Appendix A

Documentation of Forecasting Techniques

This appendix provides technical documentation of two special studies carried out as part of this research effort. The intent of the first study was to determine which energy and economic variables were most closely correlated with past changes in transit ridership as a basis for analyzing past trends and predicting the impact on transit ridership of assumed economic and energy futures. For this purpose, two sets of national time series data (1952-74 quarterly data and 1971-74 monthly data) were analyzed using a computer based stepwise regression technique. The relationship between transit ridership and the unemployment rate taken from the regression analysis of 1952-74 national time series data was used to predict the effect of the recession and depression economic futures on transit ridership. These results are discussed in Chapter V. The relationship between transit ridership and highway vehicle miles of travel (VMT) taken from the regression analysis of 1971-74 national time series data was used to predict the effect of energy decrease futures. These results are discussed in Chapter VII.

The intent of the second study was to develop a technique for assessing the impact of changes in the times and costs of auto and transit travel on national transit ridership. This technique was applied to predict the transit ridership response to major transit incentive and auto restraint actions. These results are discussed in Chapters VIII and IX.

The reader is warned at the outset of the rough nature of these studies. They were carried out to inform policy analysts at a level where the availability of tested models is limited and the relationships to be modeled are complex. Recognizing this, special emphasis was placed on assessing the reasonableness of findings in the context of whatever empirical evidence was available.

Time Series Analyses of the Effect of Economic and Energy Conditions on Transit Ridership

Two time series analyses were carried out to assess the relationship between transit ridership and energy and economic conditions. The first used national quarterly data from 1952 to 1974 and the second used national monthly data from 1971 to 1974. The intent of these analyses was to determine which energy and economic variables are most closely related to transit ridership and to develop equations using these variables to predict transit ridership under various assumed future conditions.

The need for two different time series was based on the assumption that energy conditions have exerted a significant influence on transit ridership only in the recent past, particularly during and after the oil embargo, while the effects of economic conditions could be better estimated over a longer time period which included the several postwar recessions. This assumption was verified by the results discussed below.

Long Run (Quarterly from 1952 to 1974) Input data

Quarterly data from 1952 to **1974** was collected for the variables shown in Table 39. Additional long run time series variables were generated as indicated in Table 40.

Short Run (Monthly from 1971-74) Input Data

Monthly data from ***1971*** to 1974 was collected for the variables shown in Table 41. The variable "Revenue Passengers" was adjusted by the application of a factor which reflects the number of weekdays, Saturdays, Sundays, and holidays in each month from 1971 to 1974, i.e.:

$$\text{Adjusted Revenue Passengers} = \frac{(\text{Revenue Passengers})}{(1.00 \times \text{WEEKDAYS} + .675 \times \text{SATURDAYS} + .425 \times \text{SUNDAYS} + .425 \times \text{HOLIDAYS})}$$

Data Transformation

All of the above variables prefixed by the letter "B" were transformed by (1) calculating their ratio with respect to the same month or quarter of the previous year (we will refer to this as the annual change ratio) and (2) taking the natural log of this ratio:

$$L(i) = \ln \frac{B(i)}{B(i-4)}$$

for quarterly data, and

$$L(i) = \ln \frac{B(i)}{B(i-12)}$$

for monthly data.

TABLE 39

Quarterly Time Series Input

Name	Description	Sources
BGNP	GNP (billions of 1958 dollars)	*Business Conditions Digest*
BUR	Seasonally adjusted unemployment rate (% of civilian workers)	Bureau of Labor Statistics
BUCW	Seasonally adjusted unemployed civilian workers (thousands)	Bureau of Labor Statistics
BDPI	Disposable personal income (billions of 1958 dollars)	*Business Conditions Digest*
BHUF	Highway use of motor Fuel (millions of gallons)	*FHWA Highway Statistics*
POP	U.S. Population (thousands)	*1973 Business Statistics* and *Survey of Current Business*
BRP	Transit Revenue Passengers (thousands)	APTA *Monthly Transit Traffic Bulletin*
BAFRP	Average fare per revenue passenger (undefeated)	System Design Concepts computation from APTA *Transit Fact Book*
TMPG	All highway vehicles miles per gallon	FHWA *Highway Statistics*

