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16. Abstract

The multimodal system planning technique described in this report is an improvement of the methodology used in the Dallas System Planning Study. The technique includes a spreadsheet-based process to identify the costs of congestion, construction, and operation of transportation alternatives for a corridor. There are also several steps before and after the spreadsheet that identify system constraints, the effect of parallel rail transit and toll highways, and the compatibility of system components.

The technique is useful in several types of analyses from corridor to regional system improvements. The basis of the approach is that all costs should be included (or considered) and that they are equal. The objective of the technique is to identify the lowest total cost alternative that is consistent with ongoing budgets, public concerns, and system constraints.

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MULTIMODAL SYSTEM PLANNING TECHNIQUE:
AN ANALYTICAL APPROACH TO PEAK PERIOD OPERATION

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IMPLEMENTATION STATEMENT

The system planning technique is a useful tool for analyzing several alternative transportation corridor configurations and identifying system level considerations and constraints. The major investment study process may include consideration of these elements. The technique summarized in this report will be useful in this, and similar analyses.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Transit Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation, and is not intended for construction, bidding, or permit purposes. Carol H. Walters, P.E. (registration 51154) and Dr. Timothy J. Lomax, P.E. (registration 54597) are the principal investigators for the project.

ACKNOWLEDGMENT

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SUMMARY

The current era of transportation facility planning and design must concentrate on multimodal coordination and providing a transportation system that is sensitive to fiscal constraints and environmental concerns. The System Planning Methodology developed in previous studies, and refined in this report, is a combination of techniques. One aspect is a spreadsheet program that allows the analyst to obtain information on the operating characteristics and cost implications of several alternative freeway corridor configurations. The program includes provisions for local experience with freeways and HOV lanes to be included and for the user to modify several reasonableness constraints to fit local situations.

The corridor analysis technique also includes some procedures outside the spreadsheet. These steps occur both before and after the use of the spreadsheet and can be characterized as quantifiable, but not automated, decisions. The inclusion of a particular cost or decision in the spreadsheet has been made based on the extent to which the information in the spreadsheet can be used with current knowledge about the factor. Several considerations and factors that are very important in developing a system plan are not included in the spreadsheet portion of the methodology. Additional guidance on these decisions is provided in this report. This report also provides a systematic procedure for including all of the important considerations in the corridor and system planning process.

The methodology can be summarized in the following steps which begin with corridor and system concerns, get more specific, and conclude with a system-level assessment of the results.

- Identify constraints in the corridor and the system.
- Estimate demand.
- Test alternatives for corridors.
- Examine results of individual corridors for system consistency and adjust improvements.

Demand estimation will typically occur in the regional transportation and land use planning model, and the alternative analysis uses the system planning spreadsheet. The first and last general steps are not automated but are key to the usefulness of the system planning methodology.

The methodology includes consideration of facilities such as parallel urban rail transit and toll highways, high-occupancy vehicle lanes, express freeway lanes, and general freeway lanes. The process can also incorporate operational and travel demand management improvements.

The decision-making process presented in the report is centered on the concept that all public costs of transportation should be included in an alternatives analysis process. While this methodology does not include some costs that would comprise a "full-cost" approach, it does represent an expansion and change in existing procedures. Congestion cost, construction cost, and operation and maintenance costs are all included in the process. The basic analysis procedure seeks to minimize the sum of these costs.

CHAPTER ONE

INTRODUCTION

The current era of transportation facility planning and design must concentrate on multimodal coordination and providing a transportation system that is sensitive to fiscal constraints and environmental concerns. The Dallas District of the Texas Department of Transportation (TxDOT), with the Texas Transportation Institute (TTI) as the performing agency, has been developing a system planning methodology that selects multimodal corridor alternatives which serve peak-hour person demand with the lowest total cost to the public while providing system continuity. These public costs have been identified as travel delay, construction and right-of-way, and operation costs of the facilities.

Development of this methodology has benefitted from a multi-agency approach, being guided by technical staff from TxDOT in Dallas, from Dallas Area Rapid Transit (DART), North Central Texas Council of Governments (NCTCOG), and TTI. Known as the Joint System Planning Study (1), it represents a considerable financial investment by TxDOT and a major investment in staff time by the agencies involved in its development; it has been utilized successfully in the Dallas area in developing NCTCOG's financially-constrained regional plan required by the Intermodal Surface Transportation Efficiency Act (ISTEA). This plan, titled Mobility 2010 Update, represents the results of the Joint System Planning Study with only a few modifications and has been accepted as the current regional plan.

The Dallas Freeway/HOV System Planning Study was intended to assist in the development of an area wide freeway/HOV system that recognizes implementation constraints (right-of-way and construction costs), and provides reasonable peak-hour operating conditions on all transportation facilities, while incorporating the long-range plans developed by TxDOT, DART, and NCTCOG.

The recommended system in the Dallas System Planning Study was developed using a methodology that focused on peak-hour person travel demand in the year 2015 for the urban freeways in the Dallas area. The goal of the Dallas System Planning Study has been to find the lowest-public-cost alternative in each corridor, for a given volume of peak-hour person trips. This framework views travel delay, construction, and operation of roadways as costs to the public. It also recognizes that some motorists will change their mode of travel when given the opportunity to avoid congestion, resulting in more transit and carpool use.

The System Planning Methodology developed in previous studies, and refined in this effort, is a combination of techniques. One aspect is a spreadsheet program that allows the analyst to obtain information on the operating characteristics and cost implications of several alternative freeway corridor configurations. The program includes provisions for local experience with freeways and HOV lanes to be included and for the user to modify several "reasonableness" constraints to fit local situations.

The corridor analysis technique also includes some procedures outside the spreadsheet. These steps occur both before and after the use of the spreadsheet and can be characterized as quantifiable, but not automated, decisions. The inclusion of a particular cost or decision in the spreadsheet has been made based on the extent to which the information in the spreadsheet can be used with current knowledge about the factor. Several considerations and factors that are very important in developing a system plan are not included in the spreadsheet portion of the methodology. Additional guidance on these decisions is provided in this report. This report also provides a systematic procedure for including all of the important considerations in the corridor and system planning process.

TTI conducted another research project involving this methodology through the Southwest University Transportation Center (SWUTC), located at Texas A&M University. The project, titled "Incorporating Intermodalism into Freeway System Planning," refined the methodology by incorporating the cost of fuel consumption, vehicle emissions, and commercial vehicles (2). Those improvements are incorporated into this report.

In addition, the study team has included researchers from the University of Texas at El Paso to test the transferability of the methods and give feedback on the technical reasonableness of the methods as well as their ease of application. These recommendations have been incorporated into the methodology.

CHAPTER TWO

SYSTEM PLANNING METHODOLOGY OVERVIEW

The methodology developed in this and previous studies requires several steps—some of which are included in the spreadsheet, and other steps which must be performed for a complete analysis of all relevant factors. This chapter is an overview of the steps in the methodology. This provides a context to understand the data and procedures described in the report. Subsequent chapters address the improved procedures and the review of the transferability of the corridor and system analysis methodology. Figure 1 summarizes the steps.

The methodology can be summarized in the following steps which begin with corridor and system concerns, get more specific, and conclude with a system-level assessment of the results.

- Identify constraints in the corridor and the system.
- Estimate demand.
- Test alternatives for corridors.
- Examine results of individual corridors for system consistency and adjust improvements.

Demand estimation will typically occur in the regional transportation and land use planning model, and the alternative analysis uses the system planning spreadsheet. The first and last general steps are not automated but are key to the usefulness of the system planning methodology.

Step 1. Identify Long-Range Plans and Available Corridors

The existing freeway corridors, their potential for expansion, and any other corridors that might be available should be identified in the initial phase of analysis. This establishes where data are required and encourages the analyst or study team to examine other areas such as railroad rights-of-way, rivers, drainage areas or other land that may be used to support additional transportation facilities of any mode.

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│                       Step 1                            │
│              Identify Long-Range Plans and              │
│                  Available Corridors                    │
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│                       Step 2                            │
│                Identify System Constraints              │
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│                       Step 3                            │
│    Identify Peak-Hour Person Travel Volume on Parallel Rail │
│                   and Toll Facilities                   │
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│                       Step 4                            │
│        Identify Peak-Hour and Peak Period Demand        │
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│                       Step 5                            │
│              Divide the Corridor into Sections          │
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│                       Step 6                            │
│      Identify Alternate Travel Mode Characteristics     │
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┌─────────────────────────────────────────────────────────┐
│                       Step 7                            │
│              Critical Lane Volume Spreadsheet           │
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│                       Step 8                            │
│              Estimate Unit Cost Components              │
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│                       Step 9                            │
│                 Describe the Alternatives               │
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│                       Step 10                           │
│             Identify Lowest Cost Alternative            │
│                     for the Corridor                    │
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┌─────────────────────────────────────────────────────────┐
│                       Step 11                           │
│           Select Alternative(s) for Each Corridor       │
│                    on a System Map                      │
└─────────────────────────────────────────────────────────┘
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Spreadsheet-Based Procedures (bracket spanning Steps 4 through 10)

Figure 1. Multimodal System Planning Technique—Steps in the Process

The basic assumption of the system analysis process is that the existing long-range plan can be improved through examination of specific operating conditions during the morning and evening peak periods. This methodology uses the existing plan and supporting data. The spreadsheet portion of the methodology uses the assumption that congestion will encourage some trips to shift travel mode or travel start time. The information in the current plan that relates congestion level and travel mode provides an excellent starting point and important local calibration point.

Step 2. Identify System Constraints

The long-range plan and available corridor list are particularly important in situations where existing bottlenecks must be bypassed. If there are no construction or operation alternatives (e.g., widened or multi-level freeways, new location freeway, improved operation of the streets and freeways), demand management options will be the only alternative for a particular corridor and may limit the number of system-level improvement options. These should be identified early in the process.

The constraints may be in the form of narrow right-of-way, environmentally or socially sensitive right-of-way, visual or noise pollution problems or other considerations. These may be either bottlenecks or prohibitions of construction, or they may be situations where abatements will be required for certain construction or operational treatments.

The goal of this task is to identify existing and possible future conditions that will affect the improvement options. The decision may be to make improvements elsewhere, invest in different techniques or construct relatively expensive but important improvements in a corridor. The result of this knowledge will be that funds will not be obligated in areas where one congestion point will be alleviated only to have traffic caught in the next congested area downstream where no improvement options are available.

Step 3. Identify Peak-Hour Person Travel Volume on Parallel Rail and Toll Facilities

The system planning spreadsheet requires an estimate of the amount of travel that must be accommodated within the freeway right-of-way as an initial value. Travel in the corridor on passenger rail (urban heavy or light rail and commuter rail) and toll facilities must be "removed" before the spreadsheet program can be used. The relatively simple analytical process included in the spreadsheet uses congestion level as the factor that encourages mode shift. The demand for

both passenger rail and toll highway facilities is a function of several economic and demographic characteristics in addition to congestion level.

This method of addressing mode shift is not completely satisfying but does appear to be a reflection of the state of the knowledge base. Even an improved knowledge level brought on by rail operation and increased toll highways in Texas cities may not significantly change the recommended procedures; the number of factors required to predict mode and route shift may be too numerous and complex to handle in the spreadsheet.

Step 4. Identify Peak-Hour and Peak Period Demand

The daily vehicle traffic volume, peak-hour travel percentage, the percentage of traffic in the direction being analyzed (usually the peak direction, but not always), truck volume and existing carpool and bus volume and occupancy are required to identify the amount of travel.

The planning methodology assumes that this person volume must be accommodated within the freeway right-of-way. The volume is either assigned to the freeway or other facility in the peak hour, or shifted to another time period when the peak-hour is too congested. This is the first step that involves the spreadsheet.

Step 5. Divide the Corridor into Sections

The corridor travel volume and corridor design characteristics are used to group corridor road segments into sections. The sections should be relatively homogenous for daily volume, directional and peaking characteristics, and number of lanes.

Sections should not typically be longer than seven or eight kilometers (four or five miles). When congestion cost is assigned using the critical lane volume of each section, it is assumed to apply to the entire section. If this section is very long, it could overestimate the effect of congestion.

Step 6. Identify Alternate Travel Mode Characteristics

The spreadsheet includes a formula that relates congestion level to HOV ridership. This linear relationship ensures that the HOV ridership changes as freeway lanes are added or taken away. The analyst can change both the starting point and the incremental increase to reflect local

conditions and knowledge about the HOV and rideshare incentive system. The user can also identify maximum values of mode shift and minimum ridesharing levels to set upper and lower boundaries of reasonableness. The reports provide guidance for the selection of each of these values, and, if local information is available, the analyst is encouraged to use it.

The spreadsheet also requires information on the percentage of long distance trips if express lanes are included as an alternative. This information is usually available in the regional planning model. The value is used to ensure that the express lanes are not inappropriately loaded.

Step 7. Critical Lane Volume Spreadsheet

The volume, design, and modal comparison factors generate a critical lane volume for whatever freeway, HOV lane, and express facilities are included in each alternative. The "reasonableness" checks ensure that HOV lane and express lane traffic volumes do not exceed capacity and that mode shifts are within reason. The analyst must be aware of the system and corridor constraints on facility width when composing alternatives. The output statistics are used in the Cost Estimation spreadsheet.

The analyst may wish to reevaluate the corridor configurations when the critical lane volumes are developed. Bottleneck locations should be identified and alternatives adjusted accordingly. If the constraint can be removed, the less-congested alternative may be added to the range of alternatives.

Another concept to investigate is the reduction of lanes upstream of the constraint. If the bottleneck will continue to exist, the construction of an improved facility upstream may represent an inefficient expenditure of transportation funds. The critical volume and cost spreadsheets allow an investigation of the magnitude of these tradeoffs.

Step 8. Estimate Unit Cost Components

The cost per lane-kilometer foot of at-grade or depressed construction and the cost of right-of-way in each roadway section are used in the cost spreadsheet, with descriptions of the existing roadway and each alternative. The unit cost estimates can also include the cost of addressing noise and visual impact. The unit costs can also be used to represent associated costs of a facility. For instance, park-and-ride lots, traffic management, intelligent transportation system, access and egress ramps, transit centers, rideshare programs, or other support facilities or programs can be

represented in the cost spreadsheet as separate items, or included as allocations to the per kilometer costs.

Operating costs are quantified to assess the impact of the higher cost of reversible or special use facilities. This section may also include enforcement activities for HOV lanes. These costs will not be used by the cost spreadsheet unless the type of facility is included in the alternative. The operation of traffic management equipment has been included as a cost on many previous analyses and assigned to the general purpose lanes.

The researchers suggest that congestion cost should be valued at a rate representative of the individual's value of time. This model uses behavior as a basis for assigning value, rather than societal values that might be based on the wage rate and trip purpose. The analyst enters these values.

The improved spreadsheet described in this report also includes estimates for the cost of fuel consumed, the cost of mitigating air pollution, and operating costs related to commercial vehicle delay. Unit values for each of these aspects are also required as well as rates for fuel consumption and emissions.

Step 9. Describe the Alternatives

The products of the critical lane volume spreadsheet, the number of lanes in each section of the freeway, and the length of each section are the main inputs required for the cost estimation spreadsheet. These elements describe the congestion and travel volume characteristics of each freeway, HOV, and express lane segment.

Step 10. Identify Lowest Cost Alternative for the Corridor

The critical lane volume is used to identify the congestion level, and the total number of persons and trucks in each congested hour is used to estimate delay costs. Speeds are also used to estimate fuel consumption and emissions. The construction, right-of-way, and operation costs for each alternative are calculated from the existing and future configuration descriptions.

The analyst may reevaluate the alternatives at this point in the analysis process, as with the critical lane volume results. Different cost assumptions can be examined with the cost spreadsheet alone. The vertical placement of elements of the design (at-grade, elevated, depressed) can also

be evaluated without reworking the critical lane volume spreadsheet, but many options will require new volumes, as well. The significant benefit of the System Planning methodology is that this reexamination and testing can be accomplished in minutes.

Step 11. Select Alternative(s) for Each Corridor on a System Map

There are several approaches for developing a system plan from the information provided by the spreadsheets. The most obvious is to locate all of the lowest cost alternatives on the map with any system constraints and see if the corridors match at the connections. This is the alternative that is closest in spirit to the optimization of each corridor. All of the connections may not match; however, alternatives can be made using the list of next lowest cost corridor alternatives.

The transportation agencies must also be able to afford the selected system plan, and this may provide an additional constraint. Just as the analyst can prepare a lowest total cost value for the system, a construction and operation budget can also be kept. As the allowable totals are exceeded, different corridor alternatives can be selected.

Another consideration that may alter the chosen set of alternatives away from the lowest total cost is the carpool designation for HOV lanes. If a 3-or-more person HOV lane connects to a 2-or-more person HOV lane, additional roadway connections may be required, or different alternatives can be selected.

Of primary importance is the lane balance and consistency at the connection points. Most of these locations will be near the center of the system. There are several advantages to this central focus. The system constraints were identified early in the process before corridor analyses were pursued, so many problems should already be known. One endpoint of many peak period trips is in the central business district, so ramps can be appropriately used to add or eliminate lanes from the freeways. The high parking cost, relative difficulty in obtaining parking, and dense concentration of jobs mean that downtowns are also the logical focus for HOV lanes and transit facilities. Transit and carpool terminal points ideally connect to the downtown street system and do not have to be accommodated in the freeway network.

General Summary

The multimodal system planning process described in this report includes a spreadsheet-based analytical procedure and several considerations before and after the spreadsheet operation. The technique generally follows an inside-outside-inside geographic arrangement. System constraints (usually most frequent near downtowns) are initially identified. Individual corridors are analyzed and the alternatives optimized, possibly for several factors. The corridors are brought together on a system map and the match points harmonized.

The system planning methodology provides information to quantify decisions regarding the most efficient expenditure of transportation funds for a multimodal system. It includes operational experience in the framework and provides a balance in difficult concepts such as congestion level and mode shift to ridesharing alternatives. It can optimize transportation systems based on the lowest cost to the public and also optimize within agency construction and operation budgets. The spreadsheet-based analytical program is open to user assumptions, and all default values are supported by documentation in this report.

In practice, the outcomes of the corridor analyses vary depending on travel demand. Low demand corridors (less than 150,000 daily trips) where little or no construction is warranted are usually optimized with freeway general purpose lanes. Moderate demand corridors (up to 200,000 daily trips) may require some limited access express lanes, but the lowest public cost is usually achieved with only general purpose improvements. High demand corridors (in excess of 200,000 daily trips) are usually most efficient with a combination of HOV lane and freeway improvements.

CHAPTER THREE

DESCRIPTION OF METHODOLOGY ELEMENTS

The system planning methodology is technical in nature and does not address issues such as the programming responsibilities of the agencies involved, the staging or priority of projects within each corridor, the source of funding for or the community concerns about recommended capacity improvements. The system of corridor improvements can be tailored to transportation construction and operation budgets, and the technique quantifies the impact of multimodal projects on roadway operations.

There are two key aspects that distinguish this system planning effort from typical planning efforts. First, the sizing of the facilities is based on peak-hour operation of the freeways and freeway interchanges. Sections of facilities should have no more capacity than can be loaded and unloaded during the peak hour. Peak-hour constraints on the existing and future freeway systems can be analyzed to determine where bottlenecks can be removed, where additional parallel capacity can be built, and where constraints are inevitable.

Second, the different transportation modes (commuter rail, light-rail, buses, carpools, and single-occupant vehicles) are analyzed as a system. During the analysis, the peak-hour person demand for each corridor and for the system is held constant, while various alternatives are evaluated on how efficiently and cost effectively the demand is served. An important difference between the system planning methodology and traditional freeway planning efforts is the quantification of congestion on the mainlanes for any alternative. The cost of building additional capacity is weighed against the cost of congestion to the motorist. The alternative with the lowest total cost is selected as the "best" alternative, assuming the alternative is compatible with the connecting facilities.

