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16. Abstract

Effective trip speeds were calculated from reported mean travel times from the 1980 Urban Transportation Planning Package and the 1990 Census Transportation Planning Package special census tabulations for six urban areas: Houston, Dallas-Fort Worth, Philadelphia, Boston, San Francisco, and Atlanta. Comparison methodology is presented in a detailed pilot study, followed by an analysis of the six urban area comparisons. Data were combined in a pooled comparison for three modes of transportation: drive alone, carpool, and transit.

The data indicate a slight decrease in effective trip speed of less than 1 mph for those who drove alone to work, while there was a slight increase in overall trip speed for those who reported using a carpool or public transportation for at least one leg of the journey to work. Also, the census samples indicated a wide variability of ±12 mph for those who drove alone or carpooled, while transit users varied slightly less in their responses, 9 mph. Moreover, trip speed changes by orientation (radial, circumferential, and reverse flow) seem to be stabilized from 1980 to 1990, which indicates that transportation systems in larger metropolitan areas are keeping abreast of demands.

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# TRANSPORTATION SYSTEM PERFORMANCE CHANGES, 1980-1990 BASED ON THE DECENNIAL CENSUSES

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Research Study Title: Transportation System Performance Changes I, 1980-1990

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## IMPLEMENTATION STATEMENT

The information presented in this report is based on data obtained from the 1980 and 1990 decennial censuses and is intended to provide general information on changes in transportation system performance. The analysis can be used to support broad transportation policy orientation. Also, the methodology developed herein can be used for comparing census data in other urban areas.

The limitations of the data are centered on the fact that actual travel speeds were not measured but are calculated based on reported perceived travel time to work. There exists a possibility of error in a given single reported travel time selected from the data set at random, since "reported travel time" could include non-travel oriented activities such as stops on the way to work or wait times for transit service. However, it is assumed that the large number of respondents and aggregation of the geographic levels of reporting will provide consistent and accurate results.

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The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. Additionally, this report is not intended for construction, bidding, or permit purposes. Gordon A. Shunk, Ph.D., was the Principal Investigator for the project.

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## SUMMARY


This research report documents findings of a three-year study of census travel time data from six of the largest urban areas in the United States. For the first time in history, travel time data for the journey to work was collected at a detailed geographic level for two censuses: 1980 and 1990. This has created a data set of reported perceived travel times to work for almost 17 percent of the U.S. population of workers (8 percent in 1980). The size, extent, and consistency of this survey is unparalleled.

This research compared travel times to work reported in the 1980 and 1990 censuses aggregated by trip orientation and mode. Travel times were converted to effective trip speed to indicate changes in transportation system performance, since "users" have travel times and "systems" have speeds, although they are interchangeable in this study.

The data indicate a slight decrease in effective trip speed of less than 1 mph for those who drove alone to work, while there was a slight increase in overall trip speed for those who reported using a carpool or public transportation for at least one leg of the journey to work. Also, the census samples indicated a wide variability of $\pm 12$ mph for those who drove alone or carpooled, while transit users varied slightly less in their responses, 9 mph.

While any slight change in overall mean effective trip speeds is significant because of the large amount of respondents, it is clear that large changes in transportation system performance are not indicated. Moreover, trip speed changes by orientation (radial, circumferential, and reverse flow) seem to be stabilized from 1980 to 1990, which indicates that transportation systems in larger metropolitan areas are keeping abreast of demands. Another theory indicated from this study which deserves further research is that the location of jobs and housing operate in a market structure, and the price is determined in part by the performance of the transportation system.

# SECTION 1

# COMPARISON METHODOLOGY

# INTRODUCTION

## PURPOSE

This section reports pilot study findings to determine the feasibility of comparing changes in mean speeds based on travel times reported in the 1980 and 1990 decennial censuses. Houston, Texas, was chosen as a pilot area to develop methodology and determine the reasonableness of using census travel times for this type of comparison.

## SUMMARY

At the beginning of this study, concern existed that the travel times reported in the decennial censuses may not be a useful indicator of system performance. After carefully considering the Houston 1980 Urban Transportation Planning Package data and the 1990 Census Transportation Planning Package special tabulations, the opposite was found. The travel times reported in the censuses serve a very useful purpose, particularly for this type of study. They represent perceived travel times in the journey to work, indicating the most fundamental level of the transportation system performance: the performance as reported by system users.

The pilot study data show that the perceived mean effective speeds for Houston, Texas, have increased only slightly from 1980 to 1990; most of the changes are insignificant. More important, the data indicate that speeds have stabilized since 1980 implying that the transportation system and activity system remain in balance, at least on a perceived basis. The methodology developed as part of this study can be used to determine changes in travel times reported in the censuses from 1980 to 1990 and is well suited to other urban areas. Further study should continue for other urban areas.

# PROJECT DESCRIPTION

## SYSTEM PERFORMANCE CHANGES

This project compared travel times reported in both the 1980 and 1990 special tabulations of the decennial census data for several large urban areas in the U.S. This project also determined if change is indicated in the transportation system performance in specific urban areas studied and in urban areas overall. These special tabulations are known as transportation planning packages and have been produced since the 1970 census. The 1980 package was called the Urban Transportation Planning Package (1980 UTPP); the 1990 package was called the Census Transportation Planning Package (1990 CTPP). The 1980 UTPP was the first package to contain information on perceived travel times in the journey to work. The questions concerning travel time to work were repeated for the 1990 census. For the first time in history, detailed travel time data have been collected across the U.S. in a uniform, comparable manner.

The reported travel times in the special tabulations of the census data can be converted to effective trip speeds by using the distance from the residence end of the trip to the work end of the trip. This is simply a reporting convention, since travel time and travel speed are inversely related. An increase in effective trip speed would indicate an improvement in the transportation system performance.

The data contained in the 1980 UTPP and 1990 CTPP are aggregated by small geographic levels, either census tracts or traffic analysis zones as defined by the specific urban area. This allows trip speeds to be reported by orientation: radial, circumferential, and reverse flow. Radial trips are work trips which terminate in the central business district (CBD) or in other high density employment centers within the urban area. Circumferential trips are work trips exhibiting cross-town travel patterns such as those originating in suburban areas and terminating in other suburban areas. Reverse flow trips originate in more centrally located areas of the city and terminate in areas farther out from the center. Reverse flow trips are normally in the opposite direction of the major flow for the morning work commute, such as central city to suburban.

## CENSUS DATA ADVANTAGES

Travel time to work data are documented in various sources. Large and small scale urban travel surveys are routinely conducted in large urban areas. Specific speed studies are performed on a continuing basis along major corridors in all urban areas. The Nationwide Personal Transportation Survey (NPTS) is a travel pattern survey of several thousand individuals across the U.S.

The 1980 UTPP and 1990 CTPP sample more individuals than the urban travel surveys. The urban travel surveys are broader in scope than the census travel questions. Urban travel surveys usually encompass all types of travel including shopping trips and work trips. The sample sizes needed for urban travel surveys are usually based on the need to acquire data for urban travel demand forecasting models. Normally, fewer than 20,000 households are sampled in these multi-million dollar surveys. The 1980 UTPP was tabulated for one in 12 households and the 1990 CTPP for one in six households. In the Houston UTPP there were over 1.3 million one-way trips to work resulting in over 100,000 reported travel times.

The NPTS is conducted about every seven years and surveys thousands of individuals nationwide on several travel characteristics including travel time to work. Data in the NPTS are based on telephone interviews with individuals in several thousand households.

Speed studies are routinely conducted along major corridors in large urban areas. While these data are excellent for reporting actual variations in the performance of specific routes, they are limited to reporting the effect of a single route. The 1980 UTPP and 1990 CTPP are based on reported travel times from home to work, regardless of the route. Thus, census data can show the perceived effects of an individual changing routes in response to congestion on another route.

Since the scope of this study was to examine several of the larger urban areas across the U.S., the census data collected can be compared to the aggregate data collected in the NPTS. The document, "Summary of Travel Trends: 1990 Nationwide Personal Transportation Survey" contains the following statement:

> The average commute trip length increased by 7 percent from 1983 to 1990, from 9.9 miles to 10.6 miles. Yet the commute time declined by 3 percent during the same period. This observation might be partially due to the fact that a greater number of suburban and exurban residential areas and employment centers were developed. The resulting commutes are longer but are traveled at faster speeds. The decline in travel time is also influenced by changes in commuting modes, with a decrease in transit and carpooling and an increase in driving alone.

If this study holds true to the pattern exhibited in the NPTS data, trip speeds would increase, particularly in a circumferential orientation. Another analysis of NPTS data by Peter Gordon and Harry Richardson from the School of Urban and Regional Planning at the University of Southern California entitled "Geographic Factors Explaining Work Trip Length Changes," shows the same pattern of increasing work trip length, a stabilized or declining commute time, and, therefore, increasing trip speeds.

**PILOT STUDY AREA**

Houston was chosen as a pilot study area to develop a methodology and preliminary analysis of the feasibility of comparing 1980 UTPP travel times with the 1990 CTPP. Because the amount of data contained in the census packages is enormous, it was unknown if there would be sufficient time to complete several urban areas. Also, the data collected in 1980 differs slightly from the data collected in 1990, and the comparability of the two data sets was unknown.

Table 1 shows summary characteristics for Houston.

**Table 1**
**Characteristics of Houston, Texas**

| Characteristic | 1980 | 1990 | Pctg. Change |
|---|---|---|---|
| Population | 3,101,293 | 3,711,043 | 19.7 |
| Workers | 1,508,211 | 1,759,796 | 16.7 |
| Workers per household | 1.38 | 1.32 | |
| Share of workers commuting from: | | | |
| Central to central county | 78.06 | 74.86 | -3.20 |
| Central to suburban county | 1.53 | 2.44 | 0.91 |
| Suburban to central county | 6.98 | 9.38 | 2.40 |
| Suburban to same county | 12.88 | 12.72 | -0.16 |
| Suburban to other suburban county | 0.55 | 0.60 | 0.05 |
| Mean travel time to work | 25.9 | 26.1 | 0.77 |
| Total HPMS vehicle miles of travel (000)[1] | 1982: 54,085 | 71,613 | 32.4 |
| Total lane mi[2] | 1982: 10,064 | 17,001 | 68.9 |

Source: Journey-to-Work Trends in the United States and Its Major Metropolitan Areas 1960-1990, U.S. Department of Transportation, Federal Highway Administration, Volpe National Transportation Systems Center, November 1993.
[1]Data from TTI congestion index studies.
[2]Lane miles calculated from HPMS data for TTI congestion index study.

## STUDY FOCUS

### Speeds versus Travel Times

The decennial census asks how many minutes it took to get to work on a usual day during the reference week. These data were then converted to effective trip speed by dividing the straight line distance into the travel time. Essentially, the only difference is in the reporting method.

## Geographic Levels

The 1980 UTPP and 1990 CTPP special tabulations of the census journey-to-work data were calculated to one of two geographic levels at the discretion of the urban area users in question: census tracts or traffic analysis zones (TAZs). In some cases, such as Houston, the 1980 UTPP data were aggregated to census tracts; and the 1990 CTPP data were aggregated to TAZs.

The reported travel time data from each individual are averaged with other reported travel times of individuals whose work trips began in the same tract or zone of residence and ended in the same tract or zone of work. The number of individuals reporting which constitute an average is therefore dependent on the size of the aggregation zones (census tracts or TAZs) and is further reduced in number by the limitation of having the work trip ends in the same tracts. The number of reported travel times which constitute a mean reported travel time will decrease as the aggregation level decreases.

## 1980 UTPP VERSUS 1990 CTPP DATA

Minor changes are evident in the travel time data when comparing the 1980 UTPP to the 1990 CTPP. The 1990 data were split into two separate packages: the statewide element and the urban element. The statewide element of the 1990 CTPP reports mean travel times for worker flows to the census-defined place geographic level. The urban element contains data aggregated to the small geographic levels of census tracts or TAZs.

The census-defined geographies changed because of urban area growth from 1980 to 1990. The 1980 census tracts were split into two or more census tracts; however, it is beyond the focus of this study to examine and account for all of the changes. A selection of data from both the 1980 and 1990 data sets will suffice for this analysis.

The 1980 and 1990 censuses contain essentially the same travel time to work questions. However, in 1990 a question was added concerning the departure time to work. Although cross-influencing of the added question on departure time and the question on travel time to work could occur, it cannot be taken into account.

The 1980 and 1990 censuses contained essentially the same sampling methods. The journey-to-work data were based on a reference week (the week before the census questionnaires were completed). In 1980, this week included a week with a holiday (Passover and Good Friday) which may not have been included in the 1990 reference week. This will have no effect on the journey-to-work data because the questions ask about the usual travel characteristics of these trips.

## TRAVEL MODE SUMMARY

The 1980 UTPP and the 1990 CTPP have data aggregated by primary mode of usage for the journey to work. The questions on the census concerning mode refer to only one leg of the work trip if several modes were used.

Modes must be grouped to perform a direct comparison of effective speeds for the work trip. Table 2 shows the assumed grouping of modes performed for this study. The five groups are drive alone, carpool, transit, bicycle/walk, and taxi/other. Of these groups, the ones considered important in terms of defining system performance changes from 1980 to 1990 are drive alone, carpool, and transit. The other two groups are assumed to be insignificant in terms of an aggregated, areawide study of mean travel times.

To develop the mode groupings for worker flows, the expanded sample of worker flows by transportation means was summed for each mode group. The reported travel times for each mode group were estimated by taking the weighted mean of the reported mean travel times for each means of transportation within each mode group. The following formula was used:

$$Mode\ Group\ Time = \frac{\sum ( T_{mode} \cdot W_{mode} )_i}{\sum W_i}$$

Where:

| | | |
|---|---|---|
| $T$ | = | mean reported travel time from zone of residence to zone of work. |
| $W$ | = | expanded sample worker flow from zone of residence to zone of work. |
| $i$ | = | group. |

The weighted average for carpool work trips gives a heavier weight to the mean travel times reported by the carpool size most individuals choose. The weighted means were developed for each group from each of the two data sets, 1980 and 1990.

**Table 2**
**Travel Mode Groups**

| Group | 1980 UTPP Mode | 1990 CTPP Mode |
|---|---|---|
| (1) Drive Alone | Drive Alone | Drive Alone |
| (2) Carpool | 2-Person Carpool | 2-Person Carpool |
| | 3-Person Carpool | 3-Person Carpool |
| | 4+-Person Carpool | 4-Person Carpool |
| | | 5-Person Carpool |
| | | 6-Person Carpool |
| | | 7-9-Person Carpool |
| | | 10+-Person Carpool |
| (3) Transit | Bus or Streetcar | Bus/Trolley Bus |
| | Railroad | Streetcar or Trolley Car |
| | Subway or Elevated | Subway or Elevated |
| | | Railroad |
| | | Ferry Boat |
| (4) Other | Taxicab | Taxicab |
| | Motorcycle | Motorcycle |
| | Other Means | Other Means |
| (5) Bike/Walk | Bicycle | Bicycle |
| | Walked Only | Walked |

# AREA TYPE SUMMARY

## AREA TYPE DEFINITION

A comparison of reported travel times from 1980 to 1990 for the entire urban area was performed from information available from other census tabulation packages. The mean travel times are reported in Table 1. The focus of this study is to report mean travel times by the worker's trip orientation: radial, circumferential, and reverse flow. To do this, a consistent definition of origin and destination must be addressed.

The most efficient way to aggregate tracts or zones is with area types used in travel demand models. Area types break up an urban area based on densities of employees and population within zones. For the Houston pilot study, an area type scheme was developed using the worker and population densities reported in the 1980 UTPP and the 1990 CTPP. Total workers were added to total population for each census tract from the 1980 UTPP. This sum was divided by the number of acres in each census tract as calculated from the 1990 TIGER/Line files using a geographic information system. The process was repeated using the 1990 CTPP total workers and total population by TAZ which were aggregated to census tracts. Table 3 shows the area type definition scheme used for the Houston pilot study.

**Table 3**
**Area Type Definitions**

| Area Type | Worker + Population Density |
|---|---|
| Rural | 0.0 to 0.3 per acre |
| Suburban | 0.31 to 8.0 per acre |
| Urban | 8.1 to 30.0 per acre |
| Activity Centers | 30.1 to 75.0 per acre |
| Central Business District | > 75.1 per acre |

The area type selection method to define orientation patterns was considered less biased than a selected zone comparison method. The person selecting the zone pair as representative of a suburban to CBD commute, for instance, could bias the results. Thus, the area type selection method provides an unbiased basis for selecting zone pairs to compare.

The counties selected for study appeared in the 1980 UTPP for the Houston consolidated metropolitan statistical area (CMSA). These include Harris, Montgomery, Waller, Fort Bend, Galveston, and Liberty Counties. Chambers County was included in the mapping but was not in the 1980 Houston CMSA.

The 1990 area types were assumed for defining work trip orientation. Table 4 shows the assumed work trip orientation by area type. Figure 1 shows the area types for 1990 Houston census tracts.