TABLE 40

Quarterly Time Series Data Generated

Name	Generation	Description
BPHUF	(BHUF/POP X 1000)	Per capita highway use of motor fuel (gallons)
BPRP	(BRP/POP)	Per capita transit revenue passengers
BTHM	(BHUF X TMPG)	All highway vehicle miles of travel (millions)
BPTHM	(BPHUF X TMPG)	Per capita all highway vehicle miles of travel
BPGNP	(BGNP + POP X 1,000,-000)	Per capita GNP (1 958 dollars)
BPDPI	(BDPI / POP X 1,000,-000)	Per capita disposable personal income (1 958 dollars)

TABLE 41

Monthly Time Series Input

Name	Description	Sources
BPCEZ	Personal Consumption Expenditures (billions of 1958 dollars)	*Business Conditions Digest* and *Business Statistics*
BGNPZ	GNP (billions of 1958 dollars)	*Business Conditions Digest* and *Business Statistics*
BURZ	Seasonally adjusted unemployment rate (% of civilian workers)	Bureau of Labor Statistics
BUCWZ	Seasonally adjusted unemployed civilian workers (thousands)	Bureau of Labor Statistics
BUVMTZ	All urban highway vehicle miles of travel	FHWA Program Management Division
BTVMTZ	All highway vehicle miles of travel	FHWA Program Management Division
BAFRPZ	Average fare per revenue passenger	System Design Concepts Computation from APTA *Transit Fact Book*
BGSZ	Gasoline sales	FHWA *Highway Statistics*
WKY) SAT) SUN) HOL)	The number of weekdays, Saturdays, Sundays and holidays in a given month.	APTA Monthly Transit Traffic Bulletin
RPZ	Transit revenue passengers (thousands)	APTA Monthly Transit Traffic Bulletin

Analytic Procedure

The analytic procedure employed a computer-based stepwise regression analysis. The computer tested equations of the form

$$\ln(Y) = a_i \ln X_i$$

where Y represents the annual change factor for transit ridership and the Xi represents the annual change factors of other variables.

In each step of the computation procedure, the computer could enter or remove a single variable. An F-ratio was calculated to determine which variable would be entered or removed.

The computation procedure enforced a zero regression intercept. This meant that annual changes in transit ridership would be related only to annual changes in variables measuring energy and economic conditions, If there is a strong up or down trend in transit ridership unrelated to the economic and energy variables tested, it would not show up in the results. To circumvent this problem, an artificial variable with a constant annual change factor was generated and included with the other economic and energy variables which might be entered in a particular step.

Results of the Long Run Regression Analysis of Transit Revenue Passengers

The regression coefficients, their standard errors and the R2 values (calculated about zero, not about the mean) of the first three steps of the long run regression analysis of transit revenue passengers are shown in Table 42. The variables entered were: were:

1. average fare per revenue passenger (LAFRP)
2. seasonally adjusted unemployment rate (LUR) and
3. highway vehicle miles of travel (LTHM).

Subsequent steps entered variables which were highly colinear and produced minimal increases in R2.

From 1952 to 1974, the variable most strongly related to transit ridership was average fare. The negative coefficient indicates that increases in average fare are associated with decreases in ridership, as would be expected. However, the magnitude of the coefficient is larger than expected. It suggests that the price elasticity of transit ridership is -.64 while other studies have indicated a price elasticity of about —.3 or slightly higher. A likely reason for this discrepancy is that the computer procedure does not distinguish ridership declines due to fare increases from fare increases by transit agencies to compensate for declining revenues. Thus, the decline in ridership actually caused by a 1 percent fare increase should be less than the .64 percent indicated in the above equation.

After average fare, the unemployment rate proved to be the variable most strongly related to transit ridership. The finding that the unemployment rate is the national economic indicator most closely correlated with transit ridership suggests that the primary impact of worsening economic conditions on transit ridership is a reduction in transit work trips associated with increased unemployment, rather than a general reduction in more discretionary transit travel associated with decreased personal income. However, despite the (statistical) significance of the relationship between unemployment and transit ridership, the actual decrease in ridership which would be predicted from an increase in unemployment is relatively small. Assuming that the fare remains constant, an increase in the unemployment rate from 5.0 percent to 7,5 percent would cause a decline in transit ridership of about 2 percent.

The relationship used to estimate the effect of the recession and depression and economic futures on transit (discussed in Chapter V) was taken from the second step of the regression analysis of **1952-74 national data.** To assess the validity of this relationship between transit ridership and the unemployment rate, it was applied to the increase in unemployment which occurred between October 1973 and December 1974. The resulting estimate of the associated decrease in transit ridership was compared with the decrease estimated from national data using an analysis of the impact of incremental unemployment on transit riders hip (described in Chapter V). In both cases, the decrease in transit ridership estimated to be caused by the increase in unemployment was about 2 percent.

