Southwest Region University Transportation Center

Improving Travel Projections for Public Transportation

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16. Abstract

Public transportation use saves energy and reduces emissions by taking people out of single passenger automobiles and putting them into high occupancy, energy efficient transit vehicles. Furthermore, public transit ridership and vehicular trip estimates are the base information required for estimating energy consumption and air pollution. Trip generation models as developed and used within Texas predict the number of trips expected to occur in a typical 24-hour day. The need to estimate peak-period trips has generated innovative techniques for estimating peak-period travel from the 24-hour trip tables. Improved methods of estimating the number of trips that will be generated during the peak period will potentially improve the estimation of ridership on public transportation, as well as related energy and emission forecasts. This project produced a trip generation model for predicting peak-period trips based on the travel surveys conducted in Texas during 1990 and 1991 for Amarillo, Beaumont-Port Arthur, Brownsville, San Antonio, Sherman-Denison, and Tyler.

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IMPROVING TRAVEL PROJECTIONS FOR PUBLIC TRANSPORTATION

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ABSTRACT

Public transportation use saves energy and reduces emissions by taking people out of single passenger automobiles and putting them into high occupancy, energy efficient transit vehicles. Furthermore, public transit ridership and vehicular trip estimates are the base information required for estimating energy consumption and air pollution. Trip generation models as developed and used within Texas predict the number of trips expected to occur in a typical 24-hour day. The need to estimate peak-period trips has generated innovative techniques for estimating peak-period travel from the 24-hour trip tables. Improved methods of estimating the number of trips that will be generated during the peak period will potentially improve the estimation of ridership on public transportation. This information is critical for mode split modeling. Greater accuracy in estimating peak period travel directly will significantly improve ridership projections for public transportation, as well as related energy and emission forecasts. This project produced a trip generation model for predicting peak-period trips based on the travel surveys conducted in Texas during 1990 and 1991 for Amarillo, Beaumont-Port Arthur, Brownsville, San Antonio, Sherman-Denison, and Tyler.

DISCLAIMER

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EXECUTIVE SUMMARY

Public transportation use saves energy and reduces emissions by taking people out of single passenger automobiles and putting them onto high occupancy, energy efficient transit vehicles. Furthermore, public transit ridership and vehicular trip estimates are the base information required for estimating energy consumption and air pollution. Trip generation models as developed and used within Texas predict the number of trips expected to occur in a typical 24-hour day. This approach is consistent with general practice in transportation travel behavior research. The existing literature revealed no previous attempts at estimating peak-period travel using actual trip rates by time of day.

The need to estimate peak-period trips has generated innovative techniques for estimating peak-period travel from the 24-hour trip tables. Improved methods in estimating the number of trips that will be generated during the peak period can potentially improve the estimation of ridership on public transportation. This information is critical for mode split modeling. Greater accuracy in estimating peak-period travel directly from survey data can significantly improve ridership projections for public transportation as well as related energy and emission forecasts.

This study focuses on household surveys conducted in Amarillo, Beaumont-Port Arthur, Brownsville, San Antonio, Sherman-Denison, and Tyler in order to develop a trip generation model for predicting transit trips during peak periods of travel. Various applications of the model developed in this report are discussed. Recommendations are made for a variety of situations, including areas which have no survey data of their own and areas that are planning new transit systems where none currently exist.

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CHAPTER 1
INTRODUCTION

BACKGROUND

Public transportation use saves energy and reduces emissions by taking people out of single passenger automobiles and putting them onto high occupancy, energy efficient transit vehicles. Furthermore, public transit ridership and vehicular trip estimates are the base information required for estimating energy consumption and air pollution. Trip generation models as developed and used within Texas predict the number of trips expected to occur in a typical 24-hour day. This approach is consistent with general practice in transportation travel behavior research. Travel surveys and forecasting models report daily person or household trips but do not disaggregate them into hourly trip rates (1,2,3,4,5). Studies that report temporal distributions of total vehicular or transit travel typically present percentages of total daily travel by time of day that are derived from single 24-hour counts (6,7). The existing literature revealed no previous attempts at estimating peak-period travel using actual trip rates by time of day.

The need to estimate peak-period trips has generated innovative techniques for estimating peak-period travel from the 24-hour trip tables. Improved methods in estimating the number of trips that will be generated during the peak period can potentially improve the estimation of ridership on public transportation. This information is critical for mode split modeling. Greater accuracy in estimating peak-period travel directly from survey data can significantly improve ridership projections for public transportation, as well as related energy and emission forecasts.

Travel surveys are the informational basis by which trip generation models are developed and, in some instances, may be used to study and/or analyze travel patterns within an urban area. In the 1960s and early 1970s, surveyors conducted home interviews in randomly selected homes throughout an urban area. This method provided the most reliable and accurate information; but it required a great deal of time, manpower, and money. These first surveys were designed to gather information on the characteristics of the household and the number, purpose, and mode of travel for each trip made by persons five years and older in the household during a 24-hour period, typically during the middle of the week. The information gathered from the surveys and from secondary sources (e.g., employment) was used to develop trip production models and trip attraction models. These models were used to predict future trip productions and attractions by assuming that trip-making characteristics remain stable over time with any increase/decrease in travel being caused by changes in either households and/or land use activities.

In Texas, the Dallas-Fort Worth and Houston areas were the first to update their regional travel surveys in the mid-1980s. The Dallas-Fort Worth survey was actually several distinct independent surveys. It included a household travel survey, a workplace survey (of both employees and individuals traveling to the workplace for reasons other than work), and a special generator survey. The Houston travel survey was primarily a household travel survey. In 1989, a travel survey was also conducted in Texarkana, Texas. These surveys and the experience gained in their implementation subsequently led to a consistent survey methodology for use in conducting similar travel surveys.