**Table 4**
**Orientation by Area Type**

| Orientation | Origin Area Type | Destination Area Type |
|---|---|---|
| Radial | Activity Centers | CBD |
| | Rural | CBD |
| | | Activity Centers |
| | | Urban |
| | Suburban | CBD |
| | | Activity Centers |
| | | Urban |
| | Urban | CBD |
| | | Activity Centers |
| Circumferential | Activity Centers | Activity Centers |
| | Rural | Rural |
| | | Suburban |
| | Suburban | Rural |
| | | Suburban |
| | Urban | Urban |
| Reverse Flow | CBD | CBD |
| | | Activity Centers |
| | | Rural |
| | | Suburban |
| | | Urban |
| | Activity Centers | Rural |
| | | Suburban |
| | | Urban |
| | Urban | Rural |
| | | Suburban |

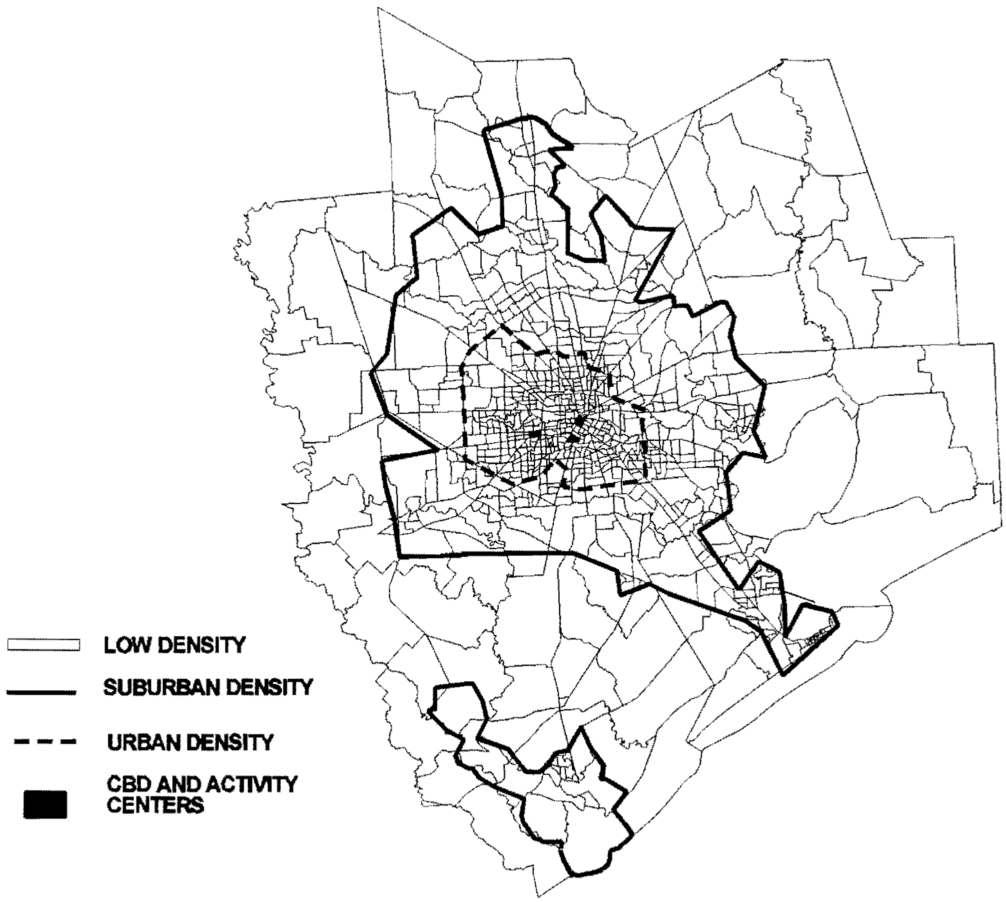


**Figure 1. 1990 Area types used for the Houston pilot study.**

## COMPARISON METHODOLOGY

### DERIVING A COMMON GEOGRAPHIC LEVEL

The Houston urban area comprises several counties. Harris County is the central county. The 1980 UTPP data sets were aggregated to 1980 census tracts and were the smallest geographic level reported. The 1990 CTPP was aggregated to the Traffic Analysis Zone (TAZ) level. In 1990 there were approximately 2,600 TAZs in the Houston area and over 500 census tracts.

The first problem was aggregating both the 1980 UTPP and the 1990 CTPP worker flows and reported mean travel times to a common geographic level. A TAZ to census tract equivalency table was used to aggregate the 1990 CTPP data to the tract level. The worker flows by means of transportation for TAZs were simply summed by census tract. The reported mean travel times were averaged using a weighted means procedure by worker flow within each mode group.

Weighting the mean travel times by worker flow ensures that the intrazonal trips from small zones (TAZs) do not carry a heavy weight when aggregated to the tract level. Many of the previously TAZ-to-TAZ interzonal trips become intrazonal trips within one tract. Because the travel times are shorter for smaller geographic summaries, such as TAZs, a weighted means softens the effect of the short trips because there are fewer intrazonal trips within the TAZ level.

### DERIVING A DISTANCE MATRIX

To convert the mean reported travel times to effective speeds, a distance in miles was derived from the tract of residence to the tract of work. Although using a network to determine shortest paths between tract centroids is preferable for deriving a distance matrix, this level of analysis is beyond the scope of this study. A straight line distance was calculated using a simple geometric distance equation between tract centroids. The tract centroids were created using a geographic information system and the 1990 TIGER/Line files. Intrazonal distances were calculated using 75 percent of the distance to the nearest tract.

Since the 1980 and 1990 distances between tract pairs selected were identical, the use of circuity factors would have minimal effect on the comparison of mean speeds. A circuity factor, however, would be appropriate to correct for actual reported mean speeds for each of the two years. Note that the actual means reported here may be biased due to the lack of a circuity factor.

## DEPENDENCE OF SAMPLES

When comparing changes in travel times and speeds from 1980 to 1990 by trip orientation, care was taken to ensure that paired statistics were calculated within each trip orientation. Although the two census samples could be analyzed assuming independence of the samples, the variability is increased. For instance, speeds derived from the 1980 data using 1980 definitions of suburban-to-CBD tract pairs could be compared with speeds derived from the 1990 data using 1990 definitions of suburban-to-CBD densities. The variability in treating the two samples as independent, random samples is high and may not provide accurate results.

A better method is to use only the 1990 definition of area types and pair the data by tract of origin and tract of destination. This removes the variability due to the dimension on which the observations are paired (across tracts).

By using the 1990 area type densities, the highest common density between 1980 and 1990 is most commonly used. For instance, if a tract of residence moved from rural to urban between 1980 and 1990, the mean change in speed is reported in the urban classification. This probably would not impact the orientation class chosen, however.

## COMPARISON SUMMARY

### OVERALL COMPARISON, 1980 TO 1990

After aggregating the 1990 CTPP worker flows and mean reported travel times from TAZ to census tract, a selected set of sample tracts were chosen. The selection method was a simple, ordered merge based on tract of origin and tract of destination to develop paired data. Not all possible tracts were matched from 1980 to 1990 since tract pairs in the 1980 UTPP may not have worker flows in 1990 and vice versa. Also, split tracts in 1990 did not match unsplit tracts for 1980. No effort was made to aggregate the split 1990 data to the whole 1980 tract level. Figure 2 shows the set of tracts sampled for the Houston urban area.

Figure 3 shows the sampling distributions of the differences in mean speeds for drive alone, carpool, and transit trips. They exhibit a high degree of normality because differences in means will prove to be very normal in distribution, regardless of the actual distribution of elements from which the means were taken. This allowed the use of simple statistics for calculating significance levels for the mean difference in speeds by area type and trip orientation.

The overall mean speed for the drive alone work trips in Houston has increased slightly, less than 1 mph, since 1980. The speed for carpool and transit modes increased at a slightly higher rate, 1.41 and 1.86 mph, respectively. Looking at the trip speed distributions by mode group in Figures 4 through 7, a larger percentage of work trips are occurring at speeds between 20 and 50 mph in 1990 versus 1980. Also, a smaller percentage of workforce individuals had effective speeds less than 20 mph in 1990 versus 1980. For transit trips (i.e., riding the bus in Houston), the most notable difference is the number of riders reporting very low effective speeds, less than 5 mph. Outliers were eliminated from the speed data on the high end (greater than 65 mph) but not on the low end.

To use the Houston data to validate the NPTS claim of increasing job migration to suburban areas, increasing work trip distances, stabilizing travel times, and, therefore, increasing speeds, the trip distance distributions for Houston would need to be estimated.

