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16. Abstract

The metropolitan transportation organizations in the eight largest metro regions of Texas and the Texas Department of Transportation jointly developed a process to investigate the congestion resulting from a range of investment levels. Part of this process, the Texas Metropolitan Mobility Plan, was the development of a set of performance measures. The measures are based on calculations from the long-range planning model output data. The same procedures used in air quality analyses are applied to congestion estimates. The measures are based on travel time information and comparisons with freeflow travel speeds. The Texas Congestion Index is a comparison of the travel condition during the peak period to the travel time in freeflow. The procedures provide a method to estimated benefits from a range of operational treatments to provide a more robust set of performance measures. A set of spreadsheets and training materials are also available.

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Anthony Simmons and David Schrank of the Texas Transportation Institute, College Station, produced the predicting travel reliability appendix for use in the Texas Congestion Index process.

TABLE OF CONTENTS

Page

Page

LIST OF EXHIBITS

INTRODUCTION

Researchers developed the Texas Congestion Index (TCI) as a part of the Texas Department of Transportation's (TxDOT's) Metropolitan Mobility Program (TMMP) from 2003 to 2005. TMMP seeks to broaden the understanding of transportation needs and goals in Texas' larger cities. The current federally mandated transportation planning process develops a financially constrained plan—essentially a list of the projects, programs and policies that will be funded over the next 20+ years to address congestion and mobility needs within the larger context of regional goals. There is no requirement, however, to develop a list of strategies that would be pursued if more funding or different funding arrangements were available. TMMP standardizes the process for developing mobility goals and the strategies used by each area to meet their locally determined goals.

The process and calculation procedures described in this report are the first generation of an evolving process and program. The research team designed the measures and calculation procedures to develop a set of comparable values for the eight largest metropolitan areas in Texas. These procedures—the method used to analyze the transportation planning models and the performance measures themselves—may change over the next few years. There will be more experience with the analytical components of the model, the process of using the outputs, understanding from the public and the decision-makers, as well as advances in the data sources, estimation and calculation procedures. This experience will lead to changes in the process described in this report.

This report describes the basic concepts and the calculation procedures that are included in a spreadsheet program designed to work with the long-range transportation planning models for each area. A companion slide show and workbook provide more information for those interested in the specific detail of the calculation process.

The Texas Metropolitan Mobility Program addresses eight goals:

- relieve congestion,
- improve safety,
- improve air quality,
- improve quality of life,
- improved opportunities for enhanced economic development,

- enhance infrastructure maintenance,
- streamline project delivery, and
- incorporate TxDOT strategic goals.

Congestion is only one of the eight goals, but because it is one of the few with a comprehensive measurement process at this early stage, there may be a temptation to regard congestion reduction or management as the primary goal. There will be similar measurement techniques or processes developed for the other goals to provide a broader set of measures for use in determining the proper mix of projects, programs, or policies to include in the long-range plans.

Concept Overview

The Texas Congestion Index is both a performance measure and a set of techniques and procedures. The measure provides information about both person and freight movement and illustrates the effect of most of the urban transportation improvement actions and land use pattern changes. The index is relatively easy to compute, understand, and communicate to a wide variety of audiences. While a single index can obscure some elements or characteristics, the Texas Congestion Index process also includes data to develop several other more focused measures or indices aimed at assessing various elements of metropolitan transportation services. Corridor and subarea analyses, for example, should be used for selecting specific projects, programs, policies, or strategies. Measures similar to the TCI can be used as one element of a prioritization process, but other goals such as air quality, safety, economic development, economic justice, and others are also part of the consideration.

The Texas Congestion Index methodology was initially applied to the eight largest Texas metropolitan areas. Long-range planning models are the best tool for developing the Texas Congestion Index. The procedures also allow for estimates to be produced from generally available roadway, rail, freight, and public transportation data including inventory, performance, and operations databases. The Texas Congestion Index is designed to be part of a long-range vision-oriented planning and funding process. The Index evaluates the programs and strategies that are pursued to accomplish mobility objectives, but it is not designed to replace existing tools or procedures or to be the only measure relevant to funding considerations.

For a more complete assessment of congestion in urban Texas, the TCI might be enhanced by growth and density dimensions, economic and employment impacts, freight logistics dynamics, transportation security elements, regional transportation policies, construction and maintenance activity, and several other factors. The essential point is that congestion relief, prevention, and mitigation expenditures should be evaluated in terms of their effects upon a fully enhanced index. A comprehensive and inclusive Texas Congestion Index is more likely to properly evaluate the relative costs, benefits, implementation steps, and political acceptability of proposed transportation improvements, operating strategies, incentives or other programs.

Developing the Texas Congestion Index

The Texas Department of Transportation, in the initial Breaking the Gridlock report (*1*), identified a need for a single congestion measure that addressed the transportation of persons and freight by all modes within the major metropolitan areas of the state. The measure would show the effect of many strategies to relieve congestion by all agencies and the private sector, and should be useable for current or future year conditions. The intent was to use the measure to examine a range of geographical areas from the entire metropolitan area, to sub-regions, corridors, and individual projects. The major congestion reduction techniques used in the areas were to be included.

Congestion and delay are defined in terms of travel time. Average travel time is a well-accepted transportation measure, and it can be estimated or measured directly. Travel time is also a key element in many transportation-related decisions. Major decisions such as location of homes, offices, and shops are partly determined by travel time. Many everyday decisions such as travel mode are also determined by travel time expectations. Travel time reliability is another concept that has been recognized as important. Until recently, however, reliability has been very difficult to measure. The variation in travel time requires much more detailed measurements than are typically required for average measurements.

The joint working group of staff from the metropolitan planning organizations (MPOs) and local TxDOT offices developed the following goal statement for the metropolitan congestion reduction program.

Eliminate Serious Congestion by 2025. This congestion level is not "zero congestion." The optimum congestion concept is a combination of factors including expectations of the residents, businesses, and travelers in the area and realistic assessments of the solution alternatives. Optimum congestion also allows for differences between congestion at a place such as a major job center, and congestion between activity areas or between job centers and homes.

- Job center congestion is the result of activity density. It typically covers a smaller area, imposes a shorter travel time penalty, and in most cases has a variety of solutions including walking, biking, shuttle vehicles, schedule changes, etc. Many of these solutions will be difficult to include in a congestion index, so the targets must be adjusted.
- Congestion "between" areas imposes a more significant travel time penalty and brings with it unreliable travel conditions. The congestion causes both travel time penalties and business or personal decisions that have a significant effect on the economy, land use patterns, and social structures.

PERFORMANCE MEASURE CALCULATION

The Texas Congestion Index is a variation in the Travel Time Index developed by the Texas Transportation Institute in the Urban Mobility Report (*2*). This index compares the travel time in the peak period to the travel time that would be required for the same travel at freeflow speeds. The index value is a ratio that identifies the travel time penalty for peak period congestion. The practical minimum value is 1.0, where the travel time is the same as it would be at freeflow conditions. A value of 1.3, for example, indicates that a peak period trip requires 30 percent more time than the same trip at freeflow speeds—a 20 minute off-peak trip would require 26 minutes in the peak.

The Texas Congestion Index is an extension of the Travel Time Index concept. It measures both freight and person movement, assesses the contribution of roads and public transportation services and operational efficiency improvements, as well as the effects of land use pattern changes.

General Model Structure

The congestion index statistics are generated using the transportation planning models and procedures that have been developed to estimate mobile source emissions. The specific Texas Congestion Index formula is a new element, but the data and supporting analyses are a combination of the long-range transportation planning model, post-processing steps for model outputs, and other procedures necessary to estimate current and future urban congestion conditions either not included in a model or for locations where current models are not available. The chosen form uses a "modally oriented" construction of the index (Exhibit 1) that includes both person and freight travel, although one that does not require continual monitoring of the rail freight network but does allow freight project benefits to be included. Exhibit 2 illustrates an outline of the information flows in the process. Additional discussion of the model is subsequently included.

Exhibit 1. General Model Structure

The Texas Congestion Index (TCI) will be a weighted average of the travel time value (a ratio of the value of person and truck travel time during the peak period to travel time value at freeflow speeds). The ratio shows the time penalty for travel during the peak periods. Estimates of both recurring delay and incident delay will be made, and delay reductions will be estimated for actions that improve the operation of the transportation network. A separate index will be calculated for person movement and for freight movement; the resulting indices will be combined using the value of the travel time (Current estimates—$13 per person hour and $68 per truck hour).

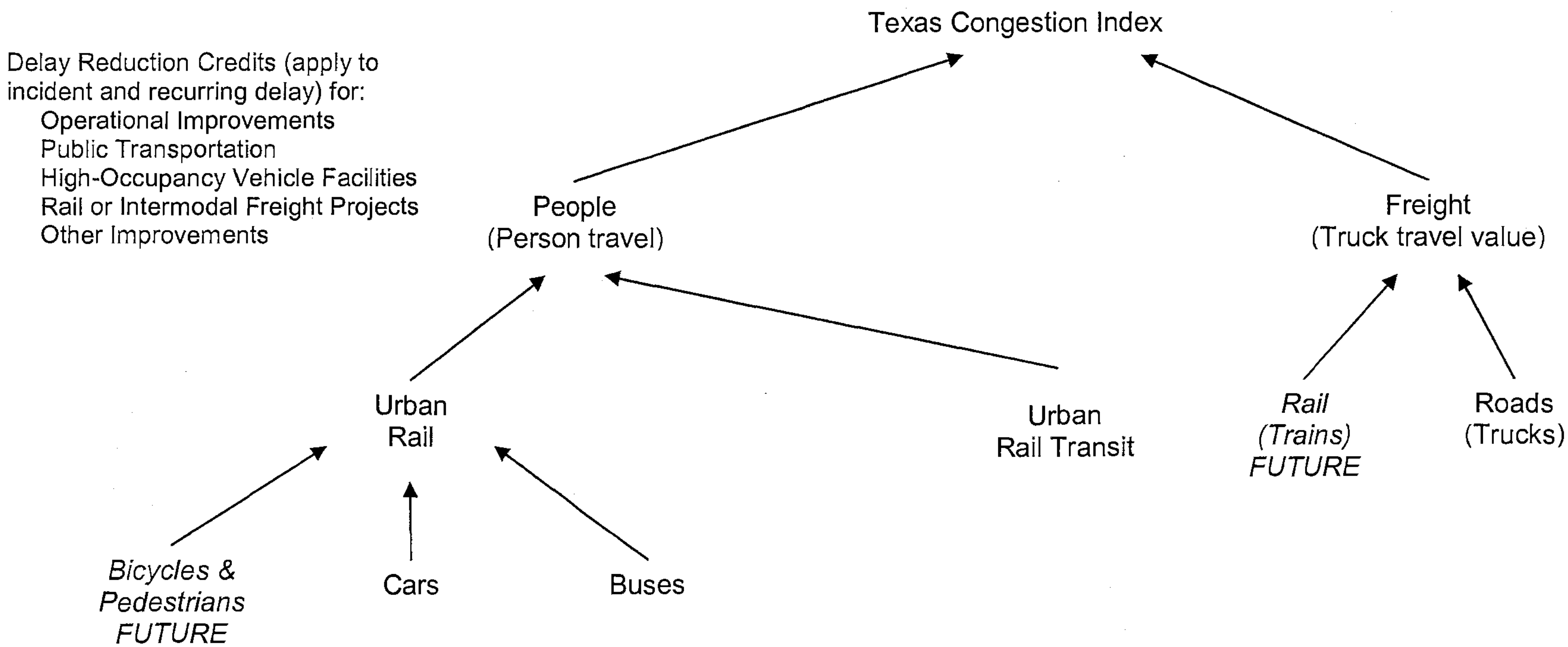


Exhibit 2. Texas Congestion Index Information Flow

- **Step 1: Remove travel demands served by other modes**
  - ✓ Reduce the roadway demand to identify benefits from public transportation service, pedestrians, bicycles and freight rail improvements

- **Step 2: Use long range planning models**
  - ✓ Produce travel volume and speed data for peak periods *(for freeways, principal arterial streets; for trucks and passenger vehicles)*

- **Step 3: Create a comparison baseline**
  - ✓ Calculate freeflow speed to identify the beginning of congested conditions

- **Step 4: Add extra delay from incidents, weather**
  - ✓ Estimate additional delay not included in the planning models

- **Step 5: Benefits from operations treatments**

  Estimate reduction in hours of delay due to:
  - ✓ Traffic signal coordination
  - ✓ Arterial street access management
  - ✓ Freeway ramp metering
  - ✓ Freeway incident management

- **Step 6: Benefits from other mobility improvements**
  - ✓ High-occupancy (HOV) vehicle lanes
  - ✓ Freight rail improvements

- **Step 7: Texas Congestion Index and other measures**
  - ✓ Combine morning and evening peak period estimates
  - ✓ Include value of time—$13 per person-hour; $68 per truck-hour
  - ✓ $$\begin{array}{c}\textit{Texas}\\ \textit{Congestion}\\ \textit{Index}\end{array} = \frac{\textit{Peak Period Travel Time Value (Dollars)}}{\textit{Freeflow Travel Time Value (Dollars)}}$$
  - ✓ Delay per person – Annual extra hours of travel time per person in the modeled region
  - ✓ Areawide total delay
  - ✓ Emissions index – ratio of mobile emissions in 2000 to those in 2025

Long-range planning models serve as the basis for the person and freight movement components. The calculation procedures performed on the model output statistics to estimate the actual travel speeds (known as post-processing steps) have been refined for use with air quality analyses. The process uses hourly traffic volume projections and roadway and public transportation system configurations to estimate travel speeds, miles, and other statistics. Some additional procedures are applied to provide credits for transportation actions such as operational improvements that are not currently included in the models or the speed estimates.

The freight component initially consists of truck operations and does not include rail freight. The statistics are derived by examining the truck component of the speed model used in the air quality analyses. Rail freight movements are much more difficult to monitor due to their ownership by private sector companies. Data that would be used for the congestion measurement process is often considered proprietary information and would be difficult or impossible to obtain in sufficient quantity and level of detail. Information that public sector agencies consider basic data elements can be the competitive business advantage that one company has over another. The important characteristic of rail freight, in this case, is travel delay reduction; estimates of this factor may be obtainable. That is, if rail freight improvement projects are submitted for public sector funding, the delay reduction effects of the project should be estimated and included as a benefit in the truck freight analysis component.

Truck performance is estimated using the long-range planning model outputs for estimated truck travel volume, distance, and speed. The model, truck-specific data items, and a set of steps in the post-processor are used to create a subset of the model data that includes truck speed and volume. The Texas Congestion Index uses freight information being developed in Texas and at the national level, but the freight measures currently rely more on models and less on directly collected data than the person-movement measures.