This chapter discusses the five major efforts of the system planning methodology.

- Data required for the system planning methodology;
- Demand and travel volume estimates;
- Cost analysis;
- Alternative selection; and
- Operational analysis.

Data Required for the System Planning Methodology

The following data elements are the primary input items required for the system planning methodology:

- Existing 24-hour volumes for freeways, HOV lanes, bus systems, and transit systems at critical locations;

- Design year 24-hour volumes for freeways, HOV lanes, bus systems, and transit systems;

- Percent of daily traffic in the peak hour, peak-hour directional splits, and peak-hour truck percentages at several points throughout the system;

- Roadway plan sheets for freeway corridors, showing existing lanes, right-of-way limits, roadway structures, and buildings and environmentally or socially sensitive areas adjacent to the corridor; and

- Updated lists of planned projects in the region.

Existing Freeway Traffic Volumes

For the Dallas System Planning Study, TTI conducted extensive weekday freeway and ramp counts during 1989 and 1990. These data were collected by both manual and machine methods. Mechanical counters collected 24-hour volumes on the freeway mainlanes when loops were present in the pavement and on each freeway ramp. Manual peak period mainlane counts were also conducted at various locations throughout the freeway system.

Researchers computed the mainlane volumes for each freeway subsection by adding and subtracting ramp volumes along each corridor from a manual or machine mainlane count. The mainlane volumes were spot checked for accuracy through additional manual counts and/or machine counts. The accuracy check criteria was a 10 percent difference between computed volumes and volume counts on the freeway mainlanes. If a calculated volume differed from a count by more than 10 percent, the ramp counts throughout the corridor were adjusted by 10 percent or less to bring the calculated volumes back in balance with the count.

The result of this effort was 24-hour and morning and evening peak-hour volumes for each ramp and freeway section between ramps on urban freeways in the Dallas urban area. From these counts, researchers calculated peak-hour directional splits and peak-hour truck percentages. In addition, they used these data to estimate the percentage of daily traffic occurring in the peak hour (K-factor).

Design Year 24-Hour Volumes

The design year 24-hour volumes are usually the result of several computer model assignments performed for the long-range transportation plan. The forecasted volumes should include carpools, buses, commuter rail, light-rail, and general-purpose freeway vehicles.

The design year assignment is used to develop volumes for all freeway sections and ramps. In some cases where existing ramps are not modeled in the assignment, refinements must be made to determine the freeway ramp and mainlane volumes.

Selected link data, which give the origins and destinations of trips on a specific link of roadway, are also very useful. The selected link locations are used to determine the travel patterns for HOV lanes and express facility trips. The magnitude and destination of these trips are required to effectively plan mainlane and interchange facilities.

K-Factors and Directional Splits

The design hour volume is used to determine the size of a facility, which in turn affects the amount of right-of-way needed, the quantity of materials needed to build the facility, the design of the connections to other sections of freeway or arterial streets, and the effort needed to operate and maintain the facility. Accurate estimations of design year peak-hour volumes are, therefore, critical in the system planning methodology. Peak-hour assignments may also be used to estimate peak-hour demand, but these may not be available in most areas.

The 24-hour volume is usually multiplied by the K-factor (ratio of the 30th highest hour to average daily traffic) and the directional split (the proportion of traffic occurring in the peak direction of travel during the peak-hour) to estimate the amount of traffic that will use a facility during the design hour. Examination of research on K-factors and directional splits found that little information existed on use of these planning parameters for forecasting purposes in urbanized areas. The results of a research study on this issue are in a TTI research report titled

"Development of Planning Values for Urban Freeways in Large Texas Cities" (3). The database used in that research effort to evaluate these planning parameters was the permanent automatic traffic recorders in five major cities in Texas. The permanent automatic traffic recorders, maintained by TxDOT, are installed at limited locations on the freeway system throughout the state.

The problem with the database used in the research was that many of these count locations are located in congested sections of freeway, resulting in constrained volumes and relatively low values of K-factors and directional split (as compared to unconstrained sections). The constrained points were, therefore, eliminated from the database. There were not enough remaining count locations to do a statistically significant analysis. The research report does, however, include reference tables that stratify ranges of K-factors and directional splits based on values of the following variables: 1) daily volume per lane; 2) distance from major employment centers; 3) employment density in the corridor; 4) volume-to-capacity ratio; 5) length of peak-period congestion; and 6) type of facility (radial or circumferential).

Two findings from the research are significant, however, and were used in developing the system planning methodology. The traditional K-factor is inappropriate for use in estimating design hour volumes because the 24-hour volumes are forecast for a typical weekday, and K-factors are based on average daily traffic which includes holidays and weekends. The directional split during the 30th highest hour may also not be appropriate for a typical weekday because it also includes holidays and weekends. The freeway K-factors and directional distribution that should be used in the system planning methodology are values that represent demand, rather than constrained flow, in the weekday peak hour. These are best obtained from a study of local data such as that described in the previous section, combined with the more traditional sources of K-factor and directional distribution.

Roadway Plans and Planned Projects

Roadway plans, an updated list of planned projects for each freeway corridor, and the status of each project should be obtained from state and local agencies. The roadway plans are used to verify the existing configuration of the freeways and to identify any existing operational problems due to freeway design. Roadway plans also identify sections of freeway on structure and the existing right-of-way lines, which have an effect on the cost of improvements. The project list should include improvements that are committed and those that are ideas or possible

projects. The objective is to have a complete assessment of the issues that may affect improvement alternatives for the study area.

Demand and Travel Volume Estimation

The methodology developed for the Dallas System Planning Study used the total demand volume from the long-range planning model. Specific facility volumes were determined for each alternative by applying a modal shift process (persons change their modes of travel due to congestion) as appropriate. This section describes the process of HOV demand estimation that the spreadsheet includes and methods to address potential mode shift to rail transit and toll road facilities.

HOV Ridership Estimation

The methodology developed for the Dallas System Planning Study included a means to relate carpool and bus ridership with freeway congestion levels. The original ridership relationship used data from Houston, Texas, high-occupancy vehicle (HOV) lane projects from the years 1989 and 1990. That procedure used the average daily traffic per lane as an indicator of congestion. The percentage of traffic in the peak hour (K-factor) and percentage of traffic in the peak direction (D) on these freeways were similar. The average daily volume varied significantly across the operating projects, and the best relationship was obtained using ADT per lane to predict the percentage of daily traffic volume in the HOV lane in the peak hour. This combined the observed relationship between congestion level and HOV ridership with a factor that could be used with a range of freeway volume (HOV ridership as a percentage of daily freeway volume).

The research project sponsored by the SWUTC sought to advance the Dallas System Planning Study HOV ridership relationship. This was accomplished by analyzing data from HOV systems in operation across the United States (Table 1). Appendix A includes values for each variable used in the analysis. This section summarizes the results of that study and describes the relationship that should be used in the system planning methodology.

Table 1. Operating HOV Facilities Used as Data Sources

Type of Facility	City and County	Freeway Corridor
Barrier-Separated	Los Angeles Co., CA	I-10
	San Diego Co., CA	I-15
	Minneapolis, MN	I-394
	Pittsburgh, PA	I-279
	Houston, TX	I-10W
		I-45S
		I-45N
		US 59
		US 290N
	Northern Virginia[1]	I-66
		I-395
	Norfolk, VA	I-64
Concurrent-Flow: Buffer-Separated and Non-Separated	Phoenix, AZ	I-10
		SR 202
	Alameda Co., CA	I-880
	Contra Costa Co., CA	I-580
	Los Angeles Co., CA	SR 91
	Marin Co., CA	US 101
	Orange Co., CA	I-5
		SR 55
		SR 57
		I-405
	Riverside Co., CA	SR 91
	Sacramento Co., CA	SR 99
	San Mateo Co., CA	US 101
	Santa Clara Co., CA	SR 85
		US 101
		SR 237
		I-280
	Minneapolis, MN	I-394
	Nashville, TN	I-65
	Northern Virginia[1]	I-95
	Norfolk, VA	SR 44
	Seattle, WA	I-5 N of CBD (SB)
		I-5 N of CBD (NB)
		I-5 S of CBD (SB)
		I-90
		I-405 (SB)
		I-405 (NB)
Contraflow	Dallas, TX	I-30E

[1] Northern Virginia facilities are in the Washington, D.C. area.

Freeway Characteristics Considered. Researchers obtained several data items thought to have some relationship to HOV lane usage in freeway corridors for operating HOV projects in the U.S. A few projects that represent significantly different circumstances were removed from the analysis as it proceeded; that process is described later in this section. The data vary from those collected only one time during an evaluation process, to those collected several times per year for an ongoing analysis. Other variables, such as parking cost, violation fine, or state location were added by the project team upon examination of the initial data. The variables used and the method of identifying the data are described below.

- Average Daily Traffic per Lane (ADT/Lane)—This can be used as an indicator of congestion level. It should be noted that to estimate demand in a design year, future volumes would be used.

- Directional Hourly Volume per Lane (DHVLN)—An estimate of the freeway volume per lane in the peak direction was derived from the daily volume. This may be a better estimate of peak congestion level if it is estimated at the point where traffic flow exits from a congested section and begins to increase speed. Frequently, however, a volume count is made within the congested section, and low volume per lane values are obtained. These values are not indicative of the congestion in the corridor. The DHV value used in this analysis was derived from Equation 1.

$$\frac{DHV}{per\ lane} = \frac{ADT}{per\ lane} \times \frac{\overset{K}{(\%\ traffic}}{in\ peak\ hour)} \times \frac{\overset{D}{(\%\ traffic}}{in\ peak\ direction)} \qquad \text{Equation 1}$$

- California—This variable was used to identify whether the freeway was located in California. This factor was used because the California corridors tend to have higher person movement on the HOV lanes for similar congestion levels. This distinction allowed the effects of the higher California ridership to be tested.

- Class—This variable was established to test for variations in ridership which could be attributable to the differences in HOV facility types. The HOV types were classified as barrier-separated, concurrent flow buffer-separated and non-separated, and contraflow.

- Fine—This factor accounts for the effect of the first time fine amount charged for violating occupancy requirements on the HOV lane.

- The number of HOV lanes.

- Occupancy—This variable accounts for the HOV occupancy requirements.

- Operating hours—This factor accounted for the length of time that the HOV facility operates during a day.

- Parking costs—This variable was used to test the effect that parking costs around the destination end of the HOV corridor would have on HOV ridership.
  Note that no carpool discount rates were used. This factor tested how much the higher single-occupant parking rates will encourage additional formation of carpools.

- Radial or circumferential—This variable was employed to test the impact on ridership associated with whether the freeway can be considered circumferential or radial relative to the central business district (CBD).

- Years—The number of years that an HOV facility has been opened appears to affect HOV ridership. It should be noted that the design year minus the completed HOV construction year would have to be used when trying to predict HOV ridership for new facilities.

HOV Facility Data Analysis. The initial step in the data analysis was to identify projects or values which might represent "outlying" data. During this process, the need for the "California" and parking cost variables were identified. The parking cost variable could not be determined with sufficient detail for enough projects to make it a useful part of the analysis, so it was not used.

Researchers removed the I-395 HOV project in northern Virginia (Shirley Highway) from the data set due to the significant influence of the high parking cost and low parking availability in Washington, D.C. on HOV ridership.

Researchers also removed the I-580 project in Contra Costa County, California because the HOV ridership was much lower than the other projects.

The data from all remaining projects were tested to identify the model with the best combination of good predictability of HOV ridership with the fewest number of factors.

Simplicity in equation type and compatibility with a spreadsheet format were the two main concerns in developing an HOV ridership estimation procedure. While there may have been more confidence in equations with high coefficients of determination (R^2), if the factors were difficult to estimate or exhibited relationships that were not logical, an equation with a lower R^2 and higher "usefulness" was selected. The goal of this task was to achieve an equation or procedure that would be appropriate for a wide range of situations.

The "years" variable exhibited a strong relationship with HOV ridership. This may be due to the feasibility of HOV projects, in addition to the growth in ridership over several years. Very good candidates for HOV projects were identified in the 1980s as the concept was being tested. As HOV lanes have become more accepted, projects with lower ridership potential have been constructed. This factor was used in several analyses, but the study team did not believe it to be a reliable predictor. Operating hours would have the same difficulty; they describe some of the variability in HOV ridership, but are not particularly useful in a predictive equation.

Conclusions Regarding Potential National HOV Ridership Estimation Equation. The selection of an HOV ridership model was performed only after examining the possible limiting constraints. The data used to form any model will greatly influence the ability to predict HOV ridership. Researchers obtained most of the national data from various operating or planning agencies. These groups use different concepts in their data collection process. For instance, it is best to use the constrained section of the freeway for the count locations. The relationship between HOV ridership and congestion is governed by these sections, but it is often difficult to get data for these sections of freeway.

The models may also be influenced by the different views that the public and governing agencies take towards HOV projects across the U.S. For example, some areas may not have adequate enforcement or marketing to promote consistent HOV use. Parking cost and availability are also key to determining mode of travel, particularly in work trips. Transit availability (number of routes, bus trips, park-and-ride lots, etc.) and ridesharing efforts are also key variables not included in the data set.

The variation in data collection techniques and project and urban area characteristics led the study team to conclude that a regression equation that focused on Texas HOV data would be better suited to predicting ridership for Texas projects. As evaluation data are collected for more HOV projects and as better models are developed to predict HOV ridership, there may be another opportunity to develop national HOV ridership estimation tools for such broad planning level

applications. Additional data will also help answer the question of how much of the variability is due to data collection procedures and how much is due to factors that are not included in regular evaluation programs. There are not enough HOV projects with extensive evaluations to answer these questions.

Texas HOV Ridership Prediction. The data from the HOV projects in Dallas and Houston were tested independently to determine alternative relationships between HOV ridership and freeway characteristics. This involved data from the years 1992 to 1994 for IH 30 East in Dallas and from the years 1988 to 1994 for Houston. These projects include a range of congestion levels from very high to relatively low.

Researchers tested several alternative ridership prediction equations with the Texas HOV data. The relative similarity of many of the factors led the research team to decide on an equation with traffic congestion as the only predictor variable. The directional hourly volume counts for some of these freeways were conducted in congested sections, and the apparent peak-hour traffic volumes are not consistent with a high congestion level. The daily volumes were, therefore, multiplied by actual D values and by somewhat higher than actual K values that are more consistent with peak-hour *demand* rather than the constrained peak-hour volumes. This will be necessary in many urban areas (3).

Researchers developed two HOV ridership prediction models from the Texas data set using daily and hourly traffic volume per lane. Equation 2 and Figure 2 present the information relating daily traffic levels to peak-hour HOV ridership. Equation 3 and Figure 3 illustrate the relationship between hourly volume and HOV ridership.

$$\text{Ridership as a } \% \text{ of ADT} = -5.33 + 0.51 \times \left[\frac{ADT\ per\ Lane}{(1000)}\right] \quad \begin{matrix} R^2 = 0.58 \\ Standard\ Error = 2.0 \end{matrix} \qquad \text{Equation 2}$$

$$\text{Ridership as a } \% \text{ of ADT} = -14.0 + 11.0 \times \left[\begin{matrix} Directional \\ Hourly\ Volume \\ per\ Lane \\ (1000) \end{matrix}\right] \quad \begin{matrix} R^2 = 0.71 \\ Standard\ Error = 1.6 \end{matrix} \qquad \text{Equation 3}$$
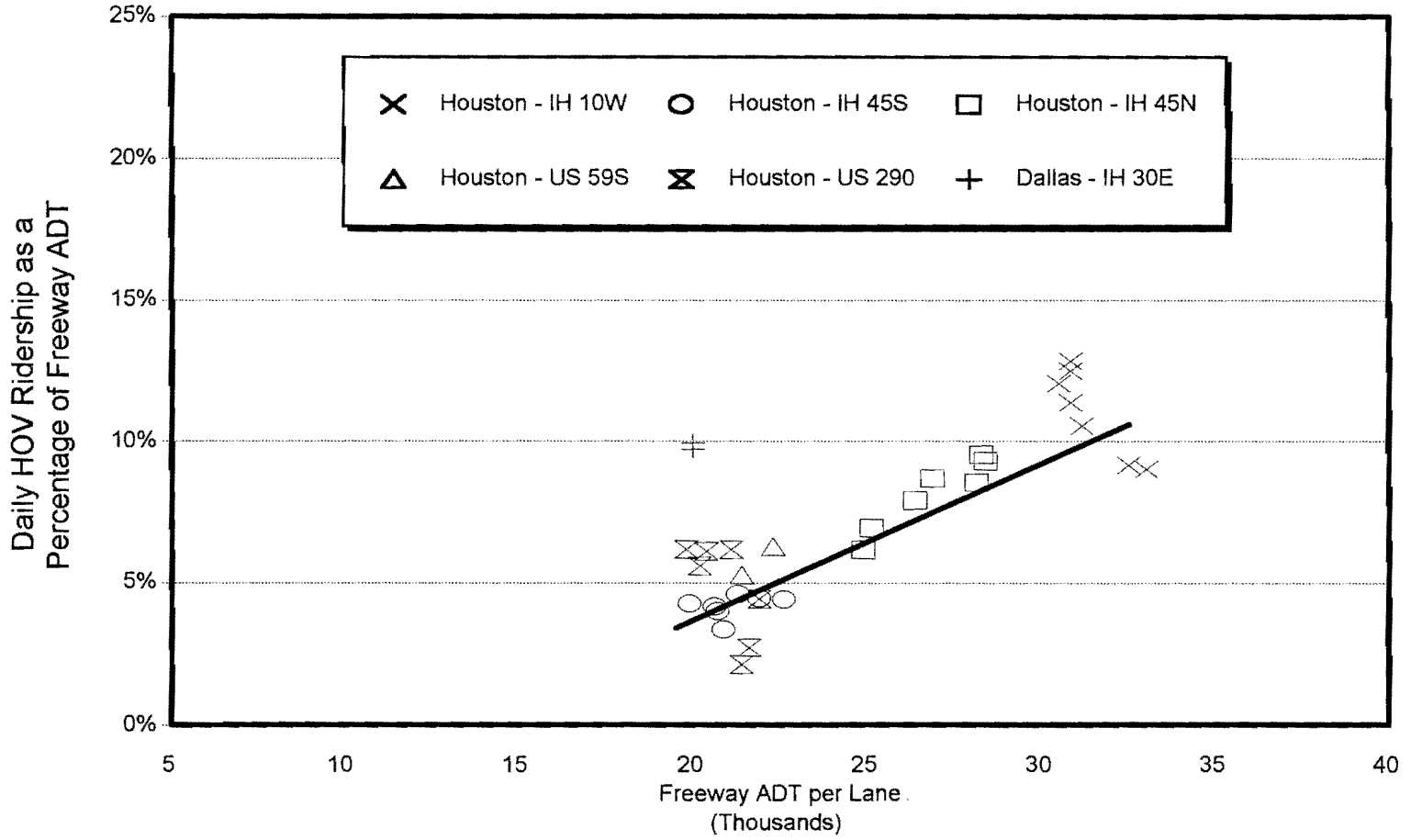
Figure 2. Texas HOV Lane Ridership Related to Daily Freeway Volumes
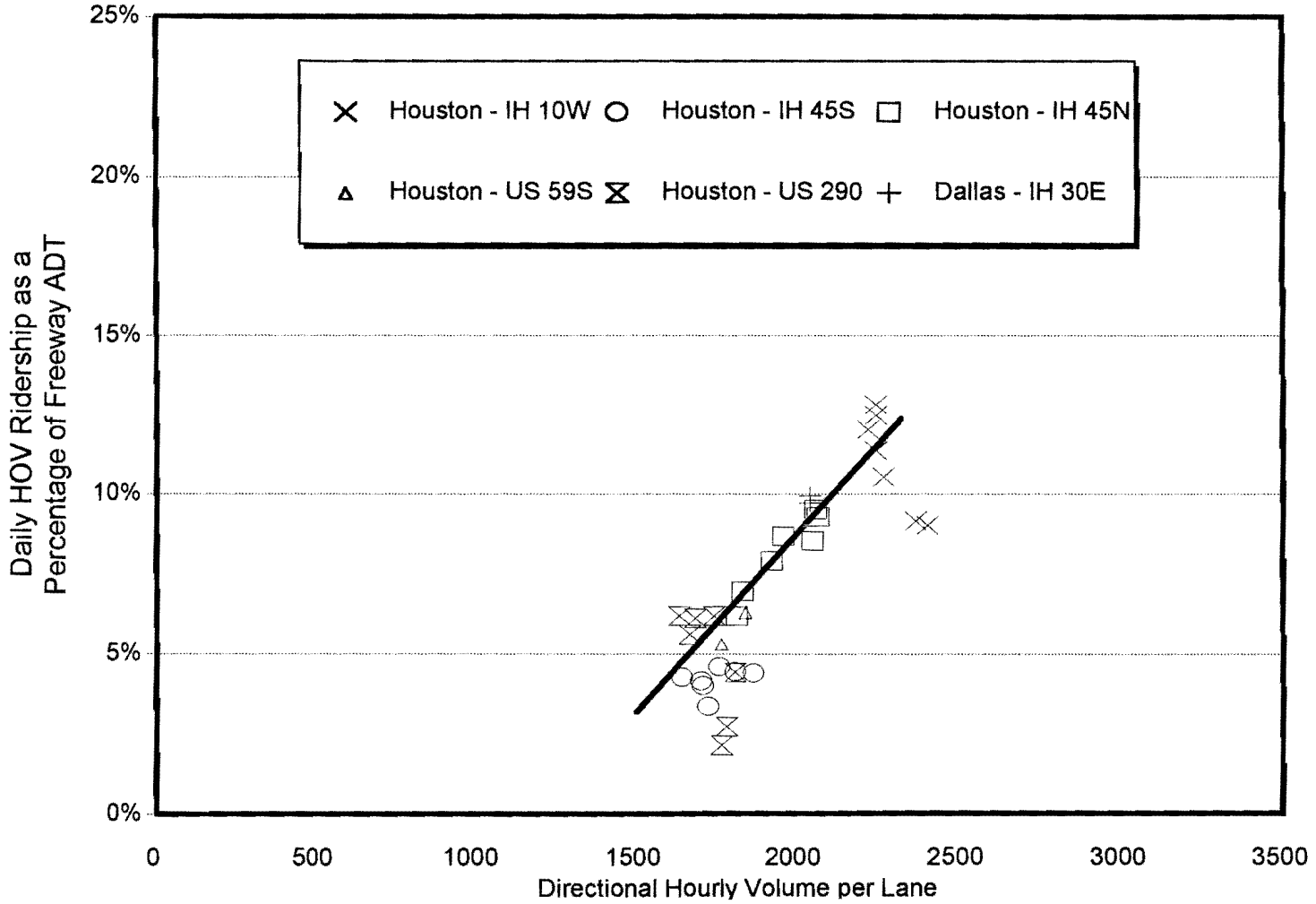
Figure 3. Texas HOV Lane Ridership Related to Hourly Congestion Levels

