:00	.221	.156
11:15	.228	.152
11:30	.235	.157
11:45	.271	.168

Table 14
15-Minute Ramp Factors for the Express Ramps, Evening Evaluation Period

Time (p.m.)	NB Express Exit NB Express Entrance	SB Express Entrance	SB Express Exit
3:00	.288	.284	.163
3:15	.277	.274	.176
3:30	.301	.298	.163
3:45	.328	.325	.168
4:00	.346	.341	.173
4:15	.358	.354	.179
4:30	.396	.389	.191
4:45	.423	.416	.203
5:00	.423	.412	.210
5:15	.450	.439	.211
5:30	.446	.434	.197
5:45	.389	.383	.180
6:00	.391	.379	.178
6:15	.350	.346	.183
6:30	.310	.305	.167
6:45	.289	.285	.157
7:00	.309	.304	.168
7:15	.269	.265	.159
7:30	.260	.256	.141
7:45	.244	.241	.139
8:00	.230	.226	.141
8:15	.213	.210	.120
8:30	.213	.210	.116
8:45	.196	.193	.109

Table 15
15-Minute Factors for Mainlane Entry Points

Time (a.m.)	Southbound[1]	Northbound[2]	Time (p.m.)	Southbound[3]	Northbound[4]
6:00	.142	.181	3:00	.210	.238
6:15	.165	.170	3:15	.193	.208
6:30	.181	.193	3:30	.192	.227
6:45	.209	.212	3:45	.206	.242
7:00	.253	.216	4:00	.220	.235
7:15	.259	.249	4:15	.242	.259
7:30	.257	.258	4:30	.235	.242
7:45	.231	.276	4:45	.250	.265
8:00	.202	.233	5:00	.259	.243
8:15	.216	.216	5:15	.227	.206
8:30	.203	.201	5:30	.260	.266
8:45	.200	.189	5:45	.254	.222
9:00	.172	.181	6:00	.272	.237
9:15	.139	.139	6:15	.222	.214
9:30	.121	.124	6:30	.263	.206
9:45	.122	.112	6:45	.245	.208
10:00	.126	.137	7:00	.266	.227
10:15	.133	.117	7:15	.207	.191
10:30	.134	.119	7:30	.211	.192
10:45	.142	.102	7:45	.170	.178
11:00	.137	.104	8:00	.167	.163
11:15	.131	.085	8:15	.138	.127
11:30	.147	.107	8:30	.146	.087
11:45	.145	.124	8:45	.111	.089

[1]North of Braker exit ramp.
[2]South of William Cannon entrance ramp.
[3]North of US183 entrance ramp.
[4]South of Holly exit ramp.

Table 16
15-Minute Factors for Mainlane Destination Points

Time (a.m.)	Southbound[1]	Northbound[2]	Time (p.m.)	Southbound[3]	Northbound[4]
6:00	.078	.103	3:00	.141	.122
6:15	.088	.092	3:15	.154	.124
6:30	.138	.139	3:30	.165	.135
6:45	.174	.191	3:45	.186	.146
7:00	.226	.221	4:00	.195	.166
7:15	.258	.252	4:15	.243	.198
7:30	.271	.250	4:30	.224	.190
7:45	.245	.278	4:45	.261	.248
8:00	.246	.253	5:00	.261	.230
8:15	.293	.241	5:15	.278	.276
8:30	.337	.260	5:30	.245	.272
8:45	.244	.215	5:45	.216	.222
9:00	.266	.283	6:00	.199	.183
9:15	.241	.227	6:15	.181	.154
9:30	.244	.189	6:30	.171	.142
9:45	.213	.193	6:45	.150	.134
10:00	.246	.202	7:00	.151	.129
10:15	.225	.238	7:15	.149	.101
10:30	.227	.236	7:30	.125	.079
10:45	.208	.233	7:45	.125	.114
11:00	.265	.238	8:00	.125	.101
11:15	.239	.230	8:15	.109	.100
11:30	.259	.258	8:30	.114	.104
11:45	.249	.250	8:45	.119	.092

[1]South of Riverside exit ramp.
[2]North of US290 exit ramp.
[3]South of the Second Stassney exit ramp.
[4]North of Yager exit ramp.

CHAPTER V. RESULTS AND RECOMMENDATIONS

Under Study 7-1953, a number of modeling techniques have been developed and implemented for the Austin Region. These include:

- development and implementation of time-of-day travel models to facilitate morning and afternoon peak-period analyses of forecast volumes for IH-35 in the Austin area;
- implementation of the Texas Mezzo-Level HOV Carpool Model to estimate the forecast carpool usage of the proposed HOV lanes;
- development of detailed highway network coding techniques and parameters; and
- implementation of the FREQ10 model for the operational analyses of the freeway designs using results from the detailed assignments.

The application of these modeling techniques for the analyses of the IH-35 design alternatives has proven successful and useful in reviewing and refining the alternatives.

