Considerations of a Multi-Modal Congestion Index

Dave Mootchnik
September 11, 2001

Abstract
In one way or another, dealing with congestion consumes the attention of most people and businesses as well as urban and transportation planners. Congestion impacts everyone almost every day. For these reasons, measuring and evaluating congestion is a critical planning issue. There is considerable literature on how to and actually measuring the effects of congestion but most of the work has been focused on personal vehicle travel. This paper focuses on developing a multi-modal (auto/transit) congestion index. The paper discusses a previous attempt, derives a new measure and discusses available data related to the subject. The paper shows that, in contrast to earlier work, a multi-modal congestion index would not support the contention that transit reduces the impact of congestion.

Introduction

The impact of congestion on urban life and planning is profound. Congestion impacts every citizen almost every day; it causes delay, anxiety, accidents, pollution, and wasted fuel consumption. For commerce it increases fuel and delivery costs and in all cases it causes not only added trip duration, but its unpredictability compounds daily planning and scheduling. Dealing with congestion consumes the attention of most people and businesses as well as urban and transportation planners. For these reasons alone, measuring and evaluating congestion is a critical planning issue.

Congestion prediction and impact analysis is a critical element in both the planning process for urban development and transportation projects and in monitoring the status of the existing transportation infrastructure. Congestion is monitored by federal agencies particularly the Federal Highway Administration (FHWA, 1999), most states (CalTrans, 1998), and by academic institutions and others. The Texas Transportation Institute (TTI), through its annual mobility reports (Schrank, 2001), has become a de facto standard for assessing congestion in our major urban areas. TTI has developed several measures of congestion dealing principally with travel delay, but also with fuel consumption and societal costs. They have developed two measures, the Travel Rate Index, and recently the Travel Time Index which both deal with the excess trip duration caused by congestion. The TTI work is excellent and serves as a recognized guide to the country. But it is limited in several respects, one being it currently measures only the impact of congestion on automobiles and users of personal vehicles. As the desire to increase the usage of public transportation grows, it is important to develop measures of congestion which also includes those users. Multi modal congestion indexes are discussed by various groups (Turner et. al. 1996). An attempt at a multi modal congestion index has been made by the Surface Transportation Policy Project (STPP, 2001).

This paper first describes the TTI index. It then reviews the STTP effort and points out its weakness. It then discusses the necessary scope of a comprehensive multi modal index and develops a proposed index formulation. However sufficient data was not available to employ this formulation accurately. The paper then examines some of the available travel statistics that will point the way to some trends which a full evaluation should support.

Background

The study of congestion has been of interest for some time and has been dominated by both the search for meaningful measures of performance and of the need to collect large quantities of statistically significant data. Czerniak and Gerard (Cerniak et. al. 1996) surveyed the practices of 14 states and identified 16 performance goals for passenger traffic with 260 specific measures including 16 for travel time. Abrams and DiRenzo considered multi-modal issues in 1979 (Abrams et. al. 1979). Others surveyed measures used in planning analysis (FHWA, 1995., Turner et. al, 1996).

Measures of congestion include travel speed, hours of delay or excess travel time, travel time variance and predictability, congestion impacts on safety, fuel consumption and emissions, personal and commercial congestion costs. Almost all these measures are directly or indirectly related to travel time effects. In all these studies, there is general agreement on the types of performance indicators such as travel time but there is a very wide variety of the specifics of measuring these. Variations on travel time measures include, diurnal period of interest, all day, peak period, all or congested direction, passengers or vehicles counted, transportation facilities included, total time or delay, area wide or per capita, etc. All these variations have reasons to exist but the plethora of definitions makes standardization difficult.