The adjustments for peak hour and directional distribution of traffic significantly improve the regression statistics beyond the daily traffic volume per lane factor. The R^2 of 0.71 for the directional hourly volume per lane factor (Equation 3) is a good relationship for the purpose intended. At a 95% confidence level, and with the 32 HOV lane ridership observations, the standard error of 1.6 yields a confidence interval of plus or minus 0.55 percent. This interval is approximately 5 to 15 percent of the ridership percentage values of most of the observations, which would seem to be acceptable for most applications of this model.

Conclusions of HOV Estimation. It is advisable to pursue the collection of national data using more consistent terms and procedures for all the parameters used in the SWUTC study. The relationships between HOV ridership and the various parameters can be improved if the data issues are addressed. If this consistency cannot be obtained, the best models will be developed on a state or local area basis.

The information from Texas HOV projects provides good relationships for predicting HOV ridership. It might also be useful for other areas with parking, land use, and other characteristics similar to Houston and Dallas. For Texas applications and TxDOT system planning studies, Equation 3 and Figure 3 using the variable of directional hourly volume per lane should be employed because it provides a simple equation, adjusts the daily volume for peak hour traffic characteristics, and maintains an acceptable coefficient of determination ($R^2 = 0.71$) and standard error (1.6).

Design Hour Volume Spreadsheet Summary

The Design Hour Volume Spreadsheet is designed to allow the user to estimate input factors to arrive at the number of vehicles, persons, and occupancy rate for sections of a corridor. The spreadsheet will perform the necessary calculations to estimate output values with the input factors and equations. It is very important for the user to determine the reasonableness and sensitivity of the model to changes in input values. This can be accomplished by changing input values (e.g., increasing and decreasing volume by 10 percent) or testing several alternative cross sections. If HOV lane projects are tested, the user should examine the percentage of new carpools and transit riders for reasonableness; values that are too high should be adjusted before proceeding to the Cost Estimation spreadsheet.

The "Ouputs" section contains the estimates provided by the DHV spreadsheet. The critical lane volume outputs calculated include

- General Purpose—The number of vehicles in a peak direction general purpose lane in the peak hour of traffic flow;

- Express—The number of vehicles in an express lane during the peak hour;

- HOV—The number of vehicles in an HOV lane during the peak hour of the day;

- General Purpose Auto—The number of vehicles in the critical general purpose lane that are non-truck automobiles; and

- General Purpose Truck—The number of trucks in the critical general purpose lane.

The general outputs section contains additional descriptive output information including

- Vehicles—Total number of vehicles in a freeway section;

- Persons—Total number of persons in a freeway section;

- Occupancy—The value obtained by dividing the total number of persons by the total number of vehicles in a freeway section;

- Vehicle Distance of Travel (VDT)—Distance traveled by vehicles in the section (units specified by user); and

- Person Distance of Travel (PDT)—Distance traveled by persons in the section (units specified by user).

All of these outputs are used in comparing alternatives for a freeway corridor.

The DHV Spreadsheet was modified from its original form used in the Dallas Freeway/HOV System Planning Study report. Modifications to the organization were performed to provide a better understanding of the use of the spreadsheet and its output values. Other revisions that were included in the "Outputs" section of the spreadsheet are

- Estimation of HOV ridership based on the new Texas relationship between directional hourly volume per lane and HOV ridership;

- Adjustment for maximum allowable new HOV users;

- Identification of truck volume in the critical general purpose lane volume; and

- Calculation of vehicle and person travel distance.

Other modifications can be made to the DHV Spreadsheet to meet particular needs. Use caution, however, when altering the spreadsheet from its current form so to preserve existing cell references.

Impact of Rail Transit

In the initial Dallas System Planning Methodology, the demands for parallel light rail transit were held constant as no means were available to assess how they would be influenced by any of the freeway alternatives. The impact on transit demand in a corridor may vary significantly depending on the alignment, operating characteristics, and travel rate of rail transit in a corridor. There is no simplified procedure for incorporating this in the system wide planning spreadsheet. The NCTCOG cited examples of two corridors in the Dallas area (US 75 and IH 35E South) that had substantially different impacts on freeway demand from the addition of a light rail facility.

The sensitivity of demand for different modes in a particular corridor varies greatly depending on demographics, congestion on parallel routes, availability of parking, density of employment, and income level of residents in and near the corridor as well as other factors. In the two examples cited in Dallas, ridership on a parallel light rail system varied from 5 percent to 40 percent of the peak period demand depending on the previously mentioned variables. Although there are rail systems operating in other areas of the U.S., there is currently no system operating in Texas where actual data can be used in an estimate of the impact on demand for various freeway alternatives.

The current procedure in Texas for evaluating rail transit lines is to conduct a detailed corridor feasibility study. This process is consistent with the goals of the system planning methodology—the demand for rail transit will, however, be handled outside the spreadsheet. The suggested procedure is similar to the method that would have been used with HOV projects if the methodology would have been in use in the early 1980s, before HOV projects were widespread. The demand for a rail system should be estimated and removed from the corridor demand that must be served by the freeway system. The roadway configuration used in the area wide model

should be similar to the final plan achieved from the system planning methodology. If the assumed and derived configurations are similar enough to result in similar transit demand, the initial assumptions and transit demand should be considered consistent with the final plan.

Impact of Tolls and Tollroads

The initial Dallas System Planning Methodology did not consider tollroads as alternatives in any of the corridors. While federal law currently restricts tolls on Federal-aid highways and prohibits introducing new tolls on interstates, legislation in ISTEA requires that new facilities be evaluated as tollroads. As a general rule, the demand for a tollroad is 60 percent of the demand for a non-toll facility in a corridor. Similar to the effect of rail transit in a corridor, many factors influence the change in demand due to a toll facility, including socioeconomic factors as well as the amount of the toll.

A different application of tolls, and one that has been receiving increased and renewed attention, is congestion pricing. Congestion pricing projects charge motorists to use a facility based on congestion and peak travel periods. Congestion pricing may consist of charging tolls for single-occupant vehicles to use an HOV facility or express lanes during congested periods of the day.

While ISTEA provides federal funds for congestion pricing pilot programs, limited data and experience are available to incorporate the impact of tolls into the system planning spreadsheet. NCTCOG is currently attempting to incorporate the impact of tolls and tollroads in the development of the Mobility 2020 Plan, the long range transportation plan for the Dallas area. Toll projects should be handled in the same manner as rail transit projects—the initial assumptions should be checked against the final configuration of the corridor.

Cost Analysis

For each alternative developed within each corridor, costs are determined for the total capital cost, operating and maintenance cost, and, costs related to congestion and vehicle operation.

Capital Costs

Total capital cost included in the evaluation of alternatives consists of construction cost and right-of-way cost.

Construction. The construction cost is associated with the addition of general-purpose lanes, HOV lanes, and/or express lanes to the freeway. In the original Dallas System Planning Study, costs for construction of various possible roadways were investigated at the planning level of analysis. General purpose lane, HOV lane, and express lane cost values shown in Table 2 reflect average unit bid prices from Houston and Dallas construction projects in the late 1980s and early 1990s. HOV lane costs include park-and-ride support facilities (such as "T" ramps into lots, but not the lot itself), elevated interchanges, and associated street and freeway improvements necessary to operate the HOV lane.

Table 2. Unit Construction Costs

Construction Item	Width Meters (Feet)	Cost - $ Million Per Kilometer (Per Mile)
Mainlane (one lane at grade)	3.7 m (12')	$1.6 per km ($2.5 per mile)
Mainlane (one lane elevated)	3.7 m (12')	$2.2 per km ($3.5 per mile)
HOV lane w/ramps (one lane at grade)	6.1 m (20')	$3.1 per km ($5 per mile)
HOV lane w/ramps (one lane elevated)	6.1 m (20')	$4.3 per km ($7 per mile)
HOV lanes w/ramps (two lanes at grade)	12.2 m (40')	$4.3 per km ($7 per mile)
HOV lanes w/ramps (two lanes elevated)	12.2 m (40')	$6.2 per km ($10 per mile)
Express lanes (two lanes at grade)	12.2 m (40')	$3.7 per km ($6 per mile)
Express lanes (two lanes elevated)	12.2 m (40')	$5.6 per km ($9 per mile)
Express lanes (three lanes at grade)	17.1 m (56')	$6.2 per km ($10 per mile)
Express lanes (three lanes elevated)	17.1 m (56')	$9.3 per km ($15 per mile)
Noise abatement walls	N/A	$0.68 per km ($1.1 per mile)
Surveillance, communication & control (SC&C)	N/A	$0.31 per km ($0.50 per mile)

The costs shown in Table 2 are default values that can be changed in the spreadsheet. If construction cost data are available that reflect more accurate values in a particular area, they should be used in the spreadsheet. The small difference between the elevated versus at-grade costs per kilometer reflect the fact that widening a roadway may require retaining walls, embankment,

and drainage improvements for at-grade widening. Costs associated with removal of items and traffic handling will be incurred in both elevated and at-grade alternatives and are reflected in the Table 2 costs.

Right-of-Way. The right-of-way cost is related to any additional land required for widening a freeway. The cost of land will vary in each corridor. Data relative to right-of-way costs must be obtained in local areas. The spreadsheet requires use of a representative unit cost per section of corridor in order to estimate the right-of-way cost for a given corridor based on required land and amount of development. The costs are principally used in the analysis of elevated facilities to determine which alternative produces a lower cost—acquiring additional right-of-way or elevating a facility.

Operating and Maintenance Cost

The operating and maintenance cost varies depending on the type of facility proposed. Each corridor includes the cost of a surveillance, communication, and control (SC&C) system regardless of the cross section. The operating cost for alternatives with reversible lanes is the cost of opening and closing (or reversing) the lane on a daily basis—this would pertain to express or HOV lanes. The operating cost for alternatives with HOV lanes also includes the cost of enforcing the lane on a daily basis. Table 3 shows the operating cost for the various alternatives analyzed. The operating and maintenance costs are estimated on a corridor basis.

Table 3. Operating Costs

Operating Item	Annual Cost ($ Million)
Enforcement for separated HOV lane	$ 0.10 per facility
Reversible lane (Express and HOV)	$ 0.25 per facility
Surveillance, communication & control (SC&C)	$ 0.10 per facility

Congestion and Vehicle Operation Cost

The congestion cost quantifies the cost of delay to motorists. The methodology developed for the Dallas System Planning Study included only recurrent congestion cost as it related to delay to motorists using the facility. Improvements to the congestion cost estimation procedure include

incorporating costs of fuel consumption, air quality, commercial vehicles, and non-recurrent congestion. The value of person time is used to convert time delay to delay cost.

Value of Person Time. The value of person time used in the methodology is based on a TTI research study titled "The Value of Travel Time: New Estimates Developed Using a Speed Choice Model" (4). The study derived the value of time using a speed choice model assuming that a rational driver chooses a speed at which the driver's total trip cost is minimized. Total driving costs include value of time, vehicle operating costs, accident costs, and traffic violation costs. The study, conducted in 1985, recommended the following values of time

Drivers (1985): $8.03 per person-hour and

Passenger Cars (1985): $10.04 per vehicle-hour (assumes 1.25 persons per vehicle).

The value of time may be adjusted to a more recent time period using the current Consumer Price Index (CPI). The 1995 value of time based on the original study and using the CPI is

Drivers (1995): $11.31 per person-hour and

Passenger Cars (1995): $14.31 per vehicle-hour (assumes 1.25 persons per vehicle).

Delay Cost Due to Recurrent Congestion. As the peak-hour volume per lane approaches and exceeds capacity, the average travel speeds will decrease from free flow operation. The level of congestion is defined by the average estimated speed of freeway traffic. Minutes lost per person can be calculated from the difference between the estimated congestion speed and free flow speed. The time lost is multiplied by the value of person time, the working days per year, and persons per lane to arrive at an annual congestion cost.

The computerized spreadsheet uses a linear relationship between volume per lane and delay or speed, similar to the standard speed-flow relationship for highways. Volumes per lane or flows below 1850 vphpl are considered to be at free flow, that is no delay and a speed of 97 kph (60 mph). Lane volumes between 1850 vphpl and 2200 vphpl have a delay which increases linearly from 0 to 0.21 minutes per km (0.33 minutes per mile) and a speed which decreases from 97 kph (60 mph) to 72 kph (45 mph). Lane volumes between 2200 vphpl and the theoretical ultimate planning capacity of 2400 vphpl have a delay which increases linearly from 0.21 minutes per km (0.33 minutes per mile) to 1.86 minutes per km (3.0 minutes per mile) and a speed which decreases from 72 kph (45 mph) to 24 kph (15 mph). At these low speeds the actual flow or lane volume would likely be below 2200 vphpl. For any theoretical flow greater than 2400 vphpl, it is assumed that the additional vehicles will be forced to an hour outside the peak hour or to alternate routes. Essentially, a delay of greater than 1.86 minutes per km (3.0 minutes per mile)

is considered to be unacceptable to the driving public. The linear speed-flow relationship is plotted in Figure 4.
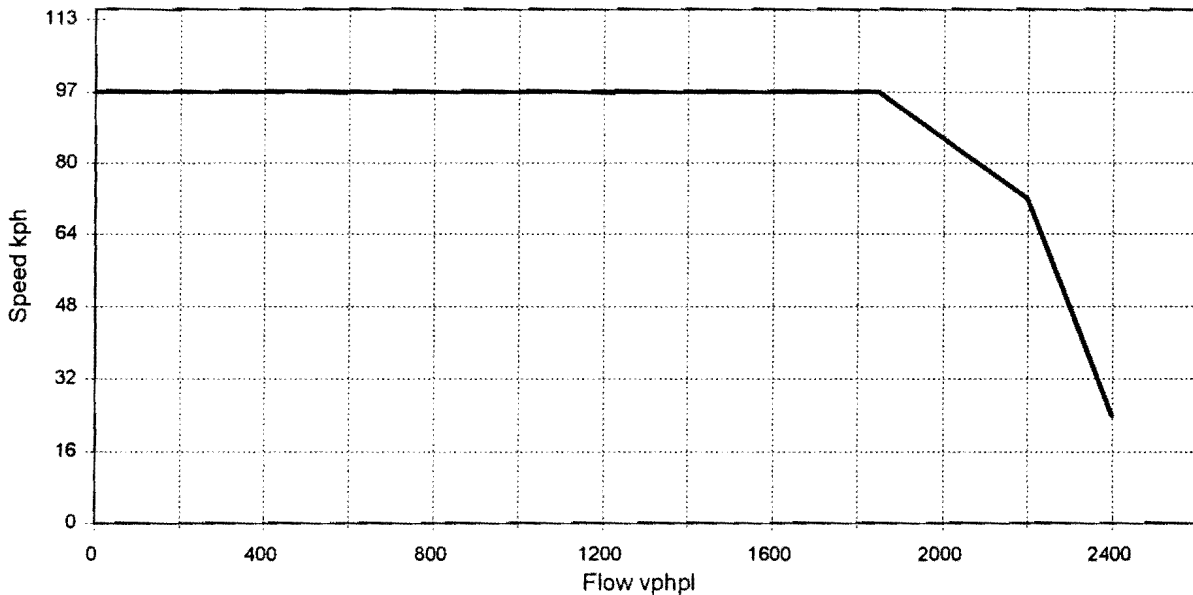
Figure 4. Speed-Flow Relationship

Additional Delay Cost Due to Non-Recurrent Congestion

More than half of the total freeway congestion experienced in urban areas can be attributed to non-recurrent congestion. The California Department of Transportation (CALTRANS) estimates total congestion delay by multiplying the recurring congestion delay by a factor of two to account for the non-recurring congestion delay (5). Non-recurrent congestion is the result of incidents and is defined as any non-recurrent event that causes reduction of roadway capacity or abnormal increase in demand.

Researchers incorporated the impact of non-recurring congestion (incidents) into the model. Because incidents have a wide variation in the impact on a freeway (i.e., shoulder blocked, single lane blocked, multiple lanes blocked), it was necessary to determine the impact on the freeway of a "typical" incident. It was also recognized that the incident's impact on freeway operations would be dependent on the number of freeway lanes. For example, two lanes blocked on a six lane freeway would affect freeway operations differently than two lanes blocked on a ten lane freeway. Therefore, it was decided to determine the reduction in capacity of a "typical" incident according to the number of freeway lanes.