As this study was nearing completion, it was learned that the ATS had developed new 2020 demographic forecasts for the region. Also, a revised long-range transportation plan is nearing completion and is expected to be adopted this fall. In compliance with the new ISTEA requirements, the new plan will reflect a financially constrained highway system. While the proposed improvements to IH-35 remain in the proposed plan, a number of other planned facilities (which were included in the networks used in the work performed under this study) will not be in the new plan.

The new demographic forecasts reportedly show a significant growth pattern for the 2020 forecasts. These changes in demographics and changes in the planned highway system can be expected to have a significant impact on the forecast volumes on IH-35. It is recommended, therefore, that the new forecasts be used to perform the Major Investment Study (MIS) which will be required for the IH-35 improvements under the new ISTEA requirements. The new modeling techniques developed and implemented under this study are recommended for use in preparing the MIS for the IH-35 improvements. TTI will be assisting the District in these analyses under an Interagency Agreement entitled "IH35 Feasibility Study."

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APPENDIX A: ESTIMATION OF HOURLY CAPACITIES FOR AUSTIN HIGHWAY NETWORKS

The purpose of this appendix is to document the formulas and parameters used in estimating the hourly capacities for the peak-hour networks used in this study. Tables A-1 through A-6 summarize the capacity calculations for the functional classifications used in the ATS highway networks. The detailed coding techniques employed in the IH-35 analyses required the delineation of additional functional classifications. Tables A-7 through A-14 summarize the capacity calculations for the hourly capacities used in the detailed coding of the IH-35 alternatives.

Table A-1
Freeway Capacity Estimates

TYPICAL AREA TYPE	SATURATION FLOW RATE CS (pcphgpl)	VOL. TO CAPACITY RATIO V/C (pk 15min)	PEAK HOUR FACTOR PHF	LANE UTIL. FACTOR U	PROP. OF TRUCKS Pt	TRUCK EQUIV. FACTOR Et	PK.HR. CAP PHCAP	ROUNDED PK.HR. CAP. (Rnded to 50's)
	OPERATIONAL CHARACTERISTICS							
1. CBD	2,150	1.00	1.00	.95	.05	1.70	1,973	1,950
2. URBAN	2,150	1.00	1.00	.95	.05	1.70	1,973	1,950
3. FRINGE URBAN	2,150	1.00	1.00	.95	.05	1.70	1,973	1,950
4. SUBURBAN	2,150	1.00	.95	.95	.07	1.70	1,850	1,850
5. RURAL	2,150	1.00	.90	.95	.10	1.70	1,718	1,700

Formulas Used:

PHCAP = (CS*V/C*PHF*U)/(1+(Pt*(Et-1)))

PHF = (Volume for peak hour)/(4*(Volume for peak 15 minutes))

Table A-2
Expressway Capacity Estimates

TYPICAL AREA TYPE	OPERATIONAL CHARACTERISTICS: SATURATION FLOW RATE CS (pcphgpl)	PROP.OF GREEN TIME G/C	SATUR. FLOW PER HR. CS*G/C (pcphpl)	VOL. TO CAPACITY RATIO V/C (pk 15min)	PEAK HOUR FACTOR PHF	LANE UTIL. FACTOR U	ASSUMED PROP.OF LFT.TRNS. LT	LFT.TRN. VOL.FROM PK. DIR. LTVPK	PROP. OF TRUCKS Pt	TRUCK EQUIV. FACTOR Et	PK.HR. CAP PHCAP	ROUNDED PK.HR. CAP/LANE (Rnded to 50's)
1. CBD	1,800	.650	1,170	1.00	.950	.950	.08	84	.05	1.50	1,114	1,100
2. URBAN	1,800	.650	1,170	1.00	.950	.950	.08	84	.05	1.50	1,114	1,100
3. FRINGE URBAN	1,800	.650	1,170	1.00	.900	.950	.08	80	.05	1.50	1,056	1,050
4. SUBURBAN	1,800	.650	1,170	1.00	.900	.950	.08	80	.05	1.50	1,056	1,050
5. RURAL	1,800	.650	1,170	1.00	.850	.950	.08	76	.10	1.70	959	950

Formulas Used:

PHCAP = ((CS*(G/C)*(V/C)*PHF*U)+LTVPK)/(1+(Pt*(Et-1)))

LTVPK = Lt*CS*(G/C)*(V/C)*U

PHF = (Volume for peak hour)/(4 * (Volume for peak 15 minutes))