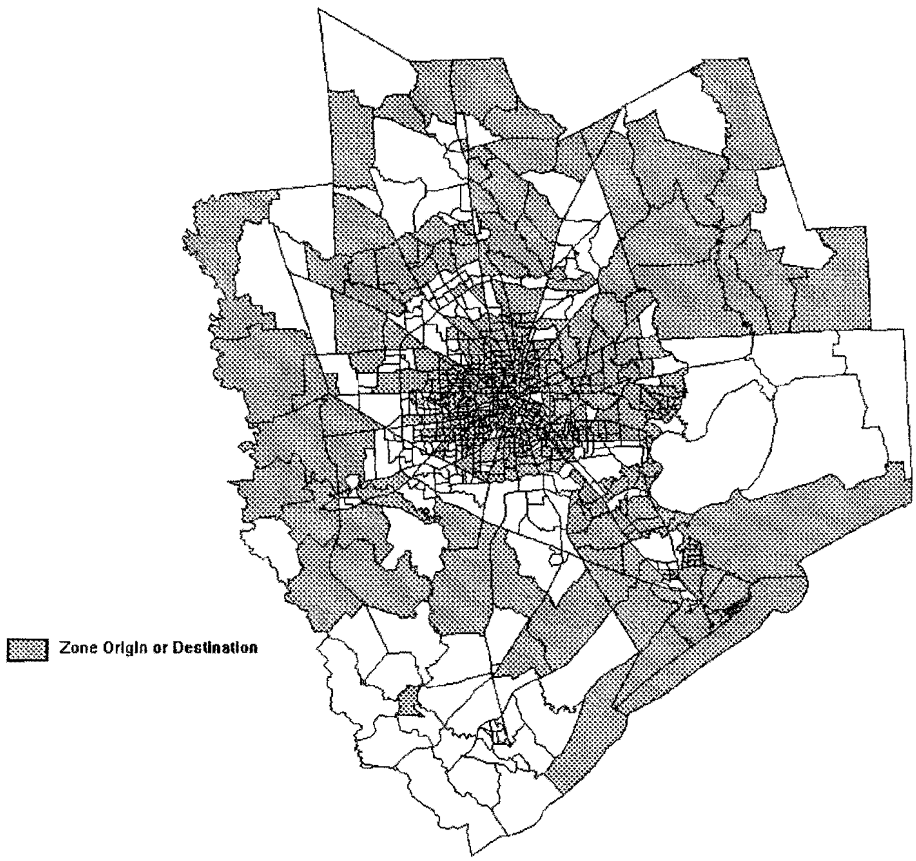


**Figure 2. Sampled tracts for paired comparisons.**

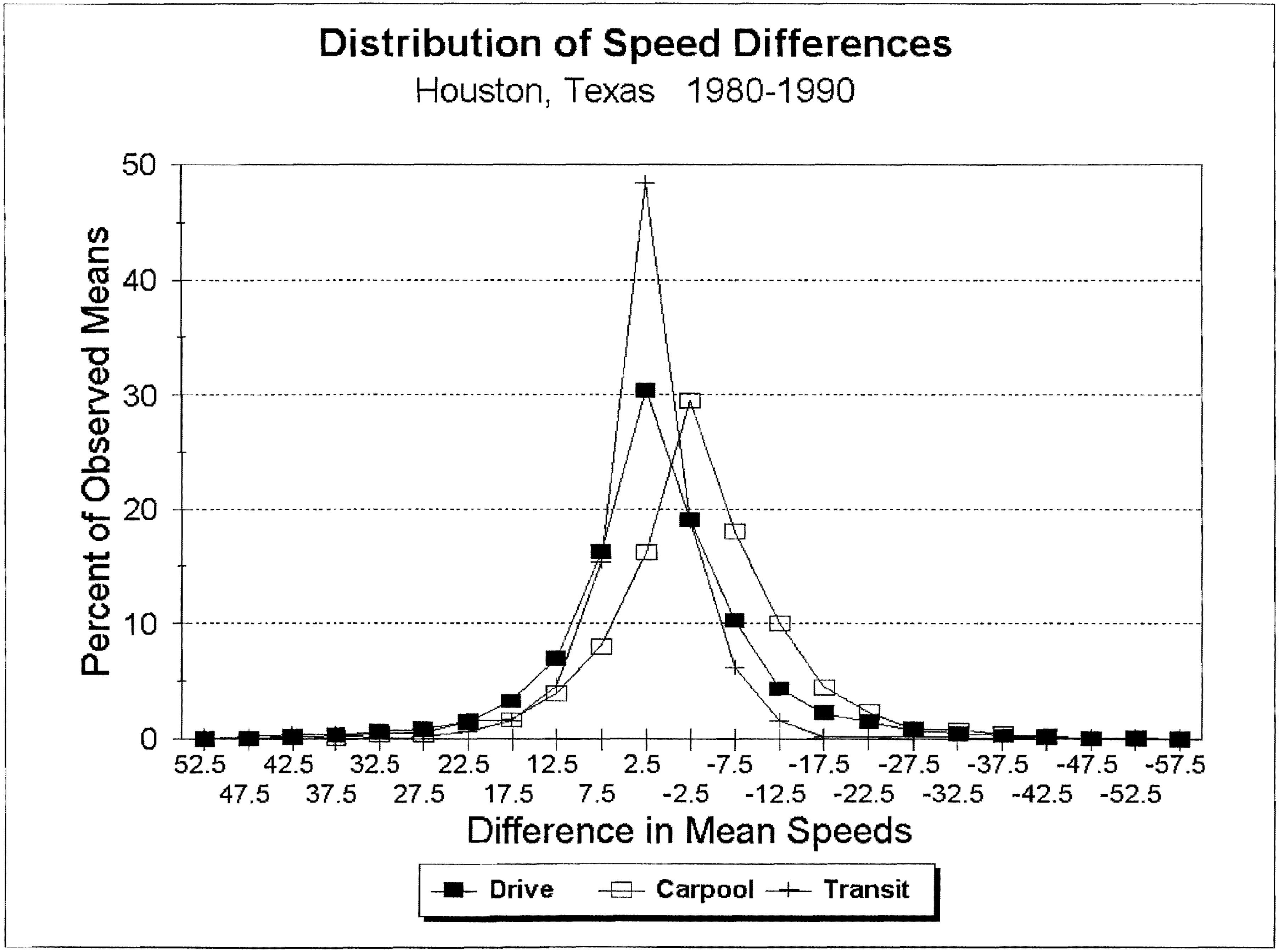


**Figure 3. Normal distributions of differences in mean speeds.**

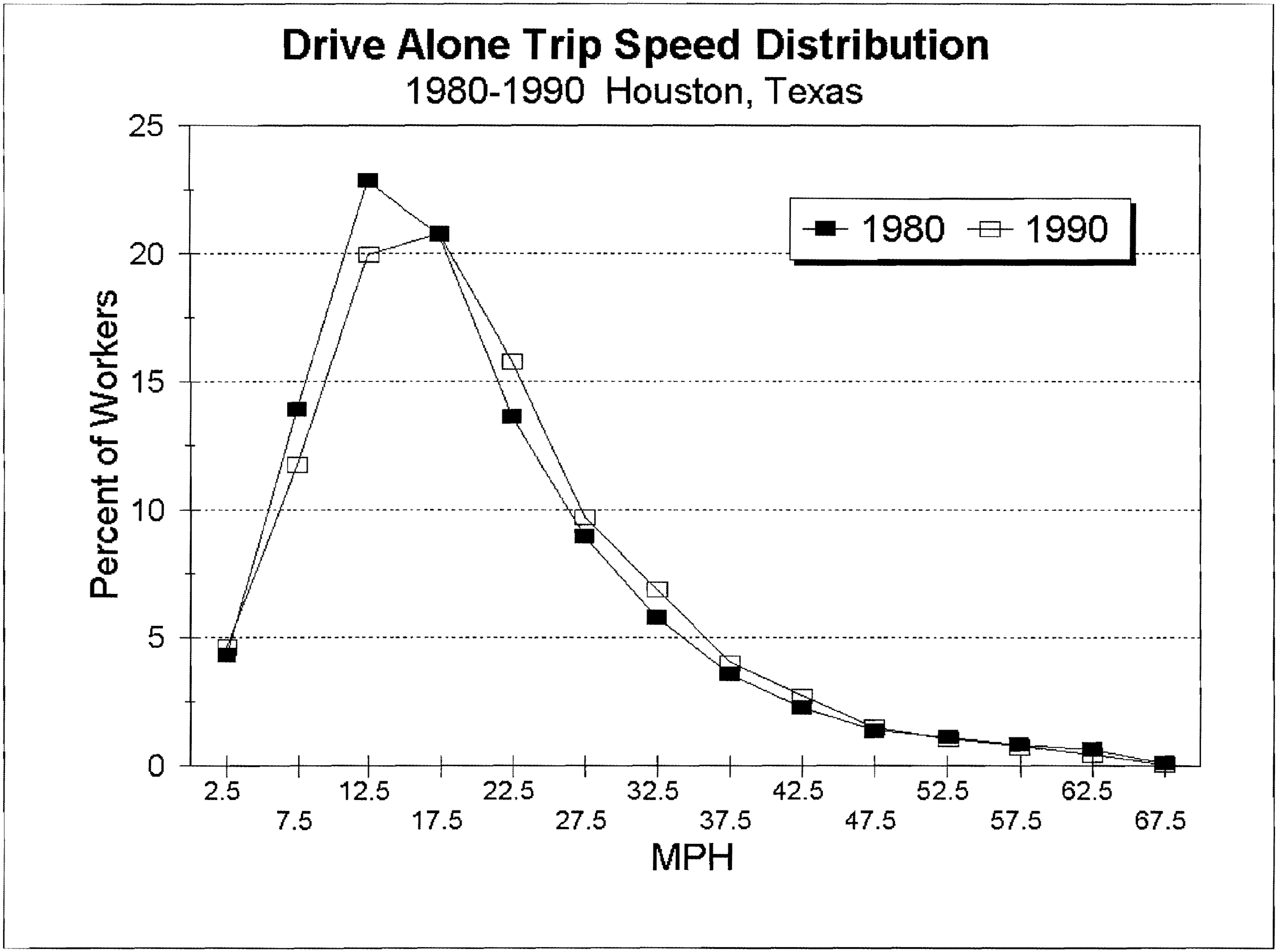


**Figure 4. Sampled drive alone trip speed distribution, 1980 and 1990, Houston, Texas.**

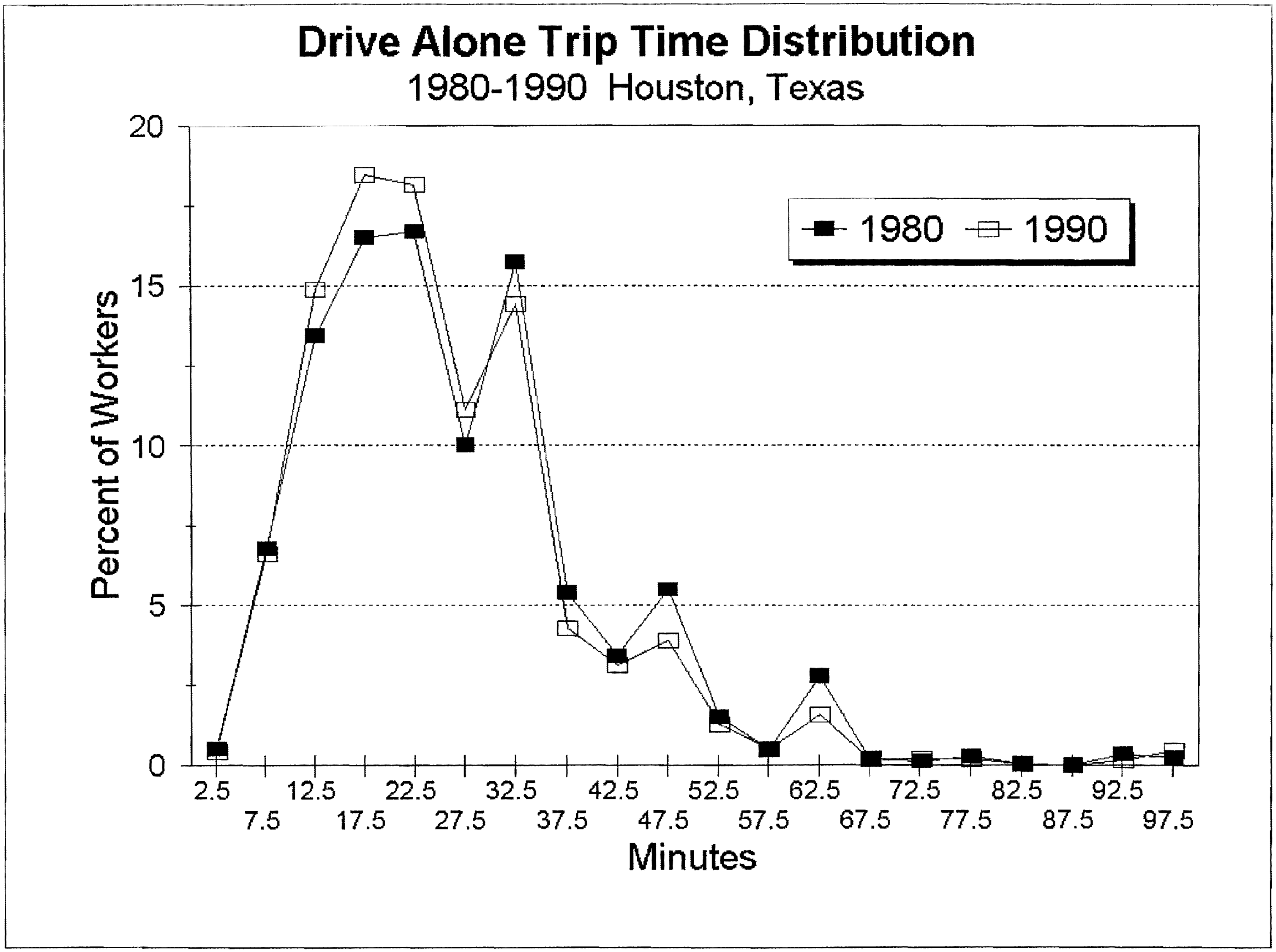


**Figure 5.** **Sampled drive alone trip time distribution, 1980 and 1990, Houston, Texas.**

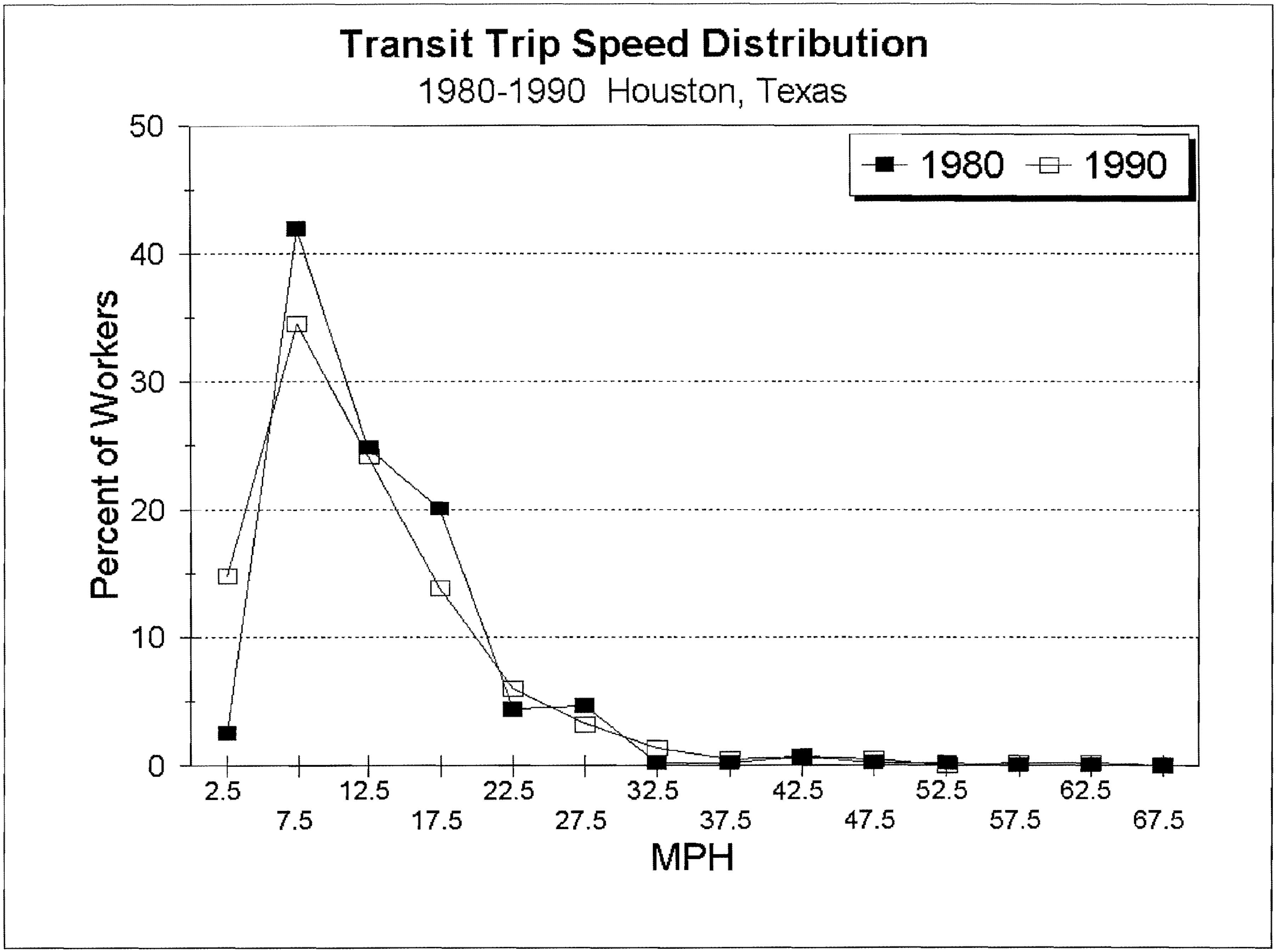


**Figure 6. Transit effective trip speed distribution, 1980 and 1990, Houston, Texas.**

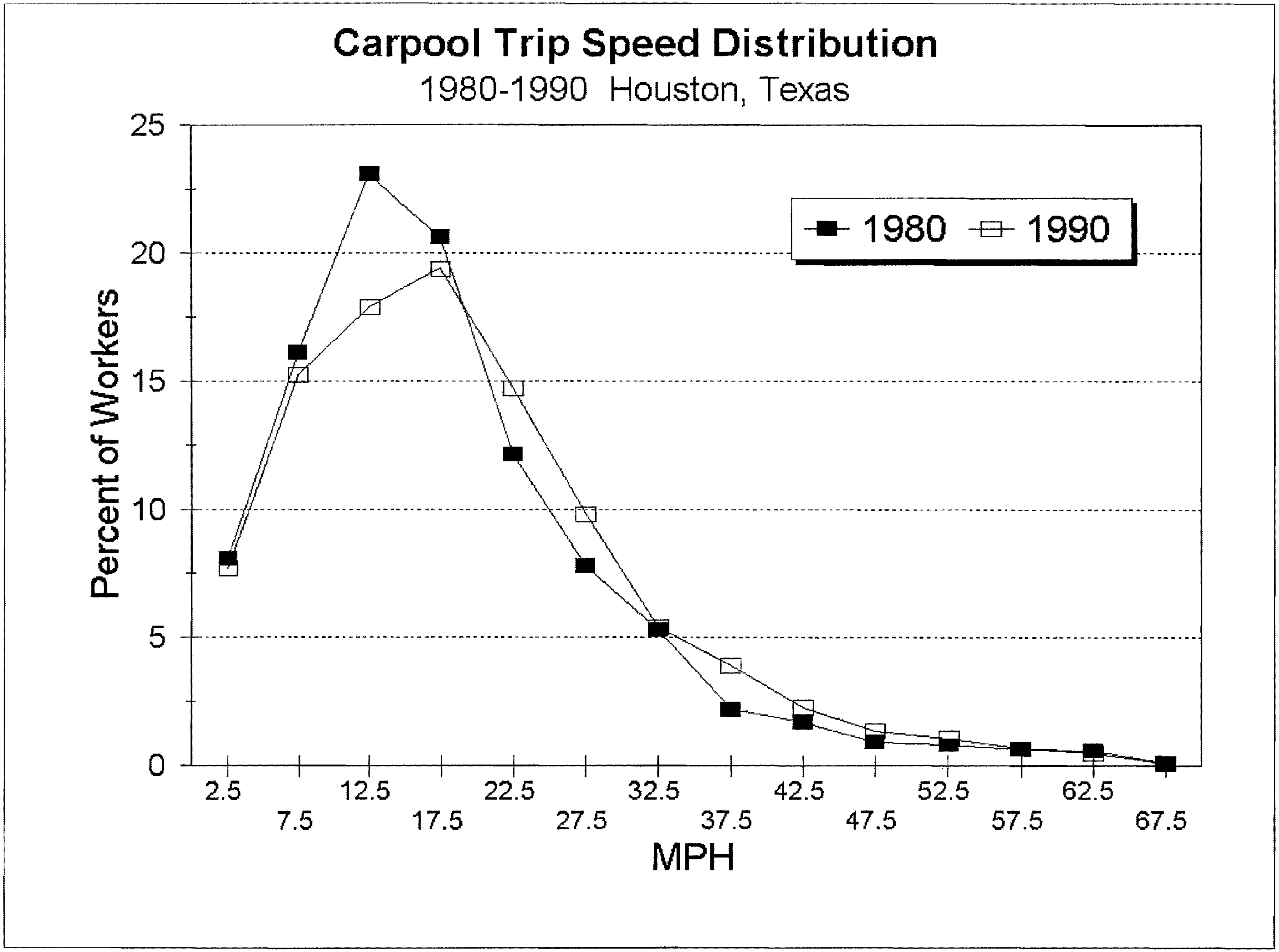


**Figure 7. Carpool effective trip speed distribution, 1980 and 1990, Houston, Texas.**

This is impossible because of the lack of completely allocated workplace locations in the 1990 CTPP data. The 1980 UTPP contained an artificial allocation of incorrectly coded or non-response workplace locations to derive an accurate control total for the worker flow tables. The 1990 CTPP did not include this information. Therefore, an accurate estimate of the distance frequency distribution cannot be ascertained for 1990 until an artificial allocation of the uncoded workplace locations is made.

However, the Houston data show an increase, although slight, in overall average speed with a corresponding decrease in travel times. More importantly, a decrease in speeds is not evident. This suggests that the system is performing better, at least on a perceived basis by working individuals.

Comparing the total workers in each orientation from 1980 to 1990 for drive alone trips in Table 5, it is evident that the decrease in work trips reported from the Houston sample tracts is due to under-allocation in the 1990 CTPP. Actually, the 1980 CTPP showed 1,034,715 drive alone work trips (after expansion), while the 1990 CTPP totals 1,327,052, an increase of 29,234 one-way trips from 1980 to 1990. The subsample drawn for this study is about one-third of the total work trips, allocated and unallocated. The lack of allocation does not affect the use of worker flows to calculate weighted mean travel times by mode group or tract (1990) within a given data set. However, using worker flows as weighting factors to calculate travel times for comparing 1980 and 1990 data could not be performed because the 1980 data would be weighted by a fully allocated measure, while the 1990 CTPP data are under-allocated. Thus, unweighted mean travel times were used to compare 1980 UTPP to 1990 CTPP data.