As a result of the surveys conducted in the Dallas-Fort Worth, Houston, and Texarkana areas and the recognition that the basis for the travel demand models was questionable due to the age of much of the data, an effort was successfully initiated by the Texas Department of Transportation (TxDOT) to fund and supervise extensive travel surveys in several urban areas of different sizes throughout the state. The intent was to compile a comprehensive data base on travel where travel demand models used for transportation planning could be updated using the latest techniques and data available. The San Antonio urban area was selected as the first site and subsequent surveys were conducted in Tyler, Amarillo, Brownsville, Sherman-Denison, and Beaumont-Port Arthur.

The travel surveys conducted in San Antonio became the preliminary design tool for the travel surveys that would follow. Using the information and knowledge gained in previous surveys, the San Antonio travel survey was structured to consist of the following five distinct travel surveys:

1. Household survey
2. Workplace survey
3. Special generator survey
4. External travel survey
5. Truck travel survey

This study will focus on household surveys conducted in Amarillo, Beaumont-Port Arthur, Brownsville, San Antonio, Sherman-Denison, and Tyler in order to develop a trip generation model for predicting transit trips during peak periods of travel.

CHAPTER 2
DATA COMPILATION

DESCRIPTION

The data for this study were obtained from travel surveys conducted in Texas during 1990 and 1991 for Amarillo, Beaumont-Port Arthur, Brownsville, San Antonio, Sherman-Denison, and Tyler. The household survey data file was split to produce two data files per city: a household file and a transit file. The household data files contained eight variables, five of which were used for the model, while only three of the 18 variables in the transit files were used. These variables are shown below in Table 1 with their program names in parenthesis. Although a trip purpose variable was recorded in the transit file, the overwhelming majority of trips were work trips. As a result, all trips were treated as work trips and trip purpose was not included as a variable in the model. All trips in this survey represent linked, origin-destination trips rather than individual trips.

Table 1
List of Variables Used in Trip Rate Model

Household File	**Transit File**
Sample Number (SAMNUM)	Sample Number (SAMNUM)
Household Size (HHSIZE)	Start Hour of Trip (STARTHR)
Number of People Employed (EMPLOYED)	End Hour of Trip (ENDHR)
Number of Vehicles Available (VEHICLES)	
Household Income (HHINCOME)	

The household file and the transit files were merged for each city to create three separate files: 1) a transit file for transit households, 2) a non-transit file for non-transit households only, and 3) a combined file for all households. During this stage, a city-code variable (CITY) was created to avoid losing households when merging duplicate sample numbers from different cities into one observation. Finally, the data for all six cities were merged for each of these three files to create an aggregate transit file, an aggregate non-transit file, and an aggregate combined file. The transit file consists of those households that recorded a transit trip on the survey; these households are referred to as "transit households" in this report. The combined file consists of all survey respondents regardless of transit use; these households are referred to as "all households".

ADJUSTMENTS

The first step involved running a frequency procedure on the original household and transit files for each city in order to identify missing and/or erroneous data points. The following adjustments were made to the data sets before proceeding with trip rate development:

- The San Antonio household file had one missing observation. This observation did not represent a transit household and was dropped from the sample.

- The Sherman-Denison combined file had seven observations that had no household survey data. Dropping these data points translated into a loss of two transit households representing a total of seven transit trips.

- The Tyler combined file had six missing observations because some sample numbers in the transit file had no counterpart in the household file. This resulted in the loss of three transit households representing a total of six transit trips.

- Each city's household file had a number of "no response" answers for the income category question. These observations were dropped, accounting for the loss of 1,164 households (7.7 percent of 15,179 households) and 68 transit trips (4.3 percent of 1,579 trips).

The final combined data file consisted of 14,014 total observations. Of these, 12,503 observations were in the non-transit file and 1,511 were in the transit file. The transit data set had multiple observations for some households. Consolidating these into unduplicated observations yielded a count of the actual number of households represented by those transit trips.

The combined file had 13,097 unique observations, and the transit file had 594 unique observations. Table 2 provides an overview of the sample size and population for each city surveyed.

Table 2
Population and Sample Size by City

City	MSA Population (1990 Census)	Transit Service Area Population	Total Households Surveyed	No. of Transit Households	No. of Transit Trips
Amarillo	187,547	95,869	2,554	52	108
Beaumont-Port Arthur	361,226	139,455	2,518	35	100
Brownsville	260,120	117,676	1,367	108	283
San Antonio	1,302,099	1,161,171	2,452	299	808
Sherman-Denison	95,021	72,850	2,284	88	185
Tyler	151,309	75,000	1,922	12	27
Total	**2,357,322**	**1,662,021**	**13,097**	**594**	**1,511**

HOUSEHOLDS CHARACTERISTICS

The frequency procedure also provided a profile of the characteristics of transit versus non-transit households. While much has been written about the differences between these groups in the transportation literature, it is appropriate to provide a description of the group of respondents that comprises the data sets used in this particular study. Table 3 provides a summary of the mean values for household size, number of people employed, vehicles available, and income category for the households contained in these data sets.

Table 3:
Mean Values for Household Characteristics

	Non-Transit Households	Transit Households
Household Size	2.65	3.50
Number Employed	1.19	1.14
Vehicles Available	1.79	0.78
Income Category	5.70	3.28

The most obvious difference between these two groups is the household income category. The mean value for transit households represents an income range of $10,000 - $14,999, while the average annual income range for non-transit households is near the upper bounds of the $20,000 - $24,999 range. The second most notable difference is household size. Transit households have an average of 3.5, and non-transit households have an average of 2.65 individuals per residence. Vehicle availability is also noticeably different between these groups. Non-transit consumers have an average of one more vehicle available per household than transit consumers.

This difference in car availability, combined with a similarity in employment characteristics, demonstrates the primary motivation for transit consumption among households in this data set. That is, the non-transit group is expected to also have more vehicles available per worker than the transit group. The difference in vehicles per worker is less pronounced than the vehicle availability per household, however. The non-transit group has an average of 1.28 vehicles per employed individual, whereas the transit households have 0.89 vehicles available per worker.