Among all these indicators, those developed by the Texas Transportation Institute (TTI) have emerged as reasonably accepted standards for comparing the performance of urban areas. The TTI have been conducting congestion studies for Texas cities for almost twenty years (Lomax et. al. 1982) and for countrywide major urban areas since 1988 (Lomax et. al. 1988)

Travel Rate Index

The principal TTI congestion parameter is referred to as the Travel Rate Index (TRI). The travel rate index (Shrank, 2001), "shows the amount of additional time that is required to make a trip because of congested conditions on the roadways." The value of the TRI is the ratio of the travel time under existing congested conditions divided by the time it would have taken under freeflow conditions.

$$TRI = \frac{congested\ travel\ time}{uncongested\ travel\ time} = \frac{Tc}{Tu}$$

where T refers to time, c to congested conditions and u to uncongested conditions.
It is evaluated annually for each of 68 urban areas. The TRI is evaluated for the peak traffic period and is a weighted average for traffic on freeways and primary arterials. The actual formulation is in terms of traffic speed based on;

$$\frac{Tc}{Tu} = \frac{D}{Sc} \Big/ \frac{D}{Su} = \frac{Su}{Sc}$$

where D is distance and S is speed. As a measure of congestion, the TRI is not perfect but quite representative. For example the index considers only the "recurring delay" caused by congestion and not that caused by accidents or construction. TTI has recently developed a new index called the Travel Time Index which does include accidents. While not perfect, the TRI is a good representation of congestion and is used widely in the community.

Other than implicitly including the effect of traffic reduction absorbed by transit, the TRI does not encompass the effect of congestion on transit travel.

Congestion Burden Index (CBI) Description

For the past several years the STPP has tried to utilize the TTI index ratings to discredit building roads to alleviate congestion (STTP, 1999). The STPP has published articles (STTP, 2001) ranking metropolitan areas based on an index they have devised. This index purportedly demonstrates that areas which develop public transportation over improving roads have a better history of reducing the impact of congestion. Their Congestion Burden Index (CBI) looks plausible at first glance but in fact is deceptively in error. The CBI ignores fully half the problem. Their conclusion that public transit eases the congestion burden is a consequence of this error and does not reflect reality. This paper describes the error in STPP's index and discusses why their conclusions will prove to be false.

The STPP built on the TRI index. They defined the CBI index by multiplying the TRI by the fraction of commuters that commute by auto.

$CBI = TRI * (1 - Ftransit) = TRI * Fauto$,

where $Ftransit$ and $Fauto$ is the fraction of commuters traveling by transit and auto.

The reasoning is that if an area depended heavily on transit instead of auto the impact of congestion would be proportionally reduced. For example, suppose that a region's TRI is 1.3 and that 80 percent of commuters do so by auto. The 1.3 index means that auto commuters travel 30 percent longer than they would have if the roadways were free of congestion. But according to STPP, the CBI for this area would be the product of 1.3 and 0.8, or 1.04. In other words the CBI seems to indicate that if 20 percent of the commuters don't use private autos then the congestion burden is reduced by 20 percent and the commuting public is better off by 20 percent. This argument is not quite right as discussed below.

The CBI would indicated that if two urban areas both had the same value of the TRI but one had a 10 percent higher percentage of transit users then its congestion index would be 10 percent lower. The STPP uses this logic to show how San Francisco with the second worse congestion rating is actually better off than Detroit which ranked 15th in congestion because San Francisco has a higher portion of transit riders.

CBI Shortcomings

These arguments may seem logical on the surface but examine more closely what is being considered. The TRI index is a useful index because it represents a physical condition we can readily relate to. As said above it represents the ratio of congested commute time to uncongested commute time. A value of the TRI of 1.5 means that it takes 50 percent longer for the commuter to travel then it ideally would have.

The TRI however only considers the auto traveler. STPP attempted to extend this analysis to include transit and other commuters. This is a worthwhile endeavor, but only if done properly. Unfortunately the CBI index is invalid for at least two significant reasons. To start with, when considering transit and other commuters, the impact of congestion on their travel time was totally ignored. Most public transit is done on buses which are subject to the same street traffic as are autos. This factor was ignored by the STPP. Second and more importantly, STPP totally ignored all travel time of transit and other commuter modes. The STPP calculations are done as if transit travel time is of no consequence. The real situation is that most transit and other modes (walking and bicycle) are inherently slower than car travel, even in significant congestion conditions. When a commuter switches to transit he almost always accepts a slower travel mode and thus incurs a penalty in travel time.