Key Elements of the Texas Congestion Index

The congestion index calculation procedures and model processing is designed to work with a range of data and procedural techniques, but in the future might incorporate a broader variety of information. The key elements of the index, however, will remain fairly stable; they include the following components:

- Speed, travel rate (e.g., minutes per mile) or travel time are used as key congestion measurements.
- Person-miles moved are used as one way to combine the mobility provided by the passenger-carrying systems.
- Truck-miles moved are used as one way to combine the mobility provided by the freight-carrying systems.
- Dollar value is used to link the various components of passenger and freight mobility.
- Travel delay and the Texas Congestion Index are compared to freeflow travel speeds and times for the current or projected condition.
- Target Texas Congestion Index values can be used as a method of identifying undesirable congestion levels. Any facility with an index value less than the target index value, for example, would not require improvement. Initially, the target values could be defined using the type and density of development and land uses in an area. After some experience with the measure, the targets could be set as part of the public comment period for the long-range land use and transportation plan.
- The measurement process includes a range of transportation improvement projects, land use, and other programs designed to yield transportation benefits.
- Delay from incidents, special events, weather, and other causes of variation in speed or reliability of travel time can be included as a component. Initially, the values will have to be estimated for most places, but directly collected data can be used in some locations.
- Bicycles and pedestrians can be included, although operating condition data will not be the appropriate mechanism due to lack of data.
- A generalized comparison of emissions was developed. The process and values for each metropolitan area are described in the report *Developing an Emissions Index for the Texas Metropolitan Mobility Plan* (*3*).

Exhibit 3. Person Travel Estimating Overview

Long Range
Planning Model

↓

Post processing steps to
estimate speeds

↓

Estimate incident delay

↓

Total delay

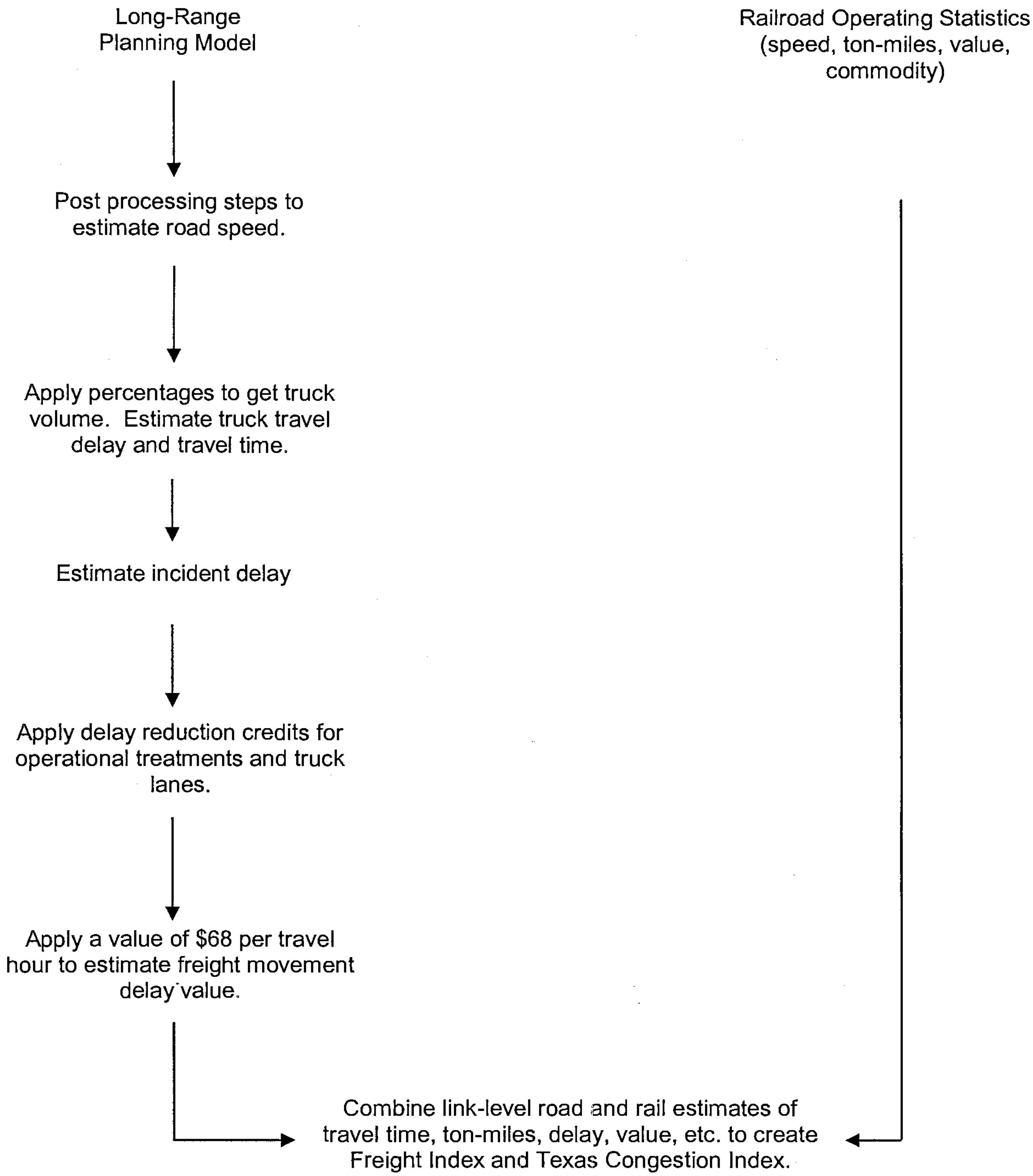
↓

Delay reduction credits for actions
not included in previous steps
(ramp metering, access
management, signal coordination,
incident management, others?)

↓

Combine link level information for
aggregate measures using a value
of $13 per hour for person travel.

Exhibit 4. Freight Travel Estimating Overview



PERFORMANCE MEASURE ESTIMATION PROCEDURE

The speed estimation process is derived from the long-range planning model data. The models that have been developed for planning and air quality analysis can also be used for congestion estimates. The models use relationships between volume and roadway capacity to estimate traffic speeds. In addition, the model can be used to forecast the effect of improved transportation networks, as well as changes in land use density and the type of developments.

A computer program (TCIINPUT and formerly known as PREPIN) has been written to calculate speeds for each hour of the typical day for air quality analysis. This program is also used in the Texas Congestion Index process. The program is run for each hour of the day, with volumes factored for trip type and travel volume during each hour, based on the daily trip table derived from the long-range planning model. The TCIINPUT model outputs are the starting point for the Texas Congestion Index calculation process and the modifications described below. In the event that better data are available, there may be some adjustments to the statistics. Each metro area should attempt to use improved statistics or congestion estimates when available. Before/after studies or direct monitoring data might improve estimates of travel time, speed, and delay.

An Excel-based spreadsheet has been developed to use the TCIINPUT program output and calculate the congestion performance measure. The travel models include roadway links labeled according to the type of development (area type) and the county where the road is located. The typical Texas regional model has five area types, generally ranging from (most to least dense) downtown, urban, urban fringe, suburban, and rural (Exhibit 5).

The calculations are performed at a level of detail that allows the user to examine congestion in each hour, county, and/or area type. The current output statistics are a combination of morning and evening peak periods (6 a.m. to 9 a.m. and 4 p.m. to 7 p.m.). The regional transportation models are comprised of from one to nine counties (Exhibit 6).

Congestion is characterized using a five-level system based on the volume-to-capacity ratio. This sorting is used in the estimation of delay benefits due to operational treatments; the vehicle-mile and vehicle-hour values are not changed by the congestion category. Exhibit 7 identifies the basic structure used in the spreadsheet. The calculation process is described in the following nine steps.

This process is schematically illustrated in the Texas Congestion Index Calculation Process diagram (Exhibit 1).

Exhibit 5. Regional Model Functional Class Groups for Eight Urban Areas (Functional Class Number and Name)

TCI Roadway Group	Austin	Corpus Christi	Dallas-Fort Worth	El Paso
Freeway	I-35 **1**	IH **1**	Fwy **1**	Fwy **3**
	Other Fwy **2**	Other Fwy **2**		Loop 375 **14**
	Express Lanes **10**			
Arterial	Expressways **3**	Princ. Art. **4,5**	Princ. Art. **2**	Border Hwy **1**
	Princ. Art. **4,5**		Frontage **7**	Expressway **3**
	Frontage **12**			Princ. Art. **4,5**
				Frontage **10**
HOV	HOV **20**			Transmtn. **13**
			HOV **8**	
TCI Roadway Group	**Hidalgo**	**Houston**	**Lubbock**	**San Antonio**
Freeway	Freeway **1**	Urban IH **1,10**	Fwy **1,2**	Fwy **1,12**
		Other Fwy **2,11**		Parkway **2,13**
		Toll Roads **3**		
Arterial	Non-Fwy Hwy **2**	Princ. Art. **5,12**	Expressway **3**	Expressway **3**
	Princ. Art. **3,4**		Princ. Art. **4,5**	
	Frontage **8**			
HOV		HOV **20**		HOV **20**

Note: Bold number refers to functional class number in regional model.

Exhibit 6. Counties Included in Regional Planning Models

Metropolitan Area	Counties Included
Austin	Hays Travis Williamson
Corpus Christi	Nueces San Patricio
Dallas-Fort Worth	Collin Dallas Denton Ellis Johnson Kaufman Parker Rockwall Tarrant
El Paso	El Paso Dona Ana (NM)
Hidalgo	Hidalgo
Houston	Brazoria Chambers Ft. Bend Galveston Harris Liberty Montgomery Waller
Lubbock	Lubbock
San Antonio	Bexar Comal Guadalupe

Exhibit 7. General Structure of Texas Congestion Index Spreadsheet

County	Hour of the Day	Area Type	Functional Class Group and Congestion Level			
			Arterial	Freeway	HOV	Other
			1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Counties in Regional Model	6 to 9 a.m. 4 to 7 p.m.	CBD Urban Urban Fringe Suburban Rural				

CBD – Central Business District

Note: Congestion level labels

1 – Uncongested
2 – Moderate
3 – Heavy
4 - Severe
5 – Extreme

Calculation Steps

1) The typical TCIINPUT model outputs—vehicle-hours of travel, vehicle miles of travel, average weighted freeflow and congested speeds—are produced for approximately 15 functional classes of roadway and grouped into approximately five area types in most regional travel models.
2) The functional classes in the models are grouped for the purposes of the TCI analyses. The freeway group includes limited access roads—freeways and tollways. The arterial group includes major streets—principal arterials, frontage roads, and expressways. If high-occupancy vehicle facilities are included, they are placed in a separate group (Exhibit 5). Other road classes are combined into an "Other roadway" group for the purposes of tracking total travel but are not used in mobility analyses.
3) The functional class group outputs are sub-divided according to congestion level for later use in the operational treatment credit process (see Step 6). The resulting matrix consists of rows of urban area type for each county and columns of congestion level for each of the major functional classes.
4) Delay is calculated as the difference between the congested speeds and the freeflow speeds. Freeflow speeds for freeways, high-speed expressways, tollways, streets, high-occupancy vehicle lanes, and other functional classes for each area type are identified from travel model parameters. The delay estimates are calculated by comparing congested speeds to the freeflow speeds for both truck travel and person travel.
5) Incident delay is estimated and added to the recurring (or "good condition day") data produced by the models. This improves the estimates of the actual conditions faced by motorists by adding delay due to traffic collisions and vehicle breakdowns. It also allows the evaluation of treatments that reduce incident delay but may not have a substantial effect on general capacity conditions.
6) The delay-reducing effect of four operational treatments is included in the congestion estimates. The factors and procedures (described in more detail in a subsequent section) are used to assess the benefits of the following programs, which are not included in the long-range transportation planning model:
    - Arterial street signal coordination,
    - Arterial street access management,
    - Freeway entrance ramp metering, and
    - Freeway incident management.
7) The travel time and delay statistics for each area type and functional classification are divided into heavy truck and passenger vehicle statistics. The current long-range transportation planning models in Texas metropolitan planning organizations do not include a separate freight model, but if such a model becomes available, the truck percentage approach described here can be modified.
8) The congested speeds, miles, and hours of travel time are summarized for the morning peak (6 a.m. to 9 a.m.) and evening peak (4 p.m. to 7 p.m.) periods for truck and car travel conditions.
9) The average Texas Congestion Index and other performance measures are calculated using the revised congestion statistics at the urban area type/functional class congestion level of detail. The car and truck travel time and delay statistics are combined using the hourly value of travel. The values used with the 2000 base year models were \$13 per person hour and \$68 per truck hour.

INCORPORATING TRAVEL DELAY BENEFITS FROM OPERATIONAL TREATMENTS

Operational improvements that reduce travel delay and improve reliability are important benefits in future transportation programs. The Texas Congestion Index process initially uses an estimate of the amount of delay that will be eliminated and subtracts it from the base delay estimate derived from the TCI spreadsheet. Current transportation planning models in Texas regions do not include methods to show the effect of most of these treatments. These travel delay "credits" are estimated from the literature and available computer simulation models.

Delay Credit Estimation

Conceptually, the effect of operational treatments is proportional to the area of coverage, the density of that coverage, and the mobility improvement provided by the treatment. The procedures used to estimate travel delay can be modified by these factors to estimate new values that more accurately reflect the mobility contributions of the treatments.

High-occupancy vehicle lanes are included in the regional planning models as a separate functional class. Public transportation ridership is removed from the roadway assignments before traffic volumes are estimated. But operational improvements are not similarly accommodated in mobility estimates.

Three factors are key to estimating the mobility effects of operational treatments:

- area covered by the treatment—how much of the system has the treatment?
- density of the treatment within the covered area (particularly as it applies to incident management programs)—how often is the area viewed or patrolled?
- delay reduction effect—how much effect does the treatment have?

The area and density factors can be estimated from federal, state, and local databases and confirmed by local reviews. The delay reduction effect of the treatments described below is tailored as much as possible to the local implementation of the treatment but typically varies with congestion level. More information on the procedures used is included in the Texas Transportation Institute (TTI) Report 4853-01-1, *Incorporating the Effect of Operational Improvements in the Texas Congestion Index Estimation Process* (*4*).