Table A-3
Capacity Estimates for Major Divided Arterials

TYPICAL AREA TYPE	OPERATIONAL CHARACTERISTICS: SATURATION FLOW RATE CS (pcphgpl)	PROP.OF GREEN TIME G/C	SATUR. FLOW PER HR. CS*G/C (pcphpl)	VOL. TO CAPACITY RATIO V/C (pk 15min)	PEAK HOUR FACTOR PHF	LANE UTIL. FACTOR U	ASSUMED PROP.OF LFT.TRNS. LT	LFT.TRN. VOL.FROM PK. DIR. LTVPK per lane	PROP. OF TRUCKS Pt	TRUCK EQUIV. FACTOR Et	PK.HR. CAP. PHCAP per lane	ROUNDED PK.HR. CAP/LANE (Rnded to 10's)
1. CBD	1,800	.450	810	1.00	.950	.950	.10	73	.05	1.50	786	790
2. URBAN	1,800	.450	810	1.00	.950	.950	.10	73	.05	1.50	786	790
3. FRINGE URBAN	1,800	.500	900	1.00	.900	.950	.10	77	.05	1.50	828	830
4. SUBURBAN	1,800	.500	900	1.00	.900	.950	.10	77	.05	1.50	828	830
5. RURAL	1,800	.550	990	1.00	.850	.950	.10	80	.10	1.70	827	830

Formulas Used:

PHCAP = ((CS*(G/C)*(V/C)*PHF*U)+LTVPK)/(1+(Pt*(Et-1))) + LTVPK

LTVPK = Lt*CS*(G/C)*(V/C)*U

PHF = (Volume in the peak hour)/(4 * (Volume in the peak 15 minutes))

Table A-4
Capacity Estimates for Major Undivided Arterials

OPERATIONAL CHARACTERISTICS

TYPICAL AREA TYPE	SATURATION FLOW RATE	PROP.OF GREEN TIME	SATUR. FLOW PER HR.	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	PROP. IN PK. DIR. IN PK.HR.	ASSUMED PROP.OF LFT.TRNS.	LFT.TRN. VOL.FROM OPP. DIR.	PROP. OF TRUCKS	TRUCK EQUIV. FACTOR	PK.HR. CAP.	ROUNDED PK.HR. CAP/LANE
	CS (pcphgpl)	G/C	CS*G/C (pcphpl)	V/C (pk 15min)	PHF	U	D	LT	LTVOP	Pt	Et	PHCAP	(Rnded to 10's)
1. CBD	1,800	.500	900	1.00	.950	.950	.550	.10	167	.05	1.50	625	630
2. URBAN	1,800	.500	900	1.00	.950	.950	.550	.10	167	.05	1.50	625	630
3. FRINGE URBAN	1,800	.550	990	1.00	.900	.950	.575	.10	157	.05	1.50	669	670
4. SUBURBAN	1,800	.550	990	1.00	.900	.950	.575	.10	157	.05	1.50	669	670
5. RURAL	1,800	.600	1,080	1.00	.850	.950	.600	.10	146	.10	1.70	669	670

Formulas Used:

PHCAP = ((CS*(G/C)*(V/C)*PHF*U)+LTVPK)/(1+(Pt*(Et-1))) - LTVOP

LTVOP = (Lt*CS*(G/C)*(V/C)*U)*((1-D)/D)*(Average number of lanes in opposite direction)
Average number of lanes in opposite direction assumed to be 2.5 for major arterials

PHF = (Volume in the peak hour)/(4 * (Volume in the peak 15 minutes))

Table A-5
Capacity Estimates for Minor Arterials

TYPICAL AREA TYPE	SATURATION FLOW RATE	PROP.OF GREEN TIME	SATUR. FLOW PER HR.	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	PROP. IN PK. DIR. IN PK.HR.	ASSUMED PROP.OF LFT.TRNS.	LFT.TRN. VOL.FROM OPP. DIR.	PROP. OF TRUCKS	TRUCK EQUIV. FACTOR	PK.HR. CAP.	ROUNDED PK.HR. CAP/LANE
	OPERATIONAL CHARACTERISTICS												
	CS (pcphgpl)	G/C	CS*G/C (pcphpl)	V/C (pk 15min)	PHF	U	D	LT	LTVOP	Pt	Et	PHCAP	(Rnded to 10's)
1. CBD	1,800	.450	810	1.00	.950	.950	.550	.15	135	.05	1.50	578	580
2. URBAN	1,800	.450	810	1.00	.950	.950	.550	.15	135	.05	1.50	578	580
3. FRINGE URBAN	1,800	.450	810	1.00	.900	.950	.575	.15	115	.05	1.50	561	560
4. SUBURBAN	1,800	.450	810	1.00	.900	.950	.575	.15	115	.05	1.50	561	560
5. RURAL	1,800	.475	855	1.00	.850	.950	.600	.15	104	.10	1.70	541	540

Formulas Used:

PHCAP = ((CS*(G/C)*(V/C)*PHF*U)+LTVPK)/(1+(Pt*(Et-1))) - LTVOP

LTVOP = (Lt*CS*(G/C)*(V/C)*U)*((1-D)/D)*(Average number of lanes in opposite direction)
Average number of lanes in opposite direction assumed to be 1.5 for minor arterials