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To determine the percent reduction in freeway capacity from a "typical" incident, the percent reduction in freeway capacity due to an incident and the distribution of incident type needed to be identified. Table 4 shows the percent capacity remaining during incident conditions according to the type of incident and number of freeway lanes (6). Table 5 shows the distribution of freeway lane blockage due to incidents. The data in Table 5 was obtained by summarizing incident reports from Motorist Assistance Patrols in the Dallas area. The data consist of 750 reports from the Motorist Assistance Patrols ranging from disabled vehicles to major accidents.

Table 4. Percentage of Freeway Capacity Remaining During Incident Conditions

# of Freeway Lanes in Each Direction	Shoulder[1]		In-Lane Disablement or Accident (Single Lane) (%)	In-Lane Disablement or Accident (Multiple Lane) (%)
	Disablement (%)	Accident (%)		
2	95	81	35	0
3	99	83	49	14
4	99	85	58	23
5	99	87	65	37
6	99	89	71	46
7	99	91	75	54
8	99	93	78	59

[1] Data collected in Dallas showed that of the total incidents blocking a shoulder, 87% are vehicle disablements and 13% are accidents.
Source: Reference 6

Table 5. Distribution of Freeway Lane Blockage by Incidents

Lane Blockage	Total Incidents (%)
Shoulder	72
One Mainlane	23
Two Mainlanes	3
Three Mainlanes	2
Four or More Mainlanes	Less than 1

For each freeway type (2 lanes, 3 lanes, etc.), the percent reduction in capacity due to a "typical" incident was determined by multiplying the percent reduction in freeway capacity for each

type of incident (Table 4) by the corresponding percentage of lane-blocking incidents (Table 5). Table 6 shows the percent of freeway capacity remaining during a "typical" incident according to the number of freeway lanes in each direction. While non-recurrent congestion can occur at any time of day, the congestion cost of incidents resulting from non-recurrent congestion during the weekday peak periods only have been incorporated into the model.

Table 6. Percent Capacity Remaining During an Average Freeway Incident

No. of Freeway Lanes in Each Direction	Capacity Remaining (%)
2	75
3	82
4	85
5	87
6	89

While data on the frequency of vehicle breakdowns is not readily available in the literature, some data in Dallas has been obtained, which has resulted in a rule-of-thumb value of one breakdown per 40,000 vehicle kilometers (25,000 vehicle miles). An accident rate on freeways in Dallas has been calculated (1994 data) as one per 1,376,000 vehicle kilometers (855,000 vehicle miles) for accidents where records were filed, typically where an injury occurred or where property damage in excess of $5,000 was estimated. This means that incidents on freeways are about 30 times more frequent than serious accidents, but incidents can cause congestion as well.

The frequency of incidents appears significantly higher where recurrent congestion occurs; more research is needed on this subject. However, because this finding is intuitively satisfying (vehicles would seem to be more likely to overheat, run out of gas, or be involved in small rear-end collisions when trapped in stop-and-go driving conditions), applying a factor to the normal incident frequency does not seem unreasonable. In Dallas, the available data suggest that in heavy congestion the number of normal incidents is one per 24,000 vehicle kilometers (15,000 vehicle miles).

Figure 5 is a graphical depiction of the potential relationship between incident frequency and recurrent congestion (here represented by speeds) postulated above. On freeways, any speed below 64 kph (40 mph) indicates the presence of congestion. If a linear relationship is posited between speeds below 64 kph (40 mph) and an increasing frequency of incidents, up to a maximum value of one per 24,000 vehicle kilometers (15,000 vehicle miles) at speeds of 16 kph (10 mph), then the expected frequency of incidents for a given speed could be taken from this graph and used with the above estimates of capacity reductions for the average incident, based upon the number of freeway lanes.
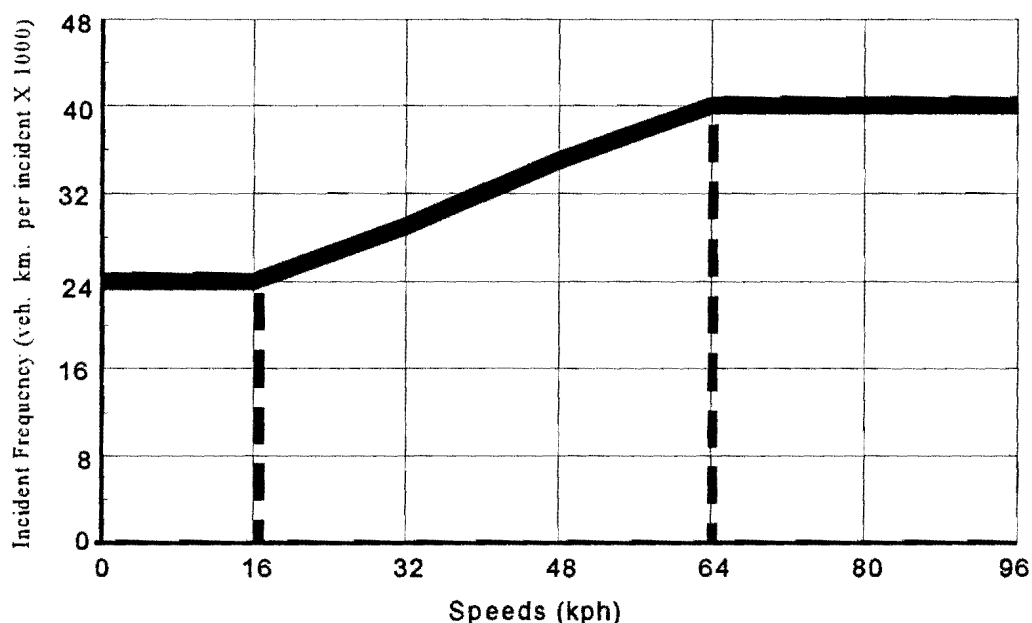
Figure 5. Incident Frequency on Freeways

While the attempt at quantification represented by the chart is only illustrative of the concept, it is obvious that a relationship between congestion and secondary incidents does exist. Estimates are that 20 percent of all incidents are caused by previous incidents (7). Since the system planning methodology being refined in this study may in some cases create justification for increased congestion under the lowest-public-cost criteria, it becomes important to attempt some assessment of the full impacts of congestion, including an increased frequency of incidents. Until better documentation is found, this study will utilize the rough, but defensible methodology illustrated in the chart for estimating the cost impacts of this increase. Costs will be limited to increased delay. Although the costs of incidents themselves, to those involved and to the public agencies responsible for their clearance, could be significant, their inclusion would require

(1) more extensive research on the types of incidents which increase in congestion situations and (2) a more reliable basis for incident frequency estimates. This level of detail is beyond the scope of the system planning methodology.

A further complicating factor which will be neglected here is the difficulty in clearing incidents under congested conditions, which can delay site access for emergency response. However, this varies widely, based upon the type and location of incidents, as well as local incident management procedures. This effect would further increase the severity of congestion impacts.

The Cost Spreadsheet incorporates costs of delay due to nonrecurrent congestion. Appendix B gives details. Essentially, incident frequency is used along with the weighted average capacity loss per incident, based upon the number of freeway lanes in each direction. This adjusted capacity is then used to adjust average speeds, with an additional delay cost calculated. The user may alter input parameters to fit local conditions on incident frequency, if they are available, or utilize the default values developed in Dallas.

Two examples are worked out in Appendix B, for the sake of discussion. In the first uncongested example, average peak hour delay per vehicle *due to incidents* amounts to a change from a 93 kph (58 mph) speed to one of 77 kph (48 mph) for 5 kilometers (3 miles), or 35 sec/veh. In the second example, average incident delay per vehicle resulted in a change from 48 kph (30 mph) to 24 kph (15 mph) per vehicle for 5 kilometers (3 miles), or a loss of 8.5 minutes per vehicle on a typical day, not even counting the extra mileage for the 25 percent of vehicles who will be required to divert to alternate routes. This dwarfs the original delay calculation, which would have been 48 kph (30 mph), compared to 97 kph (60 mph) ideal, or a delay per vehicle of 3 minutes; total average delay when nonrecurrent delay is included is 11.6 minutes, which could easily change the outcome of the alternatives analysis.

These examples, while simplistic, indicate the importance of nonrecurrent delay in estimating lowest public cost. In cases where capacity deficiencies do not exist, incidents will have less impact and will be less frequent. Where recurrent congestion exists, the frequency of incidents increases, and there is little alternative but for freeway traffic to divert to alternate routes where the increased volumes will further overwhelm a peak hour system. Although much of this impact is theoretical and more research needs to be done to verify the estimate, it is significant enough to include it as an element in the system planning methodology.

Commercial Vehicle Cost

The value of driver and vehicle time for commercial vehicles was obtained from the American Trucking Association, without respect to shipment costs, and incorporated into the computerized spreadsheets. The current estimate for the value of driver and commercial vehicle time is $60 per hour. This value was used in conjunction with peak period vehicle classification data on Dallas freeways to provide a rational basis for estimating the costs of congestion on the economic health of a community in addition to the personal costs of congestion used in the earlier study. Since shipment costs vary widely, and since the effects of just-in-time delivery schedules cannot be assessed due to security factors within private industry, it is not practical to attempt to further refine these factors.

Fuel Consumption Cost

The procedure for estimating the congestion from the SWUTC study incorporated the fuel consumption cost. The fuel consumption rates were produced using the fuel consumption model ARFCOM (ARRB Road Fuel Consumption Model) from the Australian Road Research Board which can be used on a personal computer. The ARFCOM model is a detailed power model. It estimates the power needed by a vehicle to overcome the forces acting at its wheels given vehicle speed and road geometry. All the power components are summed, and a fuel-to-power efficiency factor is used to calculate fuel consumption (8). The model can be used with several input data levels from instantaneous speed traces to average speed or running speed over a section of roadway. ARFCOM requires several vehicle parameters and road geometry data as inputs, though default values are supplied for most parameters. The model has been validated with instantaneous speed data and known parameters to estimate fuel consumption to within 5% of measured values. Using only the minimum required vehicle parameters, errors are within 15% of measured values (8).

The fuel consumption rates were estimated with the ARFCOM model. Parameters for five of the eight vehicle classes used in the MOBLE5A program were defined for input to the ARFCOM program. Light-duty diesel vehicles, light-duty diesel trucks, and motorcycles, which only make up 2% of the vehicle mix for freeways in Dallas and Tarrant counties, were not considered in the composite fuel rate. This vehicle mix was used to calculate the composite fuel consumption rate for use in this project. Figure 6 shows the curves for the five vehicle classes and the composite vehicle. A new composite fuel consumption rate can easily be created by changing the percentages for the vehicle mix.
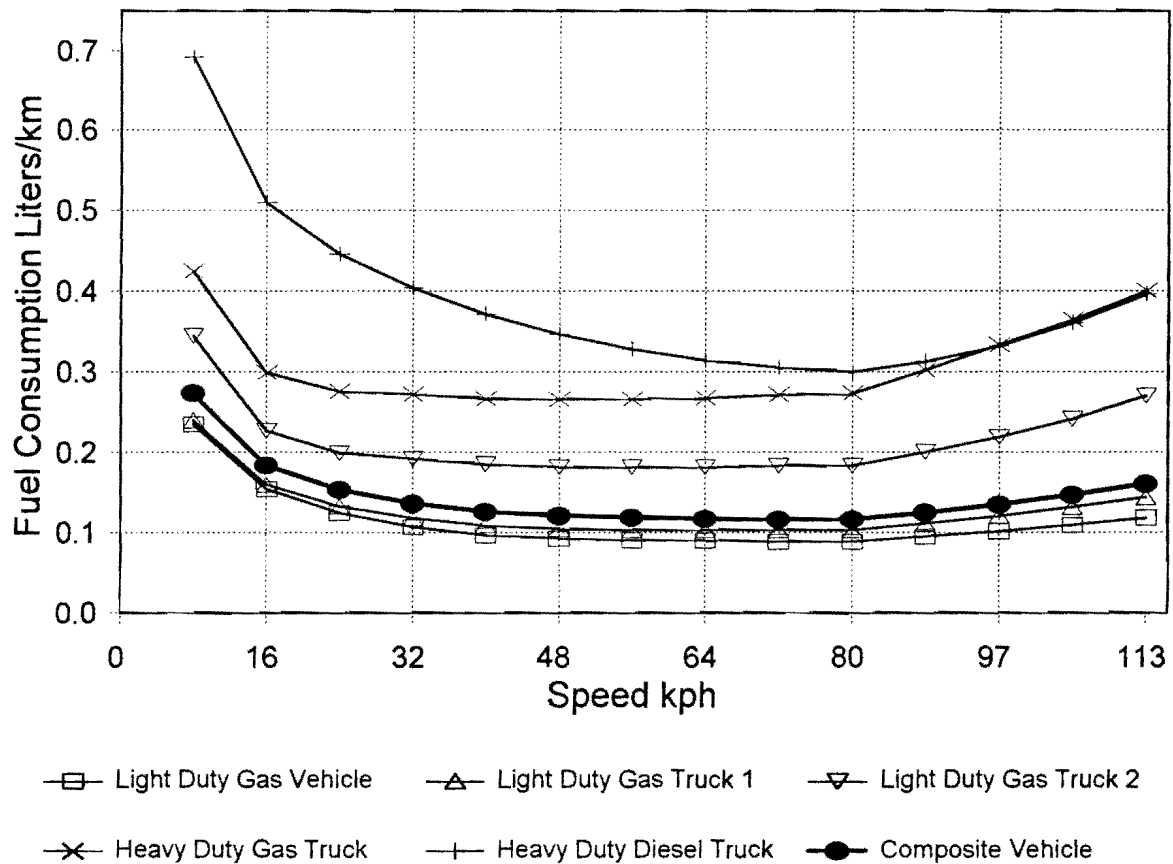
Figure 6. ARFCOM Average Speed Fuel Rates

The ARFCOM running speed model provided fuel consumption estimates for each of the five vehicle types at average speeds in intervals from 8 kph (5 mph) to 113 kph (70 mph). A running speed higher than the average speed was assumed to reflect freeway travel conditions up to 80 kph (50 mph) for each average speed. At 80 kph (50 mph) and above, the average speed was assumed to equal the running speed. The model calculates the idle time and travel time based on the given average speed and running speed. Since this analysis was used to create fuel rates for use at several locations, the factors for wind speed and roadway grade were assumed to be zero. An important factor in the running speed model is the changes in positive kinetic energy, E_{k+}, which is a measure of the amount of speed fluctuation for a given running speed. Default values of E_{k+} are provided for two types of urban areas in the ARFCOM model. However, if known values can be calculated for E_{k+}, the accuracy of the model can be improved since these values have been found to vary considerably between cities (9). Using detailed travel data taken on a

Texas Transportation Institute

Houston freeway, values for E_{k+} were obtained for freeway conditions from stop-and-go to free-flow driving.

Researchers estimated the total fuel consumption in liters per day for each alternative using the fuel consumption tables—derived from the ARFCOM program—and the speed-flow relationship discussed above. The total fuel consumption cost is the annual cost of fuel for a particular alternative. The average cost of fuel in the Dallas-Fort Worth Region for the first half of 1995 was found to be $0.28 per liter ($1.05 per gallon) of fuel.

Air Quality Cost

The primary models for estimating mobile source emissions are the MOBILE model from the Environmental Protection Agency (EPA) and EMFAC from the California Air Resources Board (CARB). Both these models relate the vehicle distance of travel (VDT) and average speed to an emission rate, which are derived from specific driving cycles that can be duplicated on dynamometers. Most other models are based on the outputs from the MOBILE and EMFAC models (10).

Emissions rates were obtained from the NCTCOG. NCTCOG provided a MOBILE5a base year run for 1993 for Dallas and Tarrant County freeways which presents the basic emissions rate for nine vehicle types and an all vehicle composite at a specific speed for a typical summer day. These emissions rates were given in grams per mile for eight vehicle types and all vehicle composite. The all vehicle composite reflects the Dallas and Tarrant Freeway vehicle mix and was used for all the emissions analysis for this study.

Figure 7 shows the curves for VOC (volatile organic compounds). The total VOC emission factors include all evaporative HC (hydrocarbon) emission factors and the exhaust component of VOC. The exhaust VOC curve shown in the figure consists of the VOC emissions released through

Figure 8 shows the emission rate curve for CO (carbon monoxide). It is similar to the VOC emission curve, but it rises more sharply at speeds in excess of 88 kph (55 mph). The optimum speed for CO emissions occurs at 77 kph (48 mph). the tailpipe. From the figure, it can be seen that the evaporative emissions are a major portion of the total VOC emissions. The optimum VOC emission rate occurs at 88 kph (55 mph).
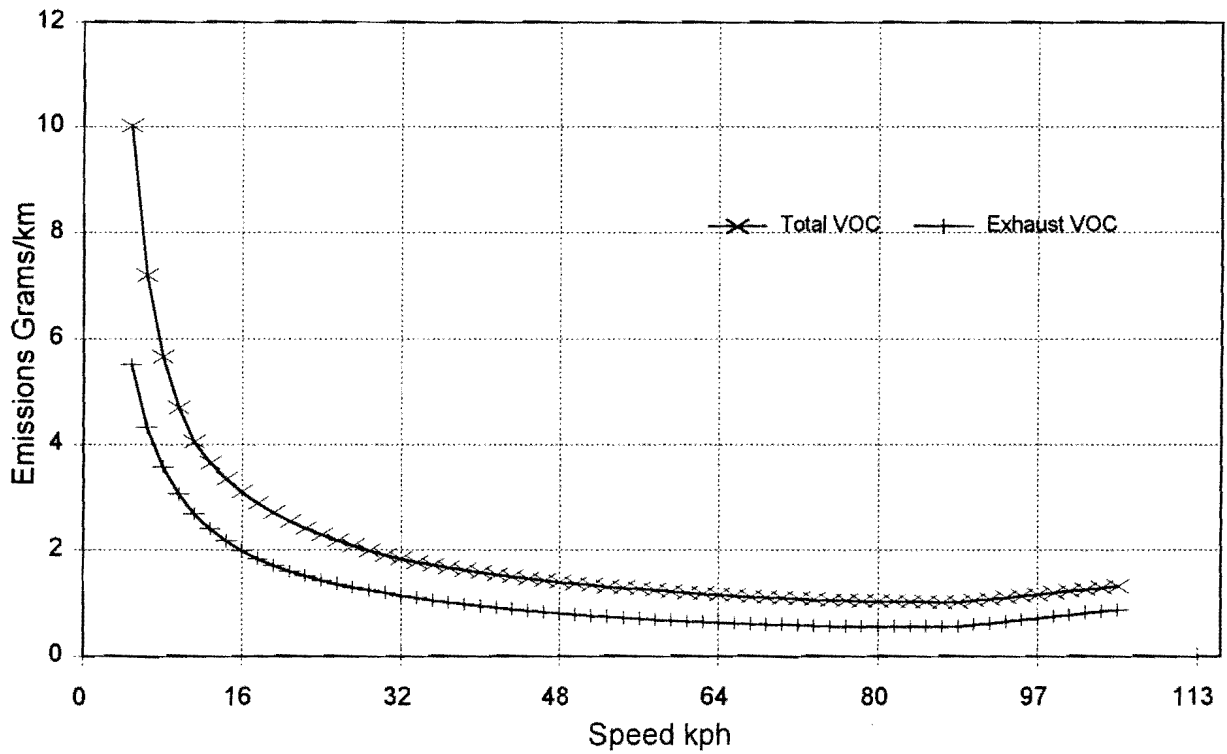
Figure 7. VOC Emission Rates - 1993, Dallas/Tarrant Freeways
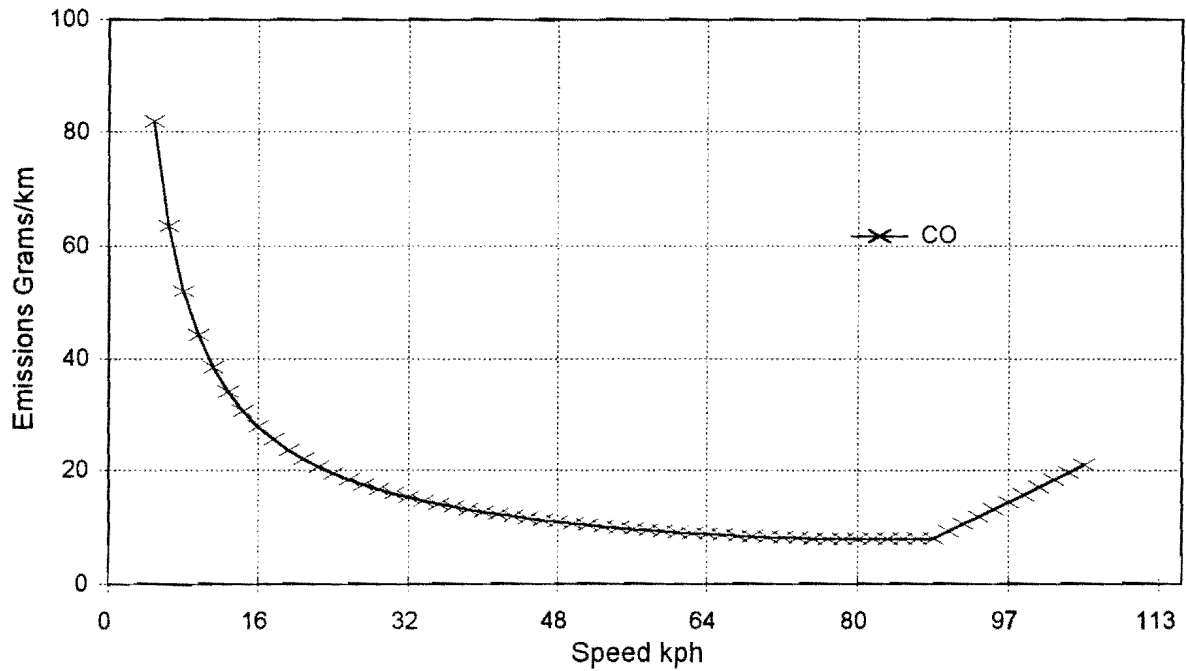
Figure 8. CO Emission Rates - 1993, Dallas/Tarrant Freeways