- Ramp Metering—Improves the ability of the freeway to maintain relatively high speeds under conditions of high demand and postpones the onset of congestion. Delay reduction ranges from 0 to 12 percent.
- Traffic Signal Coordination—Traffic signal coordination programs reduce delay by allowing more vehicles to maintain a smooth flow—particularly in the peak direction. Delay reduction ranges from less than 1 percent to 6 percent.
- Incident Management Programs—Quickly detecting and removing crashes and vehicle breakdowns reduces delay by returning traffic capacity to normal levels. The delay reduction ranges from 9 to 24 percent of incident delay.
- Access Management —Coordinating driveways, turn lanes, and adjacent developments can improve the reliability of the arterial streets and provide higher travel speeds. The increase in travel distance does slightly increase non-incident travel times, but the reduction in collisions reduces overall annual travel times in corridors with access management.

The specific treatment effects vary according to the congestion levels and treatment effects. The percentages in Exhibit 8 are used in the initial model formulation, and for projects or programs that do not have supporting evaluation data or information (*5*).

Exhibit 8. Congestion Level and Percent Delay Reduction

Operational Improvement Strategy	Uncongested (V/C ratio 0.69 or less)	Moderate (V/C ratio 0.70 to 0.76)	Heavy (V/C ratio 0.77 to 0.84)	Severe (V/C ratio 0.85 to 0.92)	Extreme (V/C ratio 0.93 or more)
Freeway Entrance Ramp Signals (Recurring and incident delay reduction credits)					
Isolated, pre-timed, centrally controlled or traffic responsive	0%	0%	5%	10%	12%
Traffic Signal Coordination (Recurring delay reduction credits)					
Traffic actuated	0%	2%	2%	1.9%	1.5%
Progressive (centralized or real-time)	0%	5%	5%	4.5%	3.5%
Incident Management (Incident delay reduction credits)					
Cameras, detection devices, variable message signs, freeway service patrol	0%	25%	28%	31%	35%
Arterial Street Access Management					
Recurring delay increase	0	0	2.5%	5%	9%
Incident delay decrease	9%	15%	17%	21%	21%
Public Transportation	On-time transit included as uncongested travel.				
High-Occupancy Vehicle Facilities	Include speed and person volume directly.				
Other Treatments	Can be added				

V/C – volume-to-capacity ratio
Source: Reference (*5*)

ADDING A RELIABILITY COMPONENT TO THE TMMP MEASURES

Reliability is a key component of the Texas Congestion Index process. The variation in travel time from day to day is one of the more frustrating parts of daily travel. Whether that causes missed meetings, delayed shipments, inefficient manufacturing, or extra time that must be allowed for travel to events, this extra time is a real component of congestion and has real economic and social costs.

For freight, reliability might be even more important than uncongested trips. This is particularly true for just-in-time manufacturing operations, but it also holds for many service-oriented companies. Some method of using congestion levels to estimate reliability levels on roads might be useful in this context, but more information is needed on how businesses view reliability to really understand the issue. Researchers did not collect that information in this project.

Rail freight reliability might be easier to assess using delivery schedules, but an initial examination of the issue indicates that railroads will be reluctant to provide the sort of information needed. It may be possible to look at this issue when there is a funding request or project proposal from a railroad, which would be supported by data that could be shared with (at least) the funding agencies. This would provide railroad companies with the business data security they seek and not require public sector agencies to create measures that may not be connected to the business processes they are intended to assist.

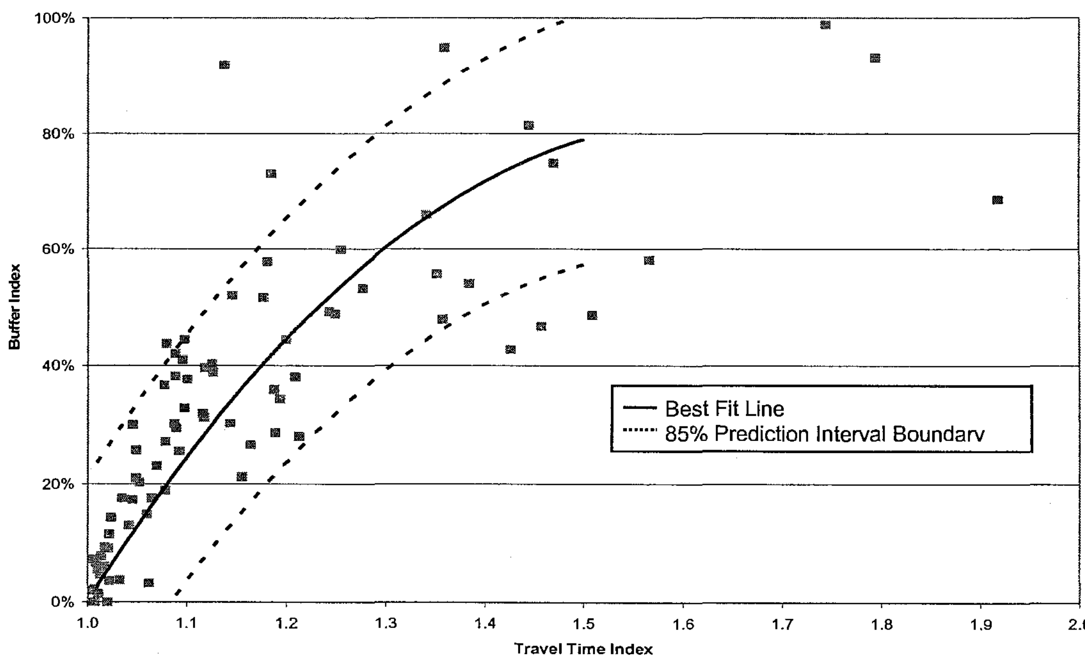
TMMP measures do not formally include all the aspects of reliability. The current estimation procedure includes a factor for incident delay. This factor increases the total delay by an amount that represents the delay-increasing effect of weather, special events, the daily variation in traffic volume, stalled vehicles, and crashes. But this allowance does not incorporate the aspects of reliability that relate to frustration, uncertainty, or poor performance due to unreliable delivery schedules.

Travel demand models also do not incorporate this unreliability factor into their output statistics. As a near-term strategy, unreliability can be estimated and communicated using the means described in the report *Incorporating the Effect of Operational Improvements in the Texas Congestion Index Estimation Process* (*4*). One measure that might be used is the Buffer Index. This is being used in the *Monitoring Urban Roadways in 2002* report (*5*) and the national overview 2005 Traffic Congestion and Reliability Report (*7*) to communicate the day-to-day variation in travel time on some freeways in selected U.S. cities. The measure and the database to calculate it have been used for only a few years, but it appears to resonate with both technical audiences and the general public. The measure is an estimate of the amount of extra time that must be budgeted for an on-time arrival for 19 out of 20 trips. The Buffer Index (Eq. 1) is a measure of the difference between the 95^{th} percentile travel time and the average travel time.

Exhibit 9 illustrates the predictive relationship developed for use in the Texas Congestion Index process (see Appendix F). This estimation method is useful for regional discussions about the role and effect of reliability on the quality of transportation service. It will be necessary to have more detailed corridor-level data such as that provided by the traffic management centers (e.g., Transguide in San Antonio or Transtar in Houston) to identify the effects of specific treatments. As those data become more available, they should be used to improve estimates.

$$\text{Buffer Index} = \left[\frac{\begin{matrix}\text{95th Percentile Travel Rate} \\ \text{(in minutes per mile)}\end{matrix} - \begin{matrix}\text{Average Travel Rate} \\ \text{(in minutes per mile)}\end{matrix}}{\begin{matrix}\text{Average Travel Rate} \\ \text{(in minutes per mile)}\end{matrix}} \times 100\% \right] \quad (1)$$

Exhibit 9. Relationship between Congestion and Reliability Performance Measures



Source: (*5*) and TTI Analysis.
See Appendix F for more information.

FUTURE MODEL IMPROVEMENTS

For a more complete assessment of congestion in urban Texas, the TCI should also include growth and density dimensions, economic and employment impacts, freight logistics dynamics, transportation security elements, regional transportation policies, construction and maintenance activity, and other factors that relate to transportation services. The essential point is that congestion relief, prevention, and mitigation expenditures should be evaluated in terms of their effects upon a fully enhanced index. The more comprehensive the TCI is, the more likely it will be used for evaluating the relative costs, implementation issues, and benefits of proposed transportation improvements.

In the near term, many of these dimensions can be incorporated during the project consideration phase as "delay reduction credits" to the congestion estimates. Over the longer term, however, it would be desirable to move more of these elements into the "monitored system" on a regular basis. For example, an improved freight transportation model might be linked to the regional transportation planning models to better evaluate the surface transportation system.

General Model Evolution

In general, the model may evolve through two phases, with some metro areas proceeding to Phase 2 more rapidly than others.

Phase 1. Use TransCAD/EMME-2 models to generate mobility statistics.

Use speed estimates from TransCAD/EMME-2 output and post-processing procedures. Modify capacities or operating speeds to accommodate operational improvements, or use the "credit" approach. The biggest benefit of this approach is to show the effect of land use changes.

Phase 2. Identify real-time data sources and methods to include them.

Freeway data exist in Houston, Austin, and San Antonio and will soon be available in Dallas-Fort Worth. These data might be used to predict reliability levels and improve the travel time and speed estimates for the transportation planning models.

COMMUNICATING THE TEXAS CONGESTION INDEX VALUES

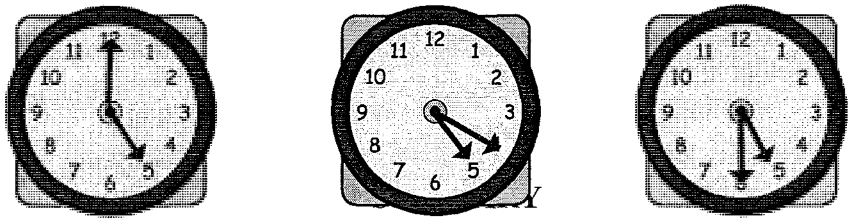
The Texas Congestion Index is constructed as a multimodal assessment of peak period travel conditions. The values are currently presented as areawide averages, but they could be prepared for subareas or corridors. The Index is designed to be calculated from the travel demand model output due to the comprehensive nature of the long-range models. The Index calculation process also provides an easily understood method for estimating the delay reduction effects of a variety of transportation improvements that are not included in the transportation-planning model functions.

In concept, the index is a ratio of the time it takes to travel in the peak period to the time it would take to travel the same distance at freeflow speeds. A TCI value of 1.0 indicates travel at freeflow conditions. A value of 1.30 would mean trips take, on average, 30 percent longer in the peak than at freeflow conditions. A 20-minute freeflow trip will take 26 minutes in the peak. One complication this presents, however, is that changes in the Index values may *appear* to understate the change in congestion. A change from a Texas Congestion Index value of 1.10 to 1.40 might be calculated as a 27 percent increase in congestion ([1.4 – 1.1]/1.1 – 27%). Actually, it is a 27 percent increase in travel time (e.g., (28 – 22 / 22)), but a 300 percent increase in travel delay (e.g., [8 – 2 / 2]). It is important to communicate the meaning of the Index values and changes between alternative scenarios by using the appropriate terminology.

Key Attributes

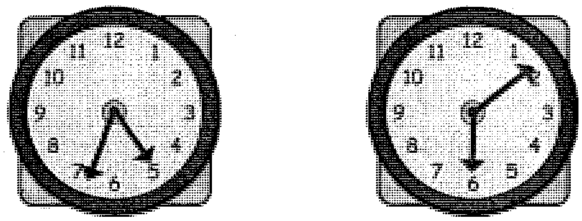
As the reliability measure is developed, the Buffer Index will provide an additional way to connect with the frustration that travelers express over the uncertainty of travel conditions. The San Antonio TxDOT District developed a clock graphic (Exhibit 10) to describe the combined effects of regular and irregular traffic congestion, which effectively captures both elements in an easy-to-understand story about urban mobility challenges.

Exhibit 10. Using the Buffer Index to Communicate Travel Time



A trip from work to the house takes you 20 minutes without traffic.

In 1995, you had to plan for a 30 minute trip to get home.



In 2000, 34 minutes...

And in 2030, you will have to plan to spend 68 minutes to get home!

Summary of Recommended Communication Approach

The Texas Congestion Index, as it is currently formulated and calculated, has most of the desired performance measure attributes. It provides an analysis tool that can be used to assess the effect of a wide range of improvement types, perform "what-if?" type analyses on both transportation and land use strategies, and uses the long-range planning models that are already the backbone of transportation planning analyses. Among the other attributes are:

- indicates progress toward mobility goals by estimating the effect of a wide variety of improvement types;
- examines congestion and mobility with a multi-modal focus at an areawide level;
- includes the effect of freight and person congestion;
- provides measures that are readily understood and technically useful;
- builds on existing planning processes and models that can reflect the projected growth in population, jobs, and travel needs;
- allows an examination of the effect of both land use and transportation actions;
- allows expansion of process and measures over the next several years while providing useful input for planning decisions; and
- provides the measures that can be used for a variety of decision-making levels from areawide to corridor level.

There are some important limitations, however, that affect the way the data are used and the decisions that can be supported. It is also important to recognize the relationship between the performance measures, the decision processes, and the data or analytical procedures.

- The measures, procedures, and data will evolve as TxDOT and the MPOs gain more experience and as better tools are developed.
- While the measures can be used for a variety of purposes, only the areawide measures are presented in the current version of the spreadsheet.
- The planning models and datasets in each region are different. The process accommodates these differences and also allows for a consistent statewide calculation procedure.
- Bicycle and pedestrian travel are currently removed from the roadway travel demand in Step 1 of the process. As travel models are improved, there may be better ways to incorporate these modes.
- While travel reliability concerns are included in the procedures, a more complete understanding of the role and effect of variations in travel time should be developed.

SUMMARY

The Texas Congestion Index concept developed over the last two years includes several performance measures and a set of techniques and procedures. The measures provide information about both person and freight movement and illustrate the effect of many urban transportation improvement actions and land use pattern changes. The measures are relatively easy to compute, understand, and communicate to a wide variety of audiences. It is equally important to view these procedures as a first step on a process that will see the measures and procedures evolve over the next several years as implementation experience, models, and data improve. Parallel with these improvements is a process to create a set of plans that address the projects, programs, and strategies needed to achieve mobility goals in the urban areas.

Because a single index can obscure some elements or characteristics of mobility, the Texas Congestion Index process creates several measures aimed at assessing various elements of metropolitan transportation services. Corridor and subarea analyses, for example, should be used for selecting specific projects, programs, policies, or strategies. Measures similar to the TCI can be used as one element of a prioritization process, but other goals such as air quality, safety, economic development, economic justice, and others are also part of the consideration.