PHF = (Volume in the peak hour)/(4 * (Volume in the peak 15 minutes))

Table A-6
Capacity Estimates for Collectors

	OPERATIONAL CHARACTERISTICS												
TYPICAL AREA TYPE	SATURATION FLOW RATE	PROP.OF GREEN TIME	SATUR. FLOW PER HR.	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	PROP. IN PK. DIR. IN PK.HR.	ASSUMED PROP.OF LFT.TRNS.	LFT.TRN. VOL.FROM OPP. DIR.	PROP. OF TRUCKS	TRUCK EQUIV. FACTOR	PK.HR. CAP.	ROUNDED PK.HR. CAP/LANE
	CS (pcphgpl)	G/C	CS*G/C (pcphpl)	V/C (pk 15min)	PHF	U	D	LT	LTVOP	Pt	Et	PHCAP	(Rnded to 10's)
1. CBD	1,800	.450	810	1.00	.900	.950	.600	.35	242	.05	1.50	434	430
2. URBAN	1,800	.450	810	1.00	.900	.950	.600	.35	242	.05	1.50	434	430
3. FRINGE URBAN	1,800	.450	810	1.00	.850	.950	.625	.35	206	.05	1.50	432	430
4. SUBURBAN	1,800	.450	810	1.00	.850	.950	.625	.35	206	.05	1.50	432	430
5. RURAL	1,800	.450	810	1.00	.800	.950	.650	.35	174	.10	1.70	401	400

Formulas Used:

PHCAP = ((CS*(G/C)*(V/C)*PHF*U)+LTVPK)/(1+(Pt*(Et-1))) - LTVOP

LTVOP = (Lt*CS*(G/C)*(V/C)*U)*((1-D)/D)*(Average number of lanes in opposite direction)
Average number of lanes in opposite direction assumed to be 1.5 for minor arterials

PHF = (Volume in the peak hour)/(4 * (Volume in the peak 15 minutes))

Table A-7
Capacity Estimates for Normal Freeway Main Lanes

TYPICAL AREA TYPE	SATURATION FLOW RATE	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	PROP. OF TRUCKS	TRUCK EQUIV. FACTOR	PK.HR. CAP	ROUNDED PK.HR. CAP.
	OPERATIONAL CHARACTERISTICS							
	CS (pcphgpl)	V/C (pk 15min)	PHF	U	Pt	Et	PHCAP	(Rnded to 50's)
1. CBD	2,150	1.00	1.00	.95	.05	1.70	1,973	1,950
2. URBAN	2,150	1.00	1.00	.95	.05	1.70	1,973	1,950
3. FRINGE URBAN	2,150	1.00	1.00	.95	.05	1.70	1,973	1,950
4. SUBURBAN	2,150	1.00	.95	.95	.07	1.70	1,850	1,850
5. RURAL	2,150	1.00	.90	.95	.10	1.70	1,718	1,700

Formulas Used:

PHCAP = (CS*V/C*PHF*U)/(1+(Pt*(Et-1)))

PHF = (Volume for peak hour)/(4*(Volume for peak 15 minutes))

Table A-8
Capacity Estimates for Elevated or Depressed Freeway Main Lanes

TYPICAL AREA TYPE	SATURATION FLOW RATE	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	PROP. OF TRUCKS	TRUCK EQUIV. FACTOR	PK.HR. CAP	ROUNDED PK.HR. CAP.
	OPERATIONAL CHARACTERISTICS							
	CS (pcphgpl)	V/C (pk 15min)	PHF	U	Pt	Et	PHCAP	(Rnded to 50's)
1. CBD	2,150	1.00	1.00	.98	.05	1.70	2,036	2,050
2. URBAN	2,150	1.00	1.00	.98	.05	1.70	2,036	2,050
3. FRINGE URBAN	2,150	1.00	1.00	.98	.05	1.70	2,036	2,050
4. SUBURBAN	2,150	1.00	.96	.98	.07	1.70	1,928	1,950
5. RURAL	2,150	1.00	.91	.98	.10	1.70	1,792	1,800

Formulas Used:

PHCAP = (CS*V/C*PHF*U)/(1+(Pt*(Et-1)))

PHF = (Volume for peak hour)/(4*(Volume for peak 15 minutes))

Table A-9
Capacity Estimates for Freeway-to-Freeway Ramps

	OPERATIONAL CHARACTERISTICS							
TYPICAL AREA TYPE	SATURATION FLOW RATE	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	PROP. OF TRUCKS	TRUCK EQUIV. FACTOR	PK.HR. CAP	ROUNDED PK.HR. CAP.
	CS (pcphgpl)	V/C (pk 15min)	PHF	U	Pt	Et	PHCAP	(Rnded to 50's)
1. CBD	2,000	1.00	1.00	.90	.05	1.70	1,739	1,750
2. URBAN	2,000	1.00	1.00	.90	.05	1.70	1,739	1,750
3. FRINGE URBAN	2,000	1.00	1.00	.90	.05	1.70	1,739	1,750
4. SUBURBAN	2,000	1.00	.95	.90	.05	1.70	1,652	1,650
5. RURAL	2,000	1.00	.95	.90	.05	1.70	1,652	1,650