## COMPARISON BY ORIENTATION, 1980 TO 1990

Tables 5 through 8 show the changes in mean effective speeds by orientation for Houston. Also shown are the paired t-statistics and p-values for the null hypothesis which showed no change in mean effective work trip speeds. Five of the nine radial flow mean changes in effective speeds for drive alone trips show a strong significance level for rejecting the null hypothesis in favor of the changes reported. These values are for trips originating in the urban and suburban area types with increases in mean speeds ranging

## Table 5
## Mean Drive Alone Work Trip Speeds, Houston, Texas, 1980-1990

| | | | | Mean Speed | | Paired Statistics | | | Workers in Flow | | Estimated Sample | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Orientation** | **From** | **To** | **N** | **1980** | **1990** | **Change** | **t** | **Prob>\|t\|** | **1980** | **1990** | **1980** | **1990** |
| Radial | Urban | Emp. Centers | 918 | 16.06 | 17.79 | 1.74 | 6.06 | <0.01 | 47,300 | 43,961 | 3,942 | 7,327 |
| Radial | Urban | CBD | 224 | 15.33 | 17.32 | 1.99 | 6.21 | <0.01 | 37,643 | 29,821 | 3,137 | 4,970 |
| Radial | Suburban | Urban | 2,174 | 21.95 | 22.76 | 0.80 | 3.23 | <0.01 | 50,548 | 42,004 | 4,212 | 7,001 |
| Radial | Suburban | CBD | 186 | 24.12 | 26.89 | 2.76 | 5.25 | <0.01 | 23,851 | 20,998 | 1,988 | 3,500 |
| Radial | Suburban | Emp. Centers | 596 | 23.60 | 25.16 | 1.56 | 3.60 | <0.01 | 23,303 | 23,074 | 1,942 | 3,846 |
| Radial | Rural | Urban | 296 | 25.74 | 26.66 | 0.92 | 1.31 | 0.19 | 5,077 | 3,788 | 423 | 631 |
| Radial | Employment Centers | CBD | 9 | 12.22 | 13.44 | 1.22 | 1.74 | 0.12 | 2,217 | 2,149 | 185 | 358 |
| Radial | Rural | CBD | 63 | 31.60 | 32.46 | 0.86 | 0.75 | 0.46 | 3,611 | 3,156 | 301 | 526 |
| Radial | Rural | Emp. Centers | 105 | 27.53 | 28.67 | 1.13 | 1.12 | 0.27 | 3,004 | 3,139 | 250 | 523 |
| Circumferential | Urban | Urban | 3,646 | 15.51 | 16.00 | 0.50 | 2.93 | <0.01 | 101,160 | 74,535 | 8,430 | 12,423 |
| Circumferential | Employment Centers | Emp. Centers | 52 | 9.90 | 9.94 | 0.04 | 0.06 | 0.96 | 4,748 | 3,930 | 396 | 655 |
| Circumferential | Suburban | Suburban | 1,187 | 20.14 | 19.95 | -0.18 | -0.62 | 0.53 | 43,604 | 50,312 | 3,634 | 8,385 |
| Circumferential | Suburban | Rural | 113 | 24.65 | 23.16 | -1.49 | -1.25 | 0.22 | 2,530 | 2,063 | 211 | 344 |
| Circumferential | Rural | Rural | 36 | 17.75 | 16.75 | -1.00 | -0.61 | 0.55 | 927 | 561 | 77 | 94 |
| Circumferential | Rural | Suburban | 157 | 27.86 | 27.52 | -0.34 | -0.35 | 0.73 | 3,397 | 4,415 | 283 | 736 |
| Reverse Flow | CBD | Rural | | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 |
| Reverse Flow | CBD | Suburban | | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 |
| Reverse Flow | CBD | CBD | 1 | 3.00 | 4.00 | 1.00 | NA | NA | 36 | 57 | 3 | 10 |
| Reverse Flow | CBD | Emp. Centers | 1 | 14.00 | 18.00 | 4.00 | NA | NA | 24 | 7 | 2 | 1 |
| Reverse Flow | CBD | Urban | | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 |
| Reverse Flow | Urban | Rural | 162 | 17.93 | 18.93 | 1.00 | 1.16 | 0.25 | 4,168 | 3,033 | 347 | 506 |
| Reverse Flow | Urban | Suburban | 746 | 19.77 | 20.47 | 0.70 | 1.67 | 0.10 | 20,692 | 17,323 | 1,724 | 2,887 |
| Reverse Flow | Employment Centers | Rural | 2 | 23.00 | 29.50 | 6.50 | 4.33 | 0.14 | 75 | 31 | 6 | 5 |
| Reverse Flow | Employment Centers | Urban | 144 | 16.05 | 15.51 | -0.54 | -0.58 | 0.56 | 4,271 | 2,756 | 356 | 459 |
| Reverse Flow | Employment Centers | Suburban | 21 | 23.14 | 29.76 | 6.62 | 1.79 | 0.09 | 610 | 330 | 51 | 55 |
| **Overall** | | | **10,839** | **19.04** | **19.76** | **0.72** | **7.10** | **<0.01** | **382,796** | **331,443** | **31,900** | **55,242** |

## Table 6
## Mean Reported Drive Alone Travel Times by Orientation, Houston, Texas, 1980-1990

| | | | | Mean Times | | Paired Statistics | | |
|---|---|---|---|---|---|---|---|---|
| **Orientation** | **From** | **To** | **N** | **1980** | **1990** | **Change** | **t** | **Prob>\|t\|** |
| Radial | Urban | Emp. Centers | 918 | 24.65 | 21.96 | -2.69 | -7.72 | <0.01 |
| Radial | Urban | CBD | 224 | 26.13 | 22.96 | -3.17 | -6.63 | <0.01 |
| Radial | Suburban | Urban | 2,174 | 29.05 | 27.48 | -1.57 | -4.75 | <0.01 |
| Radial | Suburban | CBD | 186 | 36.31 | 31.97 | -4.34 | -5.57 | <0.01 |
| Radial | Suburban | Emp. Centers | 596 | 34.47 | 31.56 | -2.91 | -4.90 | <0.01 |
| Radial | Rural | Urban | 296 | 35.04 | 33.66 | -1.39 | -1.50 | 0.14 |
| Radial | Employment Centers | CBD | 9 | 19.78 | 17.56 | -2.22 | -1.53 | 0.16 |
| Radial | Rural | CBD | 63 | 46.13 | 43.67 | -2.46 | -1.53 | 0.13 |
| Radial | Rural | Emp. Centers | 105 | 40.09 | 38.22 | -1.87 | -1.31 | 0.19 |
| Circumferential | Urban | Urban | 3,646 | 20.50 | 19.78 | -0.73 | -3.13 | <0.01 |
| Circumferential | Employment Centers | Emp. Centers | 52 | 15.44 | 15.42 | -0.02 | -0.02 | 0.98 |
| Circumferential | Suburban | Suburban | 1,187 | 23.09 | 23.00 | -0.09 | -0.23 | 0.82 |
| Circumferential | Suburban | Rural | 113 | 28.32 | 30.04 | 1.72 | 1.00 | 0.32 |
| Circumferential | Rural | Rural | 36 | 28.17 | 28.97 | 0.81 | 0.27 | 0.79 |
| Circumferential | Rural | Suburban | 157 | 32.30 | 32.44 | 0.14 | 0.10 | 0.92 |
| Reverse Flow | CBD | Rural | | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Suburban | | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | CBD | 1 | 12.00 | 10.00 | -2.00 | NA | NA |
| Reverse Flow | CBD | Emp. Centers | 1 | 20.00 | 15.00 | -5.00 | NA | NA |
| Reverse Flow | CBD | Urban | | NA | NA | NA | NA | NA |
| Reverse Flow | Urban | Rural | 162 | 19.80 | 19.92 | 0.12 | 0.11 | 0.91 |
| Reverse Flow | Urban | Suburban | 746 | 22.38 | 21.16 | -1.22 | -2.48 | 0.01 |
| Reverse Flow | Employment Centers | Rural | 2 | 21.00 | 15.00 | -6.00 | -1.50 | 0.37 |
| Reverse Flow | Employment Centers | Urban | 144 | 17.26 | 17.66 | 0.40 | 0.38 | 0.71 |
| Reverse Flow | Employment Centers | Suburban | 21 | 25.29 | 19.38 | -5.90 | -2.15 | 0.04 |
| **Overall** | | | **10,839** | **25.08** | **23.84** | **-1.24** | **-9.20** | **<0.01** |

## Table 7
## Mean Carpool Work Trip Speeds by Orientation, Houston, Texas, 1980-1990

| | | | | Mean Speed | | Paired Statistics | | | Workers in Flow | | Estimated Sample | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Orientation** | **From** | **To** | **N** | **1980** | **1990** | **Change** | **t** | **Prob>\|t\|** | **1980** | **1990** | **1980** | **1990** |
| Radial | Suburban | CBD | 134 | 21.36 | 25.69 | 4.33 | 5.34 | <0.01 | 11,160 | 5,094 | 930 | 849 |
| Radial | Suburban | Emp. Centers | 210 | 22.31 | 24.90 | 2.59 | 3.11 | <0.01 | 6,395 | 4,092 | 533 | 682 |
| Radial | Suburban | Urban | 269 | 21.30 | 20.86 | -0.44 | -0.57 | 0.5700 | 5,430 | 3,203 | 453 | 534 |
| Radial | Urban | CBD | 188 | 14.37 | 17.76 | 3.39 | 5.84 | <0.01 | 17,106 | 6,781 | 1,426 | 1,130 |
| Radial | Urban | Emp. Centers | 306 | 15.14 | 17.51 | 2.37 | 3.78 | <0.01 | 10,633 | 6,481 | 886 | 1,080 |
| Radial | Employment Centers | CBD | 7 | 9.00 | 13.00 | 4.00 | 4.32 | <0.01 | 812 | 327 | 68 | 55 |
| Radial | Rural | Emp. Centers | 30 | 28.73 | 31.00 | 2.27 | 0.67 | 0.51 | 722 | 445 | 60 | 74 |
| Radial | Rural | Urban | 47 | 24.23 | 21.66 | -2.57 | -1.65 | 0.11 | 704 | 365 | 59 | 61 |
| Radial | Rural | CBD | 34 | 28.38 | 30.53 | 2.15 | 1.19 | 0.24 | 1,381 | 912 | 115 | 152 |
| Circumferential | Rural | Suburban | 34 | 26.76 | 24.79 | -1.97 | -0.93 | 0.36 | 676 | 455 | 56 | 76 |
| Circumferential | Rural | Rural | 4 | 12.00 | 25.25 | 13.25 | 1.47 | 0.24 | 84 | 35 | 7 | 6 |
| Circumferential | Employment Centers | Emp. Centers | 21 | 7.52 | 8.57 | 1.05 | 1.41 | 0.17 | 1,156 | 682 | 96 | 114 |
| Circumferential | Urban | Urban | 523 | 12.57 | 13.62 | 1.05 | 2.36 | 0.02 | 10,895 | 6,984 | 908 | 1,164 |
| Circumferential | Suburban | Rural | 17 | 19.18 | 26.65 | 7.47 | 3.40 | <0.01 | 293 | 228 | 24 | 38 |
| Circumferential | Suburban | Suburban | 251 | 17.33 | 17.65 | 0.32 | 0.48 | 0.63 | 6,188 | 4,947 | 516 | 825 |
| Reverse Flow | Employment Centers | Urban | 23 | 9.70 | 10.70 | 1.00 | 0.63 | 0.54 | 537 | 279 | 45 | 47 |
| Reverse Flow | CBD | CBD | 1 | 1.00 | 3.00 | 2.00 | NA | NA | 23 | 29 | 2 | 5 |
| Reverse Flow | Urban | Suburban | 106 | 17.52 | 16.94 | -0.58 | -0.51 | 0.61 | 2,484 | 1,643 | 207 | 274 |
| Reverse Flow | Urban | Rural | 31 | 16.42 | 17.81 | 1.39 | 0.76 | 0.45 | 640 | 429 | 53 | 72 |
| Reverse Flow | Employment Centers | Suburban | 4 | 20.75 | 11.25 | -9.50 | -2.81 | 0.07 | 128 | 88 | 11 | 15 |
| Reverse Flow | Employment Centers | Rural | 1 | 33.00 | 33.00 | 0.00 | NA | NA | 9 | 6 | 1 | 1 |
| **Overall** | | | **2,241** | **17.27** | **18.68** | **1.41** | **6.08** | **<0.01** | **77,456** | **43,505** | **6,456** | **7,254** |

## Table 8
## Mean Effective Transit Work Trip Speeds, Houston, Texas, 1980-1990

| Orientation | From | To | N | Mean Speed 1980 | Mean Speed 1990 | Paired Statistics Change | Paired Statistics t | Paired Statistics Prob>\|t\| | Workers in Flow 1980 | Workers in Flow 1990 | Estimated Sample 1980 | Estimated Sample 1990 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Radial | Suburban | CBD | 68 | 13.72 | 17.46 | 3.74 | 5.12 | <0.01 | 2,868 | 2,980 | 239 | 497 |
| Radial | Suburban | Emp. Centers | 18 | 13.56 | 12.89 | -0.67 | -0.20 | 0.84 | 442 | 297 | 37 | 50 |
| Radial | Urban | Emp. Centers | 89 | 8.26 | 8.80 | 0.54 | 0.62 | 0.54 | 2,177 | 1,644 | 181 | 274 |
| Radial | Employment Centers | CBD | 7 | 7.71 | 6.86 | -0.86 | -0.75 | 0.48 | 817 | 313 | 68 | 52 |
| Radial | Urban | CBD | 157 | 9.35 | 11.50 | 2.15 | 4.28 | <0.01 | 10,892 | 5,657 | 908 | 943 |
| Radial | Rural | Emp. Centers | 2 | 4.00 | 6.50 | 2.50 | 1.00 | 0.50 | 53 | 20 | 4 | 3 |
| Radial | Rural | CBD | 13 | 13.08 | 14.08 | 1.00 | 0.71 | 0.49 | 521 | 313 | 43 | 52 |
| Radial | Suburban | Urban | 8 | 8.75 | 11.88 | 3.13 | 0.76 | 0.47 | 104 | 75 | 9 | 13 |
| Circumferential | Employment Centers | Emp. Centers | 5 | 5.40 | 7.60 | 2.20 | 0.67 | 0.54 | 374 | 119 | 31 | 20 |
| Circumferential | Rural | Rural | 1 | 11.00 | 19.00 | 8.00 | NA | NA | 27 | 7 | 2 | 1 |
| Circumferential | Suburban | Suburban | 1 | 1.00 | 13.00 | 12.00 | NA | NA | 25 | 15 | 2 | 3 |
| Circumferential | Urban | Urban | 56 | 7.95 | 9.98 | 2.04 | 1.57 | 0.12 | 945 | 630 | 79 | 105 |
| Reverse Flow | CBD | CBD | 1 | 1.00 | 4.00 | 3.00 | NA | NA | 61 | 18 | 5 | 3 |
| Reverse Flow | Urban | Suburban | 4 | 9.50 | 6.25 | -3.25 | -1.17 | 0.33 | 91 | 32 | 8 | 5 |
| Reverse Flow | Employment Centers | Rural | 1 | 9.00 | 16.00 | 7.00 | NA | NA | 64 | 38 | 5 | 6 |
| Reverse Flow | Employment Centers | Urban | 3 | 4.00 | 3.67 | -0.33 | -0.38 | 0.74 | 48 | 21 | 4 | 4 |
| **Overall** | | | **434** | **9.74** | **11.59** | **1.86** | **5.04** | **<0.01** | **19,509** | **12,179** | **1,625** | **2,031** |

from 0.80 mph to 2.76 mph. One circumferential flow shows an increase which is statistically significant: the urban to urban cross-town flow. However, the increase in speed is small, only a 0.5 mph increase.

The most significant result of the Houston analysis is that most of the trip orientations exhibit speed stabilization since 1980. This implies that although direct measures of congestion (such as the TTI congestion index) show worsening congestion in Houston, the perceived travel speeds have remained stable since 1980. Indeed, several factors could influence this perception (or actual result).

The first factor that could influence the data is that individuals may report travel times to work with little variability. Individuals normally round the travel time to work to the nearest 5- or 10-minute level, creating spikes in the trip time frequency distribution. Figure 8 shows the level of spiking in reported travel time distributions for Houston UTPP data. Also, note that the level of spiking at the 30- and 45-minute interval is larger in proportion to other 5-minute intervals. This suggests that individuals have a propensity to report travel times to work in these ranges. It is not evident that the calculation of a mean travel time from groups of individuals with the same origin and destination has an effect on this problem if the aggregation level is small (i.e., at the tract or TAZ geography). This indicates that many of the mean reported travel times at small geographies may be based on only one or two individuals. Thus, the data may simply show that individuals lack the fine-tuning ability to report changes in trip times and speeds, even if there were a savings or increase in travel time of 5 or 10 minutes. The problem may be evident in census data because of the self-enumeration method of sampling, implying that a skilled interviewer could extract a greater level of detail in reporting travel time to work.

The second implication which could be drawn from the Houston data is that the residential and employment location markets responded to the performance of the transportation system. Indeed, intuition and general observation indicate a propensity for the suburbanization of jobs as urban areas grow. Also, NPTS data indicate that the suburbanization of employment centers since 1983 has caused work trip distances to increase while travel times have fallen, indicating an increase in effective trip speeds.

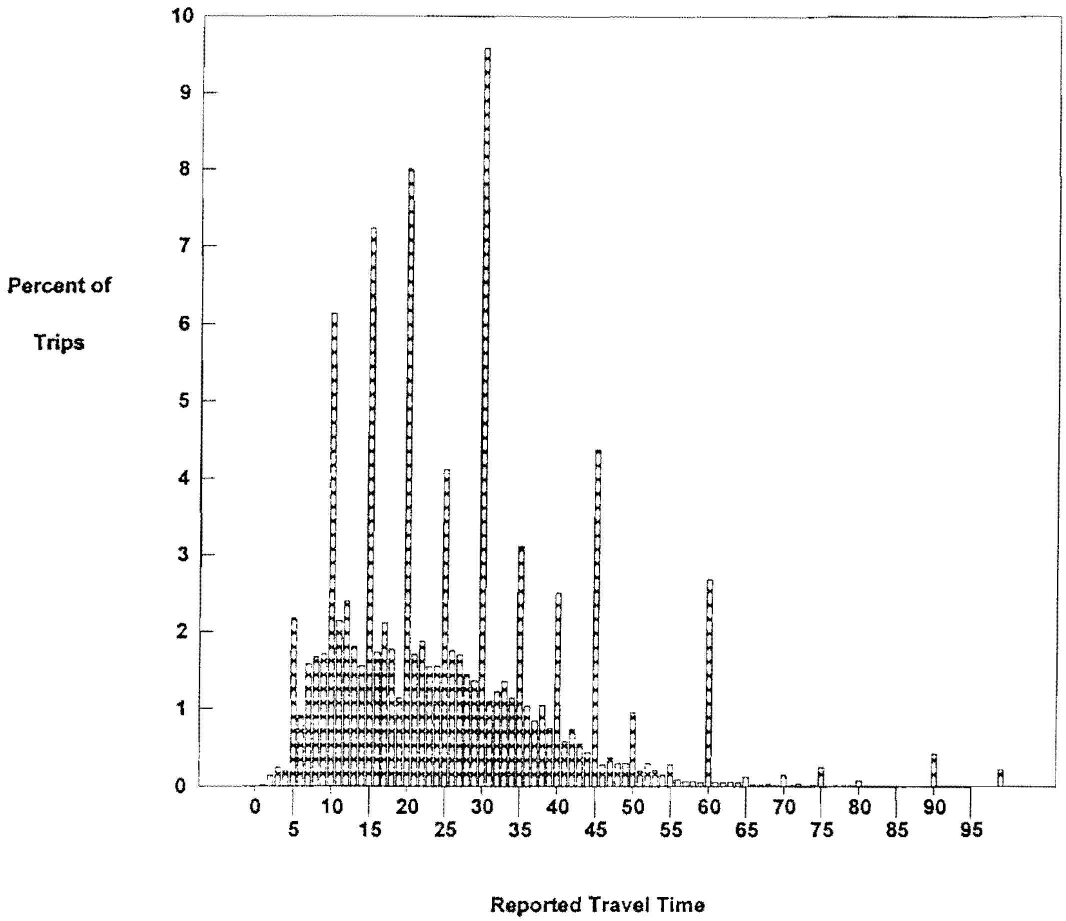


**Figure 8. Travel time frequency distribution of tract-to-tract interchanges from the 1980 UTPP for Houston, Texas. Travel times have been truncated to the nearest minute.**

The third conclusion from the Houston analysis is an enormous increase in the Houston transportation system capacity during the 1980s surpassing the travel growth. The vehicle miles traveled (VMT), in Houston grew by 32.4 percent from 1982 to 1990, while the number of lane miles in Houston grew by 68.9 percent (source: HPMS data used in calculating the TTI congestion index). The increase in capacity lightens congestion and, therefore, stabilizes or increases mean trip speeds.