The Texas Congestion Index methodology has been applied to the eight largest Texas metropolitan areas. Long-range planning models are the best tool for developing the Texas Congestion Index, but additional information can be obtained from generally available roadway, rail, freight, and public transportation inventory, performance, and operations databases. The Texas Congestion Index is designed to be part of a long-range vision-oriented planning and funding process. The Index will help evaluate the programs and strategies that should be pursued to accomplish mobility objectives. It is designed to compliment existing tools, procedures, measures, and practices, as well as develop additional analytical techniques to improve congestion relief analyses. Other procedures and techniques will be used to analyze other aspects of the Texas Metropolitan Mobility Plan such as air quality, safety, economic development, and quality of life.

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APPENDIX A

Calculation Process

Appendix A is an overview of the calculation steps, data elements and performance measures used in the Texas Congestion Index process.

Acronym	**Meaning**
TCIINPUT	Texas Congestion Index Calculation Procedure
VMT	Vehicle miles of travel
VHT	Vehicle hours of travel
TT	Travel time
TCI	Texas Congestion Index

Calculation Process

Texas Congestion Index Calculation Procedure

For each Metro County and Year. Use data for peak periods (6a-9a and 4p-7p) to create person and truck travel condition estimates.

1 **VMT and VHT Matrices**
TCIINPUT produces VMT and VHT for each County, Area Type Functional Class and Congestion Level.

VMT

VHT

2 **Freeflow VHT Matrix**

VHT freeflow

3 **Recurring Delay Matrix**

$Delay_{RECUR} = VHT - VHT_{FF}$

4 **Incident Delay**

$Delay_{INCID} = Delay_{RECUR} \times Incident\ Factor$

5 **Total Delay**

Initial Total Delay = $Delay_{INCIDENT} + Delay_{RECURRING}$

6 **Operations Treatment Credit**

Treatment Types: Frwy Incident Mgmt, Frwy Metering, Signal Coord, Access Mgmt.

$Delay_{REDUCTIONS}$ = Roadway Treated x Delay Reducing Effect

7 **Vehicle Delay with Operational Treatment Effects**

$Delay_{OPS} = Delay_{RECUR} + Delay_{INC} - Delay_{REDUCTIONS}$

8 Split matrices into **Car and Truck Travel**

9 **Estimate Total Vehicle Travel Time**

Car Travel $Time_{VEHICLE}$ = *Car* $Delay_{OPS}$ + *Car* VHT_{FF}

Truck Travel $Time_{VEHICLE}$ = *Truck* $Delay_{OPS}$ + *Truck* VHT_{FF}

10 **Estimate Person Travel Time**

Car Person TT = *Car* $TT_{VEHICLE}$ *x Person/Car*

Truck Person TT = *Truck* $TT_{VEHICLE}$ *x Person/Truck*

11 Identify **Value of Person and Truck Travel** for Peak and Freeflow.
Person $Value_{PEAK}$ = *Car Person TT x $13 per person hour*
Truck $Value_{PEAK}$ = *Truck Vehicle TT x $68 per vehicle hour*
(Repeat for Freeflow) →

12 $$\text{Texas Congestion Index} = \frac{\text{Person Value}_{PEAK} + \text{Truck Value}_{PEAK}}{\text{Person Value}_{FFLOW} + \text{Truck Value}_{FFLOW}}$$

State level TCI is sum of metro peak period person and truck value divided by sum of metro freeflow person and truck value. Can also produce other measures.

1 **Process the Travel Model Output Data.** For each Metro County and Model Year, the TransCAD output is processed by a program named TCIINPUT, which is a modified version of the TCIINPUT program developed for air quality modeling purposes. The model summarizes several measures for each hour of a relatively ideal day. The key output elements for the Texas Congestion Index process are vehicle-miles of travel (VMT) and vehicle-hours of travel (VHT). These are sorted by congestion levels so that VMT and VHT data are available for each hour for each combination of functional class, area type, and county.

Note: The number of Area Types and Functional Classes vary for Texas metro areas. For the Texas Congestion Index, the MPOs grouped the model functional classes into Freeway, Principal Arterial Street, High-Occupancy Vehicle Lane, and Other. "Other" roads are not used in the calculation of the TCI. Additional classes will be added if necessary.

The Texas Congestion Index spreadsheet creates the following matrices to begin the calculation process. These are developed using the Pivot Table feature of Excel.

TCIINPUT Output
(sorted for each hour by County, Area Type, Functional Class, and Congestion Level)

Vehicle-Miles of Travel VMT	Vehicle-Hours of Travel VHT

Sample Table structure for the matrices in steps 1 through 11.

County	Hour of Day	Area Type	Principal Arterial Group					Freeway Group				
			Congestion Level					Congestion Level				
			U	M	H	S	X	U	M	H	S	X
		1,2,3,4,5										

[1]Congestion level labels: Uncongested, Moderate, Heavy, Severe, eXtreme
[2]Area types—development characteristics (e.g., downtown, urban, urban fringe, suburban, and rural).

Note: Agencies—state and local—should produce an inventory of the treatment types or improvement options that have: 1) the improvement effects included in their long-range model, and 2) effects that are not included in the model but are part of either existing operations or are in the improvement package that will be implemented. The first category needs no special treatment. Category 2, which will likely include incident management and other operations or demand management alternatives, can be addressed in the post-processing and TCI spreadsheet steps.

2 **Develop Freeflow Travel Time Estimate**. The TCI process creates a freeflow speed travel time matrix to use as a baseline. This step estimates the time to travel the peak period distance at freeflow speeds. The user must specify a freeflow speed for each functional class and area type.

VMT matrix divided by freeflow speeds. MPOs may provide detailed freeflow speeds to use as the comparison standard, or values can be developed from the speeds on the uncongested road sections.

↓

VHT_{FF}

(Freeflow)

3 **Estimate Recurring Delay**. Recurring delay is estimated for each hour of the peak period. Recurring delay is the difference between vehicle-hours of travel time and the time to travel the peak period distance at freeflow speeds.

$Delay_{RECUR}$

$VHT-VHT_{FF}$

4 **Estimate Incident Delay**. A factor is used to estimate incident delay. This step adds delay due to crashes, vehicle breakdowns, and other events that are not included in the travel demand models. This incident-to-recurring delay factor estimates the incident delay matrix in a process similar to the Annual Mobility Report from TTI. The incident factor is different for the freeways in each area. The principal arterial street incident factor is 1.1 for all streets in all areas.

$Delay_{Inc}$

$Delay_{Recur} \times Incident\ Factor$

5 **Calculate Initial Value for Total Delay**. Combine the initial recurring delay (Step 3) and incident delay (Step 4) matrices into an Initial Delay matrix.

$Delay_{INITIAL} =$

$Delay_{RECUR} + Delay_{INC}$

6 **Estimate the Delay-Reducing Effects of Operational Treatments.** The TCI spreadsheet includes estimates for freeway incident management, freeway ramp metering, arterial street access management and street traffic signal coordination. There is also an additional worksheet for other operational treatments to be included.

The specific treatment considerations are identified below. The treatments' effects vary according to the congestion levels and treatment effects.

Congestion Level and Percent Delay Reduction

Operational Improvement Strategy	**Uncongested (v/c ratio 0.69 or less)**	**Moderate (v/c ratio 0.70 to 0.76)**	**Heavy (v/c ratio 0.77 to 0.84)**	**Severe (v/c ratio 0.85 to 0.92)**	**Extreme (v/c ratio 0.93 or more)**
Freeway Entrance Ramp Signals (Recurring and incident delay reduction credits)					
Isolated, pre-timed, centrally controlled, or traffic responsive	0%	0%	5%	10%	12%
Traffic Signal Coordination (Recurring delay reduction credits)					
Traffic actuated	0%	2%	2%	1.9%	1.5%
Progressive (centralized or real-time)	0%	5%	5%	4.5%	3.5%
Incident Management (Incident delay reduction credits)					
Cameras, detection devices, variable message signs, freeway service patrol	0%	25%	28%	31%	35%
Arterial Street Access Management					
Recurring delay increase	0	0	2.5%	5%	9%
Incident delay decrease	9%	15%	17%	21%	21%
Other Treatments	To be determined				

v/c – volume-to-capacity ratio

6a **Percent Delay Reduction Matrices.** These matrices are developed in the TCI spreadsheet for each county in the model. The information must be completed for each year of the model. This step identifies the amount of roadway in each congestion level that is treated and multiplies the delay on those road segments by the delay reduction percentage from the treatment. For example, if 50% of the road is covered with an operational treatment that reduces delay by 10%, the delay for that congestion level would be multiplied by .50 and then by .10. The resulting hours of delay are subtracted from the total delay in Step 7.

Treatment - Freeway Incident Management

	Congestion Level					
Area Type	Extreme	Severe	Heavy	Moderate	Uncongested	
1 2 3 4 5	Coverage % (from HPMS and IDTS)		X	Incident Delay Reduction % from Step 6		Apply to ⇨

Treatment - Freeway Ramp Metering

	Congestion Level					
Area Type	Extreme	Severe	Heavy	Moderate	Uncongested	
1 2 3 4 5	Coverage % (from HPMS and IDTS)		x	Ramp Metering Delay Reduction % from Step 6		Apply to ⇨

Treatment – Traffic Signal Coordination

	Congestion Level					
Area Type	Extreme	Severe	Heavy	Moderate	Uncongested	
1 2 3 4 5	Coverage % (from HPMS and IDTS)		x	Ramp Metering Delay Reduction % from Step 6		Apply to ⇨

Treatment – Arterial Street Access Management

	Congestion Level					
Area Type	Extreme	Severe	Heavy	Moderate	Uncongested	
1 2 3 4 5	Coverage % (from HPMS and IDTS)		x	Access Management Delay Reduction % from Step 6		Apply to ⇨

6b

6c

Apply to

The matrix of Freeway $\text{Delay}_{\text{Incident}}$

Results

Vehicle-Hours of Incident Delay Reduced due to Freeway Incident Management

Area Type	Congestion Level				
	Ext	Sev	Heavy	Mod	Uncong
			Delay_{IM}		

Apply to

The matrix of Freeway $\text{Delay}_{\text{INITIAL}}$

Results

Vehicle-Hours of Incident Delay Reduced due to Freeway Ramp Metering

Area Type	Congestion Level				
	Ext	Sev	Heavy	Mod	Uncong
			Delay_{RM}		

Apply to

The matrix of Principal Arterial $\text{Delay}_{\text{INITIAL}}$

Results

Vehicle-Hours of Incident Delay Reduced due to Street Traffic Signal Coordination

Area Type	Congestion Level				
	Ext	Sev	Heavy	Mod	Uncong
			Delay_{TS}		

Apply to

The matrix of Principal Arterial $\text{Delay}_{\text{INITIAL}}$

Results

Vehicle-Hours of Recurring Delay Increased & Incident Delay Reduced due to Arterial Street Access Management

Area Type	Congestion Level				
	Ext	Sev	Heavy	Mod	Uncong
			Delay_{AM}		

Note: HPMS - Highway Performance Monitoring System—includes information on several operational treatments for each section of roadway.
IDTS - ITS Deployment Tracking Survey—includes information on several operational treatments at the regional level, e.g., miles of road that have signal coordination.

7 **Include Effects of Operations Treatments.** Subtract the operational delay reduction effects to get Delay with Operations matrix.

$$Delay_{WITH\ OPS} = Delay_{INITIAL} - Delay_{IM} - Delay_{RM} - Delay_{TS} - Delay_{AM}$$

8 **Estimate Car and Truck Statistics.** Split travel conditions and matrices into Car and Truck Travel. Each region will have truck percentage estimates based on the values used in air quality modeling and/or vehicle classification counts.

$Delay_{WITH\ OPS}$ ↗ Truck percentage is estimated for each functional class and time period (if possible) by area type. Only heavy-duty trucks are included in this category.

$Delay_{WITH\ OPS}$ ↘ Other Vehicles (all car and non-heavy-duty truck travel and delay)

$$Truck\ Delay_{WITH\ OPS} = Delay_{WITH\ OPS} \times Truck\ Percentage$$

$$Car\ Delay_{WITH\ OPS} = Delay_{WITH\ OPS} - Truck\ Delay_{WITH\ OPS}$$

Similar calculation steps applied to $VHT_{FREEFLOW}$ matrix.

9 **Estimate Vehicle Travel Time.** Travel time is the basic element of the Texas Congestion Index. The modified estimate of travel delay for both truck and car groups from Step 8 are added to the freeflow travel time from Step 2 to estimate hourly travel time.

Add $Delay_{OPS}$ to VHT_{FF} to get a matrix of Vehicle Travel Time.

$$Car\ Travel\ Time_{VEHICLE} = Car\ Delay_{WITH\ OPS} + Car\ VHT_{FF}$$

$$Truck\ Travel\ Time_{VEHICLE} = Truck\ Delay_{WITH\ OPS} + Truck\ VHT_{FF}$$

10 **Estimate Person Travel Time**. Multiply the vehicle travel matrices by vehicle occupancy to express delay and freeflow travel in person terms for both car and truck travel.

Person Travel Time =	Person Travel Time$_{FREEFLOW}$ =
Car $TT_{VEHICLE}$ *x Persons per Car*	*Car* VHT_{FF} *x Persons per Car*
Truck $TT_{VEHICLE}$ *x Persons per Truck*	*Truck* VHT_{FF} *x Persons per Truck*

11 **Peak Period Travel Time**. Add hourly travel time estimates for 6 to 9 a.m. and 4 to 7 p.m. to obtain peak period travel time by Area Type and Functional Class. The person travel matrix is used in the Car calculation, and vehicle travel is used for the Truck calculation. This is consistent with the hourly value calculation.

Car Person Peak Travel Time =	Truck Vehicle Peak Travel Time =
Sum of hourly Person Travel Time matrices for all six hours of the peak periods	*Sum of hourly Person Travel Time matrices for all six hours of the peak periods*

Calculate value of Person and Truck Travel Time using the following hourly rates. This calculation provides a common comparison measure—dollars—for joining the truck vehicle and car person travel conditions.

Car Value of Travel Time = $13 per person hour x Hours of Car Person Travel

Truck Value of Travel Time = $68 per vehicle hour x Hours of Truck Vehicle Travel

Note: Apply the same value of time to the freeflow matrices for car and truck.