Formulas Used:

PHCAP = (CS*V/C*PHF*U)/(1+(Pt*(Et-1)))

PHF = (Volume for peak hour)/(4*(Volume for peak 15 minutes))

Table A-10
Capacity Estimates for Collector/Distributor Lanes

	OPERATIONAL CHARACTERISTICS							
TYPICAL AREA TYPE	SATURATION FLOW RATE	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	PROP. OF TRUCKS	TRUCK EQUIV. FACTOR	PK.HR. CAP	ROUNDED PK.HR. CAP.
	CS (pcphgpl)	V/C (pk 15min)	PHF	U	Pt	Et	PHCAP	(Rnded to 50's)
1. CBD	2,000	1.00	1.00	.90	.05	1.70	1,739	1,750
2. URBAN	2,000	1.00	1.00	.90	.05	1.70	1,739	1,750
3. FRINGE URBAN	2,000	1.00	1.00	.90	.05	1.70	1,739	1,750
4. SUBURBAN	2,000	1.00	.95	.90	.05	1.70	1,652	1,650
5. RURAL	2,000	1.00	.95	.90	.05	1.70	1,652	1,650

Formulas Used:

PHCAP = (CS*V/C*PHF*U)/(1+(Pt*(Et-1)))

PHF = (Volume for peak hour)/(4*(Volume for peak 15 minutes))

Table A-11
Capacity Estimates for HOV Exclusive Lanes

	OPERATIONAL CHARACTERISTICS							
TYPICAL AREA TYPE	SATURATION FLOW RATE	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	PROP. OF BUSSES	BUSSES EQUIV. FACTOR	PK.HR. CAP	ROUNDED PK.HR. CAP.
	CS (pcphgpl)	V/C (pk 15min)	PHF	U	Pt	Et	PHCAP	(Rnded to 50's)
1. CBD	2,150	1.00	1.00	.98	.05	1.70	2,036	2,050
2. URBAN	2,150	1.00	1.00	.98	.05	1.70	2,036	2,050
3. FRINGE URBAN	2,150	1.00	1.00	.98	.05	1.70	2,036	2,050
4. SUBURBAN	2,150	1.00	1.00	.98	.05	1.70	2,036	2,050
5. RURAL	2,150	1.00	1.00	.98	.05	1.70	2,036	2,050

Formulas Used:

PHCAP = (CS*V/C*PHF*U)/(1+(Pt*(Et-1)))

PHF = (Volume for peak hour)/(4*(Volume for peak 15 minutes))

Table A-12
Capacity Estimates for Normal Freeway Ramps

TYPICAL AREA TYPE	SATURATION FLOW RATE	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	PROP. OF TRUCKS	TRUCK EQUIV. FACTOR	PK.HR. CAP	ROUNDED PK.HR. CAP.
	OPERATIONAL CHARACTERISTICS							
	CS (pcphgpl)	V/C (pk 15min)	PHF	U	Pt	Et	PHCAP	(Rnded to 25's)
1. CBD	1,800	1.00	1.00	.85	.04	1.70	1,488	1,500
2. URBAN	1,800	1.00	1.00	.85	.04	1.70	1,488	1,500
3. FRINGE URBAN	1,800	1.00	1.00	.85	.04	1.70	1,488	1,500
4. SUBURBAN	1,800	1.00	1.00	.85	.04	1.70	1,488	1,500
5. RURAL	1,800	1.00	1.00	.85	.04	1.70	1,488	1,500

Formulas Used:

PHCAP = (CS*V/C*PHF*U)/(1+(Pt*(Et-1)))

PHF = (Volume for peak hour)/(4*(Volume for peak 15 minutes))

Table A-13
Capacity Estimates for HOV and CD High Speed Ramps to Surface Streets

TYPICAL AREA TYPE	SATURATION FLOW RATE CS (pcphgpl)	VOL. TO CAPACITY RATIO V/C (pk 15min)	PEAK HOUR FACTOR PHF	LANE UTIL. FACTOR U	PROP. OF TRK/BUS Pt	TRK/BUS EQUIV. FACTOR Et	PK.HR. CAP PHCAP	ROUNDED PK.HR. CAP. (Rnded to 25's)
	OPERATIONAL CHARACTERISTICS							
1. CBD	1,800	1.00	1.00	.90	.05	1.70	1,565	1,575
2. URBAN	1,800	1.00	1.00	.90	.05	1.70	1,565	1,575
3. FRINGE URBAN	1,800	1.00	1.00	.90	.05	1.70	1,565	1,575
4. SUBURBAN	1,800	1.00	1.00	.90	.05	1.70	1,565	1,575
5. RURAL	1,800	1.00	1.00	.90	.05	1.70	1,565	1,575