- STPP's Congestion Burden Index ignores the impact of congestion on most transit.

- STPP's Congestion Burden Index ignores the time penalty of using transit and other modes

What STPP ignores is that transit travel time is generally slower than travel by auto even considering the worst congestion conditions.

Let us recall that the TRI measures the time penalty it takes to commute under congested conditions. Multiplying this figure by the fraction of auto commuters as does the CBI gives a number which has no quantitative basis or physical meaning. It does not provide an indication of the impact of congestion on the average commuter. Only in a vague, un-quantified sense does it seem to relate to the effects of congestion.

A Multi-Modal Congestion Burden Index.

There may be other factors associated with congestion to form the basis for a measure, but the one used by TTI as its travel rate index, namely the ratio of congested to uncongested time, is certainly of importance. It is proposed that the basis for this concept also be used in the multi-modal situation. The Multi-modal Congestion Burden Index (MCBI) is defined as;

$$MCBI = \frac{\sum_i Tci * Wci}{\sum_i Tui * Wui}$$

where *ci* and *ui* refer to congested and uncongested conditions for travel mode *i* and *W* indicates the weighting for mode *i*.

By the same considerations earlier, the new definition can be expressed as a ratio of speeds, *S*.

$$MCBI = \frac{\sum_i Sui * Wui}{\sum_i Sci * Wci}.$$

In both formulations, the speed or timing is summed over all travel modes and it is proposed that the weighting factors be the fraction of travelers using each mode.

$$MCBI = \frac{\sum_i Fci/Sci}{\sum_i Fui/Sui}$$

An important element of this formulation is that the fractions for each travel mode need not be the same in the congested as the uncongested case. It is argued, for example, that urban rail and express bus systems become more desirable as alternatives to being stuck in traffic. If this is so then it will be evidenced by the rail fraction increasing in the congested situation. Note also that, given the data availability, the transit modes should be expanded into bus, rail etc. The same should be said for mixed flow and HOV lane travel where applicable. Finally it should be noted that the mode speed is not necessarily the same for transit modes in the congested and uncongested cases. Transit speeds are affected by highway speeds for co-use buses and some trolley systems. Speed may be affected (up or down) also by heavier ridership. The point is that transit is not necessarily independent of congestion.

Given the above formulation, one can see that the STPP index accounts for only some of the terms, namely;

$$CBI = \frac{Suauto * Fcauto}{Scauto}.$$

It is seen that all transit terms as well as the uncongested auto fraction is missing.

Some Supporting Data

The formulation proposed above for a multi-modal congestion burden or travel rate index may be proper and accurate but trying to find all the data to properly evaluate it is not an easy task. It will have to await future analysis by myself or others.. What we will do here instead is explore the impact of modal mix on travel time characteristics. While not a substitute for a comprehensive index, this data is enough to demonstrate that;

1) ignoring transit travel time is a significant omission of the CBI and leads to false conclusions, and,
2) Significant transit development does not mean improved commutes.

Transportation Mode Speed Comparisons.
Major sources for roadway congestion data are the Federal Highway Performance Monitoring System (HPMS, 1999), various state departments of transportation reports and the National Personal Transportation Survey (FHWA, 1997). The following analysis is based on the 1990 Journey to Work (Census, 1990) and the 1995 Department of Transportation National Personal Travel Survey.

Figure 1, developed from the 1995 NPTS data compares average speed derived as trip length divided by trip duration for various modes of travel. The data represent an average of 55 reported metropolitan areas for the journey to work commute. As seen only Amtrak and commuter rail provides travel speeds comparable or faster than auto and van transportation. Heavy rail such as in New York and Chicago provides speeds about 2.3 that of auto and bus about half the speed. Trolley, currently called light rail, is on the average significantly slower. According to other FTA documents, currently the average light rail travels at 16 mph although more recent systems travel at upwards of 20 mph. These speeds however do not account for travel to/from stations or boarding and transfer wait times. Bicycles and walking are the slowest modes but in reality represent very short trips averaging 3 and 0.7 miles respectively.