12 **Estimate Texas Congestion Index**. Add the car and truck travel value for all area types and functional classes for peak period and freeflow conditions. Calculate Texas Congestion Index for the regional level, using the value of person and truck travel.

$$\text{Texas Congestion Index}_{REGION} = \frac{\text{Car Value}_{PEAK} + \text{Truck Value}_{PEAK}}{\text{Car Value}_{FREEFLOW} + \text{Truck Value}_{FREEFLOW}}$$

The state average TCI can be calculated as the ratio of the peak travel values and the freeflow travel values.

$$\text{Texas Congestion Index} = \frac{\text{Sum of 8 Regional Peak Period Travel Values}}{\text{Sum of 8 Regional Freeflow Travel Values}}$$

APPENDIX B

Texas Congestion Index Calculation Steps:

What is Required to Operate the Spreadsheet

Here's What You Need to Start

- TransCAD model output in ASCII format for 24 hour;
- TCIINPUT model to estimate the hourly vehicle-miles and vehicle-hours of travel
- hourly distribution of volume to use in the TCIINPUT process. This can be as simple as 24 1-hour volume percentages; as detailed as hourly volumes for each functional class, county, and area type; or somewhere between; and
- range of volume-to-capacity ratios for the five congestion levels (uncongested, moderate, heavy, severe and extreme).

Format of Data from the TCIINPUT Program

- The data is in tab de-limited format.
- Data elements include vehicle-miles of travel and vehicle-hours of travel for:
  - County,
  - time of day,
  - area type,
  - functional class, and
  - congestion level.

Outputs from TCIINPUT should be copied and pasted onto the *TCIINPUT tab* of the TCI spreadsheet.

Input Format

There are several input factors, most of them located on the *Input Tab* and highlighted in light green shading. The following list of spreadsheet input factors and location tabs:

- Functional Class (FC) labels and the corresponding "Big FC" groups – freeways, arterials, HOV and other. The TCI spreadsheet uses all freeways and similar facilities; arterials consisting of major arterials and frontage roads; and high-occupancy vehicle facilities in the calculation. The Other class is used to group all other roadways. *Input Tab.*
- Vehicle occupancy rates for cars and trucks (persons per vehicle). *Input Tab.*
- Value of time (dollars per hour). Default values are $13 per hour for car occupants and $68 per hour for truck travel. *Input Tab.*

- Truck percentage of vehicle-miles of travel for some level of detail (for example: by time of day, county, functional class, area type). *Input Tab.*
- Freeflow speed for each Big FC and area type. *Input Tab.*
- Percentage of roads with operational treatments in each county, area type, and functional class. There are *separate tabs for incident management, ramp metering, and signal coordination treatments*.

The pivot tables on the *VMT, VHT, Speed Tab* must be refreshed. These are located near cells D11, AD11, and U11. The data are transferred to the other tabs, and the other measures are calculated automatically.

Data Quality

The data should be examined for reasonableness. The data quality steps are highlighted in light turquoise.

- On the *VMT, VHT, Speed Tab* there should be a column of data for each of the five congestion levels for both freeways and arterials. If not, the user should go to the *TCIINPUT tab*, find an hour included in the analysis (6 to 9 a.m. or 4 to 7 p.m.) and a functional class in the missing group (freeways or arterials) with a relatively low VMT value (zero would be best). The user should manually change the volume/capacity ratio so that it will create an observation in the missing column. The matrices in the other tabs require that there be five congestion levels for each functional class (otherwise the columns will not be arranged correctly).
- The *VMT, VHT, Speed Tab* includes an average speed table that should be examined which begins in cell AD111. The speeds should generally decline with higher congestion levels and should be higher in the rural and suburban area types than in the downtown areas.
- The *Recurring and Incident Delay Tab* includes a calculation of the percentage of delay in each matrix cell beginning in cell AD111. This should be examined to see if there are any cells with very high delay.
- The *Delay and Operations Tab* includes a total of the percentage delay that is reduced by the operations treatments which begins in Cell D111. The cell values should not show delay reduction that is inconsistent with the treatments deployed on the road system.
- The *Index Tab* includes data quality lines for the VMT and speed by functional class and congestion level. This allows the user to examine the speeds at an aggregate level and examine the VMT distribution.
- The *Index Tab* includes Texas Congestion Index values for each functional class and congestion level. These should identify problems in calculation procedures or cell alignment.

Results

The open architecture of the TCI spreadsheet provides the user with the opportunity to view several travel time and delay statistics at many points of the calculation process. The *Index Tab* provides a summary of the key output statistics at the regional level of detail. The primary performance measures are highlighted in yellow and described below. The Texas Congestion Index is the metric that has been examined and refined in the most analyses to date. Other measures are important and will be more useful when regional model variations are lessened and more experience is gained with the calculation.

- Texas Congestion Index—ratio of the value of travel time at congested speeds to the value at freeflow conditions.
- Travel delay—extra travel time due to congestion.
- Travel time—total time for travel during analysis periods.
- Cost—the value of time based on a unit cost of $13 per person hour and $68 per truck hour; also shown as cost per person or cost per traveler.
- Emissions Index—simplified comparison of peak period emissions on freeways and major arterials in 2000 and 2025 or 2030; not a substitute for mobile source emissions modeling.

APPENDIX C

Speed Estimation for Texas Congestion Index Study

The basis for the Texas Congestion Index performance measures is estimated roadway link speeds for six peak hours (6:00 a.m. to 9:00 a.m. and 4:00 p.m. to 7:00 p.m.). The areawide travel demand model output is used as the data source for the TCI study. Six out of the eight TCI areas (except Houston and Dallas) currently have a 24-hour traffic assignment in their travel models. The travel model outputs for the six areas, therefore, include the estimated 24-hour traffic volume and 24-hour operational speed (congested speed) for each link.

As part of the calibration and validation practice of the travel model, the link volumes are compared to the observed traffic counts to make sure the differences are small enough (i.e., root mean square error [RMSE] is small) to provide reliable estimates of traffic volume. The output link operational speed, however, may not be as reliable as the link volume, especially when the 24-hour assignment is performed in the travel model. Most air quality non-attainment areas, therefore, use a post-process procedure to estimate speeds for air quality modeling purposes instead of using the speeds resulting from the travel model directly.

Operational speeds were needed for each peak hour in the TCI study. Researchers used a similar post process procedure to estimate operational speeds for the TCI study as was used for non-attainment areas in Texas. The Dallas-Fort Worth Speed Model developed by the North Central Texas Council of Governments (NCTCOG) is used to post process the model output to estimate speeds for the TCI study. The function is shown below:

$$Congested\ speed = \frac{60}{\dfrac{60}{Free flow\ speed} \times Delay}$$

$$Delay = Min\left[A\,e^{B\left(\frac{V}{C}\right)} ; M \right]$$

Where:

Delay = congestion delay (in minutes/mile),

A & B = volume-delay equation coefficients,

M = maximum minutes of delay per mile,

V/C = time-of-day directional v/c ratio.

The values for the A, B, and M parameters are shown in Exhibit C-1.

Exhibit C-1. Volume-Delay Equation Parameters

Parameters	Parameter Values	
	High-capacity Facilities	Low-capacity Facilities
A	0.015	0.050
B	3.5	3.0
M	5.0	10.0

Exhibit C-2 lists the hourly capacity used to estimate roadway speeds for the congestion measures. The same hourly capacity is used for all areas. This differs from the daily traffic capacities, which are different in each regional model. While hourly capacities can be approximately the same, to match traffic volumes on the current road system and to account for differences in the distribution of hourly traffic volumes during the day, the planning model daily capacities must be different from region to region.

Exhibit C-2. Hourly Capacity (vehicles per hour per lane)

Roadway Class	Area Type				
	CBD	CBD Fringe	Urban	Suburban	Rural
Freeway	2050	2125	2150	2225	2300
Prin. Art. (D)	719	781	844	938	1031
Prin. Art. (U)	656	719	781	844	938

CBD – Central Business District

As can be seen from the speed equation, the freeflow speed and V/C ratio are critical data groups for congested speed estimation. In the travel demand models, link free flow speed and capacities are inputs before the traffic assignment step. The primary purpose of link free flow speed in a travel model is as a factor in assigning travel to roads in the network. The link free flow speed is, therefore, primarily used as a measure of impedance to travel rather than a prediction of accurate travel characteristics. Sometimes, link free flow speeds are adjusted in the model (along with demand parameters) as necessary to achieve realistic traffic forecasts. For example, freeway speeds might be changed to encourage the model to assign more or less traffic to parallel streets. Nevertheless, the travel demand model is a source of link free flow speeds if no better free flow data are available.

TxDOT uses a slightly different practice in the traffic assignment step of travel demand modeling. Instead of using the link free flow speeds, the link 24-hour average speeds are used for traffic assignment. These daily average speeds are equivalent to the speeds at a V/C ratio of approximately 0.85. Six of the eight TCI areas (except Houston and Dallas) use the 24-hour average speeds for traffic assignment. The link free flow speeds for these six areas are, therefore, not available from their respective travel model. They are estimated for the TCI study using their travel model functional class and area type.

For these six areas, researchers first adjusted the 24-hour average speeds to the estimated free flow speeds in the TCIINPUT model. Using the speed equation shown previously, the congested speeds can be estimated by TCIINPUT. The inverse of the congested speed is vehicle-hours traveled. TCIINPUT aggregates VHT for each area type and TCI functional class weighted by the vehicle-miles of travel on each link.

The travel time delays were calculated by subtracting the time used in free flow conditions from the time used in congested conditions. The travel time delays were calculated at the TCI functional class group and area type level, not at the individual road link level. The TCI functional class is more aggregated than the travel model functional class. The free flow speeds used in TCIINPUT for travel model functional class were aggregated in the delay calculation for the TCI functional class group.

The free flow speeds used in the TCIINPUT model are listed in Exhibit C-3 for the functional class groups in the Texas Congestion Index process.

Exhibit C-3. Functional Class Groups in Texas Congestion Index Process

Estimated Typical Freeflow Speeds for Austin Network

Roadway Type	Area Type: CBD	CBD Fringe	Urban	Suburban	Rural
IH 35	55	55	60	60	65
Other Freeways	55	55	60	60	65
Expressways	30	30	40	40	40
Principal Arterials (D)	30	30	40	40	40
Principal Arterials (U)	30	30	40	40	40
Express Lanes	55	55	60	60	65
Frontage	30	35	35	35	35

IH – interstate highway; D – divided; U – undivided

Estimated Typical Freeflow Speeds for Corpus Christi Network

Roadway Type	Area Type: CBD	CBD Fringe	Urban	Suburban	Rural
IH	55	60	65	70	70
Other Freeways	55	60	65	70	70
Principal Arterials (D)	45	47	50	55	60
Principal Arterials (U)	43	45	47	54	60

IH – interstate highway; D – divided; U – undivided

Estimated Typical Freeflow Speeds for Dallas-Fort Worth Network

Roadway Type	Area Type: CBD	CBD Fringe	Urban Residential	Suburban Residential	Rural
Freeways	55	63	67	70	73
Principal Arterials	17	28	34	43	61
Frontage Roads	30	35	37	42	44
HOV Lanes	60	60	62	65	

Estimated Typical Freeflow Speeds for El Paso Network

Roadway Type	Area Type: CBD	CBD Fringe	Urban East	Suburban North	Rural	Suburban New Mexico	Rural New Mexico
Border Highway	25.00	30.00	35.00	45.00	50.00	45.00	50.00
Freeway Radial	55.00	60.00	60.00	63.00	70.00	63.00	70.00
Expressway	25.00	30.00	35.00	45.00	50.00	45.00	50.00
Principal Arterial (D)	20.00	30.00	35.00	45.00	50.00	45.00	50.00
Principal Arterial (U)	20.00	30.00	35.00	45.00	50.00	45.00	50.00
Frontage Road	20.00	30.00	35.00	45.00	50.00	45.00	50.00
Transmountain Road	25.00	30.00	35.00	45.00	50.00	45.00	50.00
Loop 375	55.00	60.00	60.00	63.00	70.00	63.00	70.00

D – divided; U – undivided

Exhibit C-3. Continued

Estimated Typical Freeflow Speeds for Hidalgo Network

	Area Type				
Roadway Type	CBD	CBD Fringe	Urban	Suburban	Rural
Freeway	55	55	60	60	65
Principal Arterial (D)	30	30	40	40	40
Principal Arterial (U)	30	30	40	40	40

D – divided; U – undivided

Estimated Typical Freeflow Speeds for Houston Network

	Area Type				
Roadway Type	CBD	Urban	Urban Fringe	Suburban	Rural
Freeways	55	60	65	72	75
Principal Arterials	22	28	35	45	65

Estimated Typical Freeflow Speeds for Lubbock Network

	Area Type				
Roadway Type	CBD	CBD Fringe	Urban	Suburban	Rural
Circumferential Freeway	55	55	60	60	65
Other Freeway	55	55	60	60	65
Expressway	30	30	40	40	40
Principal Arterial (D)	30	30	40	40	40
Principal Arterial (U)	30	30	40	40	40

D – divided; U – undivided

Estimated Typical Freeflow Speeds for San Antonio Network

	Area Type					
Roadway Type	CBD	Urban	Urban Residential	Suburban	Rural	Military
Radial Freeway	55	55	60	60	65	60
Radial Parkway	55	55	60	60	65	60
Expressway	25	30	35	40	40	35
Principal Arterial (D)	25	30	35	40	40	35
Principal Arterial (U)	25	30	35	40	40	35
Frontage Road		21	29	31	35	
Circumferential Freeway		55	60	60	65	
Circumferential Parkway		55	60	60	65	
Circumferential Arterial			35	40	40	

D – divided; U – undivided

APPENDIX D

Value of Time for Passenger Vehicles and Commercial Trucks 2004 Texas Metropolitan Mobility Plan

Introduction

Value of time in the context of calculating congestion cost is an estimate of the average differential cost of the extra travel time as a result of the congestion. For personal travel, value of time is the sum of the driver's perceived value of time plus the value of the extra fuel that is consumed in congested conditions. For commercial trucks, value of time is expressed as the wage rate of the driver plus the various components of operating costs associated with the truck or tractor-trailer. The sum of these costs, multiplied by the hours of delay, result in the total congestion cost. In the case of personal travel, the value of time eventually accrues to the vehicle (value of time *x* average vehicle occupancy). For commercial vehicles, the value of time represents the operating cost to the truck owner. This memorandum summarizes the components of each cost estimate and the hourly value to be used in the Texas Congestion Index calculations.

Current Methodology for Passenger Vehicles

Speed Choice is the model used by the State of Texas and Texas Department of Transportation and was developed by the Texas Transportation Institute (*1*). The same model is also used by the State of Virginia. The model derives its utility from the notion that speed is regarded as one of the most important factors in any travelers' choice. Travel time is directly related to the choice of speed that one chooses to travel. The first attempts to discern any relationship between speed and the value of travel time were by Mohring (*2*). The speed choice model assumes that a rational driver chooses to drive at a speed, which minimizes his or her total trip cost. The underlying assumption of the model is that a driver chooses a speed at which his or her marginal cost is equal or less than the marginal benefit. Driving costs include vehicle operating costs, time costs, accident costs, and traffic violation costs.