Formulas Used:

PHCAP = (CS*V/C*PHF*U)/(1+(Pt*(Et-1)))

PHF = (Volume for peak hour)/(4*(Volume for peak 15 minutes))

Table A-14
Capacity Estimates for Frontage Roads

TYPICAL AREA TYPE	SATURATION FLOW RATE	PROP.OF GREEN TIME	SATUR. FLOW PER HR.	VOL. TO CAPACITY RATIO	PEAK HOUR FACTOR	LANE UTIL. FACTOR	ASSUMED PROP.OF LFT.TRNS.	LFT.TRN. VOL.FROM PK. DIR.	PROP. OF TRUCKS	TRUCK EQUIV. FACTOR	PK.HR. CAP.	ROUNDED PK.HR. CAP/LANE
	OPERATIONAL CHARACTERISTICS											
	CS (pcphgpl)	G/C	CS*G/C (pcphpl)	V/C (pk 15min)	PHF	U	LT	LTVPK per lane	Pt	Et	PHCAP per lane	(Rnded to 10's)
1. CBD	1,800	.450	810	1.00	.950	.950	.10	73	.05	1.50	786	790
2. URBAN	1,800	.450	810	1.00	.950	.950	.10	73	.05	1.50	786	790
3. FRINGE URBAN	1,800	.500	900	1.00	.900	.950	.10	77	.05	1.50	828	830
4. SUBURBAN	1,800	.500	900	1.00	.900	.950	.10	77	.05	1.50	828	830
5. RURAL	1,800	.550	990	1.00	.850	.950	.10	80	.10	1.70	827	830

Formulas Used:

PHCAP = ((CS*(G/C)*(V/C)*PHF*U)+LTVPK)/(1+(Pt*(Et-1))) + LTVPK

LTVPK = Lt*CS*(G/C)*(V/C)*U

PHF = (Volume in the peak hour)/(4 * (Volume in the peak 15 minutes))

APPENDIX B:
FORMULATION OF MODELS IMPLEMENTED IN THE TEXAS MEZZO-LEVEL HOV CARPOOL MODEL

The purpose of this appendix is to describe the formulation of the three HOV carpool models implemented in the Texas HOV Mezzo-Level Carpool Model (10). These models are used to estimate the changes in the number of HBW carpools expected to use the HOV based on the time savings offered by the HOV facility. Also described in this appendix is the Texas average auto occupancy developed using Texas data for implementation in the Texas Mezzo-Level HOV Carpool Model (10).

TRAVEL TIME RATIO MODEL

The Travel Time Ratio Model is an adaptation of a model developed by JHK and Associates for use in Washington, D.C., and modified by Barton Aschman and Associates for application in Atlanta. The JHK model utilizes peak-period travel time ratios to estimate transit, auto, and carpool modal probabilities and calculate the shift in carpool modal probabilities. This is done by estimating the carpool probabilities with and without HOV lanes and applying the change or "shift" in probabilities to a base amount of trips.

Two sets of cross-classification curves relate (1) the transit to highway (auto) travel time ratio to the ratio of transit person trips to highway person trips and (2) the auto to HOV (carpool) travel time ratio to the ratio of highway person trips to carpool person trips. By using the cross-classification curves and mathematical formulations, the model can estimate the percentage of transit, auto, and carpool modal probabilities.

The JHK model was developed using Shirley Highway data where the minimum carpool definition is 4+ persons. To account for the fact that the model would be applied in Texas, where the minimum carpool definition is as low as 2+ and the proportion of auto trips would be different for different levels of carpooling, new values were developed for the 2+ and 3+ minimum carpool definition, respectively. Table 6A-1 shows the three sets of values for the various minimum carpool definitions (R1), as well as the values for the transit to auto trip ratios (R2) and the corresponding travel time ratio.

Based upon these functions, modal probabilities are initially estimated for the no HOV lane condition using the following mathematical definitions:

$$A = \text{Percentage Automobile Person Trips}$$

$$C = \text{Percentage Carpool Person Trips}$$

$$T = \text{Percentage Transit Person Trips}$$

$$A + C + T = 100$$

$$R1 = A/C$$

$$R2 = T/A$$

Given these definitions, the following mathematical manipulations can be performed:

$$A = R1 * C$$

$$R2 = T/(R1 * C)$$

$$T = R1 * R2 * C$$

$$R1 * C + C + R1 * R2 * C = 100$$

$$C * (R1 + 1 + R1 * R2) = 100$$

With the following equations, the percentage mode usage is estimated for the no HOV lane condition:

$$C = 100/(R1 + 1 + R1 * R2)$$

$$A = R1 * C$$

$$T = R2 * A$$

The no HOV lane condition simply means that the R1 value used corresponds to an auto-to-carpool travel time ratio of 1.0 (i.e., no travel time savings) The R2 value is computed based on the input person trip table and transit mode share. The transit person trip part of the ratio is estimated from the input percentage transit. The auto portion of the ratio is calculated by subtracting the estimated transit person trips from the total person trips obtained from the input trip table.