In the third step of the long run regression analysis, the variable entered was highway vehicle miles of travel. While the size of the coefficient of this variable was roughly consistent with the results of the shorts run regression analysis described below, the entrance of this variable caused an unreasonably large reduction in the coefficient of average fare due to problems of collinearity.

Results of Ihe Short Run Regression Analysis of Transit Revenue Passengers

The regression coefficients, their standard errors and the R2 values of the first three steps of the short run regression analysis are shown in Table 43. The variables entered were:

1. highway vehicle miles of (LTVMTZ)
2. the artificial variable representing a constant annual change factor (LCONZ)
3. gross national product (LGNPZ)

As with the long run analysis, subsequent steps entered variables which were highly colinear and produced minimal increases in R2.

The variable most strongly related to transit ridership in the 1971-74 time period was total highway vehicle miles of travel. In selecting vehicle miles, the regression procedure rejected average fare and the unemployment rate, the variables

TABLE 42

Long Run (Quarterly) Regression of Transit Revenue Passengers (LRP)

- **First three steps shown**
- **Independent variables entering were LAFRP, LUR, LTHM,**

o R2 and standard errors of coefficients calculated about zero, not about the mean.

Step Number	Coefficients of Independent Variables (Standard Errors of Coefficients) LAFRP	LUR	LTHM	R2
1	–.7081 7 (.06772)			.5597
2	–.64044 (.06854)	–.04943 (.01 641)		.6022
3	–.1 7607 (.1 0225)	–.09545 (.01 636)	–.64858 (.1 1 668)	.7092

TABLE 43
Short Run (Monthly) Regression
of Adjusted Transit Revenue Passengers (LFRPZ)

- **First three steps shown**
- **Independent variables entering were LTVMTZ, LCONZ, LGNPZ**
- ***R2 and standard errors Calculated about* zero, not about the mean**

Step Number	Coefficients of Independent Variables [Standard Errors of Coefficients] LTVMTZ	LCONZ	LGNPZ	R^2
1	-.58696 (.1 2505)			.4004
2	–.86580 (.09881)	.03196 (.00533)		.7175
3	–.48734 (.1 2670)	.04888 (.00691)	–.65668 (.1 6747)	.8111

which were most strongly related to transit rldership in 1952-74 time period. A possible interpretation of the increased importance of vehicle miles is that prior to the gasoline shortage, changes in that variable reflected changes in discretionary trips which individuals might forego rather than make by transit. With the coming of the gasoline shortage, TVMT included more trips which individuals would not forego and, as a result, reductions in vehicle miles would become more closely related to increases in transit ridership. It is also likely that the relationship between highway travel and transit is not very significant in the Iongrun analysis simply because of the lack of variability in energy price and availability conditions over the long period taken as a whole.

In the second step of the shortrun analysis, a constant term entered the equation. This implies that, if highway vehicle miles of travel remain constant over time, transit ridership would increase at a rate of 3 percent/year,

The shortrun regression analysis did not explicity incorporate measures of the quality or extensiveness of transit service (due to the lack of monthly data). Thus, any net effect on transit ridership due to changes in transit service would be reflected in the constant term of the estimated equation.

Preliminary estimates in the 1973-74 ATA Transit Fact Book indicate that transit vehicle miles, a measure of the extensiveness of transit service increased by 4 percent from 1972 to 1973. Previously, this measure had declined each year from 1950 to 1972. If the extensiveness of transit service also increased from 1973 to 1974 and if there were also improvements in the quality of transit service, this would account for a significant portion of the 3 percent/year increase.

The relationsip between transit ridership and highway vehicle miles of travel taken from the second step of the shortrun regression analysis was applied to predict the impact of energy decrease futures on transit ridership (described in chapter VII). For this purpose, estimates of the decrease in highway vehicle miles of travel associated with each of the three energy decrease futures were made based on assumed improvements in passenger car fuel economy in the 1975-80 time period.

To assess the validity of the relationship between transit ridership and highway vehicle miles of travel, it was applied to the 8.5 percent decrease in highway VMT which occurred between February 1973 (prior to the fuel crisis) and February 1974 (when the fuel crisis was at its peak). These months differed little in terms of average transit fare or unemployment. The regression relationsip predicted a 7.9 percent increase in transit ridership as compared to an 8.4 percent measured increase, according to APTA Monthly Transit Traffic Bulletins.