Other factors include the phrasing of the census questions. A "work commute" and the travel time associated with it could include other trip purposes and several legs during the journey to work. Thus, a direct comparison with NPTS data or other unlinked reports should be performed with caution. Also, wait times associated with tripmaking activities would be included such as picking up passengers or waiting for transit service.

# SECTION 2

# TRIP SPEED CHANGES IN SIX METROPOLITAN AREAS, 1980-1990

## METHODOLOGY

### URBAN AREAS STUDIED

Six urban areas were selected for study. Two criteria were used for selection: urban area size and data availability. The primary goal of this research was to study the ten largest urban areas in the United States. However, because of data acquisition problems, only six were used.

The method of aggregating the 1980 and 1990 census data was a determining factor in using the data. Each urban area Metropolitan Planning Organization (MPO) chose the level of geography for aggregating the worker flow and travel time data matrices: census tract, MPO-defined TAZ, or census block group. To their credit, most MPO's had foresight to ensure that if TAZs were chosen as the aggregation level they would be defined as sub-zones of census tracts and, therefore could be compared to 1980 census data.

Table 9 is a list of urban areas used in this study and their geographic aggregation level for 1980 and 1990.

**Table 9**
**Urban Areas Studied**

| Urban Area | 1990 Population | Population Rank 1990 | Aggregation Level 1980 | Aggregation Level 1990 |
|---|---|---|---|---|
| San Francisco-Oakland | 6,253,311 | 4 | Tract | TAZ |
| Philadelphia | 5,899,345 | 5 | Tract | Tract |
| Boston | 4,171,747 | 7 | Tract | Block Group |
| Dallas-Fort Worth | 3,885,415 | 9 | Tract | TAZ |
| Houston | 3,711,043 | 10 | Tract | TAZ |
| Atlanta | 2,833,511 | 12 | Tract | TAZ |

Source: Journey-to-Work Trends in the United States and Its Major Metropolitan Areas, 1960-1990, U.S. Department of Transportation

Changes in mean perceived speed, 1980 to 1990, were calculated for each urban area and for all urban areas combined. A t-test was performed on each calculated statistic to determine if there was sufficient evidence from the sample to reject the null hypothesis that the true mean speed remained the same in 1990 as it was in 1980.

## AREA TYPE DEFINITION

Area types are a method of defining urban areas by relative population and employment density and are used by transportation planners across the country. The stratification of area types for this study was performed to analyze the 1980 and 1990 census data for changes in journey-to-work speeds which would indicate different levels of performance for radial, circumferential, or reverse flow trips. Using GIS-generated area measurements for census tracts, Figure 9 shows the relative amount of land defined in each area type for the six urban areas studied. Table 10 provides a list of statistics calculated for the geographies used. Table 11 lists area type calculation methods for the six urban areas.

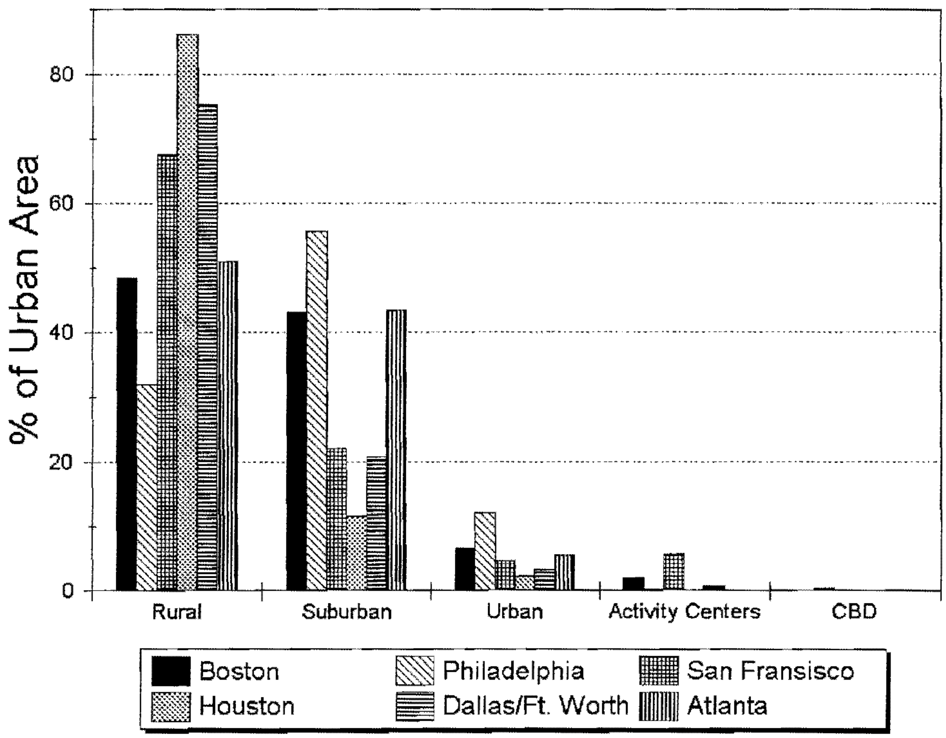


**Figure 9. Land area by selected area type for study cities, 1990.**

## Table 10
## Area Type Statistics for Selected Urban Areas

| Area Type | Boston | | | Philadelphia | | | San Francisco | | |
|---|---|---|---|---|---|---|---|---|---|
| | # of Tracts | Square miles | % | # of Tracts | Square miles | % | # of Tracts | Square miles | % |
| Rural | 293 | 2,720 | 48 | 73 | 1,215 | 32 | 470 | 5,941 | 67 |
| Suburban | 306 | 2,425 | 43 | 434 | 2,120 | 56 | 287 | 1,948 | 22 |
| Urban | 520 | 369 | 7 | 763 | 462 | 12 | 653 | 410 | 5 |
| Activity Centers | 28 | 104 | 2 | 18 | 7 | 0 | 42 | 496 | 6 |
| CBD | 11 | 10 | 0 | 34 | 11 | 0 | 11 | 3 | 0 |
| Total | 1,158 | 5,628 | 100 | 1,322 | 3,815 | 100 | 1,463 | 8,798 | 100 |

| Area Type | Houston | | | Dallas-Fort Worth | | | Atlanta | | |
|---|---|---|---|---|---|---|---|---|---|
| | # of Tracts | Square miles | % | # of Tracts | Square miles | % | # of Tracts | Square miles | % |
| Rural | 322 | 7,551 | 86 | 88 | 7,110 | 75 | 57 | 2,291 | 51 |
| Suburban | 229 | 1,018 | 12 | 447 | 1,959 | 21 | 212 | 1,950 | 43 |
| Urban | 242 | 198 | 2 | 312 | 305 | 3 | 174 | 247 | 5 |
| Activity Centers | 12 | 8 | 0 | 15 | 63 | 1 | 6 | 9 | 0 |
| CBD | 1 | 2 | 0 | 7 | 4 | 0 | 5 | 2 | 0 |
| Total | 806 | 8,777 | 100 | 869 | 9,441 | 100 | 454 | 4,499 | 100 |

## Table 11
## Area Type Calculation Method

| | Boston | Philadelphia | San Francisco | Houston | Dallas-Fort Worth | Atlanta |
|---|---|---|---|---|---|---|
| Rural | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 |
| Suburban | 0.31 - 5.00 | 0.31 - 5.00 | 0.31 - 8.00 | 0.31 - 8.00 | 0.31 - 8.00 | 0.31 - 5.00 |
| Urban | > 5.00 | > 5.00 | > 8.00 | 8.01 - 30.00 | 8.00 - 30.00 | 5.01 - 10.00 |
| Employment Centers | 28 Selected Tracts | 18 Selected Tracts | Tracts with > 10,000 Workers | 30.01 - 75.00 | 30.01 - 75.00 or > 20,000 Workers | > 10.00 or > 8,000 Workers |
| CBD | 11 Selected Tracts | 34 Selected Tracts | 11 Selected Tracts | > 75.01 | 7 Selected Tracts | 5 Selected Tracts |

## NOTE ON COMPUTER IMPLEMENTATION

All of the 1980 data were extracted from the original 1980 UTPP 9-track data tapes using an IBM mainframe computer. The extraction programs were written using Fortran code, since higher level languages (e.g., SAS) would have been too costly for reading such large data sets. The 1980 data were downloaded to a microcomputer in ASCII format.

The 1990 data were obtained directly from the Bureau of the Census on CD-ROM for all urban areas except San Francisco-Oakland. The Houston data were obtained on both CD-ROM and 9-track tape. The same Fortran code used on the mainframe to extract the 1980 data was used on the microcomputer to extract the 1990 CTPP data.

Census Bureau TIGER/Line files were used to develop census tract boundary graphics files and were implemented on a UNIX-based GIS workstation. Population and worker data from the 1990 CTPP CD-ROMs were incorporated into the tract boundary GIS and used to calculate densities for estimating area types. The GIS was also used to calculate geographically-centered centroids for each census tract; state plane coordinates and calculated area types were ported to a microcomputer.

Distances were calculated using Euclidean straight-line formulas and QBasic code. QBasic code was also used to merge the area type and distances with 1990 CTPP worker flow and travel time data. SAS code was written using SAS for Windows on a microcomputer. Over 80 megabytes of working hard disk space was required to implement the statistical comparison SAS programs on the microcomputer.

The advent of microcomputer technology, CD-ROM storage, high-speed network data transfer capability, GIS software, and the Census Bureau's TIGER/Line digital geography files made this analysis possible at relatively minimal cost.

# URBAN AREA RESULTS

## CHANGES IN SYSTEM CHARACTERISTICS

To preface an analysis results discussion of the 1980 UTPP and 1990 CTPP data for the six urban areas, a description of the overall investment in the transportation system is helpful. Table 12 shows the increase in VMT on freeways and arterials compared to the number of lane miles added from 1982 to 1990. The data are calculated using the Highway Performance Monitoring System data for the Texas Transportation Institute's congestion measurement program.

**Table 12**
**Change in Freeway and Arterial System Characteristics, 1982-1990**

| | Growth | | Percentage Change | |
|---|---|---|---|---|
| City | VMT | Lane Miles | VMT | Lane Miles |
| Boston, MA | 5,490,000 | 290 | 19.2 | 7.3 |
| Philadelphia, PA | 8,340,000 | 810 | 26.6 | 20.5 |
| Houston, TX | 8,255,000 | 890 | 26.8 | 28.2 |
| Dallas-Fort Worth, TX | 12,475,000 | 515 | 35.0 | 10.7 |
| San Francisco-Oakland, CA | 18,035,000 | 645 | 46.8 | 16.0 |
| Atlanta, GA | 12,535,000 | 695 | 58.3 | 26.9 |
| Total | 65,130,000 | 3,845 | 35.4 | 18.3 |

In the six urban areas studied, the number of lane miles grew at only half the rate of the growth in VMT from 1982 to 1990. In San Francisco, Dallas-Fort Worth, Atlanta, and Boston, the growth in capacity was less than half of the growth in demand. Atlanta experienced the highest percentage change in VMT adding over 12 million VMT over the 8-year period, while travel in San Francisco increased by over 18 million VMT. Overall, growth in demand for transportation systems greatly outpaced the growth in lane distance throughout the 1980s. Houston is the only exception where, as mentioned before, lane distance has kept abreast of growth in VMT.

These statistics, however, do not address the initial condition of the transportation system in 1982 nor the resulting conditions by 1990. Instead, they are indications of the total investment in freeway and arterial infrastructure during the 1980s. Many such measures exist, such as the TTI congestion index, which all indicate worsening problems with the nation's transportation systems. The analysis of reported travel times from the 1980 UTPP and 1990 CTPP provides some insight into the user's perspective of how well the transportation system is performing. Does it take longer to perform the task of getting to work now than it took in 1980? While there has clearly been an increase in the total congestion amount during the 1980s, what impact has this increase had on travel time to work?

**DRIVE ALONE MEANS OF TRANSPORTATION**

Table 13 shows drive alone mean perceived speeds for the six urban areas studied. Four of the six urban areas exhibited a decrease in overall mean perceived speed. Philadelphia and Houston showed an overall increase in mean perceived speed with Houston having the larger increase of the two. This trend is consistent with the changes shown in Table 12. Houston and Philadelphia are the only two urban areas of the six studied where the increase in lane distance has paced the increase in VMT.

While all of the summary level statistics show strong statistical significance, Philadelphia and Atlanta exhibit the lowest significance levels. The reason for the lower significance levels, 0.04 and 0.06, respectively, is probably due to the low overall change in mean perceived speeds, 0.16 and -0.17, respectively.

Of the statistically significant radial flows (95 percent confidence, Prob>|t| less than 0.05) from the six urban areas, the urban-to-employment centers and urban-to-CBD flows show an increase in mean perceived speed from 1980 to 1990 with Houston showing an increase of almost 2 mph. However, the other statistically significant radial flows, with the exception of Houston, show a decline in mean perceived speed ranging from a 0.51 mph decline (suburban to urban, Atlanta) to a 1.37 mph decline (suburban-to-employment centers, San Francisco).