Table 4 provides a comparison of vehicle availability and employment characteristics between these groups. The frequency distributions were disaggregated by number of vehicles and number of workers for the two groups. The table indicates that the most obvious difference between these groups lies in the incidence of zero-vehicle households. While it is surprising that 6.7 percent of the non-transit households have no vehicle availability, this remains a small proportion compared to 50.2 percent of the transit households.

Table 4
Frequency of
Automobile Ownership and Employment

No. of Vehicles	% of Transit HHs	% of Non-Transit HHs	No. of Employed	% of Transit HHs	% of Non-Transit HHs
0	50.2	6.7	0	30.1	25.5
1	30.1	34.7	1	35.4	37.4
2	13.2	38.7	2	26.9	31.0
3	4.7	15.1	3	5.8	5.0
4	1.7	3.7	4	1.4	1.0

While the employment percentages are comparable between these groups, the vehicle distribution is similar only among one-vehicle households. In addition to the abundance of zero-vehicle households among transit users, the relative scarcity of two- and three-vehicle households among this group contributes further to the distinguishing features of transit consumers.

CHAPTER 3
MODEL DEVELOPMENT

The Statistical Analysis Software (SAS) package was used to develop the trip generation model for this project. The SAS code was designed to generate hourly and total transit trip rates per household by income category. Trial runs were performed on the Tyler data set because its modest size afforded the ability to hand-check the SAS code. Once the code performed to satisfaction, the hourly and daily trip rates were determined for the other cities.

After checking all the data sets the total, transit, and non-transit data files for each city were sorted by sample number. The individual city files were then merged by sample number and city-code to create the three (total, transit, non-transit) aggregate files mentioned previously. The city-code variable was created at this stage to prevent the loss of observations during the merge procedure. The final objective in writing the SAS code was to obtain the number of trips per household per hour for each income category. The procedures described below were performed for the combined data set as well as the transit data set.

EXPANSION FACTORS

The survey sampling methodology did not select households based on mode. That is, the sample is unbiased regarding transit use. In order to capture a reasonable proportion of transit users, however, the sample specifically targeted low income households. This requires that expansion factors be used when interpreting the survey data in order to reflect the true social and economic characteristics of each city surveyed. Expansion factors are classified by income category and household size and represent the number of households of a specific size and income category expected to be found in each particular city. For example, the expansion factor for households of size one and an annual income between $0 and $4,999 for the city of Amarillo is 40.4. This means that each household in the survey that falls into that category "counts" as 40.4 households in Amarillo.

Expansion factors were used for households as well as trips. Two new variables, designated as "trips" and "households", were created to incorporate the expansion factors into the household counts and trip counts. That is, each sample number has two additional variables: one for expanded trips and one for expanded households.

TRIP COUNTS

The first objective of the trip counts was to obtain a value for the number of (expanded) trips for each household. The data were sorted by sample number, city code, household income, and starting hour of the trip. Each sample number corresponds to a household, and each trip made by someone in that household counts as a separate observation. Thus, the data set contained more than one observation per sample number for some of the households. The means procedure in SAS has a feature which provides a count of the number of times a chosen variable appears. In this case, that variable was trips. Because each sample number is associated with a certain number of (expanded) trips, the means procedure produced a data set containing the number of (expanded) trips for each sample number, i.e. household. The resulting data set (called "NewSet") will be used to count the total expanded trips for all households in order to obtain a daily trip rate for survey respondents.

A second objective of this preliminary step was to find the number of trips per hour for each income category. The step involved obtaining the number of expanded trips per hour for each income category. The variable start-hour, which is recorded in real time on the surveys, was converted to equal the expanded trips for each sample number. That is, for each trip recorded in a certain hour, the program assigns a value equal to the expanded trips for that hour. For example, if the logged trip began in the 6 a.m. hour, SAS assigned a value equal to that household's expanded trips to a new variable called "Hr06". Reassigning the trip starting hour in this manner resulted in multiple observations of each of the new variables "Hr01" through "Hr24".

This time, the sum feature of the SAS means procedure was used by income category. Running the means procedure on multiple variables ("Hr01" through "Hr24") produced an output data set containing the sum of all the values of each variable "Hr01" through "Hr24" for each income category. In other words, the output data set provided the number of trips taken in each of those 24 hours for each income category. (This data set is called "Trips" in the SAS code.)

HOUSEHOLD COUNTS

One objective of the household count is to find the total number of expanded households in each income category. The first step is to obtain a single expanded household value for each sample number. This involved condensing the original data set with multiple observations per household to a data set with one observation per household with a corresponding expanded household value. The SAS means procedure was used on the variable household by sample number and city code. Because multiple observations of any given sample number have the same value for the expanded household variable, the "average" value is identical to the original income entry. The resulting data set (called "NewSet1") contains the expanded household value for each sample number, i.e., surveyed household. This data set will be used to count the total expanded households in order to calculate a daily trip rate for survey respondents.

A second objective of the household count is to find the total number of expanded households in each income category. The first step involved obtaining an income number for each sample number. That is, the original data set was consolidated to obtain one observation per household with a corresponding income number. The SAS means procedure was used on the variable household income by sample number and city code. Since multiple observations of any given sample number have the same value for household income, the "average" income per household is identical to the original income entry. Averaging household income in this fashion results in one income number per sample number, i.e., per household. (This data set is called "NewSet2" in the SAS code.)

To obtain the number of households per income category "NewSet", "NewSet1", and "NewSet2" were sorted by household income and merged to form the data set "Total1". The means procedure was performed on the expanded household variable, by household income. Once again, the sum feature of the means statement was used to provide the total number of expanded households in each of the ten income categories. This resulted in a data set ("NewSet4") containing the number of expanded households per income category.