Figure 9 shows the emission rate curve for nitrogen oxides (NO$_x$). This curve differs considerably from the other emission curves as well as the fuel consumption curve. The optimum speed occurs at 40 kph (25 mph), and the curve is almost linear and constant between 32 kph (20 mph) and 77 kph (48 mph). At speeds above 77 kph (48 mph), the emission rate rises sharply.
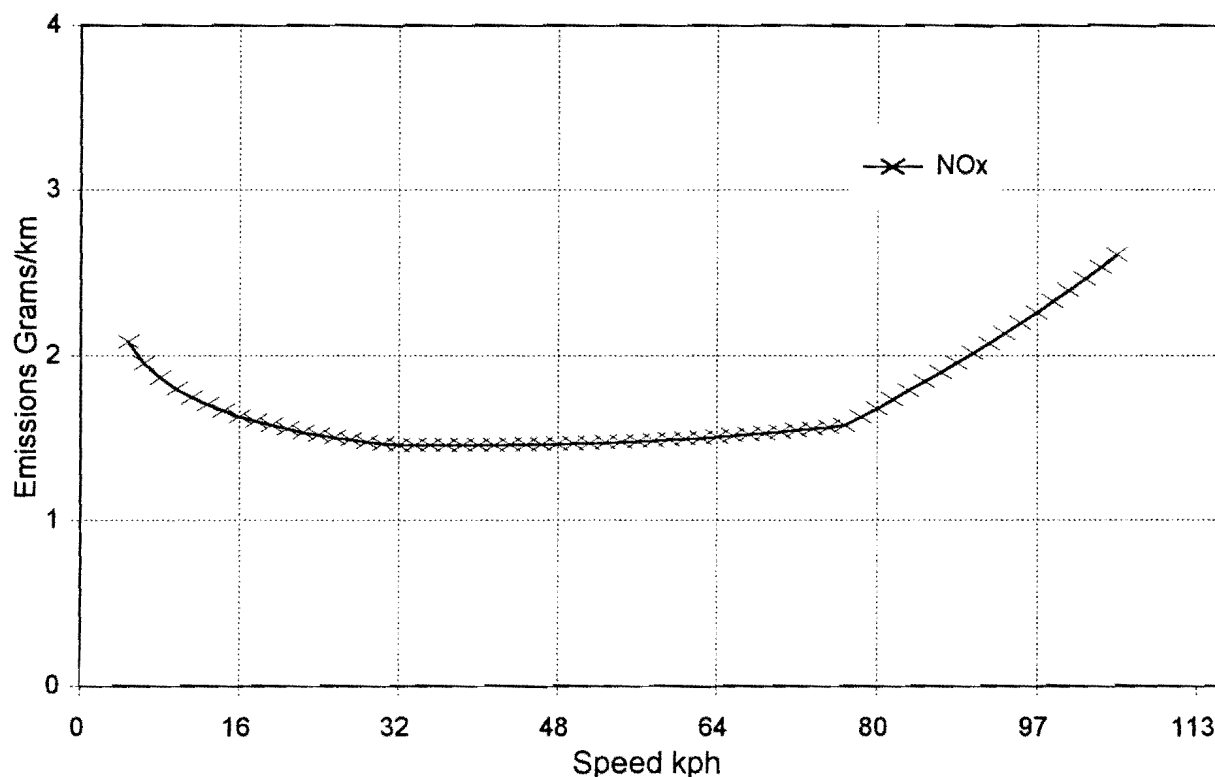
Figure 9. No$_x$ Emission Rates - 1993, Dallas/Tarrant Freeways

There are some problems with use of these curves. First, most transportation officials agree that VOC and CO emissions from mobile sources are significantly underestimated by existing mobile source models (11). Two possible reasons why the existing models underestimate emissions are (1) miscalculating the impact of cold starts and (2) not fully representing high-emitters in the study fleet.

Second, another significant source of an emissions underestimation is that the test procedures to develop the emissions rates do not fully represent actual driving conditions. The federal test procedure (FTP) driving cycle used to develop the MOBILE models specifically does not include high speeds or sharp accelerations (11) which have been shown for one specific vehicle

to increase CO emissions by about 2,500 times and HC emissions by 40 times over the stoichiometric emission rates (12).

Third, obtaining accurate data on speeds and acceleration is difficult and not usually broken into small enough segments to allow for accurate analysis. However, having said all that, for planning purposes, the spreadsheet utilizes the MOBILE5a methodology.

The amount of emissions for VOC, CO, and NO_x in kilograms per day is estimated in the same manner as the fuel consumption cost using rates from MOBILE5A and the speeds estimated with speed-flow relationship. However, the amount of emissions is not easily quantified in monetary terms for use in the "lowest public cost model." Two general methods are used to estimate emission values—the damage estimate method and the control cost estimate method. Wang and Santini examine both of these methods (13). They present regression relationships for both methods based on measured emissions data from several US cities. The control cost based emission values were chosen for this project. Using the regression equations and data for ozone (O_3) and CO obtained from the Texas Natural Resource Conservation Commission (TNRCC) for the Dallas-Fort Worth Region, the control cost per kg for VOC, CO, and NO_x were estimated. The regression relationship was established for 1989 values, and the CPI was used to adjust the 1989 values to 1995 values (Table 7).

Table 7. Control-Cost-Based Emission Values for Dallas-Fort Worth

Emission	$ per kg
VOC (volatile organic compounds)	$12.97
CO (carbon monoxide)	$ 2.51
NO_x (nitrogen oxides)	$13.68

Environmental Costs

An alternatives analysis should consider environmental impacts such as air quality, noise, and visual effects although they are not directly paid by the user. Air quality impacts have been incorporated into the model and are described in the previous section. It is difficult, however, to estimate the cost of social impacts such as community preferences regarding highway noise abatement and aesthetic visual quality. Freeway traffic noise, predominantly produced by vehicle motors, aerodynamics, and the interaction of tires with the roadway, is more of a concern in noise-

sensitive areas such as residential areas, schools, hospitals, etc. Several procedures have been developed to predict noise levels based on DHV and average operating speed; however, since noise walls are the most frequently used method of noise mitigation, attention to the visual quality of the design then becomes the challenge to transportation agencies. Although natural barriers, such as earth mounds, can be effective noise barriers, the amount of additional right-of-way required typically precludes their use in developed urban areas. Noise walls can become visual pollution due to their visual dominance in the highway environment. Additionally, while visual aesthetics refer to the general impression of a facility from adjacent properties, it also refers to the visibility of adjacent commercial property by users of the facility. Noise walls in nonresidential areas may have negative value. While the cost of noise walls have been incorporated into the model, the issues previously discussed must be considered.

Alternative Selection

Once the system constraints are determined, the individual corridors are analyzed for the best alternative. The alternatives analysis for each corridor consists of development and evaluation of several cross sections. The alternatives for an entire freeway system is an iterative process based on the constraints that would control where traffic could be loaded and unloaded to other facilities and the demand for each portion of the corridor.

The cross sections evaluated for each corridor (typically) include the existing cross section, the existing long range plan, an all general purpose lane cross section, and cross sections including express lanes, a 2-or-more person HOV lane, and a 3-or-more person HOV lane. In many cases, variations of each alternative should be evaluated. These may include different number of lanes, at-grade versus elevated lanes, and combinations of express and HOV lanes.

The highest ranking alternative (based on lowest total cost) for each corridor is superimposed on the system to check for compatibility. At locations where corridor components are not compatible, the next best alternative should be evaluated for system compatibility. This process should continue until the number of lanes, facility types, and congestion level is balanced for the freeway system.

Operational Analysis

The last step in the System Planning Methodology is the fine tuning of the alternatives analysis procedure to establish the number of ramps and the need for auxiliary lanes at freeway-to-

freeway interchanges. Not only is it necessary to plan for a fit between capacities on interchanging facilities, which requires in some cases a selection of the second best alternative under the lowest-public-cost criteria, but it is also necessary to be sure that the junction elements are correctly sized for the projected peaking that will occur among joining movements during the morning and evening commuting peaks. This step is the one that best prevents bottlenecks from developing in the system that may be expensive to rectify.

However, this is not entirely straightforward for two reasons: peak hour volumes on ramps are not easy to predict; and accepting congestion as a given for future freeway operations creates an entirely new design environment.

Peak Hour Volumes on Ramps

Although peak hour volumes are used to identify the best alternative in each corridor, the travel demand models are limited in their output to daily volumes interchanging among freeway facilities. Extreme variations occur in peaking ratios for these ramps, depending upon their location with regard to land uses—population and employment densities—served by them. A generic value of K and D is usually applied to all 24 hour volumes provided the designer for development of all design elements, main lanes, and ramps alike. A study of ramps peaking characteristics in comparison with those on the adjacent freeway showed almost no correlation, with much higher peaking occurring on the ramps. One freeway-to-freeway ramp in Dallas has a K factor of 25%. Further, which movements peak in which direction, during each peak? Which movements compound a problem, and which movements balance out? Without a peak hour model, these volumes can be severely underestimated, and the resulting designs can cause operational nightmares, even in new facilities. On the other hand, a costly overestimate would waste precious resources.

Here researchers suggest that where the demand movements can be measured in the field, use this method to determine peak hour patterns. A negligible amount of data collection could save millions of dollars in fixing future bottlenecks. Where planning for new facilities, it is probably wise to design flexibility into the system so that needed elements can be added at relatively low cost, if necessary.

The application of the System Planning Methodology in Dallas resulted in fewer freeway lanes than were originally planned for the person-volume expected. As congestion levels increased, in alternatives with fewer freeway lanes, the demand for HOV facilities increased; as these were expanded to handle the HOV demand, the system was able to carry the same person volume at less total public expense.

These results, while welcome in a capital-constrained environment, left designers in a quandary. If congestion is expected in the planning of these facilities, how can design methodologies based on an acceptable level of service be adapted? One response might be to select a design hour which is out of the peak period, and design for an acceptable level of service at that time, recognizing that during peak periods low speeds would prevail. And under congested conditions, what constitutes an acceptable design? Has anyone established safety standards for a congested freeway environment?

These questions are not easily answered. The first response, selection of an appropriate design hour *outside* the peak period, was addressed by the North Central Texas Council of Governments when it prepared the Mobility 2010 Update, which required capital constraint. As in the System Planning Study, their efforts to constrain capital to existing sources of funding caused the freeway system to fail for several hours per day; they found it could handle the fourth highest hour of the weekday, at normal freeway speeds. During peak hours, it was possible to travel at low speeds, or to use transit on HOV facilities at higher speeds.

However, though this may be expedient for planning purposes, it is still necessary to obtain fourth highest hour design volumes in order to begin design. A database has not been established to give reliable estimates of this new factor, analogous to the K factor, which was defined as the 30th highest hour of the year. In some areas, the fourth highest hour may still be highly congested. Further, many freeway facilities are federal, and use of a new factor for development of design hour volumes has not been accepted. Research is vitally needed in order to select the appropriate design hour.

The second concern is one of design for congested periods. At present, designers cannot use currently accepted analytical methods to evaluate their designs under congested conditions. At Level of Service F, all further analysis stops until it can be corrected. But how bad is F? At what point does each element truly break down and begin to cause accidents? Are there techniques for

smoothing the impacts of merges and weaves in low-speed conditions? No research has yet been done on appropriate design standards for stop and go driving on freeways. How do we optimize the design if congestion is inevitable?

At this point, these questions are unanswerable. However, a research project, "Planning for Optimal Roadway Operations in the Design Year" SPR 0-1483, sponsored jointly by the Federal Highway Administration and TxDOT, is now underway to answer some of these questions.

For purposes of this project to refine the system planning methodology, it is only possible to offer some general guidelines for performing the operational analysis step. Volumes must be used which make it possible to evaluate merging and weaving under conditions that will be reasonable most of the day. Researchers suggest the designers use 80% of the calculated DHV to evaluate the design using standard methodologies.

CHAPTER FOUR

TRANSFERABILITY OF METHODOLOGY

The University of Texas at El Paso (UTEP) tested the computer spreadsheet of the methodology to determine how successfully it could be applied to another urban area. The spreadsheet was used on the IH 10 corridor in El Paso, Texas, which connects the central business district to residences and businesses east of the central business district.

Both the Design Hour Volume spreadsheet and the cost spreadsheet underwent substantial revisions from the original spreadsheets used in the Dallas System Planning Study, to make data entry easier to input and to make data output more understandable to the user. The Design Hour Volume spreadsheet has all of the input and output clearly labeled and located at the top of the spreadsheet. The cost spreadsheet has shaded cells for the user inputs, and the outputs are clearly labeled and located at the top of the spreadsheet. The cost spreadsheet has shaded cells for the user inputs, and the outputs are clearly labeled and arranged in a logical manner. The Freeway/HOV System Planning User's Manual, included in the appendix, describes the spreadsheets in detail. This report also includes more descriptive information about steps to be taken outside of the spreadsheet.

There were two concerns identified when the spreadsheet was applied to the IH 10 corridor. The first concern was computer hardware and software requirements, and the second concern was the amount of data required to estimate the total project cost and emissions and fuel consumption output. Both of these concerns are addressed in the following section.

The spreadsheet is a Quattro Pro version 6.0 file that requires a certain amount of random access memory to run at a reasonable speed. The spreadsheet was first tested on an 80386 computer with 4 megabytes of memory, and it ran very slow making it difficult to use. The spreadsheet was then tested on an 80486 computer with 8 megabytes of memory, and it ran "well." The spreadsheets were developed to test several alternatives on one spreadsheet. In order to reduce the amount of memory required to run the program, it is recommended that each alternative be input on a separate spreadsheet and the blocks to input data for other alternatives be deleted. This should improve program operating speed.

The second problem that was identified was that the program is very data intensive and requires estimates on many parameters. For some of these parameters, it may be difficult for a

user to determine an appropriate estimated value. For several of the input parameters, default values are given to assist the user when inputting data for a corridor. It is also recommended that the user test the sensitivity of the parameters by changing the values of the parameters in question to determine how much it affects the output of the program.

CHAPTER FIVE

CONCLUSIONS

The system planning methodology is one process to bring least-cost planning techniques into a format useable for multimodal project assessment. The methodology is not as detailed as some attempts at developing a full-cost method of allocating project characteristics. Nelson and Shakow have developed a conceptual design for a computer model that will allow the user to consider a wide range of transportation modes, trip purposes, alternatives to travel, and land-use changes in a format that focuses on access to trip ends, rather than travel at high-speed (14). Their outline of the methodology is not, however, intended as a planning model for individual travel corridors. It is, rather, an areawide assessment of the performance of the land use and transportation systems that may be used to satisfy user needs.

The system planning methodology presented in this report fills the gap between the broad policy level studies and the conceptual design of roadways, transit facilities, operational improvement plans, or demand management strategies. It consists of a set of steps that identifies key system constraints, provides a spreadsheet-based program that is open to user input and interpretation of results, and identifies a consistent decision-making process based on the lowest total cost to the public.

The methodology is open to other constraints such as agency budget or transportation corridor width. It is also consistent with transit, toll, and other system elements that are not contained within the spreadsheet program. The methodology is based on the concept that users will accept different travel modes or options if faced with congested single-occupant auto travel. The basis for the shift from single-occupant travel is the demonstrated performance of HOV lanes in Texas and other states. The data for Texas high-occupancy vehicle projects provide an excellent database for other Texas corridors that may be in the planning stage.

The current state of the data and professional practice is included in the improvements made to the methodology in this research effort. There may be additional items that can be handled within the spreadsheet at some future date, but many of the considerations will always be addressed outside of a spreadsheet-based program. The advantage of the system planning methodology is that the assumptions and calculation methods are open for all users to see and modify as local data become available. The demonstrated performance of local transportation projects will always provide a very useful check on any national averages used for corridor planning.

Corridor planning is changing with the requirements for major investment studies. The system planning technique outlined in this report can benefit these analyses by providing a quantitative way of assessing several modes of travel to identify the lowest cost method of addressing transportation needs. The methodology was tested in El Paso during this study, and a more complete set of instructions are provided as a result of that test. However, there may be other improvements necessary for TxDOT District personnel to fully utilize the technique. These improvements should be pursued as either secondary tests or in attempts to use the technique in corridor or system planning efforts and report the areas for improvement. This will speed the acceptance of the technique for regular use by TxDOT and others.

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APPENDIX A

State Departments of Transportation (DOT), Metropolitan Planning Organizations (MPO), and other organizations provided data for operating HOV systems. The following HOV facilities were included in the study database:

California:

Alameda County:	I-880
Contra Costa County:	I-580
Los Angeles County:	I-10, SR 91
Marin County:	US 101
Orange County:	I-5, SR-55, SR 57, I-405
Riverside County:	SR 91
Sacramento County:	SR 99
San Diego County:	I-15
San Mateo County:	US 101
Santa Clara County:	SR 85, US 101, SR 237, I-280
Dallas, TX:	I-30E
Houston, TX:	I-10 (Katy), I-45 (Gulf), I-45 (North), US 59 (Southwest), US 290 (Northwest)
Minneapolis, MN:	I-394
Nashville, TN:	I-65
Norfolk, VA:	I-64
Norfolk/Virginia Beach, VA:	SR 44
N. Virginia:	I-66, I-95, I-395
Pittsburgh, PA:	I-279
Phoenix, AZ:	I-10, SR 202
Seattle, WA:	I-5, I-90, I-405

This Appendix presents the data obtained for each of these HOV lanes.

Information for HOV lanes in California was obtained from the California Department of Transportation (Caltrans) (15). Table A-1 shows a summary of the HOV and freeway information provided by Caltrans.