The fact that GNP was entered on the third step with a minus sign is counter to expectation, given that highway vehicle miles of travel had been entered on the first step. The shift of travelers from transit to auto would be expected with increases in GNP. However, this effect should be accounted for by the highway vehicle miles of travel term in the equation and increases in GNP at a fixed level of highway travel would be expected to increase transit ridership.

A Technique for Forecasting the Effect of Major Transit Incentive and Auto Restraint Actions on Transit Ridership

This section describes an analysis of the impact upon transit ridership of changes in the times and costs of auto and transit travel. The analysis led to the development of an equation relating these changes (expressed in absolute terms) to percentage changes in transit ridership.

This equation was applied to predict the ridership response to major transit incentive and auto restraint actions (discussed in Chapters VIII and Ix) .

This equation was based on an extension of logit mode split models to account for the fact that improvements in the time and cost of transit travel may induce additional trips, rather than just divert travelers from other modes. As will be discussed below, this extension is important if the technique is to produce results consistent with past experience in the implementation of transit fare reductions and service improvements. Another virtue of the technique is that it provides reasonable results for large changes in the time and cost of travel by various modes. Several other techniques produce results consistent with empirical evidence for small changes in times and costs but produce unreasonable results for large changes.

Key findings of this analysis cited in the main body of the report include the following:

- the predicted transit ridership response to eliminating the out-of-pocket cost of transit travel is a 40-60 percent increase in transit ridership. An additional 20 percent ridership increase would result from associated service improvements including a 40 percent increase in transit vehicle miles of operation and faster bus speeds in the peak period made possible by eliminating the time associated with fare collection. Thus, the net effect of no fare transit and related service improvements is estimated to be a 60-80 percent increase in transit ridership.

Past experience with small transit fare increases suggests that for a unit percent increase in the fare, a .33 percent decrease in ridership results (i. e., a transit price elasticity of –.33).

The equation used to estimate the effect of changes in travel times and costs produces results consistent with this experience for small fare increases or decreases. However, for large fare decreases, the equation produces larger ridership increases per unit percent reduction in the transit fare, e.g., the 40-60 percent increase in ridership noted above rather than a 33 percent increase which would be the case if the percent ridership increase per unit percent reduction in the transit fare was a constant ratio.

The finding that this ratio increases for large fare reductions is consistent with the Atlanta experience where a decrease in the transit fare from 40$ to 15C (a 62.5 percent decrease) is estimated to have caused a 28 percent increase in ridership. This increase is larger than would be anticipated by applying the transit price elasticity estimated for small fare changes.

- The effect of a 50 percent increase in the price of gasoline would be less than a 10 percent increase in transit ridership.

- A $1.50/day increase in the price of commuter parking in areas well served by transit (downtown areas of large SMSAS, containing about 25 percent of SMSA employment) has a far greater effect on transit ridership than a 50 percent gasoline price increase, causing about a 15 percent increase in transit ridership on a national basis.

As an independent check of the effect of a 50 percent increase in the price of gasoline on transit ridership, the decrease in highway VMT associated with this increase in the price of gasoline was estimated and the relationship between transit ridership and highway VMT taken from the short run (1971-74) regression analysis was applied. This led to the same conclusion—that a 50 percent increase in the price of gasoline would cause less than a 10 percent increase in transit ridership. This conclusion is also consistent with the Chicago Area Transportation Study estimate of the effect of fuel costs on transit ridership discussed in Chapter X.

The estimate that a $1.50 increase in the price of commuter parking would cause a 15 percent increase in transit ridership is roughly consistent with the findings of an independent analysis of the effect of an increase in Washington, D.C. parking costs (discussed in Appendix D). In that analysis, a $1.50 increase in the average parking cost was estimated to cause a 20 percent increase in transit trips.