The travel characteristics in Texas during the development of the speed choice model included a relatively small number of toll roads and small percentage of people using mass transit systems in Texas. The model was developed to analyze the nature of traffic in Texas at that time. More or less, the same conditions exist today with the exception of a large increase in truck traffic in some border areas after the implementation of the North American Free Trade Agreement (NAFTA) and the resulting growth in trade between the US and Mexico. The model provides travel time value estimates that are in line with other models used by the other States. An additional report provided the details of the values used by other states through a telephone survey (*3*). The results reported in this study are presented in Exhibit D-1.

Exhibit D-1. Value of Time Used by States

State	Autos (1997 Dollars)
North Carolina	8.70
New York	9.00
Florida	11.12
Georgia	11.65
Texas	**11.97**
Virginia	11.97
California	12.10
Pennsylvania	12.21
Washington	12.51
Ohio	12.60
Mean	**11.26**

Exhibit D-2 takes the $11.97 value of time shown for Texas in Exhibit D-1 and adjusts it for inflation by the Consumer Price Index (CPI) back to 1995 and forward to 2004.

Exhibit D-2. Value of Passenger Car Time (Nominal $)

Year	Value of Time (Passenger Cars)
1995	$11.37
1996	$11.70
1997	$11.97
1998	$12.16
1999	$12.42
2000	$12.84
2001	$13.21
2002	$13.42
2003	$13.72
2004	$13.89

In summary, the Texas application of the Speed Choice Model produces a value of time estimated to be $13.22 for 2002 ($11.97 adjusted to 2002 for inflation) and appears to be in line with estimates produced by other states using different approaches.

Adjustments of Current Methodology for Passenger Vehicles

Given that the value used in the Texas Congestion Index appears to be consistent with values used by other states and derived by other means, there does not appear to be any compelling reason to adjust the methodology used for calculating value of time for passenger vehicles.

Current Methodology for Commercial Vehicles

In the past, the Urban Mobility Study commercial truck costs were calculated on a cost per mile basis. The original base-year cost per mile value used by the Texas Transportation Institute was obtained from the American Trucking Association in 1986 ($1.65 per mile). In subsequent years, the value was adjusted to account for general inflation using the Consumer Price Index (Exhibit D-3). The cost per mile value includes depreciation, interest, general maintenance, tires, repairs, and other similar costs, but it does not include fuel. The amount of fuel used per mile was then multiplied by the cost of fuel to determine the fuel cost per mile.

Exhibit D-3. Commercial Vehicle Cost per Mile Value Updated with Consumer Price Index

Year	Cost per Mile
1986	$1.65
1987	$1.65
1988	$1.75
1989	$1.85
1990	$1.95
1991	$2.05
1992	$2.15
1993	$2.25
1994	$2.35
1995	$2.45
1996	$2.55
1997	$2.65
1998	$2.75
1999	$2.85
2000	$2.95
2001	$3.05
2002	$3.15

Adjustments to Calculating Value of Time for Commercial Trucks

Two primary sources of data were identified for determining true road user costs for trucks as a check against the CPI-adjusted values.

The first is a report published annually by Transport Canada entitled *Operating Costs for Trucks 2000* (*4*). The data are segregated by Canadian province and U.S. region. The U.S. South includes Texas and is the region used in the Texas Congestion Index calculations. These data include trucks with a gross vehicle weight (GVW) more than 14,000 lbs. For the year 2000, the data in Exhibit D-4 indicates the cost for several different truck categories for the U.S. South region.

The data in Exhibit D-4 include costs from three main categories: tractor costs, trailer costs, and other costs. Tractor costs include driver wage, fuel, repairs, tires, depreciation, and licenses. Trailer costs include repairs, tires, depreciation, and licenses. Other costs include insurance, administration, and interest.

Exhibit D-4. Truck Category Costs for the Southern U.S.

Unit Type	Cargo	Annual Miles	Hourly Cost (incl. fuel) US$
5 axle semi-unit (van)	dry	50,000	66.28
5 axle semi-unit (van)	dry	100,000	55.89
5 axle semi-unit (van)	dry	150,000	52.43
5 axle semi-unit (flat deck)	dry	50,000	66.88
5 axle semi-unit (flat deck)	dry	100,000	57.17
5 axle semi-unit (flat deck)	dry	150,000	53.99
5 axle bulk liquid tanker	bulk	50,000	65.93
5 axle bulk liquid tanker	bulk	100,000	53.70
5 axle bulk liquid tanker	bulk	150,000	49.62
5 axle bulk dry tanker	bulk	50,000	68.67
5 axle bulk dry tanker	bulk	100,000	55.11
5 axle bulk dry tanker	bulk	150,000	50.58
2 axle straight truck (6-wheel)	dry	25,000	71.09
2 axle straight truck (6-wheel)	dry	50,000	65.25
2 axle straight truck (6-wheel)	dry	75,000	63.30

To obtain a single weighted-average value of time to apply in calculations for the Urban Mobility Study, an estimate of the number of trucks that fall into each truck category was developed from data used as inputs in the air quality model. When those categories were reclassified to conform to the categories of data from the Transport Canada study for which the Texas Transportation Institute has hourly costs, researchers determined that 65 percent of the trucks fall into the 5-axle category and 35 percent of trucks fall into the 2-axle (6-wheel) category (*4*).

The truck cost data was then grouped into the same two main categories by averaging the hourly rates from the exhibit on the preceding page. The cost per hour figures for the lowest mileage category within each truck class was used. The average produced the following rates:

Cost per hour for Trucks in the 5-axle category	\$67
Cost per hour for Trucks in the 2-axle (6-wheel) category	\$71

Finally, these hourly rates were multiplied by the percentage distribution of trucks per category to produce a weighted average cost of per hour of \$68 in 2000 U.S. dollars.

The second source of data used to calculate a value of time for commercial vehicles is a report entitled, *An Evaluation of Expenses per Ton-Mile, Expenses per Mile and Expenses per Ton for Major Commercial Carriers in Numerous Segments of For-Hire Trucking* (*4*). Data from this report indicate the following costs per mile for all commercial trucks for the following years (Exhibit D-5).

Exhibit D-5. Commercial Truck Cost per Mile Developed for the Federal Highway Administration, Office of Freight Management and Operations

Year	Commercial Truck Cost Per Mile[1]
1995	\$1.65
1996	\$1.65
1997	\$1.66
1998	\$1.65
1999	\$1.70
2000	\$1.78
2001	\$1.79
2002	\$1.79[2]
2003	\$1.81[2]
2004	\$1.83[2]

[1] *Cost per mile values in Exhibits D-3 and D-5 cannot be used as direct comparisons because the values in Exhibit D-3 do not include the cost of fuel while the values in Exhibit D-5 do include fuel costs.*

[2] *Costs per mile for 2002-2004 are estimates based on trends seen in 2000. Operating costs for 2001 and 2002 from the trucking industry have yet to be published for the Office of Freight Management and Operations, Federal Highway Administration. Fuel costs so far for 2004 are higher than anticipated in 2000 and, as a result, will likely increase the per mile cost for 2004 over what is indicated here.*

Calculating Cost on a Value of Time Basis vs. a Cost per Mile Basis

The cost per mile value from Exhibit D-3 includes depreciation, interest, general maintenance, tires, repairs, and other similar costs, but it does not include fuel. The amount of fuel used per mile is multiplied by the cost of fuel to determine the fuel cost per mile and the total cost per mile (Exhibit D-6).

Exhibit D-6. Components of Cost per Mile Value as Developed for the Urban Mobility Study

Year	Cost per Mile	Fuel Price per Gallon	Fuel Cost per Mile	Total Cost per Mile (w/fuel)
1995	$ 2.45	$ 1.16	$ 0.063	$ 2.51
1996	$ 2.55	$ 1.27	$ 0.070	$ 2.62
1997	$ 2.65	$ 1.24	$ 0.068	$ 2.72
1998	$ 2.75	$ 1.13	$ 0.062	$ 2.81
1999	$ 2.85	$ 1.24	$ 0.068	$ 2.92
2000	$ 2.95	$ 1.51	$ 0.083	$ 3.03
2001	$ 3.05	$ 1.61	$ 0.088	$ 3.14
2002	$ 3.15	$ 1.45	$ 0.080	$ 3.23
2003	$ 3.25	$ 1.50	$ 0.083	$ 3.33
2004	$ 3.35	$ 1.80	$ 0.099	$ 3.45

The inclusion of fuel cost in the cost per mile value allows a direct comparison with those calculated by the Federal Highway Administration, Office of Freight Management and Operations and obtained from truck operators' data (Exhibit D-7).

Exhibit D-7. Comparison of CPI-Updated and FHWA Cost per Mile Value (Including Fuel in the Urban Mobility Study Cost)

Year	CPI-Updated Cost per Mile Value	FHWA Cost per Mile Value
1995	$ 2.51	$ 1.65
1996	$ 2.62	$ 1.65
1997	$ 2.72	$ 1.66
1998	$ 2.81	$ 1.65
1999	$ 2.92	$ 1.70
2000	$ 3.03	$ 1.78
2001	$ 3.14	$ 1.79
2002	$ 3.23	$ 1.79
2003	$ 3.33	$ 1.81
2004	$ 3.45	$ 1.83

Again it should be noted that values for 2001 to 2004 for the FHWA data do not include the higher fuel prices that were experienced in 2004. The calculation of the CPI-updated cost per mile does include an estimated fuel price of $1.50 per gallon for 2003 and $1.80 per gallon for 2004.

By taking the cost per mile calculations from Exhibit D-7 and multiplying them by the average peak period speed (i.e., congested speed) weighted by vehicle miles traveled, it is then possible to derive a value of time associated with each cost per mile. The results of these calculations are shown in the last two columns of Exhibit D-8.

Exhibit D-8. Conversion of Cost per Mile Value to a Cost per Hour (Value of Time)

Year	Weighted Avg. Speed[1]	CPI-Updated Cost per Hour[2]	FHWA Cost per Hour[2]
1995	38.0	$ 95.50	$ 62.63
1996	37.9	$ 99.24	$ 62.45
1997	37.8	$ 102.77	$ 62.67
1998	37.8	$ 106.23	$ 62.28
1999	37.7	$ 109.89	$ 64.13
2000	37.7	$ 114.26	$ 67.06
2001	37.7	$ 118.24	$ 67.44
2002	37.7	$ 121.32	$ 67.24
2003	37.6	$ 125.14	$ 67.97
2004	37.5	$ 129.06	$ 68.70

[1]*Average congested speed for each urban area weighted by VMT in each urban area.*
[2]*For presentation purposes cost per mile values are normally shown in whole dollars only.*

Summary

The cost per mile values developed by the Federal Highway Administration Office of Freight Management and Operations (when multiplied by peak period speed) are a more reliable statistic for use in the Texas Congestion Index process than the "inflation adjusted" cost per mile figure previously used.

One obvious question is why did the two costs per mile values begin to differ over time (as shown in Exhibit D-7). The answer is that the deregulation of the trucking industry in the 1980s served to significantly increase the competitive environment in which trucking companies operate. To whatever degree there were "excess" profits in the industry, that "excess" has disappeared. Further, whatever increased labor, insurance, and benefit costs the industry has experienced have been moderated by decreases in computer and information-processing costs as well as communication and tracking costs. Further, there has been (up to this point) little price increase pressure from equipment prices, tire and parts costs, or tax and regulatory costs. All of these factors taken together have held the nominal costs per mile almost constant and produced a decrease of some significance in constant dollar trucking costs in real terms.

For purposes of Texas Congestion Index calculations, the following unit values are suggested for use in calculating the cost of congestion in 2000:

- passenger vehicle occupant value of time: $13 per hour,
- passenger vehicle fuel cost: $1.50 per gallon, and
- truck operations cost: $68 per hour.

For 2004, projected values are as follows:

- passenger vehicle occupant value of time: $14 per hour,
- passenger vehicle fuel cost: $1.80 per gallon, and
- truck operations cost: $69 per hour.[1]

[1] *This value will likely be revised upward as average fuel costs for 2004 are calculated.*

The consumer price index will be used to update the passenger car time values. The commercial truck and average fuel cost will be obtained each year. Periodic review of the literature and the economic analysis should be conducted to maintain the best estimates possible. Additional cost elements may be added, and the analysis can be expanded to include other aspects of cost and effect.

Sources

1. Chui, Margaret K., and William F. McFarland. *The Value of Travel Time: New Estimates Developed Using a Speed-Choice Model.* College Station, Texas: Texas Transportation Institute, 1986.
2. Mohring, Herbert. *Transportation Economics.* Cambridge, Mass.: Ballinger Publishing, 1976.
3. Daniels, Virginia, David Ellis, and William R. Stockton. *Techniques for Manually Estimating Road User Costs Associated with Construction Projects.* College Station, Texas: Texas Transportation Institute, 1999.
4. Transport Canada. *Operating Costs for Trucks 2000.* Ottawa, Ontario: Transport Canada, 2001.
5. Federal Highway Administration. *Expenses for the for-Hire Motor Carrier Industry: 1976 through 1999.* Washington, D.C.: FHWA, Office of Freight Management and Operations, 2001.

APPENDIX E

Categories and Calculation of Lane-Mile Costs

Prepared for the 2004 Texas Metropolitan Mobility Plan

For the purposes of this analysis, lane-mile costs of roadways were divided into four main categories:

- new capacity on new right of way,
- new capacity on existing right of way,
- new capacity and reconstruction, and
- and reconstruction only.

To assemble data, researchers examined over 1,500 TxDOT projects from September 2000 to March 2004 on which bids were accepted. Of those projects, 263 fit into one of the four categories above and were selected for inclusion in the database. The projects were categorized by:

- area (DFW-Houston, Austin-San Antonio-El Paso, Lubbock-Corpus Christi-Hidalgo), project category (the categories listed above),
- roadway type (freeway or arterial), and
- area type (CBD, urban, suburban, or rural).

These data were used to produce four exhibits. Exhibit E-1 shows the estimated cost per lane mile for new construction on new right of way.

Exhibit E-2 combines three categories (new capacity on existing right of way, new capacity and reconstruction, and reconstruction only) to produce one category called Other Construction. The average cost per lane-mile of the three components of the Other Construction category was weighted as follows:

- new capacity on existing right of way: 40 percent,
- new capacity and reconstruction: 50 percent, and
- reconstruction only: 10 percent.