## Table 13
## Change in Drive Alone Perceived Speeds, 1980 -1990

| Orientation | Origin | Destination | Boston | | Philadelphia | | San Francisco | | Houston | | Dallas-Fort Worth | | Atlanta | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ |
| Radial | Urban | Emp. Centers | -0.25 | 0.26 | 1.18 | <.01 | -0.69 | <.01 | 1.74 | <.01 | -0.50 | 0.14 | 1.39 | 0.01 |
| Radial | Urban | CBD | -0.35 | 0.13 | 1.25 | 0.01 | -0.69 | 0.03 | 1.99 | <.01 | 0.67 | 0.07 | 1.15 | <.01 |
| Radial | Suburban | Urban | -0.30 | 0.10 | -0.25 | 0.19 | -0.76 | <.01 | 0.80 | <.01 | -0.77 | <.01 | -0.51 | 0.01 |
| Radial | Suburban | CBD | -0.50 | 0.21 | 0.40 | 0.65 | -0.74 | 0.34 | 2.76 | <.01 | -0.24 | 0.52 | 0.45 | 0.17 |
| Radial | Suburban | Emp. Centers | -1.06 | <.01 | -0.31 | 0.66 | -1.37 | <.01 | 1.56 | <.01 | -0.54 | 0.16 | 0.50 | 0.27 |
| Radial | Rural | Urban | NA | NA | -0.43 | 0.47 | -1.63 | 0.11 | 0.92 | 0.19 | -0.10 | 0.90 | 1.06 | 0.21 |
| Radial | Emp. Centers | CBD | 0.61 | 0.61 | -1.00 | NA | -4.07 | 0.26 | 1.22 | 0.12 | -1.29 | NA | 0.36 | 0.24 |
| Radial | Rural | CBD | NA | NA | 0.30 | 0.90 | -3.00 | 0.34 | 0.86 | 0.46 | -0.20 | 0.17 | -1.05 | 0.70 |
| Radial | Rural | Emp. Centers | NA | NA | 0.90 | 0.55 | 0.97 | 0.47 | 1.13 | 0.27 | -1.51 | 0.22 | 1.58 | 0.35 |
| Circumferential | Urban | Urban | -0.24 | 0.02 | 0.22 | 0.06 | -0.53 | <.01 | 0.50 | <.01 | -0.63 | <.01 | -0.15 | 0.44 |
| Circumferential | Emp. Centers | Emp. Centers | -0.45 | 0.49 | 0.47 | 0.67 | -1.45 | 0.12 | 0.04 | 0.96 | -0.54 | 0.42 | -2.28 | 0.20 |
| Circumferential | Suburban | Suburban | -1.44 | <.01 | -0.04 | 0.85 | -1.40 | <.01 | -0.18 | 0.53 | -0.13 | 0.59 | -0.96 | <.01 |
| Circumferential | Suburban | Rural | NA | NA | -1.04 | 0.17 | 1.29 | 0.69 | -1.49 | 0.22 | -4.00 | 0.27 | 4.43 | <.01 |
| Circumferential | Rural | Rural | -16.00 | NA | -1.96 | 0.25 | -3.50 | 0.54 | -1.00 | 0.55 | -0.60 | 0.86 | 1.60 | 0.55 |
| Circumferential | Rural | Suburban | NA | NA | -0.17 | 0.82 | -3.74 | 0.09 | -0.34 | 0.73 | -0.38 | 0.70 | 0.63 | 0.52 |
| Reverse Flow | CBD | Rural | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Suburban | -3.00 | 0.50 | -2.96 | 0.38 | NA | NA | NA | NA | 4.00 | NA | NA | NA |
| Reverse Flow | CBD | CBD | 0.33 | 0.61 | 0.85 | 0.21 | -2.00 | NA | 1.00 | NA | 0.67 | 0.53 | NA | NA |
| Reverse Flow | CBD | Emp. Centers | -0.50 | 0.86 | 0.00 | NA | -13.50 | 0.29 | 4.00 | NA | -19.00 | NA | NA | NA |
| Reverse Flow | CBD | Urban | 1.71 | 0.28 | 1.53 | 0.04 | -0.50 | 0.85 | NA | NA | -6.00 | NA | 1.00 | NA |
| Reverse Flow | Urban | Rural | NA | NA | -1.62 | 0.07 | 3.33 | 0.19 | 1.00 | 0.25 | NA | NA | 6.09 | 0.02 |
| Reverse Flow | Urban | Suburban | -0.71 | 0.01 | 0.52 | 0.01 | -0.61 | 0.03 | 0.70 | 0.10 | -0.88 | <.01 | -0.14 | 0.64 |
| Reverse Flow | Emp. Centers | Rural | NA | NA | NA | NA | NA | NA | 6.50 | 0.14 | NA | 0.17 | -10.00 | NA |
| Reverse Flow | Emp. Centers | Urban | -0.76 | 0.18 | 0.00 | 1.00 | 0.29 | 0.64 | -0.54 | 0.56 | 3.44 | 0.64 | 0.20 | 0.83 |
| Reverse Flow | Emp. Centers | Suburban | -0.49 | 0.64 | 1.25 | 0.60 | 0.44 | 0.69 | 6.62 | 0.09 | 2.71 | 0.04 | 1.08 | 0.39 |
| Overall | | | -0.45 | <.01 | 0.16 | 0.04 | -0.66 | <.01 | 0.72 | <.01 | -0.48 | <.01 | -0.17 | 0.06 |
| Number of Tract Pairs | | | 13,164 | | 15,978 | | 17,328 | | 10,839 | | 10,355 | | 10,355 | |

Note: Shaded cells indicate a rejection of the null hypothesis that the difference in the true mean perceived speeds (1980 to 1990) equals zero.

The statistically significant circumferential flows show a trend toward declining speeds with an almost 1.5 mph decrease in the suburban to suburban flows for Boston and San Francisco. One exception is Houston which shows a mild increase in speed in urban-to-urban areas. Another exception is Atlanta, which shows a large increase in mean perceived speed, over 4 mph in the suburban-to-rural orientation. Growth in roadway capacity in these cities in outlying suburban areas could account for the increase in mean perceived speeds.

## CARPOOL MEANS OF TRANSPORTATION

Table 14 shows the analysis results of changes in perceived mean speeds for those who used a carpool on at least one leg of the journey to work. Of the statistically significant flows, most show increases in mean perceived speed. Overall, three of the six urban areas showed a statistically significant, although modest, increase in speed while San Francisco was the only area for which the data indicated a decline in mean speed for carpoolers. The radial flows contain the most cells with significant values, and all of them increase in speed except San Francisco.

The data indicate much larger differences in mean perceived speed for carpools than drive alone modes of transportation. While NPTS statistics show a declining percentage of person miles per VMT (average auto occupancy), these data indicate an increase in speeds for those who remain in carpools. Much of the increase in mean speed is exhibited by the Houston data where the addition of HOV lanes is clearly evident in the responses to the census. In fact, the two radial flows to which HOV lanes are directed, urban-to-CBD and suburban-to-CBD, show increases in mean perceived speed of 3.39 and 4.33 mph, respectively.

## TRANSIT MEANS OF TRANSPORTATION

Table 15 shows the changes in transit perceived mean speeds for all six urban areas. Again, the radial flow provides the most statistically significant data for transit users simply because of the nature of work trips using transit. All of the significant radial flows show increases in speed, although mild. Houston had significant increases in

# Table 14
# Change in Carpool Perceived Speeds, 1980-1990

| | | | Boston | | Philadelphia | | San Francisco | | Houston | | Dallas-Fort Worth | | Atlanta | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Orientation | Origin | Destination | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ |
| Radial | Urban | Emp. Centers | 0.03 | 0.95 | 0.47 | 0.64 | -0.38 | 0.31 | 2.37 | <.01 | 0.23 | 0.69 | 2.00 | 0.10 |
| Radial | Urban | CBD | 1.08 | 0.01 | 0.54 | 0.52 | -1.49 | 0.01 | 3.39 | <.01 | 1.14 | 0.05 | 2.42 | <.01 |
| Radial | Suburban | Urban | 0.42 | 0.53 | -0.14 | 0.83 | -1.44 | 0.08 | -0.44 | 0.57 | 0.06 | 0.93 | -0.63 | 0.21 |
| Radial | Suburban | CBD | -0.27 | 0.66 | -0.23 | 0.92 | -0.72 | 0.55 | 4.33 | <.01 | 1.16 | 0.04 | 2.25 | <.01 |
| Radial | Suburban | Emp. Centers | -1.15 | 0.20 | 1.08 | 0.76 | -1.92 | 0.02 | 2.59 | <.01 | 1.34 | 0.08 | -0.83 | 0.44 |
| Radial | Rural | Urban | NA | NA | -1.41 | 0.41 | -4.50 | 0.53 | -2.57 | 0.11 | 1.72 | 0.40 | -0.06 | 0.98 |
| Radial | Emp. Centers | CBD | 1.00 | 0.66 | NA | NA | 3.00 | 0.81 | 4.00 | <.01 | -3.67 | 0.37 | 1.25 | 0.08 |
| Radial | Rural | CBD | NA | NA | NA | NA | NA | NA | 2.15 | 0.24 | -0.21 | 0.88 | -5.25 | 0.20 |
| Radial | Rural | Emp. Centers | NA | NA | 4.33 | 0.35 | -3.10 | 0.56 | 2.27 | 0.51 | -1.62 | 0.23 | 5.00 | 0.17 |
| Circumferential | Urban | Urban | 0.49 | 0.03 | 0.31 | 0.33 | -0.05 | 0.85 | 1.05 | 0.02 | -0.59 | 0.17 | -0.55 | 0.21 |
| Circumferential | Emp. Centers | Emp. Centers | -1.83 | 0.23 | -4.25 | 0.03 | -1.00 | 0.64 | 1.05 | 0.17 | -1.40 | 0.47 | 12.00 | 0.29 |
| Circumferential | Suburban | Suburban | -0.96 | 0.16 | 1.73 | <.01 | -1.12 | 0.28 | 0.32 | 0.63 | 0.61 | 0.31 | -0.29 | 0.56 |
| Circumferential | Suburban | Rural | NA | NA | 0.16 | 0.94 | 9.00 | NA | 7.47 | <.01 | NA | NA | 5.42 | 0.06 |
| Circumferential | Rural | Rural | NA | NA | 2.76 | 0.61 | 4.67 | 0.68 | 13.25 | 0.24 | 6.00 | 0.64 | 2.50 | 0.68 |
| Circumferential | Rural | Suburban | NA | NA | 1.21 | 0.54 | -4.60 | 0.17 | -1.97 | 0.36 | -1.81 | 0.31 | 3.32 | 0.17 |
| Reverse Flow | CBD | Rural | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Suburban | 2.50 | 0.84 | -5.00 | 0.30 | NA | NA | NA | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | CBD | 1.50 | 0.66 | 2.28 | 0.11 | NA | NA | 2.00 | NA | -1.00 | NA | NA | NA |
| Reverse Flow | CBD | Emp. Centers | 6.25 | 0.17 | NA | NA | -3.00 | 0.81 | NA | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Urban | -1.00 | 0.50 | 3.70 | 0.16 | NA | NA | NA | NA | 1.00 | NA | NA | NA |
| Reverse Flow | Urban | Rural | NA | NA | -0.14 | 0.95 | NA | NA | 1.39 | 0.45 | NA | NA | -1.22 | 0.78 |
| Reverse Flow | Urban | Suburban | 0.99 | 0.24 | 1.28 | 0.01 | -0.20 | 0.81 | -0.58 | 0.61 | 0.08 | 0.92 | -0.72 | 0.36 |
| Reverse Flow | Emp. Centers | Rural | NA | NA | NA | NA | NA | NA | 0.00 | NA | NA | NA | NA | NA |
| Reverse Flow | Emp. Centers | Urban | -1.03 | 0.46 | -1.67 | 0.39 | -2.04 | 0.45 | 1.00 | 0.54 | 4.67 | 0.42 | 0.86 | 0.83 |
| Reverse Flow | Emp. Centers | Suburban | 5.08 | 0.37 | 7.33 | 0.04 | -1.38 | 0.75 | -9.50 | 0.07 | -6.33 | 0.59 | 0.80 | 0.92 |
| Overall | | | 0.32 | 0.05 | 0.65 | <.01 | -0.59 | <.01 | 1.41 | <.01 | 0.34 | 0.10 | 0.16 | 0.46 |
| Number of Tract Pairs | | | 2,806 | | 2,643 | | 2,775 | | 2,241 | | 2,502 | | 2,576 | |

Note: Shaded cells indicate a rejection of the null hypothesis that the difference in the true mean perceived speeds (1980 to 1990) equals zero.

# Table 15
# Change in Transit Perceived Speeds, 1980-1990

| Orientation | Origin | Destination | Boston | | Philadelphia | | San Francisco | | Houston | | Dallas-Fort Worth | | Atlanta | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ | Change | Prob>¦t¦ |
| Radial | Urban | Emp. Centers | 0.51 | <.01 | 0.73 | 0.15 | 0.33 | 0.40 | 0.54 | 0.54 | 0.20 | 0.82 | 0.72 | 0.50 |
| Radial | Urban | CBD | 0.22 | 0.05 | 1.94 | 0.09 | -0.07 | 0.68 | 2.15 | <.01 | 0.28 | 0.32 | 0.97 | <.01 |
| Radial | Suburban | Urban | -0.21 | 0.78 | 0.78 | 0.47 | 0.33 | 0.68 | 3.13 | 0.47 | 1.20 | 0.25 | -0.62 | 0.45 |
| Radial | Suburban | CBD | -0.33 | 0.31 | 4.80 | 0.12 | 0.36 | 0.56 | 3.74 | <.01 | 0.62 | 0.14 | 1.21 | 0.02 |
| Radial | Suburban | Emp. Centers | -0.27 | 0.70 | 3.86 | 0.28 | 2.88 | 0.22 | -0.67 | 0.84 | 1.26 | 0.37 | 0.56 | 0.85 |
| Radial | Rural | Urban | NA | NA | 2.00 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Radial | Emp. Centers | CBD | -0.14 | 0.78 | NA | NA | -1.21 | 0.12 | -0.86 | 0.48 | 0.80 | 0.54 | 3.38 | 0.19 |
| Radial | Rural | CBD | NA | NA | NA | NA | 0.00 | NA | 1.00 | 0.49 | NA | NA | -9.50 | NA |
| Radial | Rural | Emp. Centers | NA | NA | NA | NA | NA | NA | 2.50 | 0.50 | NA | NA | NA | NA |
| Circumferential | Urban | Urban | -0.04 | 0.84 | 0.91 | <.01 | 0.18 | 0.26 | 2.04 | 0.12 | -1.50 | 0.42 | 1.42 | <.01 |
| Circumferential | Emp. Centers | Emp. Centers | -1.63 | 0.22 | 1.00 | NA | 1.33 | 0.58 | 2.20 | 0.54 | -7.00 | 0.18 | -1.00 | 0.50 |
| Circumferential | Suburban | Suburban | -2.18 | 0.45 | 6.18 | 0.17 | -4.36 | 0.23 | 12.00 | NA | 0.20 | 0.96 | 0.47 | 0.81 |
| Circumferential | Suburban | Rural | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 8.00 | 0.03 |
| Circumferential | Rural | Rural | 15.00 | NA | NA | NA | NA | NA | 8.00 | NA | NA | NA | NA | NA |
| Circumferential | Rural | Suburban | NA | NA | NA | NA | 7.00 | NA | NA | NA | NA | NA | 4.00 | 0.73 |
| Reverse Flow | CBD | Rural | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Suburban | NA | NA | 1.80 | 0.87 | -4.00 | NA | NA | NA | NA | NA | 13.00 | NA |
| Reverse Flow | CBD | CBD | -0.12 | 0.71 | -2.75 | 0.41 | -1.00 | 0.08 | 3.00 | NA | 0.00 | NA | 2.00 | 0.50 |
| Reverse Flow | CBD | Emp. Centers | -0.58 | 0.33 | -1.00 | NA | -2.00 | 0.63 | NA | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Urban | -0.40 | 0.75 | 4.18 | 0.21 | -0.89 | 0.14 | NA | NA | NA | NA | -4.00 | 0.16 |
| Reverse Flow | Urban | Rural | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Reverse Flow | Urban | Suburban | -1.44 | 0.11 | 1.54 | 0.12 | -0.96 | 0.38 | -3.25 | 0.33 | 3.25 | 0.49 | 3.26 | <.01 |
| Reverse Flow | Emp. Centers | Rural | NA | NA | NA | NA | NA | NA | 7.00 | NA | NA | NA | NA | NA |
| Reverse Flow | Emp. Centers | Urban | 0.50 | 0.74 | -0.58 | 0.79 | -0.13 | 0.89 | -0.33 | 0.74 | NA | NA | 2.38 | 0.27 |
| Reverse Flow | Emp. Centers | Suburban | NA | NA | -0.67 | 0.88 | 4.33 | 0.38 | NA | NA | NA | NA | -9.50 | 0.03 |
| Overall | | | 0.10 | 0.23 | 1.08 | <.01 | 0.03 | 0.76 | 1.86 | <.01 | 0.35 | 0.18 | 1.12 | <.01 |
| Number of Tract Pairs | | | 3,118 | | 1,465 | | 2,046 | | 434 | | 513 | | 1,165 | |

Note: Shaded cells indicate a rejection of the null hypothesis that the difference in the true mean perceived speeds (1980 to 1990) equals zero.

mean speed for work trip transit users, probably because of increased service due to HOV lane implementation.

Overall, significant results were obtained in three of the six urban areas: Philadelphia, Houston, and Dallas-Fort Worth. All three of these areas showed increases in mean perceived speed of greater than 1 mph for transit users.

## POOLED RESULTS

Data from all six urban areas were pooled to show aggregate results. The pooled data were then analyzed based on specific area type orientation and then by major orientation (radial, circumferential, or reverse flow).

Tables 16 through 19 show statistics on changes from 1980 to 1990 by detailed area type orientation. Tables 20 through 22 exhibit aggregated orientation results.

### DRIVE ALONE MEANS OF TRANSPORTATION

A mild decrease in overall speed of 0.18 mph in mean perceived speed is shown for those who chose to drive alone to work. Of the four statistically significant results, three show mild declines in speed while one reverse flow commute shows an increase of greater than 1 mph. The suburban-to-suburban speed, a circumferential orientation, shows the greatest decrease of the four results.

When aggregated by major trip orientation (Table 20), the radial and circumferential flows show a decrease in mean perceived speed while reverse flow commute speeds seem to have stabilized. Although the changes are mild, the decrease in speed for the circumferential orientation is more than twice that of radial flows. This could be because of the Houston data where several HOV lanes and other radial capacity improvements were added during the 1980s which would benefit radial commute patterns.

Notably, variation in the data seems to be of significance. While the mean radial speed for both 1980 and 1990 falls around 22 mph, data indicate that 68 percent of workers' mean speed ranges from 11 to 33 mph. This is a significant spread of the data considering that at least 50 percent of workers travel at less than 22 mph mean effective trip speed for radial trips. A lesser spread in the data would indicate that the transportation system performs consistently for all users. This does not seem to be the case at least as indicated by perceived travel times.