TRIP RATES

The "Trips" data and the "NewSet4" data were merged to obtain a new data set containing income category, a corresponding number of expanded trips for each hour, and a corresponding number of expanded households. Dividing the number of trips per hour (TRIP01 through TRIP24) by the number of households created a new variable for each hour (RATE01 through RATE24). This procedure yielded hourly trips per household for each income category (see Table 8). The program also produced a total trip rate column which featured the customary daily trips per household for each income category (see Table 9). Finally, the "Total1" data set was sorted by sample number and city. The results of two ensuing means procedures provided the total number of expanded households and trips for the entire sample. The ratio of expanded trips to expanded households yields an overall daily trip rate for all survey respondents (see Table 7).

CHAPTER 4
RESULTS

EXPANDED TOTAL TRANSIT TRIPS

Expansion factors based on household income and household size must be applied to each household and trip in order to obtain a data set that represents the social and economic characteristics of each city surveyed. The total number of expanded trips obtained from survey respondents are compared with the Section 15 reported trips submitted by each city's transit authority in Table 5. While Sherman-Denison and Tyler are obvious exceptions to this statement, trips in other cities are a close match, and total expanded survey trips correspond to 84 percent of Section 15 reported trips. Discrepancies in some cities may be explained by the fact that Section 15 data report unlinked trips, while the survey data contain linked trips. This applies to Brownsville and San Antonio. San Antonio in particular is known to have about 20 percent transfers. Smaller systems have fewer routes, smaller service areas, and consequently fewer opportunities for transfer. The discrepancies in Amarillo and Beaumont-Port Arthur are within the range of measurement error. The differences in Sherman-Denison and Tyler is too large to be attributable to transfers or sampling error. Conversations with the local transit agencies did not resolve these differences. One explanation may be sampling error, in that critical cells (low income, large household size) were overrepresented for Sherman-Denison and Tyler, causing the expanded totals to be too high. (The expansion factors for those two cities did have a wider range than did the larger cities.) Another explanation may be errors in the Section 15 data. Sherman-Denison and Tyler are both relatively new systems and their Section 15 data collection may not be fully perfected.

Table 5
Survey Trips vs. Reported Trips

City	Expanded Survey Trips	Section 15 Reported Trips[1]
Amarillo	3,503	2,862
Beaumont-Port Arthur	6,604	6,503
Brownsville	4,791	5,785
San Antonio	126,370	158,329
Sherman-Denison	2,913	436 [2]
Tyler	1,008	396
Total	**145,189**	**174,311**

[1] 1992 average weekday unlinked trips.
[2] Does not include Sherman-Denison taxi trips.

The tables that follow provide daily and hourly household transit trip rates for the survey respondents in Amarillo, Beaumont-Port Arthur, Brownsville, San Antonio, Sherman-Denison, and Tyler.

Table 6 provides a breakdown of the daily transit trip percentages. The morning and afternoon peak hours (i.e., 7 a.m. and 3 p.m.) account for close to the same proportion of total daily transit trips. The afternoon peak occurs noticeably earlier than the traditional 5 p.m. peak and is attributed to the influence of school trips.

Table 6
Percent of Total Daily Transit Trips
Per Hour*

5	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1.3	5.4	14.8	7.4	5.3	4.7	5.7	4.6
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**
7.4	6.8	14.4	8.3	5.3	3.9	1.0	1.0

*Hours not shown account for 1 percent or less of daily transit trips.

HOURLY TRANSIT TRIP RATES

Table 7 includes a total daily rate for transit trips among surveyed households. The hourly trip rate numbers indicate a clear bimodal distribution with distinct peaks occurring at 7 a.m. and 3 p.m. The hourly trip rate patterns are consistent with previous findings in the transportation research. The temporal pattern of these transit rates is also generally similar to that of vehicle trip rates. (6,7,8).

Table 7
Hourly Transit Trip Rates for All Households
[Daily Rate: .188]

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
0*	0*	0	0	.003	.01	.028	.014	.01	.009	.011	.009
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
.014	.013	.027	.016	.01	.007	.002	.002	.002	.002	0*	.001

*These rates represent less than 1/1,000 of a transit trips.

According to Table 7, each household is responsible for creating 28/1000 of a transit trip during the 7 a.m. hour. This is the customary, yet somewhat awkward, way of interpreting a trip rate table. A slight perspective adjustment makes these trip rate numbers workable and straightforward estimating tools.

Reinterpreting the numbers in the 7 a.m. hour, it can be said that if each household generates 0.28 transit trips, then 36 households will generate one transit trip, since 36x0.028=1. Carrying this example further shows how these numbers can be interpreted as actual percentages. In a city with a total population of 50,000, it takes 36 individuals of that total population to create one transit trip. That is, 50,000/36=1,389 will yield the total number of trips that will be demanded in this city during the 7 a.m. hour. If each of those 1,389 trips is regarded as an individual then person units and trip units become interchangeable. Thus, 1,389/50,000 yields 0.028 or 2.8 percent. This result provides us with a specific percentage (2.8 percent in this case) of the total population that can be expected to take a transit trip at a given time.

Interpreting trip rates as percentages provides a fairly solid and straightforward estimation tool for public transportation providers and travel demand modelers. Ridership estimation based on this type of 24-hour trip rate breakdown can increase the ability of transit agencies to provide service that is more responsive to public demand. For example, knowing the number of households in a given area, one would expect that close to 3 percent of those households would undertake a transit trip during the 7 a.m. hour and 2.7 percent would use transit in the 3 p.m. hour.

Table 8
Hourly Transit Trip Rates for All Households (a.m.)
by Income Category

Household Income Category[1]	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	.004	.022	.044	.043	.032	.023	.03	.019
2	0	0*	0	0	.006	.012	.037	.011	.009	.015	.013	.011
3	0	0	0	0	.001	.011	.034	.010	.006	0*	.006	.01
4	0*	0	0	0	0	.007	.012	.005	.002	.006	.004	.004
5	0	0	0	0	.002	0	.014	.001	0	0	0	.003
6	0	0	0	0	0	0*	.012	.004	.003	.002	.004	0*
Total	0*	0*	0	0	.003	.01	.028	.014	.01	.009	.011	.009

Hourly Transit Trip Rates for All Households (p.m.)