This weighting was assigned because researchers felt that the 40-50-10 mix would most accurately represent the future mix of projects.

Exhibit E-3 shows estimates of freeway-to-freeway interchanges by area type. Exhibit E-4 shows estimates of costs for ramps/elevated lanes by area type.

It should be remembered that these cost per lane-mile estimates are averages. Obviously, any given project may cost more or less than the figure reported here—and perhaps by a significant amount depending on specific local circumstances.

Exhibit E-1. Costs per Lane-Mile for New Construction on New Right of Way (millions $) (excludes estimated cost of right of way)

	Dallas-Fort Worth Houston	Austin San Antonio El Paso	Lubbock Corpus Christi Hidalgo
CBD Freeway	8.0	5.9	2.9
CBD Arterial	3.3	3.1	1.1
Urban Freeway	6.1	4.3	2.1
Urban Arterial	3.1	2.8	1.1
Suburban Freeway	4.1	3.7	1.8
Suburban Arterial	1.4	1.4	0.7
Rural Freeway	1.5	1.4	1.0
Rural Arterial	1.4	1.2	0.7

Exhibit E-2. Costs per Lane-Mile for Other Construction (millions $) (includes new capacity on existing right of way, new capacity and reconstruction and reconstruction only)

	Dallas-Fort Worth Houston	Austin San Antonio El Paso	Lubbock Corpus Christi Hidalgo
CBD Freeway	8.4	6.3	2.9
CBD Arterial	3.0	2.9	1.5
Urban Freeway	5.3	3.1	1.8
Urban Arterial	2.7	2.5	0.9
Suburban Freeway	3.1	3.0	1.5
Suburban Arterial	1.4	1.2	1.0
Rural Freeway	1.6	1.6	1.0
Rural Arterial	1.4	1.1	0.6

Exhibit E-3. Estimated Costs of Freeway-to-Freeway (e.g., 4-level directional) Interchanges (millions $ per interchange)

	Dallas-Fort Worth Houston	Austin San Antonio El Paso	Lubbock Corpus Christi Hidalgo
CBD Freeway	300.0	220.0	185.0
Urban Freeway	250.0	185.0	90.0
Suburban Freeway	200.0	150.0	75.0
Rural Freeway	100.0	75.0	40.0

Exhibit E-4. Estimated Costs of Ramp/Elevated Lanes per Mile (millions $)

	Dallas-Fort Worth Houston	Austin San Antonio El Paso	Lubbock Corpus Christi Hidalgo
CBD Freeway	8.8	7.0	6.0
Urban Freeway	5.8	3.6	2.1
Suburban Freeway	3.6	3.4	2.3
Rural Freeway	2.3	2.1	1.2

Clearly, the acquisition of right of way can play a major role in overall project cost. The figures shown in Exhibit E-1 do not include the cost of right-of-way acquisition. In most instances, right of way is either purchased at fair market price or donated. Any figure given here, however, would represent an average cost of right of way when, in fact, the true cost of right of way would likely be at either end of the spectrum (i.e., either purchased or donated). Researchers determined that in instances where right of way is purchased, a reasonable estimate would be $4.20 per square foot for urban/CBD conditions and $2 per square foot for other areas.

APPENDIX F

Predicting Travel Reliability in Texas

Introduction

The population of the major metropolitan areas in Texas has grown in both urban and suburban areas. In most areas, the rate of population and employment growth is much faster than the transportation infrastructure can be improved or expanded.

One consequence of this growth is the increase in traffic congestion to more roads, more times of the day, and more of the metro area. Congestion now affects two-thirds of peak period travel, whereas 20 years ago it was a factor in less than one-third of peak period travel (*1*). As a consequence, there is an increased interest in pursuing the full range of transportation improvement options. The benefits of many of these treatments cannot be easily estimated in the regional transportation planning models and traditional "average condition" measures do not provide a complete picture of the effects. This paper demonstrates an interim step on the path to a comprehensive monitoring process.

The Texas Metropolitan Mobility Plan includes congestion estimates for eight metropolitan regions. One missing element of the first phase of the performance measures was a reliability measure. This paper builds on research performed by the Texas Transportation Institute concerning the estimation of reliability measures using generally available congestion and system inventory data (*2*). Basic information about the development of the dataset and exploration of the alternative estimation procedures are contained in a report titled, "Estimating Travel Reliability Measures." This paper investigates the application of the national technique to the Texas metro region freeway data.

A recent report sponsored by the National Cooperative Highway Research Program (NCHRP) discusses travel time variability and how it causes unreliable travel due to changes in the underlying conditions present in the roadway environment (*3*). The report listed seven sources of unreliable travel:

1. Traffic incidents—events that disrupt the normal flow of traffic, usually by physical impedance in the roadway.
2. Work zones—construction activities on the roadway that result in physical changes in the highway environment.

3. Weather—environmental conditions can lead to changes in driver behavior that affect traffic flow.
4. Fluctuations in demand—day-to-day variability in demand leads to some days with higher traffic volumes than others.
5. Special events—traffic flow in the vicinity of the event will be very different from the "typical" pattern.
6. Traffic control devices—intermittent disruption of traffic flow caused by control devices such as poorly timed signals, railroad grade crossings, etc.
7. Inadequate base capacity—the interaction of capacity with the six other sources of variability has an effect on variability (e.g., an incident that blocks a single lane on a 2-lane facility will have a greater impact on that facility than on a 4-lane facility).

By using reliability information, vehicle and person throughput can often be increased through more efficient use of the roadway system. Improving efficiency and increasing throughput, in turn, provides one more cost-effective method of addressing congestion problems.

Performance Measure

An early Mobility Monitoring Program study (*4*) looked at three reliability measures: Percent Variation, the Misery Index, and the Buffer Index. All three measures indicated the same trends and relative rankings. The predominant measure presented in the 2002 Mobility Monitoring Program report (*5*) is the Buffer Index, a modified version of Mitretek's Buffer Time methodology (*6*). The Buffer Index, shown in Equation 1, measures the extra travel time (above the average) needed for motorists to arrive at their destinations on-time, 95 percent of the time (e.g., 19 workdays out of 20 each month). The index uses travel rate values (in minutes per mile) to give a time and distance neutral measure. The minute values could be used by travelers for particular trip lengths similar to Mitretek's process. At a regional level, the index is calculated for each road segment and a weighted average is calculated using vehicle-miles of travel as the weighting factor.

$$\text{Buffer Index} = \left[\frac{\begin{matrix}\text{95th Percentile Travel Rate} \\ \text{(in minutes per mile)}\end{matrix} - \begin{matrix}\text{Average Travel Rate} \\ \text{(in minutes per mile)}\end{matrix}}{\begin{matrix}\text{Average Travel Rate} \\ \text{(in minutes per mile)}\end{matrix}} \times 100\% \right] \qquad \text{(Eq. 1)}$$

$$\begin{matrix}\text{Weighted Average} \\ \text{of BI for} \\ \text{Several Sections}\end{matrix} = \frac{\left(VMT_{\text{section 1}} \times BI_{\text{section 1}}\right) + \left(VMT_{\text{section 2}} \times BI_{\text{section 2}}\right) + \ldots}{VMT_{\text{section 1}} + VMT_{\text{section 2}} + \ldots}$$

If a traveler is told to expect a Buffer Index of 20 percent on a trip with an average travel time of 20 minutes, the traveler should allow four extra minutes (20 percent of 20 minutes) in order to make the normal 20 minute trip on-time 95 percent of the time. Using the 95 percent factor allows for most common events during travel, such as weather problems, a collision, or stalled vehicle. The "worst day of the month" is a relatively simple concept for travelers and businesses.

Some other observations from the data were:

- Generally, the most congested parts of freeways were also the least reliable,
- The least reliable time periods are in the midday or late evenings, even though they are not the most congested times,
- Tollways are more reliable than freeways, and
- HOV lanes were more reliable than freeway mainlanes.

A primary goal of this paper is to describe a method to estimate the effects of highway characteristics and Intelligent Transportation System (ITS) improvements on travel time reliability in Texas metropolitan areas. Using the national research as a basis, the Texas freeway system data was examined to identify a predictive procedure for the Buffer Index.

The same transportation planning model data used to estimate traffic congestion levels may also support reliability values that allow researchers and operators to report areawide levels for both measures. Factoring in different highway characteristics such as ITS improvements, number of lanes, traffic volumes alternate route availability, weather patterns and other factors could help assign reliability values based on the possible changes related to those characteristics. These types of improvements are being studied for the second generation of predictive procedures.

Data Sources and Issues

The data derived from the 2002 Mobility Monitoring Program (MMP) Report (*5*) included several types of data for directional segments of controlled-access facilities in 23 cities throughout the United States. The data used for this analysis included lane-miles of roadway, vehicle-miles of travel, Travel Time Index (TTI), and Buffer Index (BI) for each section.

The data was obtained from instrumented freeway sections in three Texas regions. The instrumented freeway coverage includes 22 percent of the freeway system in the Austin area, 36 percent coverage of the San Antonio freeways and 61 percent coverage in Houston. The significant coverage difference makes city to city comparisons of the travel data problematic (Exhibit F-1). Other differences such as the types of instrumentation used, the time intervals of the data collection, and the "space" of data collection (by lane, by direction, etc.) also complicate the comparisons. The data are very useful, however, for analyzing the issues of travel reliability within cities. With some allowance for the between-city differences, the general corridor trends might also be useful.

Exhibit F-1. Texas Cities Included in the 2002 Mobility Monitoring Program

Participating City	Freeway System Monitored, %	Single and double loop detectors	15 minutes	By lane
Austin, TX	22% (23 of 105 mi.)	Double loop detectors	1 minute	by lane
Houston, TX	61% (298 of 368 mi.)	Probe vehicle (AVI), limited double loop detectors	Anonymous individual probe vehicle travel times by link. Loop data are 20 seconds by lane.	
San Antonio, TX	36% (77 of 211 mi.)	Double loop detectors, acoustic detectors	20 seconds	by lane

Source: Reference (*5*)

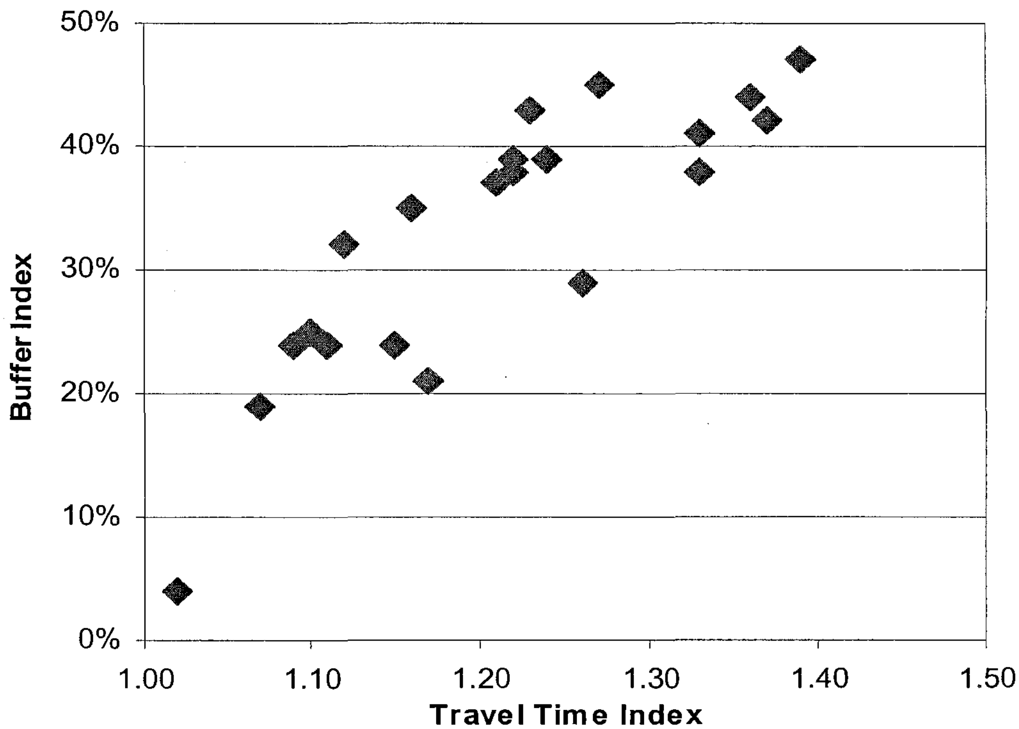
Data Analysis

The interest in developing a predictive equation for reliability began with the relatively close relationship between increasing congestion levels and increases in unreliability. Exhibit F-2 illustrates the values of Travel Time Index and Buffer Index for the portions of the freeway system monitored in 21 metropolitan areas in the 2002 Mobility Monitoring Program (*5*). While areawide averages are not the optimal dataset for prediction, the relationship in Exhibit 5 indicates there is value in examining a potential predictive procedure for Buffer Index values.

The traffic management center traffic volume and speed data from Austin, Houston and San Antonio was used to produce a picture of congestion and reliability for each area's freeway system. The initial graphs showed the Travel Time Index (TTI) and Buffer Index (BI) values for each segment in each city in the study. These graphs are shown in Exhibits F-3, F-4 and F-5.

While the best-fit lines are slightly different, there does not appear to be a significant difference in the three relationships. A second-order polynomial relationship (i.e., an equation with a squared variable) results in a line that increases rapidly for lower values and less rapidly for higher values. Congestion in San Antonio and Austin is not as severe as in Houston, so most of the values appear to indicate a sharply increasing relationship between congestion and unreliability.