This issue is more important for circumferential trips where the mean speed is about 5 mph slower than that for radial trips; the standard deviation is higher,

## Table 16
## Change in Drive Alone Perceived Speeds, Pooled Urban Areas, 1980-1990

| Orientation | Origin | Destination | Number of Tract Pairs | Mean Speed 1980 | Mean Speed 1990 | Change | Prob>\|t\| |
|---|---|---|---|---|---|---|---|
| Radial | Urban | Emp. Centers | 6,138 | 19.61 | 19.67 | 0.06 | 0.60 |
| Radial | Urban | CBD | 3,143 | 16.56 | 16.82 | 0.26 | 0.06 |
| Radial | Suburban | Urban | 14,155 | 23.18 | 22.89 | -0.30 | <.01 |
| Radial | Suburban | CBD | 1,915 | 24.39 | 24.54 | 0.15 | 0.43 |
| Radial | Suburban | Emp. Centers | 3,101 | 24.93 | 24.66 | -0.27 | 0.11 |
| Radial | Rural | Urban | 1,030 | 30.23 | 30.39 | 0.16 | 0.63 |
| Radial | Emp. Centers | CBD | 107 | 19.64 | 19.27 | -0.36 | 0.65 |
| Radial | Rural | CBD | 164 | 35.11 | 34.54 | -0.57 | 0.47 |
| Radial | Rural | Emp. Centers | 260 | 32.02 | 32.29 | 0.27 | 0.66 |
| Circumferential | Urban | Urban | 28,242 | 15.96 | 15.8 | -0.16 | <.01 |
| Circumferential | Emp. Centers | Emp. Centers | 310 | 15.95 | 15.2 | -0.75 | 0.07 |
| Circumferential | Suburban | Suburban | 8,714 | 22.18 | 21.6 | -0.58 | <.01 |
| Circumferential | Suburban | Rural | 321 | 27.49 | 27.3 | -0.19 | 0.76 |
| Circumferential | Rural | Rural | 101 | 19.18 | 17.57 | -1.60 | 0.13 |
| Circumferential | Rural | Suburban | 693 | 32.06 | 31.8 | -0.26 | 0.56 |
| Reverse Flow | CBD | Rural | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Suburban | 29 | 36.28 | 33.55 | -2.72 | 0.37 |
| Reverse Flow | CBD | CBD | 69 | 5.8 | 6.46 | 0.67 | 0.16 |
| Reverse Flow | CBD | Emp. Centers | 15 | 16.67 | 13.53 | -3.13 | 0.24 |
| Reverse Flow | CBD | Urban | 87 | 12.74 | 14.18 | 1.45 | 0.03 |
| Reverse Flow | Urban | Rural | 306 | 22.43 | 23.1 | 0.67 | 0.28 |
| Reverse Flow | Urban | Suburban | 8,038 | 21.31 | 21.2 | -0.11 | 0.34 |
| Reverse Flow | Emp. Centers | Rural | 3 | 28.33 | 29.33 | 1.00 | 0.87 |
| Reverse Flow | Emp. Centers | Urban | 813 | 17.18 | 17.22 | 0.05 | 0.89 |
| Reverse Flow | Emp. Centers | Suburban | 265 | 21.24 | 22.32 | 1.08 | 0.10 |
| Overall | | | 78,019 | 19.92 | 19.75 | -0.18 | <.01 |

Note: Shaded cells indicate a rejection of the null hypothesis that the difference in the true mean perceived speeds (1980 to 1990) equals zero.

## Table 17
## Change in Variability of Drive Alone Perceived Mean Speeds, 1980-1990

| Orientation | Origin | Destination | Standard Deviation 1980 | Standard Deviation 1990 | Coefficient of Variation 1980 | Coefficient of Variation 1990 | Coefficient of Variation Change |
|---|---|---|---|---|---|---|---|
| Radial | Urban | Emp. Centers | 10.21 | 10.11 | 52.07 | 51.40 | -0.67 |
| Radial | Urban | CBD | 9.48 | 8.83 | 57.25 | 52.50 | -4.75 |
| Radial | Suburban | Urban | 11.2 | 10.73 | 48.32 | 46.88 | -1.44 |
| Radial | Suburban | CBD | 10 | 9.31 | 41.00 | 37.94 | -3.06 |
| Radial | Suburban | Emp. Centers | 10.12 | 9.63 | 40.59 | 39.05 | -1.54 |
| Radial | Rural | Urban | 12.56 | 12.26 | 41.55 | 40.34 | -1.21 |
| Radial | Emp. Centers | CBD | 11.13 | 9.83 | 56.67 | 51.01 | -5.66 |
| Radial | Rural | CBD | 11.89 | 9.91 | 33.86 | 28.69 | -5.17 |
| Radial | Rural | Emp. Centers | 11.52 | 10.41 | 35.98 | 32.24 | -3.74 |
| Circumferential | Urban | Urban | 10.62 | 10.47 | 66.54 | 66.27 | -0.28 |
| Circumferential | Emp. Centers | Emp. Centers | 11.78 | 10.1 | 73.86 | 66.45 | -7.41 |
| Circumferential | Suburban | Suburban | 12 | 11.9 | 54.10 | 55.09 | 0.99 |
| Circumferential | Suburban | Rural | 12.81 | 13.35 | 46.60 | 48.90 | 2.30 |
| Circumferential | Rural | Rural | 13.67 | 12.48 | 71.27 | 71.03 | -0.24 |
| Circumferential | Rural | Suburban | 12.12 | 11.79 | 37.80 | 37.08 | -0.73 |
| Reverse Flow | CBD | Rural | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Suburban | 20.49 | 19.27 | 56.48 | 57.44 | 0.96 |
| Reverse Flow | CBD | CBD | 8.38 | 7.7 | 144.48 | 119.20 | -25.29 |
| Reverse Flow | CBD | Emp. Centers | 15.65 | 9.76 | 93.88 | 72.14 | -21.75 |
| Reverse Flow | CBD | Urban | 13.06 | 13.72 | 102.51 | 96.76 | -5.76 |
| Reverse Flow | Urban | Rural | 12.62 | 13.39 | 56.26 | 57.97 | 1.70 |
| Reverse Flow | Urban | Suburban | 11.59 | 11 | 54.39 | 51.89 | -2.50 |
| Reverse Flow | Emp. Centers | Rural | 11.02 | 4.51 | 38.90 | 15.38 | -23.52 |
| Reverse Flow | Emp. Centers | Urban | 10.1 | 10.3 | 58.79 | 59.81 | 1.02 |
| Reverse Flow | Emp. Centers | Suburban | 10.96 | 11.53 | 51.60 | 51.66 | 0.06 |
| Overall | | | 11.61 | 11.32 | 58.28 | 57.32 | -0.97 |

## Table 18
## Change in Carpool Perceived Speeds, Pooled Urban Areas, 1980-1990

| Orientation | Origin | Destination | Number of Tract Pairs | Mean Speed 1980 | Mean Speed 1990 | Change | Prob>\|t\| |
|---|---|---|---|---|---|---|---|
| Radial | Urban | Emp. Centers | 1,299 | 15.02 | 15.72 | 0.70 | 0.01 |
| Radial | Urban | CBD | 1,844 | 12.80 | 13.80 | 1.00 | <.01 |
| Radial | Suburban | Urban | 1,870 | 21.97 | 21.78 | -0.19 | 0.47 |
| Radial | Suburban | CBD | 962 | 21.35 | 22.85 | 1.50 | <.01 |
| Radial | Suburban | Emp. Centers | 685 | 23.67 | 24.72 | 1.05 | 0.02 |
| Radial | Rural | Urban | 153 | 30.44 | 29.87 | -0.57 | 0.54 |
| Radial | Emp. Centers | CBD | 41 | 16.12 | 16.56 | 0.44 | 0.60 |
| Radial | Rural | CBD | 93 | 33.46 | 33.47 | 0.01 | 0.99 |
| Radial | Rural | Emp. Centers | 84 | 32.95 | 33.62 | 0.67 | 0.64 |
| Circumferential | Urban | Urban | 4,359 | 11.77 | 11.99 | 0.22 | 0.08 |
| Circumferential | Emp. Centers | Emp. Centers | 67 | 9.52 | 9.42 | -0.10 | 0.90 |
| Circumferential | Suburban | Suburban | 1,638 | 19.26 | 19.52 | 0.26 | 0.33 |
| Circumferential | Suburban | Rural | 62 | 24.76 | 29.13 | 4.37 | <.01 |
| Circumferential | Rural | Rural | 26 | 15.08 | 19.81 | 4.73 | 0.24 |
| Circumferential | Rural | Suburban | 145 | 30.70 | 30.86 | 0.16 | 0.88 |
| Reverse Flow | CBD | Rural | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Suburban | 12 | 33.50 | 29.83 | -3.67 | 0.34 |
| Reverse Flow | CBD | CBD | 31 | 3.45 | 4.61 | 1.16 | 0.18 |
| Reverse Flow | CBD | Emp. Centers | 6 | 6.83 | 10.33 | 3.50 | 0.29 |
| Reverse Flow | CBD | Urban | 32 | 7.00 | 9.03 | 2.03 | 0.22 |
| Reverse Flow | Urban | Rural | 54 | 20.85 | 21.41 | 0.56 | 0.69 |
| Reverse Flow | Urban | Suburban | 1,232 | 18.71 | 19.19 | 0.48 | 0.13 |
| Reverse Flow | Emp. Centers | Rural | 1 | 33.00 | 33.00 | 0.00 | NA |
| Reverse Flow | Emp. Centers | Urban | 88 | 11.55 | 11.49 | -0.06 | 0.94 |
| Reverse Flow | Emp. Centers | Suburban | 30 | 18.97 | 20.40 | 1.43 | 0.61 |
| Overall | | | 14,814 | 16.78 | 17.26 | 0.48 | <.01 |

Note: Shaded cells indicate a rejection of the null hypothesis that the difference in the true mean perceived speeds (1980 to 1990) equals zero.

## Table 19
## Change in Transit Perceived Speeds, Pooled Urban Areas, 1980-1990

| Orientation | Origin | Destination | Number of Tract Pairs | Mean Speed 1980 | Mean Speed 1990 | Change | Prob>\|t\| |
|---|---|---|---|---|---|---|---|
| Radial | Urban | Emp. Centers | 1,666 | 12.88 | 13.06 | 0.18 | 0.34 |
| Radial | Urban | CBD | 2,271 | 9.69 | 10.03 | 0.34 | <.01 |
| Radial | Suburban | Urban | 418 | 17.05 | 16.47 | -0.58 | 0.21 |
| Radial | Suburban | CBD | 734 | 15.74 | 16.34 | 0.60 | 0.01 |
| Radial | Suburban | Emp. Centers | 305 | 19.71 | 18.98 | -0.73 | 0.19 |
| Radial | Rural | Urban | 7 | 26.14 | 22.57 | -3.57 | 0.56 |
| Radial | Emp. Centers | CBD | 79 | 9.11 | 9.41 | 0.30 | 0.55 |
| Radial | Rural | CBD | 15 | 14.87 | 14.47 | -0.40 | 0.80 |
| Radial | Rural | Emp. Centers | 12 | 27.92 | 25.75 | -2.17 | 0.62 |
| Circumferential | Urban | Urban | 3,035 | 9.88 | 10.30 | 0.42 | <.01 |
| Circumferential | Emp. Centers | Emp. Centers | 66 | 9.98 | 8.85 | -1.13 | 0.30 |
| Circumferential | Suburban | Suburban | 210 | 17.51 | 17.10 | -0.41 | 0.63 |
| Circumferential | Suburban | Rural | 2 | 20.00 | 28.50 | 8.50 | 0.04 |
| Circumferential | Rural | Rural | 5 | 21.80 | 29.20 | 7.40 | 0.26 |
| Circumferential | Rural | Suburban | 7 | 32.43 | 30.29 | -2.14 | 0.52 |
| Reverse Flow | CBD | Rural | NA | NA | NA | NA | NA |
| Reverse Flow | CBD | Suburban | 6 | 26.17 | 29.83 | 3.66 | 0.69 |
| Reverse Flow | CBD | CBD | 37 | 4.86 | 4.38 | -0.48 | 0.51 |
| Reverse Flow | CBD | Emp. Centers | 23 | 8.39 | 7.48 | -0.91 | 0.49 |
| Reverse Flow | CBD | Urban | 24 | 16.33 | 18.88 | 2.55 | 0.29 |
| Reverse Flow | Urban | Rural | NA | NA | NA | NA | NA |
| Reverse Flow | Urban | Suburban | 464 | 15.92 | 16.84 | 0.92 | 0.08 |
| Reverse Flow | Emp. Centers | Rural | 1 | 9.00 | 16.00 | 7.00 | NA |
| Reverse Flow | Emp. Centers | Urban | 70 | 12.21 | 11.66 | -0.55 | 0.64 |
| Reverse Flow | Emp. Centers | Suburban | 13 | 17.31 | 14.85 | -2.46 | 0.38 |
| Overall | | | 9,470 | 12.01 | 12.28 | 0.27 | <.01 |

Note: Shaded cells indicate a rejection of the null hypothesis that the difference in the true mean perceived speeds (1980 to 1990) equals zero.

## Table 20
## Drive Alone Statistics by Orientation, Pooled Urban Areas, 1980-1990

| | Radial | Circumferential | Reverse Flow |
|---|---|---|---|
| 1980 Mean Effective Speed | 22.39 | 17.77 | 20.85 |
| 1990 Mean Effective Speed | 22.27 | 17.50 | 20.82 |
| Difference in Means | -0.12 | -0.27 | -0.03 |
| Prob>\|t\| | 0.03 | <.01 | 0.77 |
| St. Dev. of the Differences in Means | 9.41 | 9.23 | 10.15 |
| | | | |
| St. Dev., 1980 Mean Speeds | 11.17 | 11.52 | 11.71 |
| St. Dev., 1990 Mean Speeds | 10.73 | 11.34 | 11.25 |
| Difference in Coeff. of Variation | -1.71 | -0.03 | -2.13 |
| | | | |
| Number of Tract Pairs in Group | 30,013 | 38,381 | 9,625 |
| Workers, 1980 | 1,240,052 | 1,461,804 | 342,374 |
| Workers, 1990 | 1,109,652 | 1,220,279 | 266,646 |
| Estimated Sample 1980 | 103,338 | 121,817 | 28,531 |
| Estimated Sample 1990 | 184,942 | 203,380 | 44,441 |

## Table 21
## Carpool Statistics by Orientation, Pooled Urban Areas, 1980-1990

| | Radial | Circumferential | Reverse Flow |
|---|---|---|---|
| 1980 Mean Effective Speed | 18.79 | 14.27 | 17.88 |
| 1990 Mean Effective Speed | 19.44 | 14.56 | 18.37 |
| Difference in Means | 0.65 | 0.29 | 0.49 |
| Prob>\|t\| | <.01 | 0.01 | 0.08 |
| St. Dev. of the Differences in Means | 9.89 | 9.35 | 10.83 |
| | | | |
| St. Dev., 1980 Mean Speeds | 11.27 | 11.47 | 11.92 |
| St. Dev., 1990 Mean Speeds | 11.51 | 11.87 | 11.92 |
| Difference in Coeff. of Variation | -0.77 | 1.15 | -1.78 |
| | | | |
| Number of Tract Pairs in Group | 7,031 | 6,297 | 1,486 |
| Workers, 1980 | 240,534 | 188,166 | 40,716 |
| Workers, 1990 | 140,348 | 103,150 | 23,553 |
| Estimated Sample 1980 | 20,045 | 15,681 | 3,393 |
| Estimated Sample 1990 | 23,391 | 17,192 | 3,926 |

**Table 22**
**Transit Statistics by Orientation, Pooled Urban Areas, 1980-1990**

| | Radial | Circumferential | Reverse Flow |
|---|---|---|---|
| 1980 Mean Effective Speed | 12.64 | 10.44 | 14.73 |
| 1990 Mean Effective Speed | 12.82 | 10.78 | 15.37 |
| Difference in Means | 0.18 | 0.34 | 0.64 |
| Prob>\|t\| | 0.05 | 0.02 | 0.14 |
| St. Dev. of the Differences in Means | 6.86 | 8.38 | 10.88 |
| | | | |
| St. Dev., 1980 Mean Speeds | 8.98 | 9.02 | 11.91 |
| St. Dev., 1990 Mean Speeds | 8.81 | 9.64 | 12.00 |
| Difference in Coeff. of Variation | -2.32 | 3.03 | -2.78 |
| | | | |
| Number of Tract Pairs in Group | 5,507 | 3,325 | 638 |
| Workers, 1980 | 205,500 | 66,998 | 13,119 |
| Workers, 1990 | 154,202 | 47,117 | 10,747 |
| Estimated Sample 1980 | 17,125 | 5,583 | 1,093 |
| Estimated Sample 1990 | 25,700 | 7,853 | 1,791 |

around 11-12 mph. This is a clear indication of the lack of high levels of service for circumferentially-oriented work trips versus radial trips.

Along the same lines, the variation in the mean trip speed distribution has decreased more for radial and reverse flow work trips as compared to circumferential trips. The coefficient of variation (standard deviation divided by its mean) has dropped by almost 2 percentage points for radial trips compared to -0.03 percent for circumferential trips. This statistic is probably indicative of a greater percentage of reported travel times clustering at the mean or fewer observations at the tails of the distribution. Indeed, Figure 10 shows that, while the overall mean speed for drive alone work trips oriented radially has dropped slightly, there are fewer tract pairs reporting mean speeds of less than 16 mph and more tract pairs reporting between 16 and 30 mph in 1990 versus 1980. The number of tract pairs with mean effective speeds of greater than 30 mph did not change.