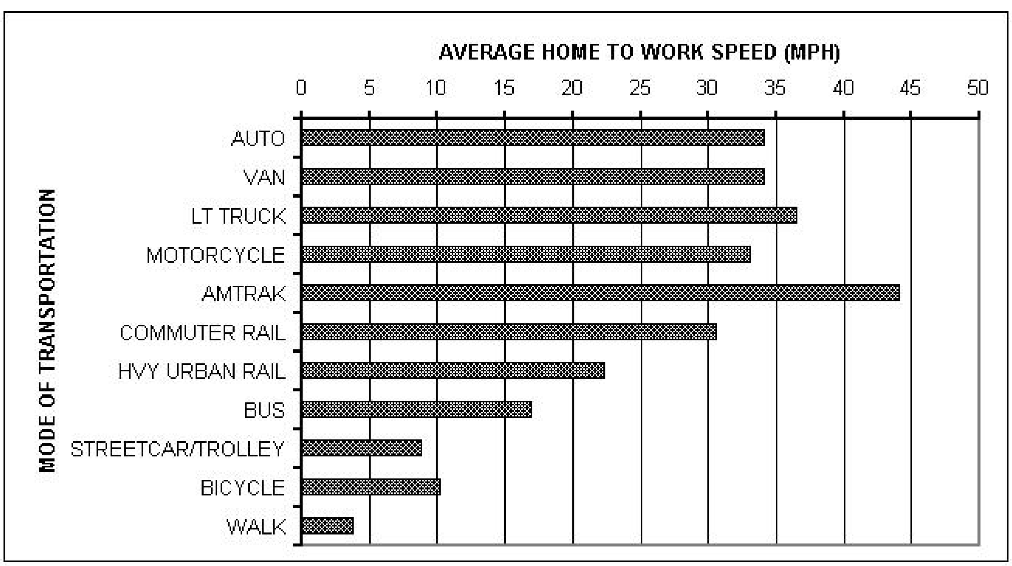

Figure 1 Comparison of travel mode speeds: source 1995 NPTS

It should be obvious that any commuter switching to transit from auto does so because of either a desire not to drive or because of extreme congestion frustration or delays. In those cases where commuter rail is available a time improvement may be the case but commuter rail is a very small fraction of transit riders. In any event, almost always, the switch to transit implies a significant penalty in travel time and this penalty would aggravate, not improve, any proper combined travel rate index.

Impact of Transit Utilization on Travel Time

How does reliance on transit impact travel time to work? data are available from the 1990 Census Journey to work and the 1995 NPTS files. Figure 2 shows the results from the 1990 census for the 49 largest MSA areas.

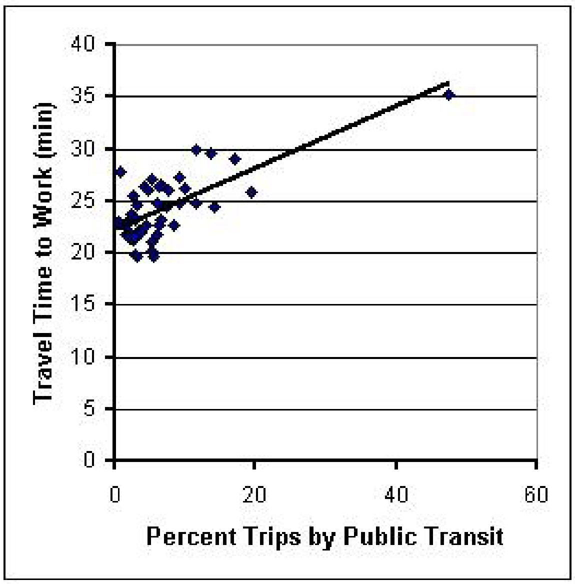

Figure 2 Average travel time to work for 49 MSA's: source 1990 Census

Figure 3 shows similar results for the cities within the above 49 MSA's. The trends are the same except for the percent of travel by transit is somewhat higher for cities compared to the entire MSA. However in both cases it is seen that there is a clear trend between trip time and transit usage. Those cities and MSA's that rely more heavily on transit show a larger trip time than those areas that rely heavily on auto. In both cases the trend indicates a one to one relation; a 50 percent use of transit corresponds to areas with a 50 percent longer trip time.