Utilizing the same functions and equations, modal probabilities for transit, auto, and carpool are reestimated based upon a new R1 value. The new R1 value will correspond to the value of the travel time ratio which reflects the travel time savings the HOV lane offers.

The shift in carpool, highway, and transit modal probabilities is then calculated by comparing the probabilities for the three modes with and without carpool lanes. These shifts are then applied to the total person trips for 1, 2, 3, and 4+ person cars as well as transit for the base condition to obtain the final person and vehicle trip probabilities for the integer car modes, as well as the person trip probability for the transit mode.

Table B-1
Ratios Used in Travel Time Ratio Model

Travel Time Ratio	R2 Transit/Auto Ratio	4+ R1 Auto/Carpool Ratio	3+ R1 Auto/Carpool Ratio	2+ R1 Auto/Carpool Ratio
0.55				
0.60	3.450	8.00	3.50	1.25
0.70	2.250	8.00	3.50	1.25
0.80	1.250	8.00	3.50	1.25
0.90	0.800	8.00	3.50	1.25
1.00	0.550	8.00	3.50	1.25
1.10	0.450	8.00	3.50	1.25
1.20	0.380	5.40	2.36	0.84
1.30	0.320	4.20	1.84	0.66
1.40	0.270	3.40	1.49	0.53
1.50	0.230	2.70	1.18	0.42
1.60	0.200	2.30	1.01	0.36
1.70	0.180	1.85	0.81	0.29
1.80	0.170	1.50	0.66	0.23
1.90	0.165	1.20	0.53	0.19
2.00	0.165	0.90	0.39	0.14
	0.165	0.65	0.28	0.10

LOGIT BASED MODEL

The Logit Based Model is an adaptation of the Bolling-Anacostia model originally developed in Washington, D.C., by Barton Aschman and Associates and modified for use in Atlanta. As its name indicates, this model is a logit model which estimates the probability of each integer car mode. The model as applied in Washington, D.C., and in Atlanta incorporated both a time and cost element into the logit equations for each of four modes (1, 2, 3 and 4+ person vehicle). The adaption of the BAA model for application in Texas has eliminated the use of the cost variable from the logit equations. The logit equations are as follows:

$$U(\text{1 person/car}) = (-0.0388 * \text{NHTT}) - 1.65075$$

$$U(\text{2 person/car}) = (-0.0388 * (\text{NHTT} + 1.1)) - 2.20850$$

$$U(\text{3 person/car}) = (-0.0388 * (\text{NHTT} + 2.2)) - 3.47975$$

$$U(\text{4 person/car}) = (-0.0388 * (\text{NHTT} + 3.2)) - 3.51075$$

where:

NHTT = peak-period highway travel time

As the above formulas indicate, the logit equations are used to calculate utile values for each of the four modes. The probability of each mode is calculated by exponentiating and summing the values of the preceding equations and applying the values as follows:

$$\text{Probability of mode}(x) = \frac{\text{EXP}(U(x))}{\sum_{I=1}^{n} \text{EXP}(U(x))}$$

where:

n = number of modes

Because the model is not considered a true "calibrated" logit model, it is applied with a "shift" technique. Initially, the logit equations are applied to obtain estimates of the modal probabilities in the no HOV lane condition. It should be noted that the probabilities that are calculated are in the form of highway person trips and not total person trips. The transit person trips are dealt with in a separate calculation.

The model probabilities are reestimated using the same logit equations as were used to calculate the non-HOV lane probabilities. However, the logit equations used to calculate the utile values for each mode contain a time variable which represents the HOV travel time (NHTT-time savings):

$$U(1\ person/car) = (-0.0388 * (NHTT) - TMESV) - 1.65075$$

$$U(2\ person/car) = (-0.0388 * (NHTT - TMESV) + 1.1)) - 2.20850$$

$$U(3\ person/car) = (-0.0388 * (NHTT - TMESV) + 2.2)) - 3.47975$$

$$U(4\ person/car) = (-0.0388 * (NHTT - TMESV) + 3.2)) - 1.65075$$

where:

TMESV = travel time savings of HOV lane

The utile values are exponentiated and summed, just as in the non-HOV lane condition to obtain estimates of modal probabilities. The shifts in the modal probabilities are computed by comparing the probabilities in the non-HOV lane condition with those in the HOV lane condition. These shifts are then applied to the highway person portion of the total person probabilities to obtain highway person probability in the HOV lane condition.