Household Income Category[1]	13	14	15	16	17	18	19	20	21	22	23	24
1	.04	.037	.05	.033	.02	.016	.004	.007	.004	.003	0	0*
2	.02	.016	.04	.015	.014	.015	.001	.001	.003	.002	0	.004
3	.012	.007	.022	.021	.011	.003	.005	0	.004	0	.001	0
4	.003	.003	.018	.007	.004	0	0*	.002	0	.002	0	0
5	0	.003	.012	.01	.001	.002	0	0	0	0	.001	0
6	.002	.001	.014	.002	.002	.002	0	0*	0	.002	0	0
Total	.014	.013	.027	.016	.01	.007	.002	.002	.002	.002	0*	.001

* These rates represent less than 1/1,000 of a transit trip.
[1] Income categories are: 1=$0-9,999; 2=$10,000-19,999; 3=$20,000-29,999; 4=$30,000-39,000; 5=$40,000-49,999; 6=$50,000 up.

DAILY TRANSIT TRIP RATES

Daily trip rates were also generated for each income category. The results, shown in Table 9, allow an analysis of the relationship between transit consumption and income among the households surveyed for this study.

Transit trip rates are a direct measure of transit consumption. If trip rates increase as income goes up, transit would be classified as a "normal" good. If these rates decrease with increasing income, transit is considered an "inferior" good. The trip rate patterns shown in Table 9 indicate that the surveyed households display a transit consumption pattern that is consistent with the general consensus classifying transit as an inferior good.

Table 9
Daily Transit Trip Rates per Household by Income Category

Household Income Category	Surveyed Households
1 ($0-4,999)	0.51
2 ($5,000-9,999)	0.36
3 ($10,000-14,999)	0.29
4 ($15,000-19,999)	0.18
5 ($20,000-24,999)	0.18
6 ($25,000-29,999)	0.13
7 ($30,000-34,999)	0.08
8 ($35,000-39,999)	0.08
9 ($40,000-49,999)	0.04
10 ($50,000 up)	0.05
All Categories	**0.19**

CHAPTER 5
APPLICATIONS OF THE MODEL

The procedure developed here to obtain hourly transit trip rates can be used by travel demand modelers in a number of ways. The first option is to simply use the transit trip rates presented in Tables 7 and 8. A second possibility is to use survey data from areas that have similar land-use characteristics and apply the methodology that is outlined here. It is also possible for modelers to administer their own survey and develop trip rate forecasts using the model and procedures presented in this report.

These hourly trip rates are also useful in determining the fluctuation in transit demand during a 24-hour period. The model results indicate that many more households are needed to generate one trip (or fewer trips are generated by any given number of households) during hours that are further removed from the morning and afternoon peaks.

USING TRANSIT TRIP RATES DIRECTLY

The transit trip rates developed in this report can be used in the aggregate through Table 7 or according to income category as shown in Table 8. This model provides the choice of applying the transit trip rates to an area's total population or to its population in a specific income category.

For example, to forecast the total number of weekday transit trips demanded during the peak hours for a city of 50,000 households, the following procedures would apply. According to Table 7, each household will demand .028 trips during the 7 a.m. hour. This means that every 36 households will demand one transit trip, or one transit trip will be generated for every 36 households in the city. In a city of 50,000 there are 1,389 "sets" of 36 households (50,000/36=1,389). This suggests that 1,389 transit trips will be demanded in that city during the 7 a.m. hour. The afternoon peak-hour demand for transit trips is determined in a similar fashion. A trip rate of .027 indicates that 37 households will generate one transit trip during the 3 p.m. hour. Therefore, 1,351 transit trips are expected to be demanded during that time.

Breaking down the transit demand estimates by income groups adds more detail to the forecasting process. Table 8 provides hourly transit trip rates for six different income groups. This level of disaggregation can be useful when estimating transit demand on a census tract level, for example. If the average household income is known for a given census tract, the modeler can apply the trip rates corresponding to that income category from Table 8. For example, in the city of 50,000 households, planners could estimate peak-period transit demand in a 4,000 household census tract with an average household income between $10,000 and $19,999. According to the numbers in Table 8, each household in that category demands .037 trips at 7 a.m. and .04 trips at 3 p.m. That is, one transit trip is demanded for every 27 households in the morning peak hour, and one transit trip is demanded for every 25 households in the afternoon peak hour.. This translates into 148 transit trips demanded at 7 a.m. and 160 trips demanded at 3 p.m in that particular census tract.

Although this is the least expensive and time-consuming method of producing transit trip forecasts, it is also the least reliable. The demographic and land-use characteristics that generated the trip rates produced by this model represent a combination of cities. Therefore, the more reliable application will be with cities that are within the range of those surveyed in terms of key demographic variables. One particularly appropriate application of the model presented in this report is to use its methodology with survey data that reflect the demographic and land-use characteristics of the city or area being studied. This model can also be applied in areas where no data other than census data are available, and can be extremely useful for planning transit systems in areas where none currently exist.

USING THE MODEL METHODOLOGY

Applying the model methodology to new survey data is much more time consuming but will produce more reliable transit demand forecasts than the previous option. This alternative would involve applying the model developed in this report to the survey data in order to obtain the transit trip rates. These rates could then be applied in the same manner as described above, depending on how the modeler chooses to define the population used for the actual demand forecasts.