What exactly causes this correlation is not totally obvious, One explanation is as stated above, transit travel is significantly slower than auto travel. Another is that areas that invested more heavily on transit and less on roadways are suffering the consequence of diverting funds to a less effective mode of travel. Both these explanations are likely contributors to the actual data presented, but no further proof is offered here.

One interesting feature of measuring trip time as opposed to speed is the impact of density demographics. It is commonly accepted that urban areas with higher density tend to invest more heavily in transit and that transit is more effective in high density areas.

One would also think the effect of higher density is to shorten trip length and that this would then be reflected in shorter trip times. These are basic tenets of the "smart growth anti-sprawl" advocates. If this trend were true and powerful enough, then trip time should be reduced with high transit usage even if the mode speeds are less. This is clearly not the case. Even New York, with the highest population densities in the USA and about 50 percent reliance on transit has the longest home to work trip times of any other city. And Los Angeles, that so called den of the evil auto and sprawl with only a low 6.5 percent transit usage has a very average 26 minute trip time.

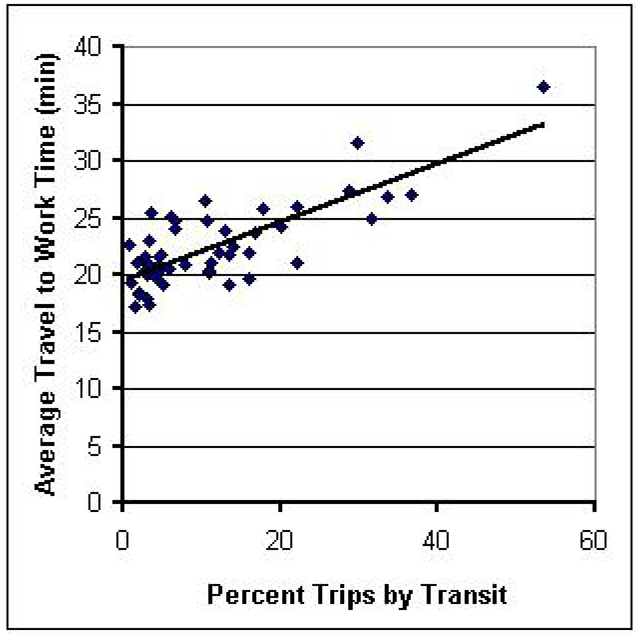

Figure 3 Average travel time to work for 49 cities: source 1990 Census

Figure 4 shows similar data for 54 largest MSA's from the 1995 NPTS data. Again the data shows an upward trend in trip time as transit usage increases. Also the percent transit usage reported in 1995 is significantly lower than in the earlier census. However the data shows a weaker correlation than the census data. The reason for this may be an actual change in travel habits and characteristics or it may be the difference in sampling methods. The census data is far more thorough in scope but both surveys are still based on respondent's memory and opinion of facts as opposed to measurement