Table A-1. California HOV Data							
HOV Facility	Year	ADT	Lanes	2+ HOV Vehicles	2+ Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume)
Alameda County I-880	1991	219,000	8	6,000	13,000	9.0	51
	1992	219,000	8	7,600	16,400	9.0	51
	1993	204,000	8	9,100	19,700	9.0	51
Contra Costa County I-580	1991	72,000	4	300	500	7.5	55
	1992	77,000	4	400	800	7.5	55
	1993	76,000	4	500	1,000	7.5	55
Los Angeles County I-10	1991	258,000	8	12,200	40,260	7.1	61
	1992	257,000	8	13,300	43,800	7.1	61
	1993	256,000	8	14,400	47,500	7.1	61
Los Angeles County SR 91	1991	266,000	8	12,400	27,500	7.8	56
Marin County US 101	1991	156,000	6	3,700	14,300	6.8	75
	1992	153,000	6	3,900	15,000	6.8	75
	1993	153,000	6	4,100	15,700	6.8	75
Orange County I-5	1991	191,000	10	15,000	33,000	6.7	53
	1992	193,000	10	16,900	37,200	6.7	53
	1993	195,000	10	18,900	41,600	6.7	53
Orange County SR 55	1991	211,000	6	28,000	61,600	7.2	60
	1992	211,000	6	31,600	69,500	7.2	60
	1993	211,000	6	33,200	73,000	7.2	60
Orange County SR 57	1991	201,000	8	15,000	33,000	7.3	53
	1992	193,000	8	16,900	37,200	7.3	53
	1993	193,000	8	18,900	41,600	7.3	53
Orange County I-405	1991	294,000	10	26,000	57,200	8.3	56
	1992	288,000	10	29,400	64,700	8.3	56
	1993	288,000	10	32,800	72,200	8.3	56
Riverside County SR 91	1992	205,000	6	9,200	20,240	7.8	54
	1993	207,000	6	10,800	23,760	7.8	54
Sacramento County SR 99	1991	146,000	6	9,300	20,900	8.1	64
	1992	146,000	6	8,400	19,000	8.1	64
	1993	146,000	6	7,600	17,000	8.1	64
San Diego County I-15	1991	215,000	8	8,200	18,040	9.1	62
	1992	226,000	8	8,600	18,900	9.1	62
	1993	227,000	8	8,900	19,600	9.1	62

Table A-1. California HOV Data							
HOV Facility	Year	ADT	Lanes	2+ HOV Vehicles	2+ Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume)
San Mateo County US 101	1991	171,000	6	3,900	8,800	8.0	56
	1992	172,000	6	5,300	11,900	8.0	56
	1993	172,000	6	6,700	15,100	8.0	56
Santa Clara County SR 85	1991	90,000	4	2,700	5,400	8.6	67
	1992	92,000	4	2,600	5,400	8.6	67
	1993	92,000	4	2,600	5,300	8.6	67
Santa Clara County US 101	1991	228,000	6	6,400	14,100	8.0	59
	1992	219,000	6	9,700	22,000	8.0	59
	1993	219,000	6	13,000	28,900	8.0	59
Santa Clara County SR 237	1991	81,000	4	4,100	9,900	11.6	76
	1992	88,000	4	4,000	9,600	11.6	76
	1993	88,000	4	3,800	9,300	11.6	76
Santa Clara County I-280	1991	220,000	8	6,500	15,400	9.5	61
	1992	220,000	8	6,000	14,300	9.5	61
	1993	233,000	8	5,500	13,200	9.5	61

The data available for 1992 and 1993 for the contraflow facility on I-30E (East R. L. Thornton Freeway) is presented in Table A-2.

Table A-2. I-30 East R. L. Thornton Freeway (Dallas, Texas)						
Year	ADT	Lanes	2+ HOV Vehicles	2+ HOV Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume
1992	160,000	8	4,900	15,600	8.5	.60
1993	160,000	8	5,000	16,000	8.5	.60

The freeway ADT value for 1992 was taken from TxDOT's Annual District Traffic Maps (16), and the value for 1993 was estimated assuming a 2% growth rate from 1992. Note that the constraining section of the freeway (i.e., the section with the highest ADT/lane value along the corridor) was used in reporting the ADT values. The HOV daily vehicles and persons were found in the "East R.L. Thornton (IH 30E) Contraflow Lane Operational Summary" (17) quarterly reports for the years of 1992 and 1993. The values from the months of March and September were averaged to obtain the number of HOV vehicles and persons for each year.

Houston, TX

Table A-3 shows the HOV facility data available for Houston from 1988 to 1994. The freeway ADT values for the years 1988 through 1992 were taken from TxDOT's District 12 Annual District Traffic Maps (16), and the values for the years 1993 and 1994 were estimated from TxDOT's monthly automatic traffic recorder count stations (18). The HOV daily vehicles and persons were found in the "Houston High-Occupancy Vehicle Lane Operations Summary" quarterly reports for each year (19). Generally, the information from the month of March was used to keep the data consistent.

Table A-3. Houston, TX HOV Data							
HOV Facility	Year	ADT	Lanes	2+ HOV Vehicles	2+ Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume)
I-10 (Katy)	1988	195,000	6	6,000	17,900	7.0	52
	1989	198,000	6	5,600	17,900	7.0	52
	1990	185,000	6	7,600	23,100	7.0	52
	1991	185,000	6	7,500	23,700	7.0	52
	1992	183,000	6	6,000	22,100	7.0	52
	1993	185,000	6	6,500	21,100	7.0	52
	1994	187,000	6	6,600	19,800	7.0	52
I-45 (Gulf)	1988	167,000	8	1,100	5,600	7.5	55
	1989	165,000	8	1,700	6,900	7.5	55
	1990	207,000	10	2,100	8,300	7.5	55
	1991	199,000	10	2,600	8,500	7.5	55
	1992	213,000	10	2,800	9,800	7.5	55
	1993	219,000	10	2,900	9,800	7.5	55
	1994	226,000	10	3,000	10,000	7.5	55
I-45 (North)	1988	201,000	8	2,900	14,000	7.0	52
	1989	199,000	8	2,600	12,300	7.0	52
	1990	211,000	8	3,500	16,700	7.0	52
	1991	215,000	8	3,600	18,700	7.0	52
	1992	225,000	8	4,800	19,300	7.0	52
	1993	226,000	8	4,800	21,500	7.0	52
	1994	227,000	8	4,800	21,100	7.0	52
US 59 (Southwest)	1993	214,000	10	3,500	11,300	7.5	55
	1994	223,000	10	5,000	14,000	7.5	55

	Table A-3. Houston, TX HOV Data						
HOV Facility	Year	ADT	Lanes	2+ HOV Vehicles	2+ Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume)
US 290	1988	214,000	10	1,600	4,600	7.5	55
(Northwest)	1989	216,000	10	2,100	5,900	7.5	55
	1990	219,000	10	3,500	9,700	7.5	55
	1991	202,000	10	4,100	11,300	7.5	55
	1992	198,000	10	4,400	12,300	7.5	55
	1993	204,000	10	4,500	12,500	7.5	55
	1994	211,000	10	4,700	13,100	7.5	55

Table A-4 includes the HOV facility data available for Minneapolis. HOV information for Minneapolis (1992 and 1993) was obtained from a report titled *I-394 Phase III Evaluation Interim Report*, by Strgar-Roscoe-Faush, Inc., November 1993 (20). The I-394 Freeway has two classifications of HOVs along its length.

Table A-4. Minneapolis, MN HOV Data							
HOV Facility	Year	ADT	Lanes	2+ HOV Vehicles	2+ Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume)
I-394	1992	96,000	6	4,600	9,200	8.0	55
(Concurrent-Flow)	1993	120,000	6	4,200	8,300	8.0	55
I-394	1992	106,000	6	4,200	8,600	8.0	55
(Barrier-Separated)	1993	134,000	6	6,400	13,000	8.0	55

The reports's appendices listed the daily freeway traffic and HOV lane volumes. The HOV daily persons were found by applying the operational period's occupancy factors to the HOV vehicles per operational period.

HOV information for I-65 in Nashville, TN (Table A-5) was obtained from the State of Tennessee Department of Transportation (21).

Table A-5. I-65 HOV Data (Nashville, TN)						
Year	ADT	Lanes	2+ HOV Vehicles	2+ HOV Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume)
1994	59,000	6	2,400	4,100	7.5	55

The freeway ADT value for the year 1994 was taken from Tennessee DOT's 1994 ADT estimate. The DOT also identified the freeway section as 4 lanes per direction which includes the HOV lanes. Six freeway lanes were used to account for the HOV lanes in each direction. The HOV daily vehicles and persons were found by using the daily count from Station #1.

HOV information (Table A-6) for Virginia was obtained from the Transportation Planning Division of the Virginia DOT (22). The freeways involved in the study include I-66, I-395, I-64, SR 44, and I-95.

Table A-6. Virginia HOV Data							
HOV Facility	Year	ADT	Lanes	2+ HOV Vehicles	2+ Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume)
Northern VA	1990	108,000	4	3,400	10,800	7.0	60
I-66	1991	111,000	4	4,100	12,900	7.0	60
Northern VA	1990	200,000	8	12,200	71,400	.08	.55
I-395	1993	178,000	8	12,000	60,100	.08	.55
Norfolk, VA	1992	122,000	6	5,400	12,300	8.0	63
I-64	1993	125,000	6	5,300	11,600	8.0	63
Norfolk, VA	1992	112,000	8	3,800	7,400	8.0	60
SR 44	1993	143,000	8	3,800	7,900	8.0	60
Northern VA, I-95	1990	142,000	6	7,000	27,000	.07	.55

Researchers obtained the listed data for each facility in the following manner.

I-66:   The daily freeway traffic volumes for the years 1990 and 1991 were calculated by taking the given 1993 ADT value of 115,000 and reducing it by 2% for each year. The HOV daily vehicles and persons were found by taking the given values of vehicles per lane per hour and persons per lane per hour for the HOV peak period and multiplying by the 5 hours of HOV use and the 2 HOV lanes in use.

I-395:   The daily freeway traffic volumes for the years 1990 and 1993 were calculated by using the volume per hour per lane values given for the general purpose lanes in the peak period. This conversion was accomplished by multiplying by the number of lanes and dividing by the given peak hour and directional distribution factors for this freeway. There are eight freeway lanes over the majority of the corridor. The HOV daily vehicles and persons were found by taking the given per lane values for the HOV peak period and multiplying by the 5.5 hours of HOV use and the 2 HOV lanes in use.

I-64:   The daily freeway traffic volumes for the years 1992 and 1993 were calculated by using the given total vehicles during the evening peak period in October 1992 and October 1993, subtracting out the HOV volumes, and converting to volume per hour. Those values were then multiplied to yield the daily traffic volume. According to the provided data, the month of October represents the overall freeway and HOV operational characteristics. The HOV daily vehicles and persons were found by taking the given values of vehicle and people volume per lane per hour and converting to volume for the HOV peak period using the 6.5 hours of HOV use and the 2 HOV lanes.

SR 44:   The daily freeway traffic volumes for the years 1992 and 1993 were calculated by taking the given total vehicles during the afternoon peak period in October 1992 and 1993 and subtracting out the HOV volumes and converting to volume per hour. Those values were then multiplied by a weighted 24 hour period to yield the daily traffic volume. The HOV daily vehicles and persons were found by taking the given values of vehicle and people volumes and converting using 6.5 hours of HOV use and the 1 HOV lane.

I-95:   The daily freeway volume for 1990 was calculated by using the given volume per lane per hour values for the general purpose lanes and shoulder lane in the peak hour. This value was multiplied by the number of lanes and divided by the given hourly and directional factors. The daily number of HOV vehicle and person volumes were found by taking the per hour per lane values for the HOV peak period and multiplying by the 5.5 hours of HOV use and the 1 HOV lane.

Pittsburgh, PA

HOV information for Pittsburgh (1989, 1991, and 1993) was obtained from the Commonwealth of Pennsylvania, Department of Transportation (23). Table A-7 shows the data used for I-279.

Table A-7. I-279 HOV Data (Pittsburgh, PA)						
Year	ADT	Lanes	2+ HOV Vehicles	2+ HOV Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume
1989	63,000	4	500	3,500	7.5	55
1991	86,000	4	1,400	3,400	7.5	55
1993	92,000	6	4,000	12,900	7.5	55

All the listed data were taken from the report form showing HOV lane and mainlane traffic volume and occupancy summaries. The HOV persons were obtained by multiplying the 24 hour HOV ADT by the provided occupancy rates.

HOV information for Phoenix (1992) was obtained from the Maricopa Association of Governments, Transportation & Planning Office (24). The freeways that have HOVs are I-10 and SR 202 (Table A-8).

Table A-8. Phoenix, AZ HOV Data							
HOV Facility	Year	ADT	Lanes	2+ HOV Vehicles	2+ Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume)
I-10	1992	210,000	8	13,400	27,700	7.2	50
SR 202	1992	91,000	6	3,400	6,600	7.2	50

The freeway ADT values for the freeways were determined using the values of persons per lane. These values were divided by the occupancy values and weighted with the daily distribution percentages to obtain the daily traffic per lane. The count locations at 10th and 11th Streets were used for I-10; the count data at 24th street for SR 202 was used. The report provided the number of lanes for each freeway section. The HOV daily vehicles and persons were found by applying the provided weighing factors to get daily totals.

The Washington State Department of Transportation, District 1 (25) provided the HOV information for the Seattle area (Table A-9).

Table A-9. Seattle, WA HOV Data							
HOV Facility	Year	ADT	Lanes	2+ HOV Vehicles	2+ Persons	Peak-Hour Volume (% of ADT)	Peak Direction Volume (% of Peak-Hour Volume)
I-5 North of CBD (SB)	1994	190,000	7	8,000	25,900	7.6	59
I-5 North of CBD (NB)	1994	190,000	7	6,100	18,400	8.4	67
I-90	1994	125,000	11	1,700	4,300	8.5	64
I-5 South of CBD (SB)	1994	182,000	7	4,400	13,000	8.8	57
I-405 (SB)	1994	126,000	4	7,300	21,800	7.8	51
I-405 (NB)	1994	126,000	4	7,800	23,400	7.4	54

APPENDIX B

FREEWAY HOV SYSTEM PLANNING USER'S MANUAL

As part of the "Dallas Freeway/HOV System Planning Study" report, a spreadsheet-based iterative process was developed to aid system-wide planning, based upon the total cost of congestion and construction of several corridor alternatives. This process allowed the user to test alternative freeway configurations in sections of a corridor. The technique used a Critical Lane Volume (CLV) spreadsheet and a Cost Estimation spreadsheet. In order to use the software, the user must have access to a PC computer with QuattroPro version 6.0 or higher. In addition, it is recommended that the user have access to a 386 computer with 4 megabytes memory, but preferably a 486 computer.

The first spreadsheet is the CLV spreadsheet. The user defines continuous sections of the corridor according to major changes in traffic volume, length, or changes in number of lanes, and is required to input data for each corridor section. The sectional inputs for this spreadsheet include Average Daily Traffic (ADT), K and D factors, percent carpools and percent express, corridor capacity, bus and carpool occupancy, and proposed number of lanes in each section, and the outputs are critical lane volumes, number of vehicles, persons, and occupancy rate for each user specified corridor section. The second spreadsheet is the Cost Estimation spreadsheet. The inputs for this spreadsheet include proposed number of lanes, critical lane volumes, and transit ridership, which are the outputs from the CLV spreadsheet, and the output is an estimation of total cost for each alternative.

The following two sections describe the inputs and outputs to the CLV spreadsheet and the Cost Estimation spreadsheet.

Critical Lane Volume Spreadsheet

The Critical Lane Volume spreadsheet is designed to allow the user to estimate input factors to arrive at the number of vehicles, persons, and occupancy rate for sections of a corridor. The following procedure shows the input steps needed in the "Section Inputs" of the CLV spreadsheet. It should be noted that the cell references made in the following list of instructions correspond to columns and rows that can be found in the attached three pages that show the columns, rows, and cell formulas of an example alternative of the CLV spreadsheet. The cell references can also be

found in worksheet A of the Quattro Pro file "CLVSHEET.WB2" which is included on the floppy disc.

- **Note the design year to be tested (Row 2) and the corridor for analysis (Row 3) listing all existing conditions and possible freeway expansion or enhancement limitations in the title.** The step also requires the alternative number (Row 4) and description to be specified.

- **Define the number of continuous sections along the corridor according to major changes in traffic volume, length, changes in the number of lanes or other vehicle movement influencing factors and give the section names according to endpoint markers (Row 6).** The number of sections in a corridor is unlimited; however, the number of columns will have to be increased to the specified number by copying the last column multiple times. The equation shown in location Row 69 must be modified. For the "@SUM($B25..$F25)" part of the equation, the letter of the column corresponding to the last (right most) column used must be inserted for the current value "F." The equations in Rows 100, 101, 106 and 107 most also be altered in the same manner. All other equations refer to only one section or column at a time.

- **Develop and input sectional information (Rows 8 to 21):**
  Row 8   Length—Freeway section length (kilometers or miles).
  Row 9   Freeway ADT—Predicted 24-hour volumes for design year.
  Row 10   HOV ADT—Predicted 24-hour volumes for multiple rider vehicles in a designated HOV lane (from area wide planning model if available).
  Row 11   Bus Person ADT—Predicted 24-hour volumes for buses in section.
  Row 12   K—Percentage (in decimal) of daily traffic in peak hour.
  Row 13   D—Percentage (in decimal) of traffic traveling in the peak direction during the peak hour (also known as the peak-hour directional distribution). This factor can also be used to estimate traffic congestion and HOV ridership in the off peak direction (i.e., D is less than 0.50).
  Row 14   Percent Carpools—Percentage (in decimal) of carpools in the defined corridor section that can be expected if no preference is given to bus and carpool traffic.
  Row 15   Percent Express—Percentage (in decimal) of through traffic for a corridor.
  Row 16   Capacity—Hourly freeway capacity per lane (often determined using the Highway Capacity Manual HCM procedures).

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Row 17   Max % New Carpools—The maximum percentage (in percent) of new carpools that are allowed to be formed in the freeway section due to HOV treatment.

Row 18   Bus Occupancy—The average number of persons utilizing a single bus.

Row 19   Carpool Occupancy—The average number of persons per eligible carpool vehicle (e.g., 2+, 3+) in an HOV lane.

Row 20   GP Occupancy—The average number of persons per vehicle in the general purpose lanes if an HOV lane is present in the alternative.

Row 21   GP Truck Percent—The percentage (in decimal) of trucks in general purpose traffic lanes.

- **Input number of general purpose (Row 23), express (Row 24), and HOV (Row 25) lanes to be used in the specified alternative for each section.**

- **Define the intercept (Row 27) and coefficient(s) (Row 28) associated with the ridership equation to be used for the freeway corridor.** The equation assumes that directional hourly volume per lane will be used to predict HOV ridership. If another variable is used, the spreadsheet cells that reference this equation (i.e., Rows 140, 147, 154, 161, and 168) must be modified to reflect the new ridership prediction equation inputs.

The spreadsheet will perform all necessary calculations to estimate output values with the input factors and equations. It is important for the user to determine the reasonableness and sensitivity of the model to changes in input values. This can be accomplished by changing input values (e.g., increasing and decreasing volume by 10 percent) or testing several alternative cross sections. If HOV lane projects are tested, the user should examine the percentage of new carpools and transit riders for reasonableness; values that are too high should be adjusted before proceeding to the Cost Estimation spreadsheet.

Description of Output Variables

The estimates provided by the CLV spreadsheet are located in the "Outputs" section. The critical lane volume outputs (Rows 32 to 37) calculated include:

- General Purpose (Row 32)—The number of vehicles in a peak direction general purpose lane in the peak hour of traffic flow.

- Express (Row 33)—The number of vehicles in an express lane during the peak hour.

- HOV (Row 34)—The number of vehicles in an HOV lane during the peak hour.