Logit Modal Split Models

A logit modal split model estimates the share of travelers (or the probability of an individual traveler) using a particular mode i in making a particular trip by an equation of the form

$$MS_i = \frac{e^{+U_i}}{\sum_{\text{all modes } j} e^{+U_j}}$$

where

MSi = the fractional share of travelers using mode i in making the trip

and U_j = an index of the utility of using mode j in making the trip

Using home interview survey data for various areas and trip purposes, a number of studies have calibrated logit modal split models with utility functions specified as:

$$U_j = \beta_j \, IVTT_j + \gamma_j \, OVTT_j + \delta_j \, OPTC_j$$

Socio-economic variables.

where:

$IVTT_j$ is in-vehicle travel time in minutes by mode j

$OVTT_j$ is out-of-vehicle travel time (walking and waiting) in minutes by mode j

$OPTC_j$ is out-of-pocket travel cost (fares, tolls, vehicle operating expense) in cents by mode j

and β_j, γ_j, and δ_j are parameters which were empirically estimated.

The logit mode split equations can be used to estimate the effect of changes in travel times and costs by a particular mode upon the share of travelers using that mode, i.e.

$$MS_j' = \frac{MS_j}{MS_j + (1-MS_j) \times \exp(U_j - U_j')}$$

where

MS_j is the share of travelers using mode j before the change in travel times and costs

MSj' is the share of travelers using mode j after the change in travel times and costs

U_j is the utility of travel by mode j before the change in travel times and costs, and

Uj' is the utility of travel by mode j after the change in travel times and costs.

To estimate the term $(U_j - U_j')$, it is necessary to know only the changes in the time and cost variables, OVTT, IVTT and OPTC, and the appropriate coefficients for these variables in the linear utility equation.

Table 44[1] shows estimates of β_T, γ_T AND δ_T from various studies which calibrated logit modal split models using home interview survey data from

TABLE 44

Logit Modal Split Model Coefficients for Transit Travel Time and Costs

Model	Logit Coefficients for IVTT (β_T), OVTT (γ_T) and OPTC (δ_T) β_T	γ_T	δ_T
Charles River Association 1967 Pittsburgh HIS[3]			
• Work Trips	-.0369	[1] -.150	-.0242
• Shopping Trips	-.0636	[1] -.398	-.0466
Cambridge Systematics Inc. 1968 Washington HIS[3]			
• White Collar Work Trips	-.0198	-.06422	-.014368
Moshe Ben-Akiva 1968 Washington HIS[3]			
• Shopping trips	-.0328	-.1266	[2] -.0252

[1] The estimates of γ_T shown were for walk time only. Wait time was not included.

[2] This coefficient was estimated as -.1514/INCODE where INCODE is a nonlinear function of household income. The value shown is for household incomes between $10,000 and $12,000.

[3] HIS means Home Interview Survey

1967-68. All these studies attempted to predict the split between only two modes—auto driver and transit passenger. The diversion of auto passengers and the inducement of new trips will be added to the equation as discussed later in this section.

For all models except the Cambridge Systematics White Collar Work Trip Model, the logit coefficients for auto times and cost were constrained to equal the corresponding logit coefficients for transit times and cost. The Cambridge Systematics logit coefficients for auto times and cost were (for one way trips):

$$\beta_A = -.0225$$

$$\gamma_A = -.05502$$

$$\delta_A = -.02946$$

Of these, only the auto out-of-pocket cost coefficient (δ) differs significantly from the corresponding transit coefficients and, in this regard it should be noted that the auto cost includes only parking, not vehicle operating cost.

To the extent that vehicle operating costs are positively correlated with parking costs, it is anticipated that the value of δ_A would have been lower had auto operating costs been included.

The ratio β_T / δ_T represents empirical evidence of the rate at which travelers trade in-vehicle travel time and money in making travel decisions. For the studies referenced in Table 44, this ratio ranges from 1.30 to 1.52, surprisingly little variation considering that different trip purposes and different cities were studied. These studies indicate that in making travel decisions in the 1967-68 time period people on the average weighted in-vehicle travel time at a rate of 1.3-1.5¢ per minute.

The ratio γ_T / β_T represents empirical evidence of the relative unpleasantness of in-vehicle travel time and out-of-vehicle (walking and waiting) travel time. For the studies referenced in Table 44, this ratio varies from 3.2 to 6.2. However, the studies used different definitions of out-of-vehicle time. Those with the higher ratios (Shop) used only walk time, while the other used both walk and wait in estimating γ_T.

For the purpose of predicting the effects of changes in the times and costs of travel in this study, the following values were selected:

- $\delta = -.01333$
- $\beta = -.03$
- $\gamma = -.09$

As indicated below, these values are consistent with recent empirical evidence.

The ratio of β to δ is 2.25. This is the result of updating the 1.5 ratio suggested from Table 44 to account for the 50 percent rate of inflation from 1968 to the present.