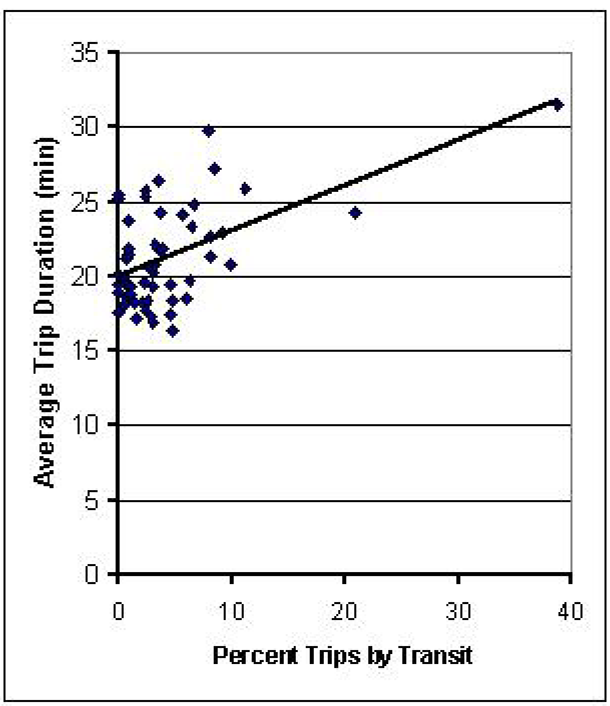

Figure 4 Travel Time to work for largest MSA's: source 1995 NPTS

of the facts themselves. We suspect all these factors influence the differences.

One feature of the NPTS data is the added detail available for analysis. For example the average trip speed which presumably includes both in and out of vehicle times can be derived as shown in Figure 5. The data shows a clear correlation of decreasing speed as transit usage increases. Thus the data supports the basic premise of this paper; that increased usage of transit as the response to congestion increases the congestion burden as opposed to reducing it.

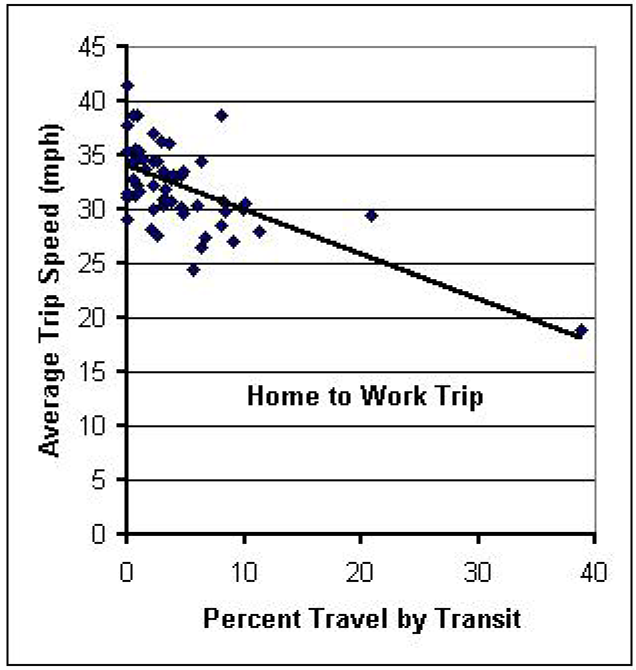

Figure 5 Average Trip Speed, source 1995 NPTS

Regarding the idea that transit usage would be more prevalent in denser urban areas with shorter trip lengths, the idea does not seem to be born out by the facts. Figure 6 shows trip length versus transit usage. The figure shows that not only is there almost no trend, but the data is dominated by significant scatter. It is this scatter that would cause the trend in trip time versus transit usage to be less than the trend shown for diminishing speed versus transit usage.

Conclusions

We have discussed the need for a multi modal travel rate or congestion burden index. We have examined several current alternatives and have developed a comprehensive formulation for such an index. We have examined the STPP index and find that it does not satisfy the requirements. Finally we have examined some available data and found that transit may indeed impact such an index, but in a direction opposite of previous findings.

The STPP claim that the Congestion Burden Index provides a more comprehensive index for the measurement of congestion than the TTI Travel Rate Index has been shown to be wrong. We have described the factors omitted in the CBI and have explained why they are important and significant. We have discussed how including these factors would change the earlier evaluations and would reverse the trends and conclusions presented by the STPP. We have presented data to support this argument based on available government databases.

The idea of reducing the Travel Rate Index by the fraction of people using transit, without including the travel rate of those transit users is invalid. It is no more proper than reducing the index by the fraction of commuters wearing green pants and then claiming green pants reduces the congestion burden.