- New Bus Passengers (Row 35)—The number of additional transit riders during the peak hour.

- General Purpose Auto (Row 36)—The number of vehicles in the critical general purpose lanes that are automobiles.

- General Purpose Truck (Row 37)—The number of trucks in the critical general purpose lanes.

Additional descriptive outputs are located in the general outputs section (Rows 40 to 44). This information includes:

- Vehicles (Row 40)—Total number of vehicles in a freeway section.

- Persons (Row 41)—Total number of persons in a freeway section.

- Occupancy (Row 42)—The value obtained by dividing the total number of persons by the total number of vehicles in a freeway section.

- Vehicle Distance of Travel (VDT) (Row 43)—Distance traveled by vehicles in the section (units specified by user in Row 8).

- Person Distance of Travel (PDT) (Row 44)—Distance traveled by persons in the section (units specified by user in Row 8).

All of these outputs are used in comparing alternatives for a freeway corridor.

Description of Intermediate Calculation Variables

The final three sections of the CLV spreadsheet are represented by the headings of "Calculations" (A47), "Adjustments" (A66), and "Iterations" (A118). The following discussion will

briefly describe the process employed through these sections to manipulate the provided inputs into the listed outputs.

Preliminary values are computed from the input factors in the "Calculations" section. The capacity for the general purpose (Row 50), express (Row 51), and HOV (Row 52) lanes are calculated. The initial CLV information (Rows 54 and 55) is determined from the freeway ADT and HOV ADT inputs. The values of expected carpools (Row 57), new carpools (Row 58), and adjusted freeway CLV (Row 59) are found by employing an iterative adjustment located in the "Iterations" section (Rows 120 to 132). Last, the values of CLV needed for the "Adjustments" section are computed for total general purpose (Row 61), express only general purpose (Row 62), non-express general purpose vehicles (Row 63), and carpools (Row 64).

The "Adjustments" section has the purpose of balancing the freeway, express, and HOV volumes based on various factors. The four adjustments on the values of CLV accomplished in this section are as follows:

- Adjusted CLV from the volume per lane versus Ridership Iteration (Row 68 to Row 72)—This correction takes the input value for freeway CLV and applies the predictive HOV ridership equation to find the number of new HOV riders that can be created. This correction utilizes the "Iterations" section which begins in Row 134 and continues until Row 172. Additional information is also referenced in this adjustment and is provided in Rows 174 to 182. The result is a freeway congestion level that is consistent with the HOV ridership value.

- Adjusted CLV for HOV Capacity (Row 75 to Row 81)—This modification examines the HOV CLV per lane and compares it to the listed capacity. If the capacity has been exceeded, carpool and bus passengers are "sent back" to the general purpose lanes in the occupancy rate specified in Row 20.

- Adjusted CLV for General Purpose Congestion (Row 84 to Row 90)—In some circumstances, new HOV riders are estimated even though freeway capacity is not exceeded. This adjustment "sends back" enough HOV riders to fill the general purpose freeway lanes to capacity.

- Adjusted CLV for Max Percent New Carpools (Row 93 to Row 97)—This adaptation is performed if the calculated percentage of new carpools exceeds the specified limit from

the inputs (Row 17). If this occurs, carpools are "sent back" to the general purpose lanes until the percentage is lowered to the maximum permitted.

- Adjusted CLV for Corridor (Row 100 to Row 115)—Knowing that carpools and bus ridership cannot be assembled and dispersed from section to section, this adjustment identifies the critical section of the corridor, and adjusts the HOV riders and bus passengers based on the critical section.

The final adjustments are used to develop the values in the "Outputs" section.

Summary

The CLV spreadsheet described in the preceding discussion was modified from its original form used in the "Dallas Freeway/HOV System Planning Study" report. Modifications to the organization were performed to provide a better understanding of the use of the spreadsheet and its output values. Other revisions that were included in the "Outputs" section of the spreadsheet are:

- Estimation of HOV ridership based on the new Texas relationship between directional hourly volume per lane and HOV ridership.

- Adjustment for maximum allowable new HOV users.

- Identification of truck volume in the critical general purpose lane volume

- Calculation of vehicle and person travel distance.

Other modifications can be made to the CLV Spreadsheet to meet particular needs. Caution must be employed, however, when altering the spreadsheet from its current form so that existing cell references are preserved.

A complete example CLV spreadsheet for an alternative of a hypothetical freeway corridor follows. This example corridor used five freeway sections in the spreadsheet. The first page of the spreadsheet shows the "Section Inputs" and "Outputs." The second page shows the "Calculations" and the "Adjustments." The last page shows the "Iterations."

A	A	B	C	D	E	F
1	22-Nov-95					
2	**Design Year:**	2015				
3	**Freeway:**	IH 99				
4	Alternative:	1	GP and HOV Alternative			
5	Freeway Section:	1	2	3	4	5
6	**Section Limits:**	I3W-U7	U7-I2	I2-S1	S1-IPKY	IPKY-EP
7	## Section Inputs:					
8	**Length (miles)**	2.60	0.57	2.34	1.30	0.75
9	**Freeway ADT**	260,000	252,000	250,000	216,000	144,000
10	**HOV ADT**	4,000	3,500	3,500	3,000	2,000
11	**Bus Person ADT**	12,000	10,000	10,000	8,000	4,000
12	**K**	0.090	0.090	0.090	0.090	0.090
13	**D**	0.57	0.57	0.57	0.57	0.57
14	**Percent Carpools**	0.15	0.15	0.15	0.15	0.15
15	**Percent Express**	0.30	0.30	0.30	0.30	0.30
16	**Capacity**	2,000	2,000	2,000	2,000	2,000
17	**Max % New Carpools**	100	100	100	100	100
18	**Bus Occupancy**	30.00	30.00	30.00	30.00	30.00
19	**Carpool Occupancy**	2.20	2.20	2.20	2.20	2.20
20	**GP Occupancy**	1.05	1.05	1.05	1.05	1.05
21	**GP Truck Percent**	0.03	0.03	0.03	0.03	0.03
22	## Number of Lanes Inputs:					
23	**General Purpose**	10	10	8	8	8
24	**Express**	0	0	0	0	0
25	**HOV**	1	1	1	1	0
26	## Ridership Equation:					
27	**Intercept**	(4.02)	(4.02)	(4.02)	(4.02)	(4.02)
28	**Coeff. DDHV/Lane**	0.010460	0.010460	0.010460	0.010460	0.010460
29						
30	## Outputs:					
31	Critical Lane Volume Outputs:					
32	General Purpose	2,017	1,979	2,471	1,983	1,667
33	Express	0	0	0	0	0
34	HOV	1,800	1,800	1,800	1,800	0
35	New Bus Passengers	1,587	1,331	1,128	1,110	580
36	General Purpose Auto	1,937	1,901	2,374	1,900	1,611
37	General Purpose Truck	80	78	96	83	55
38						
39	General Outputs:					
40	Vehicles	11,884	11,693	11,683	9,730	6,667
41	Persons	16,155	15,644	15,521	13,409	8,939
42	Occupancy	1.36	1.34	1.33	1.38	1.34
43	Veh Distance of Travel	30,897	6,665	27,337	12,650	5,000
44	Person Distance of Travel	42,003	8,917	36,318	17,432	6,704
45						

A	A	B	C	D	E	F
47	Calculations:	Alt:	1			
48	Sections	1	2	3	4	5
49	Capacity per Direction:					
50	General Purpose	10,000	10,000	8,000	8,000	8,000
51	Express	0	0	0	0	0
52	HOV	1,800	1,800	1,800	1,800	0
53						
54	Freeway CLV	13,338	12,928	12,825	11,081	7,387
55	HOV CLV (Demand)	1,000	875	875	750	500
56						
57	Expected Carpools	1,870	1,800	1,786	1,543	1,028
58	New Carpools	0	0	0	0	0
59	Adjusted Frwy CLV	13,338	12,928	12,825	11,081	7,387
60						
61	GP CLV	11,468	11,128	11,039	9,538	6,359
62	Express	4,001	3,878	3,847	3,324	2,216
63	GP Non Express	7,467	7,249	7,191	6,214	4,143
64	CP CLV	1,870	1,800	1,786	1,543	1,028
65						
66	Adjustments:					
67	Adjusted CLV from ADT/Lane vs Ridership Iteration					
68	ADT/Lane	25,270	24,406	29,540	25,896	17,813
69	General Purpose	10,020	9,625	8,486	7,953	7,387
70	HOV	2,333	2,217	2,313	1,916	0
71	New Bus Pass	477	629	1,449	803	0
72	Express	0	0	0	0	0
73						
74	Adjusted CLV for HOV Capacity					
75	GP	11,079	10,617	9,883	8,245	7,387
76	GP From Express	0	0	0	0	0
77	GP From HOV	1,041	874	1,075	244	0
78	GP From Bus	18	118	321	49	0
79	Express	0	0	0	0	0
80	HOV	1,800	1,800	1,800	1,800	0
81	New Bus Pass	459	510	1,128	754	0
82						
83	Adjusted CLV for General Purpose Congestion					
84	Total CLV	12,879	12,417	11,683	10,045	7,387
85	General Purpose	11,079	10,617	9,883	8,245	7,387
86	Express	0	0	0	0	0
87	HOV	1,800	1,800	1,800	1,800	0
88	% New Carpools	0	0	1	17	0
89	New Bus Pass	459	510	1,128	754	0
90	% New Bus Pass	16	25	58	40	0
91						
92	Adjusted CLV for Max % New Carpools					
93	Total CLV	12,879	12,417	11,683	10,045	7,387
94	General Purpose	11,079	10,617	9,883	8,245	7,387
95	Express	0	0	0	0	0
96	HOV	1,800	1,800	1,800	1,800	0
97	% New Carpools	0	0	1	17	0
98						
99	Adjusted CLV for Corridor					
100	% New Carpools	17	17	16	0	17
101	% New Bus Pass	42	33	0	18	58
102	New Carpools	312	300	284	0	172
103	New Bus Pass	1262	820	0	357	580
104	New Carpools	0	0	0	257	0
105	New Bus Pass	0	0	1128	0	0
106	Added Carpools	257	257	257	0	172
107	Added Bus Pass	1128	820	0	357	580
108	Total CLV	11561	11381	11401	9717	6667
109	General Purpose	9466	9297	9344	7906	6476
110	Express	0	0	0	0	0
111	HOV	2095	2085	2057	1812	191
112	Total CLV	11884	11693	11683	9730	6667
113	General Purpose	10084	9893	9883	7930	6667
114	Express	0	0	0	0	0
115	HOV	1800	1800	1800	1800	0

	A	B	C	D	E	F
118	**Iterations:**	**Alt:**		**1**		
119	Sections	1	2	3	4	5
120	Iteration for Expected Carpools:					
121	Iteration 1					
122	Expected Carpools	2,001	1,939	1,924	1,662	1,108
123	New Carpools	(1,001)	(1,064)	(1,049)	(912)	(608)
124	Freeway CLV	12,337	11,863	11,776	10,169	6,779
125	Iteration 2					
126	Expected Carpools	1,851	1,780	1,766	1,525	1,017
127	New Carpools	150	160	157	137	91
128	Freeway CLV	12,487	12,023	11,934	10,305	6,870
129	Iteration 3					
130	Expected Carpools	1,873	1,803	1,790	1,546	1,031
131	New Carpools	(23)	(24)	(24)	(21)	(14)
132	Freeway CLV	12,465	11,999	11,910	10,285	6,857
133						
134	Iteration for Adjustment to DHV from ADT/Lane vs Ridership:					
135	Total ADT	260,000	252,000	250,000	216,000	144,000
136	Daily Riders	20,800	17,700	17,700	14,600	8,400
137	GP ADT	256,000	248,500	246,500	213,000	142,000
138	Iteration 1					
139	ADT/Lane	25,600	24,850	30,813	26,625	17,750
140	HOV/Frwy ADT	0.10	0.09	0.13	0.10	0.06
141	Daily Riders	24,875	23,146	30,847	21,869	7,817
142	New Riders	4,075	5,446	13,147	7,269	(583)
143	SOV's Removed	4,075	5,446	13,147	7,269	(583)
144	GP ADT	251,925	243,054	233,353	205,731	142,583
145	Iteration 2					
146	ADT/Lane	25,192	24,305	29,169	25,716	17,823
147	HOV/Frwy ADT	0.09	0.09	0.12	0.10	0.06
148	Daily Riders	23,928	21,929	27,144	20,119	7,904
149	New Riders	(947)	(1,218)	(3,703)	(1,749)	88
150	SOV's Removed	(947)	(1,218)	(3,703)	(1,749)	88
151	GP ADT	252,872	244,271	237,056	207,481	142,496
152	Iteration 3					
153	ADT/Lane	25,287	24,427	29,632	25,935	17,812
154	HOV/Frwy ADT	0.10	0.09	0.12	0.10	0.06
155	Daily Riders	24,147	22,198	28,163	20,534	7,891
156	New Riders	218	269	1,020	415	(13)
157	SOV's Removed	218	269	1,020	415	(13)
158	GP ADT	252,653	244,002	236,037	207,066	142,509
159	Iteration 4					
160	ADT/Lane	25,265	24,400	29,505	25,883	17,814
161	HOV/Frwy ADT	0.10	0.09	0.12	0.10	0.06
162	Daily Riders	24,096	22,138	27,881	20,435	7,893
163	New Riders	(50)	(60)	(283)	(99)	2
164	SOV's Removed	(50)	(60)	(283)	(99)	2
165	GP ADT	252,704	244,062	236,319	207,165	142,507
166	Iteration 5					
167	ADT/Lane	25,270	24,406	29,540	25,896	17,813
168	HOV/Frwy ADT	0.10	0.09	0.12	0.10	0.06
169	Daily Riders	24,108	22,152	27,959	20,459	7,893
170	New Riders	12	13	78	23	(0)
171	SOV's Removed	12	13	78	23	(0)
172	GP ADT	252,692	244,048	236,241	207,141	142,507
173	Reference Information					
174	Bus Pass	12,000	10,000	10,000	8,000	4,000
175	Expected CP Pass	8,800	7,700	7,700	6,600	4,400
176	Percent CP	0.42	0.44	0.44	0.45	0.52
177	Percent Bus	0.58	0.56	0.56	0.55	0.48
178	CP Passengers	10,200	9,637	12,163	9,248	4,134
179	Bus Passengers	13,908	12,515	15,796	11,210	3,759
180	Pk Hr CP Pass	2,550	2,409	3,041	2,312	1,034
181	Pk Hr Bus Pass	3,477	3,129	3,949	2,803	940
182	Pk Hr CP	1,159	1,095	1,382	1,051	470

Cost Estimation Spreadsheet

The Cost Estimation spreadsheet is the second spreadsheet used as part of the "Dallas Freeway/HOV System Planning Study" report, to aid system-wide planning. This spreadsheet uses the outputs from the Critical Lane Volume (CLV) spreadsheet to obtain the cost of construction and congestion for each section of several alternative configurations of a freeway corridor.

The Cost Estimation spreadsheet is designed to allow the user to estimate input parameters, for each section of corridor, to arrive at the total cost for each alternative. There are four worksheets in the Cost Estimation spreadsheet (worksheet A, B, C, and D). The inputs and outputs to the Cost Estimation spreadsheet are contained in worksheet A, and the emission and fuel consumption calculations can be found in worksheet B. Worksheet C contains the emission and fuel consumption factors for Dallas Fort Worth. Worksheet D contains the calculations for non-recurrent congestion cost. The user only needs to input values into worksheet A, and read the results from worksheet A, though the factors in worksheet C can be replaced if better factors are available.

The following procedure identifies the inputs to the Cost Estimation spreadsheet. Before inputting values into this spreadsheet, the user should have completed the CLV spreadsheet. It should be noted that the cell references made in the following instructions, correspond to columns and rows of worksheet A which is shown on the first page of the example cost estimation spreadsheet. The cell references can also be found in worksheet A of the Quattro Pro file "COSTX5D.WB2." This file is saved on the floppy disc as "COSTEXMP.ZIP." It can be uncompressed using the "PKUNZIP" utility file also contained on the floppy disc. At the DOS prompt type "PKUNZIP COSTEXMP.ZIP C:" or any other target directory. The green and blue shaded cells indicate cells in which input values are necessary. The cells shaded in yellow may be changed from the default values.

- **Enter the corridor name in Cell C7.** The corridor name should correspond with Row 3 of the CLV spreadsheet.

- **Enter the cost ($) per hour of person time (Cell B9), the cost ($) per hour of truck time in congestion (Cell B10), and the cost ($) of fuel per volume (Cell B11).** The default values for these parameters are: $11.31 per hour of person time, $60.00 per hour of truck time, and $1.05 per gallon ($0.28 per liter) for fuel.

- **Enter the control-cost based emission factors ($/kg) for VOC, CO, and NO$_X$ in Cell I8, I9, and I10, respectively.** The control-cost based emission factors represent the cost ($) to control a kilogram (kg) of each emission. The default values for these parameters are: $12.97 per kg of VOC, $2.51 per kg of CO, and $13.68 per kg of NOx.

- **Describe the alternative in Column B.** Each block of values corresponds to an alternative being studied; therefore, a different description should be used in Column B for each block. This entry should identify the alternative being tested (i.e., 6 GP lanes & 1 HOV lane) and be the same as Row 4 of the CLV spreadsheet.

- **Record the endpoint markers of all the continuous sections along the corridor in Column C.** Each section denotes major changes in traffic volume, length, number of lanes, or other vehicle movement influencing factors. Each section should be entered as a separate row in Column C and should correspond to the section limits in Row 6 of the CLV spreadsheet. The number of sections in a corridor is unlimited; however, the number of rows will have to be increased to the specified number of sections in the corridor by inserting the needed number of blank rows and copying the preceding row in the block multiple times. This step will need to be repeated for each alternative, as well as for each corresponding alternative in worksheet B and D. The information will be automatically duplicated in each consecutive alternative as well as for the corresponding alternatives in worksheet B and D. None of the equations should need to be changed if sections are added for each alternative.

- **Develop and input sectional information (Columns D to O).**
  Column D Length AtGrd—Length of freeway section at grade.
  Column E Length Elev—Length of freeway section elevated. The sum of Column D and Column E, for each section, should be the total length of the section.
  Column F Existing Lanes—Number of lanes in the existing section.

- **Proposed Lanes: Columns G through K refer to the proposed alternative.**
  Column G General Purpose—Number of proposed general purpose lanes.
  Column H Express AtGrd—Proposed number of express lanes at grade.
  Column I Express Elev—Number of proposed elevated express lanes.
  Column J HOV AtGrd—Number of proposed HOV lanes at grade.
  Column K HOV Elev—Proposed number of elevated HOV lanes.

- **Critical Lane Volume: Columns L through N.** The critical lane volume is the number of vehicles in the peak direction during the peak hour of the day.

  Column L GP—Critical lane volume of the general purpose lanes. This value is taken from the output (Row 32) of the CLV spreadsheet.

  Column M Exp—Critical lane volume of the express lanes. The critical lane volume of the express lanes is taken from the CLV spreadsheet output (Row 33).

  Column N HOV-Critical lane of the HOV lanes. This value is taken from the output of the CLV spreadsheet (Row 34).

  Column O Transit Riders-The number (persons) of transit riders. The transit riders are calculated from two values from the CLV spreadsheet, the Bus Person ADT (Row 11) and the New Bus Passengers (Row 35). **Transit Riders is equal to (Bus Person ADT)/4 + New Bus Passengers.**

  Column R O&M Cost ($M)-Operating and Maintenance cost (millions of dollars). This parameter needs to be entered **only one time per alternative,** according to the following table.

Lane Type	O&M Cost
Basic	$0.10
Reversible lanes	$0.35
Reversible HOV lanes	$0.45

- **Truck Volumes: Column AO.** Enter the section truck volume (Row 37) from the CLV spreadsheet output.