The ratio of γ to δ is 3.0. The lowest value of this ratio, from those in Table 44, was used since the intention is to use γ only to estimate the effect of changes in wait time, not walk time.

Extension of the Logit Modal Split Model

As noted previously, the logit modal split equation was developed to predict the split of travelers between modes—in our case auto drivers and transit passengers, i.e.:

$$\frac{MS_T'}{MS_T} \quad \frac{1}{MS_T + (1-MS_T) \times \exp(\Delta U_A - \Delta U_T)}$$

However, the percentage increase in transit ridership associated with reductions in the times and cost of transit travel will be equal to the percent increase in MS_T only if all the new transit riders would otherwise have been auto drivers. If some of the new transit riders would otherwise have been auto passengers, pedestrians, or not made the trip, then the above equation will underestimate the growth in transit ridership. This can be seen as follows:

- Let T' and A' (T and A) equal the number of transit and auto driver trips after (before) the change.
- Let MST' (MST) equal the share of auto driver and transit trips which are by transit after (before) the change, i.e.

$$MS_T' = \frac{T'}{T' + A'}, \qquad MS_T = \frac{T}{T + A}$$

- Let q equal the share of new transit riders which would otherwise not have been auto drivers, i.e.:

$$(T' - T) \times (1-q) = A - A'$$

- The above equations can be solved for the growth factor for transit, i.e.:

$$\frac{T'}{T} = \frac{\frac{1}{MS_T} - q}{\frac{1}{MS_T'} - q}$$

This equation indicates that if all the new riders on transit had been diverted from other modes explicitly included in the modal split models (q=0), then the change factor for transit ridership (T'/T) is the same as the change factor for the *share* of riders using transit (MS_T'/MS_T). However, if some of the new transit riders are diverted from modes not explicitly included in the modal split models or are induced to make trips they otherwise would not make by transit fare reductions or service improvements, then the change factor for transit ridership will be greater than the change factor of the *share* of travelers using transit, i.e., if $q>0$, then

$$\frac{T'}{T} > \frac{MS_T'}{MS_T}$$

Substituting the equation for MS_T'/MS_T into the above equation for T/T, the result is

$$\frac{T'}{T} = \frac{1}{1 + \alpha \; (\Delta U_{AD} - \Delta U_T) + 1)}$$

where

$$\alpha = \frac{1-MS_T}{1-qMS_T}$$

MS_T = transit's fractional share of transit passengers plus auto drivers

and

q = the fraction of new transit riders which would *not* otherwise have been auto drivers.

This is the equation which was used to estimate the effect of transit incentive and auto restraint actions on transit ridership.

Estimates of Parameters

In applying the above equation, all transit ridership was evenly divided into two categories: peak and off-peak ridership. Based on temporal distributions of transit travel, the peak period would cover roughly 5 hours on an average weekday.

Values of α were calculated from estimates of MS_T and q for transit travel in peak and off-peak time periods. Also, in order to estimate the reduction in automobile energy consumption associated with predicted transit ridership increases, the average trip length and fuel efficiency of an auto driver trip diverted to transit in the peak and off-peak periods were estimated. These are shown in Table 45.

In estimating the values of α to use with the equation for T'T, it should be noted that a value of MS_T Typical *of transit* travel rather than of all travel should be used. This is because the T'T is a transit growth factor and using a value of MS_T typical for all travel would overestimate transit growth. Transit trips are not homogeneously distributed over all travel. Rather, they are heavily concentrated in downtown areas of large cities. For example, in all SMSA'S with population greater than 250,000, about 12 percent of the work trips are by transit. However, residents of the central cities in SMSA'S with population greater than one million account for more than 60 percent of all transit work travel. The value of MST for these work trips is about .4.[1] As a more extreme example, transit travel into and within Manhattan constitutes about 12 percent of all transit travel in the United States. The value of MST for total daily travel into and within Manhattan is .79.[2] The value for MST of .5 for the peak period (implying a 50-50 split between auto drivers and transit passengers) presented in Table 45 is the assumed median for peak period transit travel.