This implies that although there is a mild decline in average operating speed for radial-oriented work trips, the performance of the six transportation systems as a whole has improved.

Circumferentially, however, the picture is quite different. Figure 11 shows the residual plot of the trip mean perceived speed frequency distributions from 1980 to 1990. There is no indication of a shift in the number of tract pairs reporting means at lower or higher speeds. The implication is that the overall system performance has not changed substantially for circumferential drive alone work trips.

The residual plot of the reverse flow work trip orientation also shows that mean effective trip speeds changed from 1980 to 1990. Variability within the distributions for 1980 versus 1990 declined implying that reverse flow commuters reported travel times more consistently in 1990 versus 1980. Indeed, Figure 12 shows that fewer workers reported travel times at low speeds in 1990, with more clustering about the mean speed of 20.82 mph.

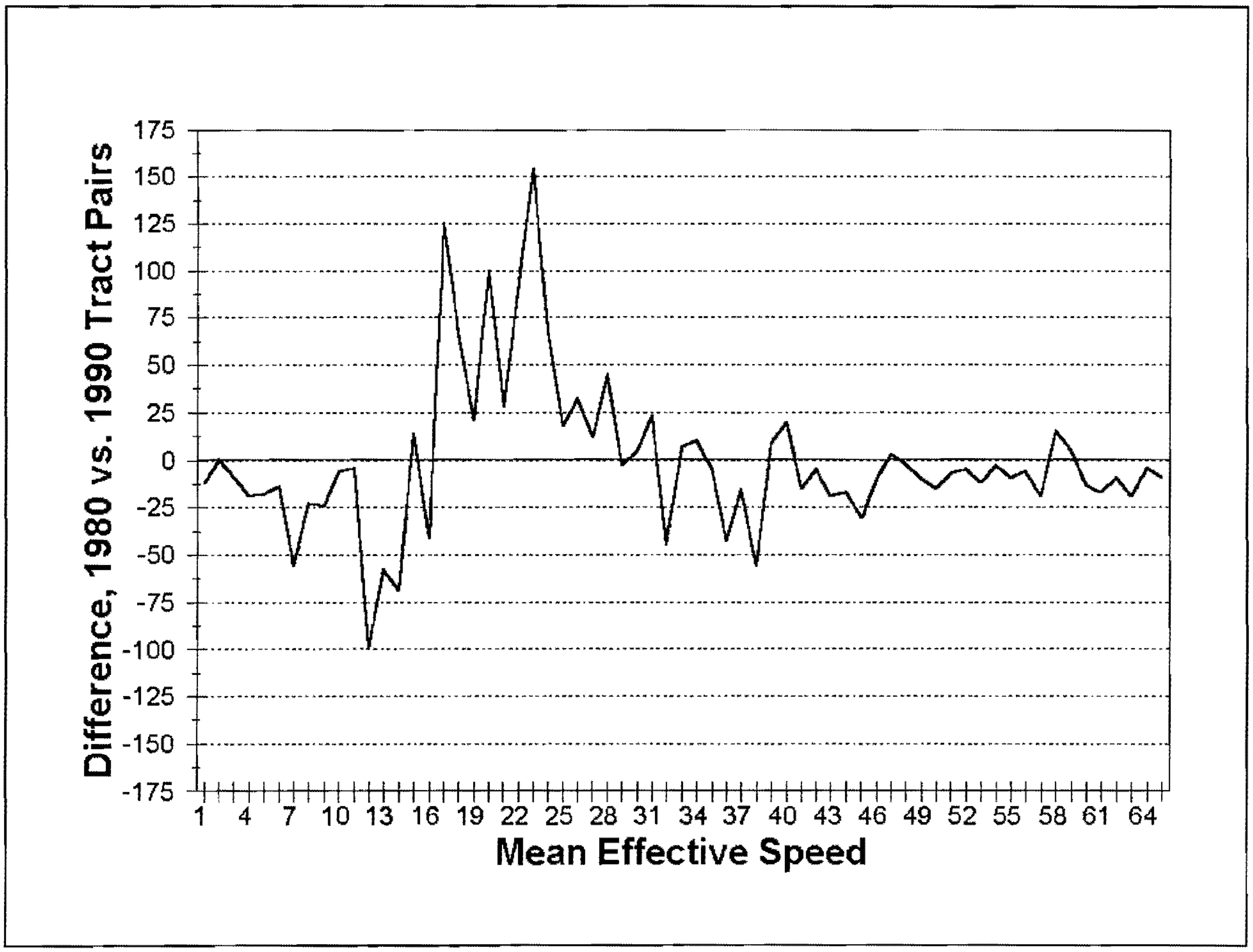


**Figure 10.** **Residual plot of 1980 compared to 1990 mean effective drive alone trip speed frequency distributions: radial orientation.**

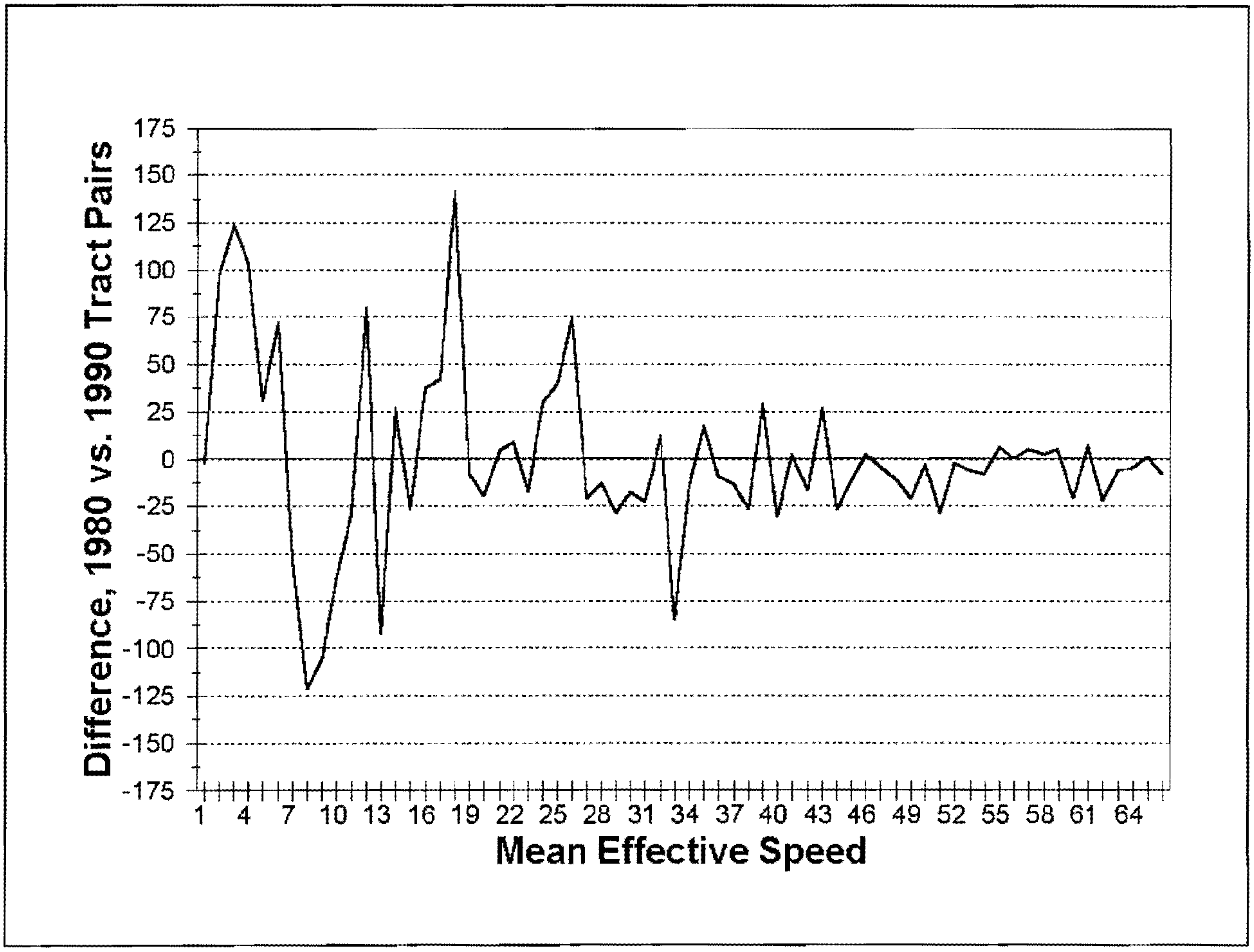


Figure 11. **Residual plot of 1980 compared to 1990 mean effective drive alone trip speed frequency distributions: circumferential orientation.**

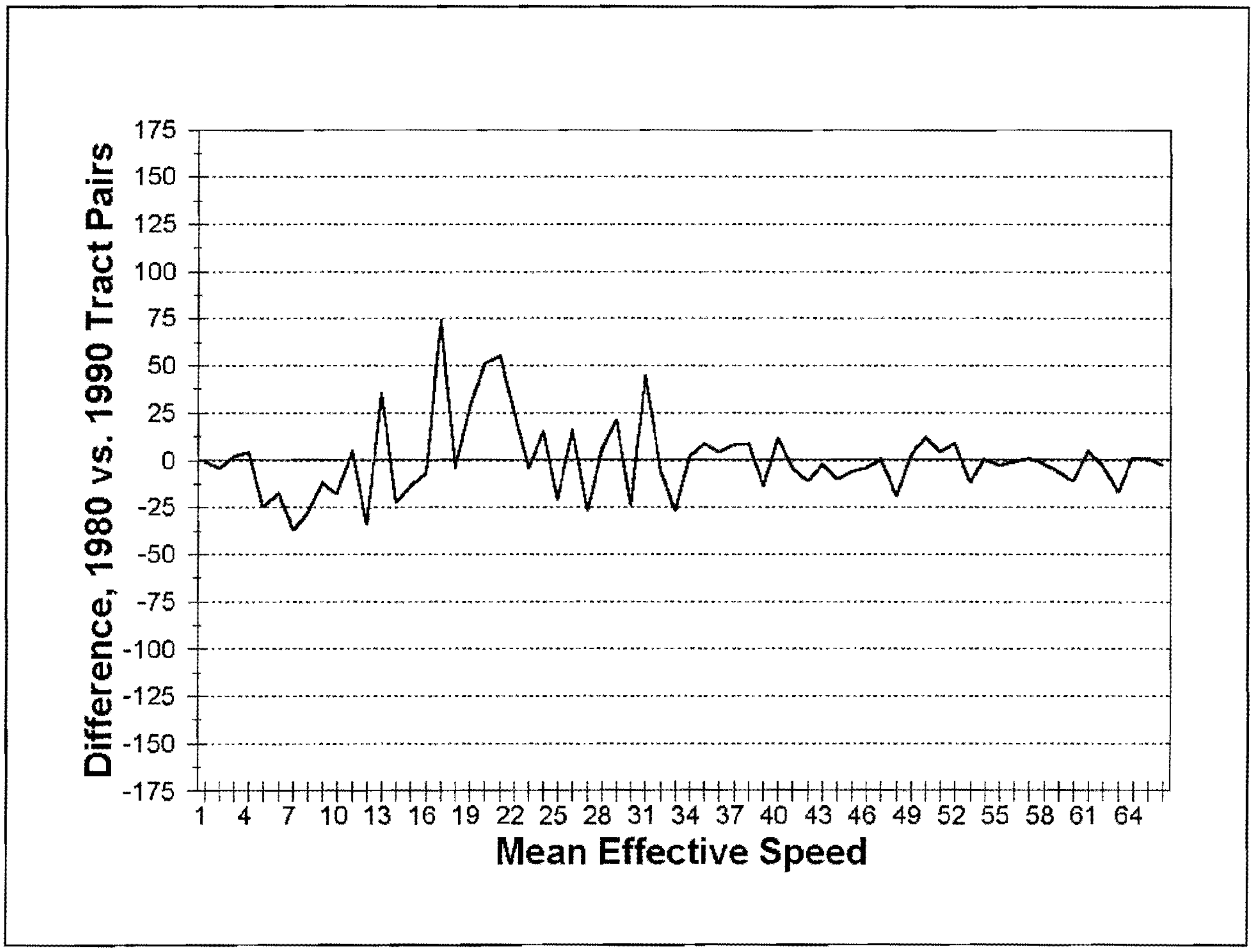


**Figure 12. Residual plot of 1980 compared to 1990 mean effective drive alone trip speed frequency distributions: reverse flow orientation.**

## CARPOOL MEANS OF TRANSPORTATION

Table 18 shows the changes in carpool effective speeds for the pooled urban areas by detailed orientation. All of the statistically significant (alpha=0.05) carpool mean perceived speeds from the pooled data set showed an increase. Overall, a change of 0.48 mph in the mean speed from 1980 to 1990 occurred. Most of the significant changes occurred for the radial orientations with suburban and urban origins to the CBD and employment centers exhibiting about a 1 mph increase. A large increase of 4.37 mph is shown for suburban-to-rural circumferential work trips. This could be because of an increase in the total number of carpoolers traveling with this trip orientation. Also, only one other orientation, urban-to-urban, has a large sample size; but the change (-0.19 mph) was not great enough to show significance.

Table 21 shows results of carpool comparisons by aggregate orientation. Radial-oriented carpool work trips were greater than 4 mph faster than circumferential trips indicating that radial systems performed better than circumferential. Also, the spread of speeds (based on the standard deviation) shows that at least 68 percent of radial commuters traveled between 7.5 and 31 mph mean effective speed, while circumferential commuters traveled between 3 and 26 mph.

Effective speeds for carpoolers increased for all three orientations from 1980 to 1990. Radial trip speeds increased the most, 0.65 mph. Again, while this increase is not a dramatic change, it is significant because of the large number of workers used to calculate the difference. An estimated 23,000 carpoolers responded to the long form questionnaire in 1990, assuming a one in six sample size.

The coefficient of variation (standard deviation divided by the mean) dropped for both radial and reverse flow carpool orientations but increased for circumferential flows. This indicates a greater amount of variability in 1990 than in 1980 for circumferential carpoolers and a lesser amount of variability for radial and reverse flow trips. This could be an indication of reduced performance (or inconsistency of performance) of the transportation system for circumferential flows.

## TRANSIT MEANS OF TRANSPORTATION

For workers who commuted using some form of transit for at least one leg of the journey to work, there was an increase of 0.27 mph overall from 1980 to 1990. Although not a large increase in effective speed, it is significant because it is based on over 9,400 mean reported travel times from tract of origin to tract of destination. Most of the significant changes were for radially-oriented trips to CBD.

Table 22 shows that the largest change for transit work trips was for circumferential orientations, 0.34 mph. Reverse flow showed a greater increase, 0.64 mph, but was not as statistically significant. Circumferential transit work trips were slower than radial trips by about 2 mph on average which is not as large a disparity as that shown for drive alone or carpool work trips.

While the mean effective speeds for circumferential transit trips is less than radial trips, the variability is greater. This is indicated by the standard deviation of the speed distributions for 1980 and 1990. Also, the variability in effective speeds increased from 1980 to 1990 for circumferential trips, while variations in radial trip speed decreased. Again, this could indicate a decrease in performance of the circumferential transportation system as compared to the radial system.

Note that the transit means of transportation includes all forms of mass transportation as calculated for this study.

## SUMMARY OF POOLED MEAN SPEED CHANGES

Clearly, the development of large urban areas is predicated on efficient radial transportation systems. The data from the six urban areas used for this study indicate that regardless of the means of transportation chosen for the journey to work, the system will perform at higher speeds for radially-oriented trips compared to circumferential or reverse flow trips.

Also, based on total travel time reported in the census, the effective speeds for drive alone commutes are generally higher than carpool or transit modes. Since the calculated effective speeds in this study are based on reported perceived speeds, transit is regarded as the slowest of all three modes of transportation to work.

Circumferential transportation systems seem to have declined in performance from 1980 to 1990. Although carpool and transit users indicate increased speeds for circumferential trips, those who drive alone show a decrease. In all cases the variation in the distribution of calculated effective speeds for circumferential work trips increased or stabilized from 1980 to 1990, while variation in radial trip speed decreased. This probably indicates that circumferential transportation systems do not perform as consistently as radial systems and are decreasing in their consistency of performance.

Overall, mean effective speeds have increased slightly for carpool trips and transit trips, while drive alone speeds have decreased. None of the changes in speeds are large; all changes are less than 0.50 mph. Perhaps what should be noted is that speeds have not changed substantially from 1980 to 1990, at least as indicated from perceived travel times.

This study shows that, to a large extent, speeds stabilized from 1980 to 1990. This is particularly notable when analyzed in the context of the growth in demand placed on the transportation systems in the six urban areas studied. Overall, daily VMT increased 35.4 percent on arterial and freeway facilities from 1982 to 1990, while lane miles grew by only 18.3 percent. While demand for freeways and arterials grew at twice the rate of supply throughout the 1980s, the performance of the transportation systems as indicated by changes in effective speeds calculated from reported census travel times did not decline substantially.

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