The computation of the shifts was performed while holding the transit probability constant. Obviously, there is some shift in the transit probability due to the implementation of an HOV lane. The Logit Based Model assumes that the shift in transit is the same as the shift in the highway or non-carpool modes. This shift is applied to the transit person portion of the total person probability and allotted to the mode representing the minimum eligible carpool.

Once all shifts have been computed and applied to the appropriate mode, the person trips are calculated by multiplying the new modal probabilities by the base person trip total. From these person trip values, new vehicle trip totals are calculated.

TIME SAVINGS MODEL

The Time Savings Model is an adaptation of the model developed in Washington, D.C., by the Metropolitan Washington Council of Governments (MWCOG) and adapted for use in Atlanta. This regression model uses travel time savings (normal highway travel time minus carpool travel time) as an independent variable and the change in average auto occupancy as the dependent variable. As with the other HOV models, the Time Savings Model is applied with a "shift" technique.

The Time Savings Model can estimate either percentage or absolute change in average auto occupancy based upon travel time savings as shown below:

$$\text{ABS. CAR OCC. CHG.} = 0.05 + 0.006 * \text{TIME SAVINGS}$$

$$\text{PCT. CAR OCC. CHG.} = 3.80 + 0.450 * \text{TIME SAVINGS}$$

The change in auto occupancy based upon travel time savings offered by the HOV lane is added to the base average auto occupancy to obtain a new average auto occupancy. The probabilities by integer auto occupancy group (1, 2, 3 and 4+) are then estimated from the new average auto occupancy estimate using a series of linear regressions which relate the average auto occupancy to the percentage of trips in each integer auto occupancy group, otherwise referred to as the Texas Average Auto Occupancy Model (described in the next section).

The shift in both the carpool and normal highway vehicle probabilities is computed by comparing the vehicle probability estimates from the Texas Auto Occupancy Model with the base vehicle probabilities. The shift in vehicle probabilities is then applied to the base vehicle probabilities, with the shift in highway vehicle probability applied to the defined normal highway modes and the shift in carpool probability applied to the defined carpool modes. The results of this application are the new integer vehicle probabilities.

The integer car vehicle probabilities are then converted to integer car highway person probabilities. In order to compute the total person probability, it is necessary to estimate the shift in transit person trip probability. The Time Savings Model assumes that the shift in transit person trip probability is the same as the shift in non-carpool mode(s) vehicle trip probability. Once the transit shift has been calculated, the total integer car and transit person trip probabilities and person trips are computed. The total integer car person trip probabilities are converted to vehicle trip probabilities for inclusion into the final statistics.

TEXAS AVERAGE AUTO OCCUPANCY MODELS

The average auto occupancy models provide a very important bridge between the regional model chain and the HOV carpool model. Given an expected average auto occupancy, the average auto occupancy models are applied to estimate the expected percentage distribution of vehicles by the four integer auto occupancy groups (i.e., 1-occupant vehicles, 2-occupant vehicles, 3-occupant vehicles and 4+-occupant vehicles). These results can then used to estimate the expected percentage distribution of highway person trips by the four integer occupancy groups.

Given the estimated percentage transit, the expected percentage distribution of total person trips by the five modal groups (i.e., transit, drive alone, 2-occupant vehicles, 3-occupant vehicles and 4+-occupant vehicles) can be easily computed. In the HOV model applications, the average auto occupancy and percentage transit data would normally be obtained from the regional model chain results. A new set of average auto occupancy models was developed for implementation in the Texas Mezzo-Level HOV carpool model.

The data base used in developing the Texas average auto occupancy model set consisted of 214 peak-period vehicle classification counts (i.e., vehicle counts stratified by the four integer occupancy groups) collected at various locations on the Houston freeway system. Forty-four of the 214 counts were collected at locations where HOV carpool facilities were in operation and included the HOV carpools in the count data collected. The observed average auto occupancies for the 214 counts ranged from 1.035 to 1.334 persons per auto. The average auto occupancy for the 214 counts was 1.155 persons per vehicle and the median auto occupancy for the 214 observations was 1.145 persons per vehicle.

The average auto occupancy model is a set of four simple linear regression models (i.e., a model for each of the four integer occupancy groups). For each model, the independent variable is the average auto occupancy, and the dependent variable is the expected percentage vehicles for the integer occupancy group. The models developed using the Texas data are:

$$P(1) = 1.79689686 - (0.80510746 * A)$$

$$P(2) = -0.64408871 + (0.65782773 * A)$$

$$P(3) = -0.10251317 + (0.09966693 * A)$$

$$P(4+) = -0.05029499 + (0.04761280 * A)$$

where:

$P(I)$ = expected percentage of vehicles in integer occupancy group I

A = average auto occupancy

The R-square values for these four models were 0.985, 0.940, 0.782 and 0.589, respectively.