The much lower value for MST of .2 in the offpeak period is a result of the fact that about 60 percent of SMSA transit travel is for the purpose of earning a living while only about 38 percent of SMSA auto driver trips are for that purpose,[3] i.e.

$$.5 \times \frac{.4}{.6} \div \frac{.38}{.62} = .2$$

Not all peak period travel is for the purpose of earning a living and not all off-peak travel is for other purposes, so the estimated value of .2 is a rough approximation. However, with $q = .7$ the value of α which is used in forecasting transit ridership increases is not particularly sensitive to changes in MS_T, i.e. $\alpha = .89$ for $MS_T = .3$ and $\alpha = .97$ for $MS_T = .1$. Thus, any value of MS_T between .1 and .3 could be used without significantly affecting the forecasted increase in ridership.

The estimated values for q are based upon an onboard survey conducted by the Metropolitan Atlanta Rapid Transit Authority in November 1972. On March 1, 1972, the Metropolitan Atlanta Rapid Transit Authority had instituted a reduction in the base fare from 40¢ to 15¢ and, during the following year, implemented a number of service improvements. The onboard survey of transit patrons was

[1] Calculated from 1970 Census Data presented in the *Urban Transportation Factbook*, American Institute of Planners and Motor Vehicle Manufacturers, Association, March 1974.

[2] *Ibid.* and *Subway Riders and Manhattan Autos*, Tri-State Regional Planning Commission, October 1971.

[3] *1974 National Transportation Report*, page IV-3.

conducted to assess the impact of reduced fare and service improvements on transit ridership patterns.

The MARTA report[4] defines new riders as those who responded "no" to the question "Did you ride the bus regularly before March 1 when the fare was 40 Q?" Old riders are defined as those who responded "yes" to this question. The report found no significant increase in weekday bus use by old riders due to the fare reduction and service improvements. However, on Saturdays and Sundays, old riders were found to have increased their trip making by 20 percent and 50 percent respectively due to the fare reduction and service improvements. Over the course of an entire week, 91 percent of the increase in trips was accounted for by new riders and 9 percent was accounted for by increased transit travel by old riders.

New riders were asked "How did you make this trip you're taking today before you started using this bus?" On weekdays, the time period during which "new riders" were estimated to account for virtually all of the increase in transit ridership associated with the fare reduction and service improvements, 41.8 percent of the new riders stated that they had previously been auto drivers. During the period from 6 a.m. to 9 p.m. on weekdays, 51.3 percent of the new riders stated that they had previously been auto drivers.

The average trip lengths for auto driver trips diverted to transit, shown in Table 45 were estimated as follows:

—The National Personal Transportation Survey indicated the average trip length for an auto work trip was 9.4 miles and the average trip length for a shopping trip was 4.4 miles.

— Approximating the peak period distribution of auto driver trips diverting to transit as 80 percent work trips and 20 percent shopping trips using the above trip lengths, the peak period average is 8.4 miles.

— Approximating the off-peak period distribution of auto driver trips diverting to transit as 40 percent work trips and 60 percent shopping trips, the off-peak period average is 6.4 miles.

The average fuel efficiency of urban autos is estimated to be 12 miles per gallon.[5] The peak spread between peak and off-peak fuel efficiencies shown in Table 45 was arrived at judgmentally, to reflect the more congested conditions of peak period travel.

Analysis of the Effects of Doubling Transit Vehicle Miles of Operation

It is anticipated that the predominant share of the indicated increase in transit vehicle miles of operation would be allocated to increasing the frequency of service on existing lines. While there may be some opportunities to develop new lines, their number is limited by the generally low employment and residential densities in suburban areas not currently linked by transit.

The allocation of additional transit vehicle miles to existing transit lines decreases the time riders spend waiting at transit stops. If transit riders arrive randomly at a transit stop rather than trying to meet a scheduled vehicle, the effect of doubling transit vehicle miles is to reduce waiting time by 50 percent. For riders meeting scheduled vehicles, the effect of doubling the frequency of scheduled service is to reduce by 50 percent the amount of time transit riders have to allow for the fact that the transit system will not get them to their destination at their preferred time of arrival. Also, if transit riders miss the scheduled vehicle they are attempting to catch, they will spend 50 percent less time waiting for the next vehicle.

The analysis of the effect on peak period ridership of doubling transit vehicle miles of operation is summarized as follows:

- Reduction of Transit Wait Time = 2.5 minutes
- Net Reduction of the Disutility of a Peak Period Transit Trip = 2.5 × .09 = .225
- T'/T (with α =.667) = 1.155
- Percentage Increase in Peak Period Transit Ridership = 15.5 percent

The analysis of the effect on off-peak period ridership is summarized as follows:

- Reduction of Transit Wait Time = 5.0 minutes
- Net Reduction of the Disutility of an Off-Peak Period Transit Trip = 5 × .09 = .45
- T'/T (with α =.93) = 1.50
- Percentage Increase in Off-Peak Period Transit Ridership = 50 percent

Average peak period wait time was assumed to be 5 minutes and average off-peak wait time was

4 The *Effect of* Fare *Reduction on* Transit *Ridership* in the Atlanta Region, Technical Report No, 2: Analysis of Transit Passenger Data, MARTA, November 1973.