These alternatives are obviously the most expensive and time consuming, especially for smaller communities or areas with limited financial or personnel resources. Modelers with restricted resources must decide whether the element of inaccuracy introduced by the use of "imported" surveys is acceptable in light of the ensuing time and money savings. It is beyond the scope of this project to explore the relative reliability of forecasts produced by these alternative methodologies. Previous research offers conflicting viewpoints regarding the transferability of trip rates. Some assert that areas should be regarded as being unique and individual, while others believe that trip rates are transferable because their primary determinants are demographic rather than geographic (9,4). Studies have shown that areawide vehicle trip frequency rates are, in fact, transferable between urban areas with similar socioeconomic household distributions (1,5).

REFERENCES

1. Mahmassani, Hani S., Oreste M. Bevilacqua and Kumares C. Sinha. 1979. Framework for Transferring Travel Characteristics of Small Urban Areas. *Transportation Research Record* 730:29-34.

2. Ou, Fong-Lieh and Jason C. Yu. 1982. Effect of Urban Character on Transferability of Travel Demand Models. *Transportation Research Record* 874:5-12.

3. Strombom, Cathy J. and G. Scott Rutherford. 1984. Socio-Economic and Travel Forecasts for Alternative Analysis in the Puget Sound Region. *Transportation Research Board, Proceedings of the 63rd Annual Meeting.*

4. Kollo, Hanna P.H. and Charles L Purvis. 1984. Changes in Regional Travel Characteristics in the San Francisco Bay Area: 1960-1981. *Transportation Research Record* 987:57-66.

5. Goode, Larry R. and Clinton L. Heimbach. 1983. Evaluation of theTranserfability of Trip Generation Models from One Urban Area to Another. *Transportation Research Record* 931:120-125.

6. Tittemore, Lawrence C., et al. 1972. *An Analysis of Urban Area Travel by Time of Day.* Peat, Marwick, Mitchell & Co.

7. Kostyniuk, Lidia P. and Ryuichi Kitamura. 1984. Trip Chains and Activity Sequences: Test of Temporal Stability. *Transportation Research Board, Proceedings of the 63rd Annual Meeting.*

8. Rothenberg, Morris J. 1992. Urban Travel Characteristics. *Transportation Planning Handbook.* Institute of Transportation Engineers.

9. Brunso, Joanna M. and David T. Hartgen. 1984. An Update on Household-Reported Trip-Generation Rates. *Transportation Research Record* 987:67-74.

APPENDIX A
TRANSIT AS BOTH A NORMAL AND INFERIOR GOOD

Based on the discussion of transit as an inferior good, the analysis was expanded in an to attempt to identify the classification of transit as a normal or inferior good among those households that consume transit. While it is widely accepted that transit use decreases with increasing income among the population at large, this does not necessarily extend to the subgroup of the population that consumes transit on a regular basis.

In fact, trip rates among transit households would actually be expected to increase as income goes up. The reasoning behind this hypothesis is that transit users are not making the choice between transit or non-transit travel. They are in the group of transit users because they habitually consume public transportation. Thus, given that they already use transit, they can be expected to increase their consumption of transit as their income goes up (i.e., transit is a normal good for them). The sections below contain tables that compare the transit trip rate patterns for transit households with those of general households presented in the main body of this report.

DAILY HOUSEHOLD TRANSIT RATES

Table A-1 recreates the transit trip rates for surveyed households (referred to here as "all" households) which were originally presented in Table 9. It also shows the transit trip rates observed among households classified as "transit" households. This group of transit households constitutes a subset of the survey data used for this project. As long as a sample number recorded a transit trip, that household was considered a transit household. The transit trip rates for these households were generated in the same fashion as those for all surveyed households.

Table A-1 indicates that transit households display no particular trip rate pattern. It is impossible to conclude anything about the classification of transit as a good for those households based on these numbers. Trip rates for transit households fluctuate around 2.0 for all income categories.

Table A-1
Daily Transit Trip Rates per Household
by Income Category

Household Income Category	Transit Households	All Households
1 ($0-4,999)	3.03	0.51
2 ($5,000-9,999)	2.77	0.36
3 ($10,000-14,999)	2.67	0.29
4 ($15,000-19,999)	2.60	0.18
5 ($20,000-24,999)	2.72	0.18
6 ($25,000-29,999)	2.32	0.13
7 ($30,000-34,999)	1.84	0.08
8 ($35,000-39,999)	1.73	0.08
9 ($40,000-49,999)	1.93	0.04
10 ($50,000 up)	2.43	0.05
All Categories	**2.62**	**0.19**

REDEFINING INCOME CATEGORIES

Based on the analysis of the transit trip rates per income category, how the economic classification of transit as an inferior good or a normal good depends on the group of people being studied was explored further. Survey income categories were redefined in order to obtain a clearer picture of the relationship between income and transit use. The modifications involved calculating per capita income categories and collapsing both the household income category and the per capita income category to reflect $10,000 intervals.

Income per Capita

The income categories were disaggregated to a per capita level to explore further the potential classification of transit as a normal good among transit households. The fact that these households have failed to display any consumption trend consistent with that of a normal good may be because the household may not be the appropriate unit of analysis. The surveyed households have such a variety of characteristics that they may not be appropriate to serve as a homogeneous set of economic agents in this case. Disaggregating income and trip rates to a per capita level may be the best way to analyze the relationship between consumption and income for transit households.

The per capita income figures were obtained in a somewhat unrefined manner. Each income category was redefined to reflect a dollar amount rather than an income range. The midpoint of each income category (e.g., $2,500 for Category 1; $7,500 for Category 2) was assigned as the annual income of the household. Thus, the mid-points for Categories 1 through 8 increased by a $5,000 increment, while Category 9 had a $45,000 midpoint and Category 10 had a $55,000 midpoint.

Once the income categories were redefined for each household, the per capita income was calculated by dividing the assigned income figure by the number of people in each given household . The resulting per capita income numbers were then again reassigned into income Categories 1 through 9. Thus, any household with per capita income between $0 and $4,999 was assigned to per capita income Category 1, and so on.