Exhibit F-2. Congestion and Travel Reliability in 21 Metropolitan Area Freeway Systems

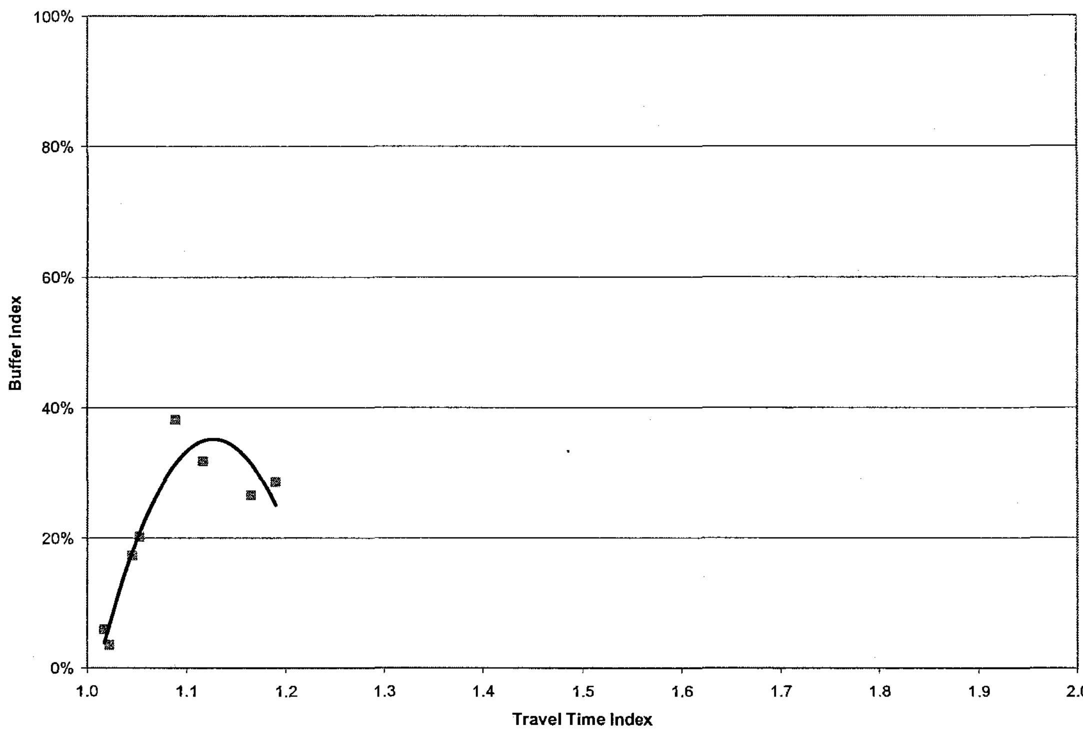


Source: Reference (5)

Austin

Exhibit 3 presents the congestion and reliability statistics for the ten Austin freeway sections in 2002. The data indicate a relatively sharp increase in reliability for each increment in congestion. While the best-fit curve matches the data relatively well, the congestion levels are not very high. Projections of congestion levels indicate higher congestion in the future, and the diagram in Exhibit 3 may not be useful beyond congestion index values of 1.10.

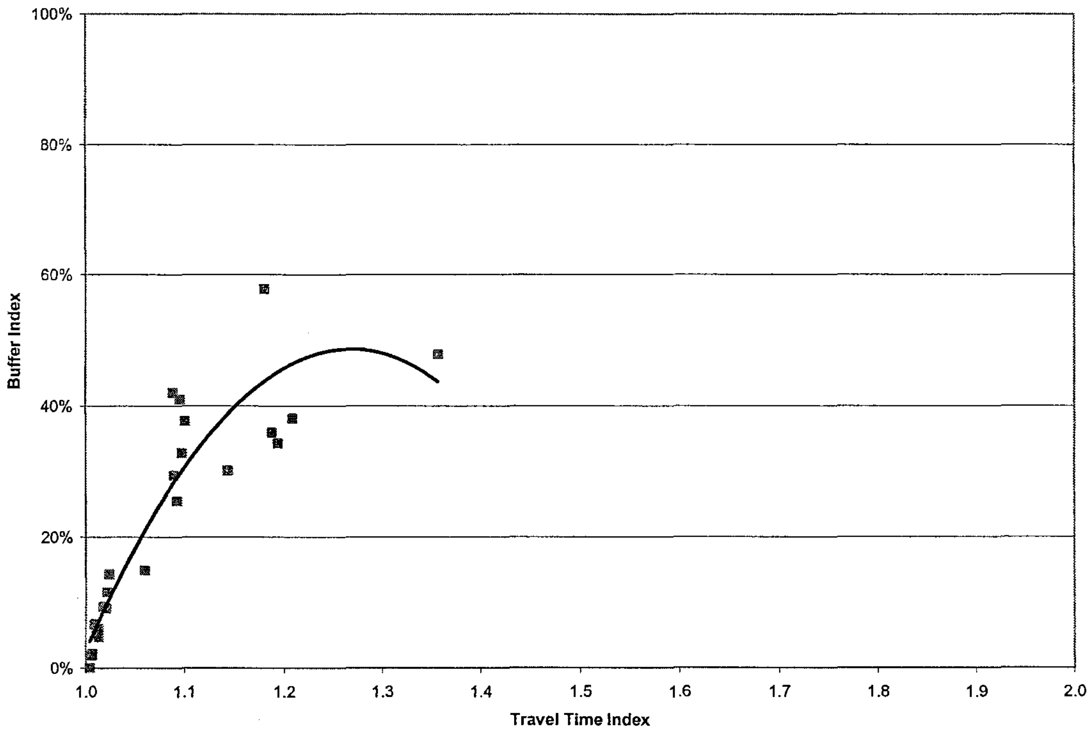
Exhibit F-3. Freeway Segments in Austin



San Antonio

Exhibit 4 illustrates the more than 20 freeway section congestion and reliability points for 2002 in San Antonio. The data show a significant increase in unreliability at relatively modest congestion levels. Above a congestion index of 1.25, the Buffer Index curve points downward. While the increase may not continue at the rate of the lower congestion levels, the down slope may not be appropriate for longer term analyses.

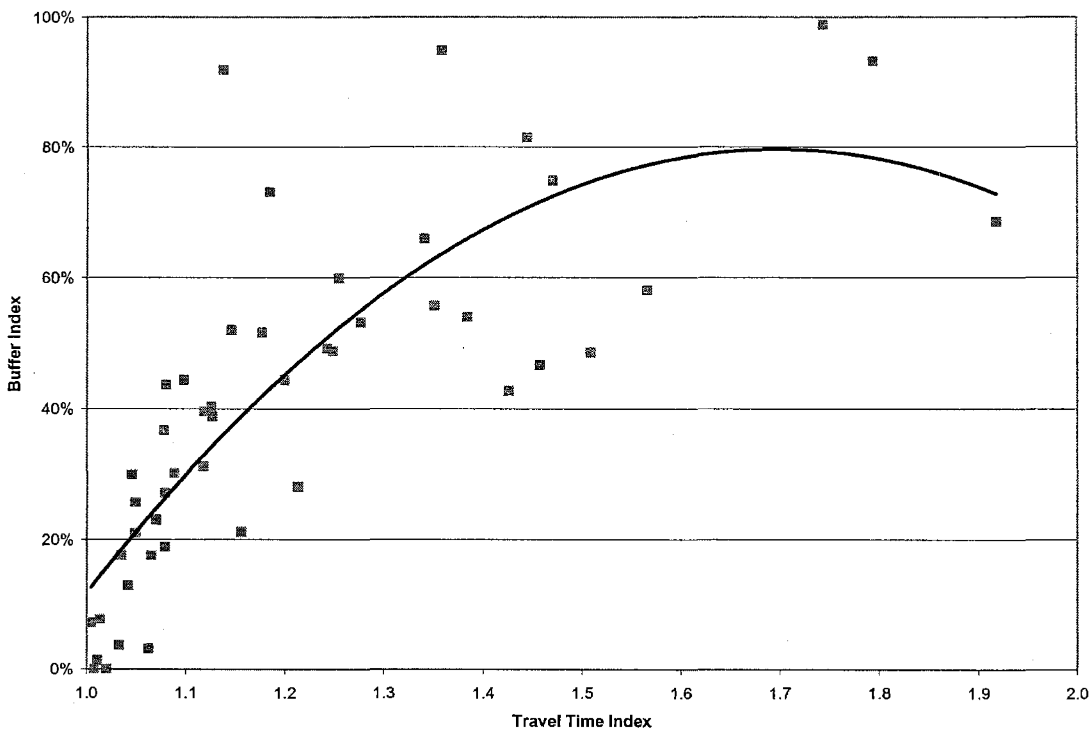
Exhibit F-4. Freeway Segments in San Antonio



Houston

The congestion and reliability on the Houston freeway system is depicted in Exhibit 5. The initial steep increase seen in Austin and San Antonio is also present in Houston. The Y axis intersection point is at a Buffer Index of 10 percent, slightly higher than Austin or San Antonio. Above 1.40, reliability does not diminish at the same rate and the best-fit line peaks below a congestion index of 1.70. There are very few sections with higher congestion index values.

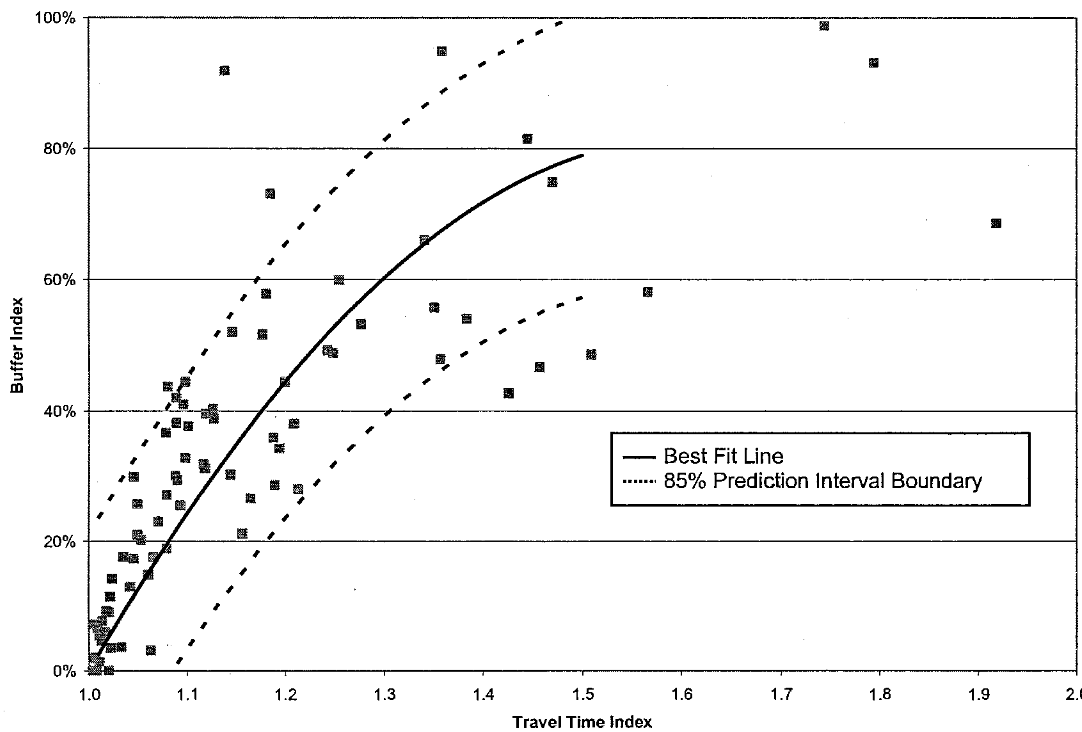
Exhibit F-5. Freeway Segments in Houston



The prediction intervals shown on a graph of the combined data from Austin, Houston and San Antonio in Exhibit 6 illustrate the region that will include 85 percent of the Buffer Index values for a Travel Time Index value. The wide interval indicates the significant variation between corridors. Research continues to investigate the reasons for these variations, but there are several factors at work. The best fit equation is shown in Equation 2.

$$\underset{\text{(Percent)}}{\overset{\text{Initial}}{\text{Buffer Index}}} = -1.5\left(\text{Travel Time Index}\right)^2 + 5.1\left(\text{Travel Time Index}\right) - 3.5 \qquad r^2 = 0.70 \qquad \text{(Eq. 2)}$$

Exhibit F-6. Travel Time Index and Buffer Index Relationship for All Texas Areas



Application to the Texas Congestion Index Process

The basis for incorporating the statewide relationship between congestion and reliability is the connection with the two different types of delay. Recurring delay is the quantity captured in the volume/capacity ratios in the transportation planning models. It is the amount of congestion that can be counted on to occur every day. The effect of incidents is one of the most significant variables that change congestion from day-to-day. If there were no incident congestion and consistent volume, in the most simplified form, there would be congestion, but there would be little or no variation from day-to-day.

The Buffer Index estimation technique will use a two-stage process. The first step will estimate the Buffer Index that would be experienced in the absence of operational treatment improvements. The expansion of those treatments, however, will reduce incident delay and improve reliability. The second step of the Buffer Index estimation process will reduce the initial Buffer Index by the percentage of incident delay reduced by the operational treatments.

The relationship in Exhibit 6 will be incorporated into the Texas Congestion Index spreadsheet by slightly modifying the existing calculation steps. A freeway congestion index will be developed in the initial steps, before the operational treatment "credits" are calculated. The incident delay hours reduced by the operational treatments will be summarized for both arterials and freeways. Equation 3 illustrates the general form of the Buffer Index estimation equation.

$$\text{Buffer Index (Percent)} = \begin{matrix}\text{Initial Buffer Index}\\ \text{(Percent)}\\ \text{(from Equation 2)}\end{matrix} - \frac{\text{Incident Delay Reduced (Vehicle - hours)}}{\text{Initial Incident Delay (Vehicle - hours)}} \qquad \text{(Eq. 3)}$$

Conclusion

All three Texas relationships are similar. For the near-term, therefore, all eight regions can use the combined Texas region dataset to estimate freeway reliability statistics. Above a freeway congestion index of 1.50, however, the research team recommends that the 80 percent Buffer Index value be used. The small number of values beyond that will have to be increased before confidence can be developed.

While there appears to be enough data to develop a preliminary estimate of the relationship between congestion and reliability, additional descriptive data is needed to determine the strength of the relationship between ITS improvements and reliability. Data in the form of more archived freeway sections that have no ITS coverage is needed as well as information from varying city sizes. Identifying a relationship between individual types of ITS (e.g. ramp metering or service patrols) and their effect on reliability will be a subject of additional research. The factors being investigated for possible better explanations of reliability levels include:

- The presence of shoulders
- Availability of alternate routes
- Weather patterns
- Location of bottlenecks in the corridor
- Length of analysis sections

However, more information will be needed to show the different characteristics with and without ITS improvements.

One other conclusion is that due to the nature of the data, the results may be better suited for a regional scale reliability estimate and as an initial effort for determining the effectiveness of ITS on reliability. This is because the grouping of the data across various cities with different characteristics decreases the certainty of reliability values at any given point, but ranges of reliability values might be more readily established.

As the quality and quantity of data increases, the presence or absence of a relationship between ITS improvements and traffic reliability can be identified with more certainty. As the Mobility Monitoring Program Report states, more standardized data collection and management methods (file formats, aggregation procedures, quality control, and data attributes) combined with greater participation among the cities and states presents greater opportunities to advance the study of this subject matter (*4*,*5*).

Sources

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