- **ROW calculations: Columns AW through AY.** The minimum right of way needed for each alternative and its cost is estimated.

  Column AW Base ROW (unit of width)—the average width of the existing ROW for each section of the freeway corridor.

  Column AX Existing F.R. Lanes—the existing number of frontage road lanes for each section of the freeway corridor. This spreadsheet only calculates the cost of new frontage roads where the frontage road currently exists and where additional ROW is needed. If no additional ROW is needed, it is assumed that the frontage roads are not relocated or reconstructed.

  Column AY ROW Cost $/Area—The average cost in dollars per area for additional ROW for each section of the freeway corridor.

- **Construction Costs: Columns BJ through BO.** The at-grade construction costs per unit of distance are located in Columns BJ through BL, and the elevated structure construction costs per mile are located in Columns BM through BO. The default values can be used, so these values do not have to be changed.

  Column BJ GP ($M)—At-grade construction cost (million $) of a general purpose lane per unit of distance per lane. The default value is $2.5 million per mile ($4.0 million per km) per lane.

  Column BK Exp ($M)—Construction cost (million $) per unit of distance per lane of at-grade express lane. The default value is $3 million per mile ($4.8 million per km) per lane for one or two at-grade express lanes, and $3.33 million per mile ($5.36 million per km) per lane for three or more at grade express lanes.

  Column BL HOV ($M)—Construction cost (million $) per lane per unit of distance of at-grade HOV lane. The default value is $5 million per mile ($8.0 million per km) per lane for one at-grade express lane, and $3.5 million per mile ($5.6 million per km) per lane for two or more at-grade HOV lanes.

  Column BM GP ($M)—Construction cost (million $) per unit of distance per lane of elevated general purpose lane. The default value is $3.5 million per mile ($5.6 million per km) per lane.

  Column BN Exp ($M)—Construction cost (million $) per unit of distance per lane of elevated express lane. The default value is $4.5 million per mile ($7.2 million per km) per lane for one or two elevated express lanes, and $5 million per mile ($8.0 million per km) per lane for three or more elevated express lanes.

  Column BO HOV ($M)—Construction cost (million $) per unit of distance per lane of elevated HOV lane. The default value is $7 million per mile ($11.3 million per km) per lane for one elevated HOV lane, and $5 million per mile ($8.0 million per km) per lane for two or more elevated HOV lanes.

- **Noise Wall Costs: Columns BQ and BR.** The costs of constructing noise walls per unit distance is given in column BQ, and the percent of the section length requiring noise walls is input in column BR.

Column BQ Noise wall costs ($M)—construction cost (million $) per unit of distance to construct noise walls where required. The default value is $1.09 million per mile ($0.68 million per km) per lane.

Column BR Percent of section requiring noise walls—the percent of the length of each section which requires noise walls. This value is assumed to be the same for each alternative, but it can be changed if necessary.

- **Rehabilitation Cost:** The last block of values in the spreadsheet (Row 90) gives the cost to rebuild or rehabilitate the existing freeway. This block is identified by 'X' in Column A and 'Rehabltn' in Column B. Zero lanes are input in Column F and the existing number of lanes or input in the proposed General Purpose lane column—Column G. There are no volumes to input in this alternative block. The cost estimated for this alternative is the construction cost that is common to each alternative.

The spreadsheet will perform all the calculations, when prompted by pressing the function key F9, necessary to estimate the total cost for each alternative. It is important for the user to determine the reasonableness of the output from the spreadsheet.

Description of Output Variables

The outputs of the Cost Estimation spreadsheet can be divided into four sections: construction and operating cost, congestion cost, emissions cost and fuel consumption cost. The total cost (Column X) is the sum of construction cost (Column P), right-of-way cost (Column Q), Operation and Maintenance cost (Column R), peak hour general purpose congestion cost (Column S), total general purpose congestion cost (Column T), non-recurrent congestion cost (Column U), emissions cost (Column V), and fuel consumption cost (Column W).

The fuel consumption and emissions calculations are located in worksheet B. The fuel consumption and emissions output is for the peak period peak direction of flow, and includes the following in addition to the section, lane and volume inputs from worksheet A:

Column O VOC—Kilograms of VOC emissions per day

Column P CO—Kilograms of CO emission per day

Column Q NO_x—Kilograms of NO_x emissions per day

Column R Fuel consumption—Volume of fuel consumption per day

Column S Emissions—Cost ($) of emissions per day

Column T Energy—Cost ($) of fuel consumption per day

The non-recurrent congestion calculations are located in worksheet D. The peak period peak direction non-recurrent congestion cost in dollars is shown in columns P, Q, and R. Column S shows the annual cost (millions $) of non-recurrent congestion. This value is the same as shown in column U of Worksheet A.

Column P GP—Cost ($) of non-recurrent congestion for the peak period peak direction general purpose lanes.

Column Q Exp—Cost ($) of non-recurrent congestion for the peak hour peak direction express lanes.

Column R HOV—Cost ($) of non-recurrent congestion for the peak hour peak direction HOV lanes.

Summary

The Cost Estimation spreadsheet, described in the preceding section, allows the user to compare alternatives for a freeway corridor, based upon total cost, fuel consumption, and emissions output. This spreadsheet can be modified from the original format to allow the user to base the alternative comparisons on additional parameters; however, caution must be employed when altering the spreadsheet from its current form such that the existing cell references are preserved.

Example of the Non-recurrent Congestion Cost Calculations:

Listed below are the steps used to calculate the non-recurrent congestion cost in the Cost estimation spreadsheet described above. Following the steps are two example calculations of non-recurrent congestion cost that are discussed on page 37 of the report.

Incorporation of Nonrecurrent Congestion into Cost Estimation Spreadsheet
A. Using Figure 5 and calculated speeds per section, determine vehicle-distance per incident.
B. Determine vehicle-distance per hour for sections under analysis.
C. Divide B by A to determine number of incidents per hour.

D. Obtain percent reduction in freeway capacity from Table 6 based on number of lanes.

E. Multiply D x 2200 vph (2300 for freeways greater than four lanes) to reach a per lane capacity reduction value per incident.

F. Subtract E from the assumed capacity to reach a diminished capacity.

G. Utilize F to arrive at adjusted speeds using Figure 4.

H. Check Figure 5 to determine whether adjusted speed (G) alters the incident frequency, and iterate.

I. Calculate delay per incident.

J. Multiply the delay per incident (I) by the number of incidents per hour (C) to arrive at the delay per hour.

K. Calculate the cost based on the delay per hour.

Example 1: 4 lanes (peak direction), carrying 1900 vphpl at the critical point in a 3 mile (4.8 km) section.

A. From Figure 4, the speed estimate is 58 mph (93 kph), which is in the incident frequency range of one incident per 25,000 veh-miles (40,000 veh-km), from Figure 5.

B. 1900 vphpl x 4 lanes x 3 miles (4.8 km) = 22,800 veh-miles (36,700 veh-km), per hour.

C. 22,800 veh-miles (36,700 veh-km)/25,000 veh-miles (40,000 veh-km) per incident = 0.9 incidents per peak hour.

D. From Table 6, 15% is the expected capacity reduction for the average incident on a 4 lane (per direction) freeway.

E. 15% reduction in capacity for the hour; 15% x 2300 vphpl = 330 vphpl capacity loss.

F. 2300 vphpl - 330 vphpl = 1970 vphpl capacity (adjusted).

G. 1900 vphpl demand/1970 vphpl capacity = 0.96 v/c. From Figure 4, a speed of 48 mph (77 kph) is expected.

H. Figure 5 indicates that the adjusted speed also has an incident frequency of 1 per 25,000 veh-miles (40,000 veh-km).

I. 48 mph (77 kph) should be used to calculate the delay per incident. This will add an average of 82 vehicle hours of nonrecurrent delay per incident, over the three mile section.

80

J. 82 vehicle hours per incident multiplied by 0.9 incidents per hour equals 74 vehicle hours of delay per hour.

Example 2: 4 lanes (peak direction), 3 miles (4.8 km) long, carrying 2350 vphpl in the critical section.

A. Figure 4, speed = 30 mph (48 kph); Figure 5, one incident per 22,000 veh-miles (35,400 veh-km).

B. 2350 vphpl x 4 lanes x 3 miles (4.8 km) = 28,200 veh-miles (45,400 veh-km) in the peak hour.

C. 28,200 veh-miles (45,400 veh-km)/22,000 veh-miles (35,400 veh-km) per incident = 1.28 incidents per peak hour.

D. From Table 6, 15% reduction in capacity per incident for a four lane section.

E. 15% reduction in capacity for the hour; 15% x 2300 vphpl = 330 vphpl capacity loss.

F. 2300 - 330 = 1970 vphpl, adjusted capacity.

G. 2350 vphpl demand/1970 vphpl capacity = 1.19 v/c, failure. Freeway speeds will drop to 15 mph (24 kph), and overflow will use alternate routes at 15 mph (24 kph).

H. Checking Figure 5 gives an adjusted incident frequency of one per 16,700 veh-miles (26,900 veh-km).

I. 1970 x 4 lanes x 3 miles = 23,640 veh-miles (38,000 veh-km) on the freeway; 4,560 veh-miles (7,400 veh-km) on arterials.

J. 23,640/16,700 = 1.42 incidents per peak hour on the freeway at 15 mph.

K. 15 mph (24 kph) should be used to calculate the delay per incident. This will add an average of 940 vehicle hours of nonrecurrent delay per incident, over the three mile section.

L. 940 vehicle hours per incident multiplied by 1.42 incidents per hour equals 1330 vehicle hours of delay per hour.

Cost Estimation Spreadsheet   Worksheet A

Input the system of units SI or US   US

Corridor Name: Example
2400 Vehicles per Hour - Ultimate Capacity $12.97 kg of VOC
$11.31 1995 Value of Person Time $2.51 kg of CO
$60.00 1995 Value of Truck Time $13.68 kg of NOx
$1.05 Gallon of Fuel

Alternative 1 — No Action

Section	Length Miles AtGrd	Length Miles Elev	Existing Lanes	General Purpose	Express AtGrd	Express Elev	HOV AtGrd	HOV Elev	Critical Lane Volume GP	Exp	HOV	Transit Riders Persons	Constrctn Cost ($M)	R.O.W. Cost ($M)	O&M Cost ($M)	Pk Hour Congstn Cost ($M)	Total Congstn Cost ($M)	Nonrecrnt Congstn Cost ($M)	Emissions Cost ($M)	Fuel Consmptn Cost ($M)	Total Cost ($M)
A - B	2.80	0.20	8	8	0	0	0	0	1900	0	0	300	$0.14	$0.00	$0.10	$0.05	$0.05	$0.45	$3.59	$1.66	$5.99
B - C	3.80	0.20	8	8	0	0	0	0	1900	0	0	300	$0.21	$0.00	$0.00	$0.06	$0.06	$0.80	$4.79	$2.22	$8.08
C - D	3.00	0.30	6	6	0	0	0	0	3000	0	0	800	$0.20	$0.00	$0.00	$2.88	$9.44	$2.95	$5.03	$2.32	$19.93
D - E	2.00	0.50	6	6	0	0	0	0	4000	0	0	1000	$0.17	$0.00	$0.00	$2.32	$17.40	$0.00	$5.05	$2.15	$24.77
E - F	0.00	0.50	6	6	0	0	0	0	2000	0	0	750	$0.05	$0.00	$0.00	$0.02	$0.02	$0.08	$0.46	$0.22	$0.83
Subtotal	13.3												$0.76	$0.00	$0.10	$5.33	$26.97	$4.28	$18.92	$8.57	$59.60
														$0.86			$31.25				

Alternative 2 — All Gen Purp

Section	Length Miles AtGrd	Length Miles Elev	Existing Lanes	General Purpose	Express AtGrd	Express Elev	HOV AtGrd	HOV Elev	Critical Lane Volume GP	Exp	HOV	Transit Riders Persons	Constrctn Cost ($M)	R.O.W. Cost ($M)	O&M Cost ($M)	Pk Hour Congstn Cost ($M)	Total Congstn Cost ($M)	Nonrecrnt Congstn Cost ($M)	Emissions Cost ($M)	Fuel Consmptn Cost ($M)	Total Cost ($M)
A - B	2.80	0.20	8	10	0	0	0	0	1520	0	0	300	$1.12	$0.00	$0.10	$0.00	$0.00	$0.00	$3.71	$1.68	$6.62
B - C	3.80	0.20	8	10	0	0	0	0	1520	0	0	300	$1.52	$0.00	$0.00	$0.00	$0.00	$0.00	$4.95	$2.24	$8.71
C - D	3.00	0.30	6	10	0	0	0	0	1800	0	0	800	$2.39	$0.00	$0.00	$0.00	$0.00	$0.34	$4.84	$2.19	$9.75
D - E	2.00	0.50	6	14	0	0	0	0	1714	0	0	1000	$6.02	$0.24	$0.00	$0.00	$0.00	$0.13	$4.89	$2.21	$13.49
E - F	0.00	0.50	6	8	0	0	0	0	1500	0	0	750	$0.59	$0.03	$0.00	$0.00	$0.00	$0.00	$0.49	$0.22	$1.34
Subtotal	13.3												$11.65	$0.27	$0.10	$0.00	$0.00	$0.47	$18.88	$8.54	$39.90
														$12.02			$0.47				

Alternative 3 — Gen Purp & Express

Section	Length Miles AtGrd	Length Miles Elev	Existing Lanes	General Purpose	Express AtGrd	Express Elev	HOV AtGrd	HOV Elev	Critical Lane Volume GP	Exp	HOV	Transit Riders Persons	Constrctn Cost ($M)	R.O.W. Cost ($M)	O&M Cost ($M)	Pk Hour Congstn Cost ($M)	Total Congstn Cost ($M)	Nonrecrnt Congstn Cost ($M)	Emissions Cost ($M)	Fuel Consmptn Cost ($M)	Total Cost ($M)
A - B	2.80	0.20	8	8	2	0	0	0	1267	1267	0	300	$1.33	$0.00	$0.35	$0.00	$0.00	$0.00	$3.25	$1.47	$6.40
B - C	3.80	0.20	8	8	2	0	0	0	1267	1267	0	300	$1.79	$0.00	$0.00	$0.00	$0.00	$0.00	$4.33	$1.96	$8.08
C - D	3.00	0.30	6	6	2	0	0	0	1800	1800	0	600	$1.52	$0.00	$0.00	$0.00	$0.00	$1.05	$4.45	$2.01	$9.04
D - E	2.00	0.50	6	8	0	2	0	0	2000	2000	0	1000	$2.47	$0.00	$0.00	$0.18	$0.18	$2.61	$4.38	$2.07	$11.71
E - F	0.00	0.50	6	8	0	0	0	0	1500	0	0	750	$0.59	$0.03	$0.00	$0.00	$0.00	$0.00	$0.49	$0.22	$1.34
Subtotal	13.3												$7.70	$0.03	$0.35	$0.18	$0.18	$3.66	$16.90	$7.73	$36.57
														$8.09			$3.85				

Texas Transportation Institute

Corridor Name: Example

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Alternative 4: Gen Purp & HOV 2+

Alternative	Section	Length Miles AtGrd	Length Miles Elev	Existing Lanes	General Purpose	Express AtGrd	Elev	HOV AtGrd	Elev	Crit GP	Exp	HOV	Transit Riders Persons	Constrctn Cost ($M)	R.O.W. Cost ($M)	O&M Cost ($M)	Pk Hour Congstn Cost ($M)	Total Congstn Cost ($M)	Nonrecrnt Congstn Cost ($M)	Emissions Cost ($M)	Fuel Consmptn Cost ($M)	Total Cost ($M)
4 Gen Purp & HOV 2+	A - B	2.80	0.20	8	8	0	0	1	0	1650	0	1000	400	$1.12	$0.00	$0.45	$0.00	$0.00	$0.05	$3.59	$1.62	$6.84
	B - C	3.80	0.20	8	8	0	0	1	0	1650	0	1000	400	$1.52	$0.00	$0.00	$0.00	$0.00	$0.09	$4.79	$2.17	$8.56
	C - D	3.00	0.30	6	6	0	0	2	0	1900	0	1200	800	$1.81	$0.00	$0.00	$0.04	$0.04	$0.79	$4.04	$1.86	$8.54
	D - E	2.00	0.50	6	8	0	0	2	0	1900	0	2000	1400	$2.38	$0.00	$0.00	$0.09	$0.09	$1.27	$4.25	$1.99	$9.98
	E - F	0.00	0.50	6	6	0	0	0	0	1800	0	0	1000	$0.05	$0.00	$0.00	$0.00	$0.00	$0.01	$0.44	$0.20	$0.69
		13.3											Subtotal	$6.88	$0.00	$0.45	$0.12	$0.12	$2.20	$17.11	$7.84	$34.60
															$7.33			$2.33				

Alternative 5: Gen Purp & HOV 3+

Alternative	Section	Length Miles AtGrd	Length Miles Elev	Existing Lanes	General Purpose	Express AtGrd	Elev	HOV AtGrd	Elev	Crit GP	Exp	HOV	Transit Riders Persons	Constrctn Cost ($M)	R.O.W. Cost ($M)	O&M Cost ($M)	Pk Hour Congstn Cost ($M)	Total Congstn Cost ($M)	Nonrecrnt Congstn Cost ($M)	Emissions Cost ($M)	Fuel Consmptn Cost ($M)	Total Cost ($M)
5 Gen Purp & HOV 3+	A - B	2.80	0.20	8	8	0	0	1	0	1800	0	400	300	$1.12	$0.00	$0.45	$0.00	$0.00	$0.18	$3.67	$1.66	$7.09
	B - C	3.80	0.20	8	8	0	0	1	0	1800	0	400	300	$1.52	$0.00	$0.00	$0.00	$0.00	$0.35	$4.90	$2.22	$8.99
	C - D	3.00	0.30	6	8	0	0	1	0	2050	0	800	600	$2.39	$0.00	$0.00	$0.21	$0.21	$5.01	$4.51	$2.11	$14.23
	D - E	2.00	0.50	6	10	0	0	1	0	2100	0	1500	1000	$2.76	$0.00	$0.00	$0.27	$0.27	$5.01	$4.54	$2.13	$14.71
	E - F	0.00	0.50	6	6	0	0	0	0	2000	0	0	750	$0.05	$0.00	$0.00	$0.02	$0.02	$0.08	$0.46	$0.22	$0.83
		13.3											Subtotal	$7.84	$0.00	$0.45	$0.49	$0.49	$10.64	$18.09	$8.34	$45.85
															$8.29			$11.13				

Alternative X: Rehabilitation Cost

Alternative	Section	Length Miles AtGrd	Length Miles Elev	Existing Lanes	General Purpose	Express AtGrd	Elev	HOV AtGrd	Elev	Crit GP	Exp	HOV	Transit Riders Persons	Constrctn Cost ($M)	R.O.W. Cost ($M)	O&M Cost ($M)	Pk Hour Congstn Cost ($M)	Total Congstn Cost ($M)	Nonrecrnt Congstn Cost ($M)	Emissions Cost ($M)	Fuel Consmptn Cost ($M)	Total Cost ($M)
X Rehabilitation Cost	A - B	2.80	0.20	0	6	0	0	0	0	0	0	0	0	$3.05	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3.05
	B - C	3.80	0.20	0	6	0	0	0	0	0	0	0	0	$4.05	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$4.05
	C - D	3.00	0.30	0	6	0	0	0	0	0	0	0	0	$3.39	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3.39
	D - E	2.00	0.50	0	6	0	0	0	0	0	0	0	0	$2.67	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2.67
	E - F	0.00	0.50	0	6	0	0	0	0	0	0	0	0	$0.69	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.69
		13.3											Subtotal	$13.85	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$13.85
															$13.85			$0.00				

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