Table A-2 shows the per capita trip rates for both transit consumers and consumers at large. While both types of consumers show trip rates that fluctuate among the income categories, distinct consumption trends are beginning to emerge between these two groups. Consumers in general continue to display trip rate patterns that are, overall, consistent with the consumption of an inferior good. Transit consumers, on the other hand exhibit a trip rate pattern that suggests increasing consumption as personal income goes up. This pattern is consistent with that of a normal good. The downward fluctuations observed at income Categories 2 and 4 are of little concern because they are followed by upswings that bring transit trip rates to an increasingly higher level.

Table A-2 Daily per Capita Transit Trip Rates by Income Category		
Per Capita Income Category	**Transit Consumers**	**All Consumers**
1 ($0-4,999)	0.78	0.14
2 ($5,000-9,999)	0.72	0.05
3 ($10,000-14,999)	0.92	0.04
4 ($15,000-19,999)	0.76	0.02
5 ($20,000-24,999)	1.73	0.03
6 ($25,000-29,999)	1.81	0.02
7 ($30,000-34,999)	--	0
8 ($35,000-39,999)	--	0
9 ($40,000-49,999)	--	0
10 ($50,000 up)	--	0
All Categories	**0.79**	**0.07**

Collapsed Income Categories

The motivation for collapsing income categories was twofold. The first was to establish more consistency between the lower income categories (1-8) and the higher income categories (9 and 10). The original survey categories increase by $5,000 increments up to Category 9 or the $40,000 household income level. Category 9 has a $10,000 increment while Category 10 is open ended and defined by incomes of $50,000 or more. The second was to determine whether the slight fluctuations in the trip rate pattern could be corrected. This was of interest especially in the transit household category for household as well as per capita transit trip rates.

Table A-3 shows that the pattern for all households remains consistent with the consumption pattern of an inferior good. The trip rate patterns for transit households continues to fluctuate around 2.0.

Table A-3
Daily Household Transit Trip Rates
by Collapsed Income Category

Household Income Category	Transit Households	All Households
1 ($0-9,999)	2.91	0.43
2 ($10,000-19,999)	2.64	0.24
3 ($20,000-29,999)	2.56	0.16
4 ($30,000-39,999)	1.79	0.08
5 ($40,000-49,999)	1.93	0.04
6 ($50,000-up)	2.43	0.05
All Categories	**2.62**	**0.19**

Table A-4 exhibits a clear tendency among all individuals to consume less transit as per capita income increases. The rates among transit consumers, however, suggest that this subgroup of individuals may be expected to increase their consumption of transit as their income goes up. In other words, transit is a normal good for those individuals that consume transit on a regular basis.

This is an interesting result because it challenges the commonly held assumption that individuals consume transit until a certain threshold income is reached. The premise is that, once this occurs, the individual would cease to consume transit and purchase an automobile. At this point, the consumer can no longer be classified as a transit user and becomes part of the general population, referred to here as "all" consumers.

Table A-4
Daily per Capita Transit Trip Rates
by Collapsed Income Category

Per Capita Income Category	Transit Consumers	All Consumers
1 ($0-9,999)	0.77	0.09
2 ($10,000-19,999)	0.88	0.03
3 ($20,000-29,999)	1.76	0.03
4 ($30,000-39,999)	--	0
5 ($40,000-49,999)	--	0
6 ($50,000-up)	--	0
All Categories	**0.79**	**0.07**