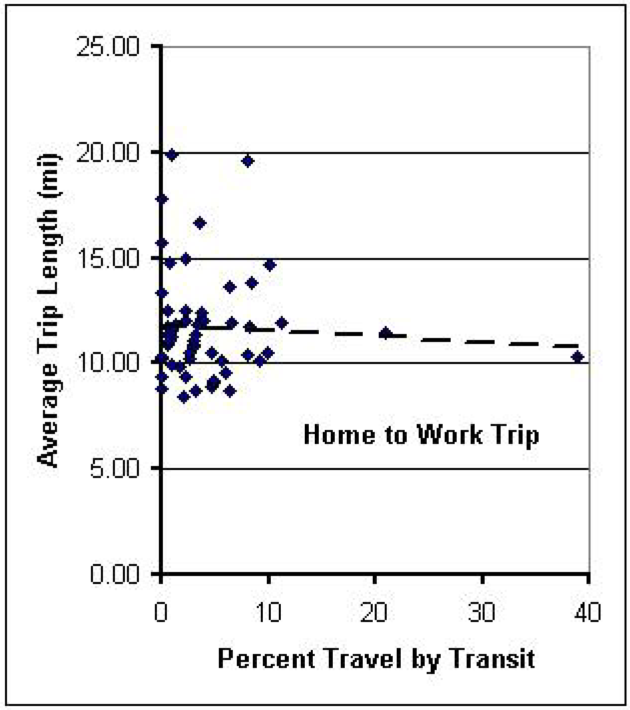

Figure 6 Trip Length versus transit usage: source 1995 NPTS

The argument that transit eases the congestion burden in areas with higher levels of transit or that areas with high reliance on transit have a lighter congestion burden, is invalid. The Travel Rate Index and multi-modal congestion burden index measures the increase in travel time compared to the uncongested situation. On that basis we have shown from data that the opposite is true; areas with increased reliance on transit exhibit both longer travel times and slower trip speeds.

References

FHWA (1999). 1999 Status of the Nation's Surface Transportation: Conditions and Performance Report, *U.S. Department of Transportation*, *Federal Highway Administration*.

CalTrans (1998). Highway Congestion Monitoring Report, Annual Report on Traffic Performance of the Bay Area Freeway System, *California Transportation Authority, District 4.*

Schrank, D. (2001). 2001 Urban Mobility Report, *Texas Transportation Institute*, May 2001.

STPP, (2001) Easing the Burden, A Companion Analysis of the Texas Transportation Institute's Congestion Study. *Surface Transportation Policy Project.* May 2001.

Czerniak, R.,Gaiser, S., Gerard, D. (1996). The Use of Intermodal Performance Measures by State Departments of Transportation, Final Report. *New Mexico State University,* DOT-T-96-18, June 1996.

Abrams, C.M., DiRenzo, J.F. (1979). Measures of Effectiveness for Multimodal Urban Traffic Management, Volume 2; Development and Evaluation of TSM Strategies. *Federal Highway Administration*, Report No. FHWA-RD-79-113.

FHWA, (1995). RESOURCE MATERIALS, ATIS and CVO Development Objectives and Performance Requirements. U.S. Department of Transportation, Federal Highway Administration. Publication No. FHWA-RD-95-109, September 1995

Turner, S.M., Best, M.E., Schrank, D. (1996). Measures of Effectiveness for Major Investment Studies. *Texas Transportation Institute*, SWUTC/96/467106-1, November 1996.

Lomax, T.J., Christiansen, D.L., Fitzgerald, A.V. (1982). Estimates of Relative Mobility in Major Texas Cities. *Texas Transportation Institute*, Research Report 323-1F, 1982

Lomax, T.J., Bullard, D.L., Hanks Jr. J.W., (1988). The Impact of Declining Mobility In Major Texas and Other U.S. Cities. *Texas Transportation Institute*. Research Report 431-1F, 1988.

STPP, (1999). Why are the Roads so Congested? A Companion Analysis of the Texas Transportation Institute's Data On Metropolitan Congestion. *Surface Transportation Policy Project*, November 1999.

HPMS, (1999) Highway Performance Monitoring System, 1982 to 1997 Data. *Federal Highway Administration,* February 1999

Census, (1990). Journey to Work Census Survey. *US Census Bureau, 1990.*

FHWA, (1997). 1995 Nationwide Personal Transportation Survey. *Federal Highway Administration. Office of Highway Information Management*