APPENDIX B

SAS CODE FOR THE TRANSIT TRIP DEMAND MODEL

```
options LineSize=105 Pagesize=75;
* New => hourly & total trip rates for surveyed HHs *;
* Transit Trip and Household Data *;

Data Total;
  Infile 'c:\totalhh.tot';
   INPUT samnum hhsize employed vehicles
   hhincome starthr endhr city trips hholds;
If HHincome=99 then delete;
If Starthr=. then Trips=.;

Proc means data=total maxdec=1 n noprint;
 var trips;
 by samnum city;
 output out=newset
 sum=trip;
*proc print;
 *var samnum trip;

Proc means data=total maxdec=1 n noprint;
 var hholds;
 by samnum city;
 output out=newset1
 mean=hhold;
*proc print;
 *var samnum hhold;

Proc Means Data = Total MaxDec=1 N NoPrint;
 Var HHincome;
 By SamNum city;
 Output OUT=NewSet2
 Mean = HHincome;
```

```
*proc Print;
 *var Samnum HHincome;

Data Total1;
 Merge NewSet NewSet1 NewSet2;
 By SamNum City;

Proc Sort Data=Total1; By HHincome;
Proc Means Data=Total1 N NoPrint;
 Var Hhold;
 By HHincome;
 Output OUT=NewSet4
 Sum = hhinc;
Proc Print;

Data Total2; Set Total;
If StartHr=1  then Hr01=Trips;
If StartHr=2  then Hr02=Trips;
If StartHr=3  then Hr03=Trips;
If StartHr=4  then Hr04=Trips;
If StartHr=5  then Hr05=Trips;
If StartHr=6  then Hr06=Trips;
If StartHr=7  then Hr07=Trips;
If StartHr=8  then Hr08=Trips;
If StartHr=9  then Hr09=Trips;
If StartHr=10 then Hr10=Trips;
If StartHr=11 then Hr11=Trips;
If StartHr=12 then Hr12=Trips;
If StartHr=13 then Hr13=Trips;
If StartHr=14 then Hr14=Trips;
If StartHr=15 then Hr15=Trips;
If StartHr=16 then Hr16=Trips;
If StartHr=17 then Hr17=Trips;
If StartHr=18 then Hr18=Trips;
If StartHr=19 then Hr19=Trips;
If StartHr=20 then Hr20=Trips;
If StartHr=21 then Hr21=Trips;
```

```
If StartHr=22 then Hr22=Trips;
If StartHr=23 then Hr23=Trips;
If StartHr=0  then Hr24=Trips;

*proc Print;
 *var SamNum Hr01 -- Hr24;

Proc Sort Data=Total2;
 By HHincome;

Proc Means N NoPrint;
 Var Hr01 -- Hr24;
 By HHincome;
 Output OUT=Trips
 Sum = Trip01 Trip02 Trip03 Trip04 Trip05 Trip06 Trip07 Trip08 Trip09 Trip10 Trip11 Trip12
       Trip13 Trip14 Trip15 Trip16 Trip17 Trip18 Trip19 Trip20 Trip21 Trip22 Trip23 Trip24;

Proc Print;
 Var HHincome Trip01 -- Trip24 ;
Data Temp; Set Trips;
  SumTrip= Sum (Trip01, Trip02, Trip03, Trip04,Trip05,Trip06,
Trip07,Trip08,Trip09,Trip10,Trip11,Trip12,Trip13,Trip14,Trip 15,
Trip16,Trip17,Trip18,Trip19,Trip20,Trip21,Trip22,Trip23, Trip24);

Proc Print; Var HHincome Sumtrip;

Data All; Merge Trips NewSet4;
 By HHincome;

 Rate01=trip01/hhinc;
 Rate02=trip02/hhinc;
 Rate03=trip03/hhinc;
 Rate04=trip04/hhinc;
 Rate05=trip05/hhinc;
 Rate06=trip06/hhinc;
 Rate07=trip07/hhinc;
 Rate08=trip08/hhinc;
```

```
Rate09=trip09/hhinc;
Rate10=trip10/hhinc;
Rate11=trip11/hhinc;
Rate12=trip12/hhinc;
Rate13=trip13/hhinc;
Rate14=trip14/hhinc;
Rate15=trip15/hhinc;
Rate16=trip16/hhinc;
Rate17=trip17/hhinc;
Rate18=trip18/hhinc;
Rate19=trip19/hhinc;
Rate20=trip20/hhinc;
Rate21=trip21/hhinc;
Rate22=trip22/hhinc;
Rate23=trip23/hhinc;
Rate24=trip24/hhinc;
SumTrip =Sum (Trip01,Trip02,Trip03,Trip04,Trip05,Trip06,
               Trip07,Trip08,Trip09,Trip10,Trip11,Trip12,
               Trip13,Trip14,Trip15,Trip16,Trip17,Trip18,
               Trip19,Trip20,Trip21,Trip22,Trip23,Trip24);
TotRate=(Sumtrip/HHinc);

Proc Print;
 Var HHincome Rate01 -- Rate24 TotRate;

Data Two; Set Total1;
 Proc sort data=two; By Samnum City;
 Proc means maxdec=1 n noprint;
 Var Trip;
 Output out=totrip
 Sum=alltrips;
Proc Print; Var alltrips;

Data Three; Set Total1;
 Proc sort data=three; By Samnum City;
 Proc means maxdec=1 n noprint;
 Var Hhold;
```

```
 Output out=tothh
 Sum=allhhs;
Proc Print; Var allhhs;

Data Four;
 Merge Totrip Tothh;
 Allrate=(alltrips/allhhs);
Proc Print; Var allrate;

Data Total3; Set Total2;
 Proc Means n noprint;
 Var Hr01 -- Hr24;
 Output out=trips
 Sum = Trip01 Trip02 Trip03 Trip04 Trip05 Trip06
       Trip07 Trip08 Trip09 Trip10 Trip11 Trip12
       Trip13 Trip14 Trip15 Trip16 Trip17 Trip18
       Trip19 Trip20 Trip21 Trip22 Trip23 Trip24;
Proc Print;
 Var Trip01 -- Trip24;

Data Five;
  Merge Trips Tothh;
 Rate01=trip01/allhhs;
 Rate02=trip02/allhhs;
 Rate03=trip03/allhhs;
 Rate04=trip04/allhhs;
 Rate05=trip05/allhhs;
 Rate06=trip06/allhhs;
 Rate07=trip07/allhhs;
 Rate08=trip08/allhhs;
 Rate09=trip09/allhhs;
 Rate10=trip10/allhhs;
 Rate11=trip11/allhhs;
 Rate12=trip12/allhhs;
 Rate13=trip13/allhhs;
 Rate14=trip14/allhhs;
 Rate15=trip15/allhhs;
```

```
Rate16=trip16/allhhs;
Rate17=trip17/allhhs;
Rate18=trip18/allhhs;
Rate19=trip19/allhhs;
Rate20=trip20/allhhs;
Rate21=trip21/allhhs;
Rate22=trip22/allhhs;
Rate23=trip23/allhhs;
Rate24=trip24/allhhs;
SumTrip= Sum (Trip01,Trip02,Trip03,Trip04,Trip05,Trip06,
              Trip07,Trip08,Trip09,Trip10,Trip11,Trip12,
              Trip13,Trip14,Trip15,Trip16,Trip17,Trip18,
              Trip19,Trip20,Trip21,Trip22,Trip23,Trip24);
TotRate=(Sumtrip/allhhs);
Proc Print;
Var Rate01 -- Rate24 Sumtrip;

Data Six;
 Merge Trips Totrip;
prct01=trip01/alltrips;
prct02=trip02/alltrips;
prct03=trip03/alltrips;
prct04=trip04/alltrips;
prct05=trip05/alltrips;
prct06=trip06/alltrips;
prct07=trip07/alltrips;
prct08=trip08/alltrips;
prct09=trip09/alltrips;
prct10=trip10/alltrips;
prct11=trip11/alltrips;
prct12=trip12/alltrips;
prct13=trip13/alltrips;
prct14=trip14/alltrips;
prct15=trip15/alltrips;
prct16=trip16/alltrips;
prct17=trip17/alltrips;
prct18=trip18/alltrips;
```

```
prct19=trip19/alltrips;
prct20=trip20/alltrips;
prct21=trip21/alltrips;
prct22=trip22/alltrips;
prct23=trip23/alltrips;
prct24=trip24/alltrips;

proc print; var Prct01 -- prct24;
run;
```