5 Highway Users Federation Technical Study Memorandum No. 9.

assumed to be 10 minutes, both of which were assumed to be cut in half by doubling transit vehicle miles. The peak period ridership increase of 15 percent was calculated with α = .667 as appropriate for peak period conditions. The off-peak ridership increase of 50 percent was calculated with α=.93 as appropriate for off-peak conditions.

Table 46 summarizes the effect of doubling transit vehicle miles of operation on energy consumption by automobiles in the peak and off-peak periods. The combined result is a savings of 24,000 barrels/day.

TABLE 45

Estimated Conditions for Transit Travel in the Peak and Off-Peak Periods To Predict Transit Ridership Increases and Reductions in Automobile Energy Consumption Associated with Transit Fare Reductions and Service Improvements

	Peak Period	Off-Peak Period
MS_T	.5	.2
q	.5	.7
α	.667	.93
Average Auto Trip Length*	8.4 miles	6.4 miles
Average Auto Fuel Efficiency*	11 miles/gallon	13 miles/gallon

*Estimates pertain to those auto driver trips which would be diverted to transit by fare reductions or service improvements.

No Fare Transit With Service Improvements

Total elimination of the transit fare will promote ridership increases by:

- reducing to zero the out-of-pocket cost of transit travel
- increasing the speed of buses (particularly in the peak period) by eliminating the time associated with fare collection and allowing passengers to board through both doors.

Also, to the extent that ridership increases due to the above factors require additional transit vehicle miles of operation, the improved frequency of service will promote further ridership increases.

The peak period effect of no fare transit with service improvements was estimated as follows:

- Reduction in the out-of-pocket cost of a transit trip = 31.96¢
- Reduction of transit in-Vehicle Travel Time = 2.0 minutes
- Reduction of Transit Wait Time = 1.4 minutes
- Net Reduction in the Disutility of a Peak Period Transit Trip = 31.96 × .0133 + 2.0 × .03 + 1.4 × .09 = .612
- T′/T (with α =.667) = 1.44
- Percentage Increase in Peak Period Transit Ridership = 44 percent.

TABLE 46

Estimates of the Effect of Doubling Transit Vehicles Miles of Operation on Energy Consumption by Automobiles

	Peak	Off-Peak	Total
(1) 1974 Annual Transit Ridership (Millions)	2803	2803	5606
(2) Estimated Increase in Transit Ridership	434 (+1 5.5°/0)	1404 (+50%)	1835 (+32.7%)
(3) Average Length of a Diverted Auto Driver Trip	8.4 miles	6.4 miles	
(4) Average Fuel Efficiency of a Diverted Auto Driver Trip	11 mpg	13 mpg	
(5) Fraction of Transit Ridership Increase Associated with the Diversion of Auto Drivers	.5	+ .3	
(6) Barrels/Day Reduction in Automobile Energy Consumption	+10809	+13498	24307

t(#6) = (#2)X (#3)X (#5) / (#4) X 365X 42

The assumed reduction in the out-of-pocket cost of a transit trip of 31.96cents was equal to the average transit fare in 1974.[5]

The reduction in in-vehicle travel time of 2 minutes was estimated as follows:

- Assume that a transit bus carries 60 passengers at its peak load point during the peak period.
- Thus, prior to reaching the peak load point, the average passenger has been on the bus while 30 other passengers boarded the bus.
- Assume that the time required for boarding the bus could be reduced by 4 seconds per passenger if no fare collection is necessary and passengers are allowed to board through both doors. The assumed 4 seconds is probably too high for suburban bus stops with fewer than three passengers boarding and too low for downtown bus stops with more than ten passengers boarding.
- Thus, on the average, the in-vehicle time spent by passengers will be reduced by 2 minutes.

The reduction in peak period wait time of 1.43 minutes was based on a 40 percent increase in the vehicle fleet to cover the peak period ridership increase, assuming that the average wait time in the peak period is 5 minutes; i.e.:

5 x ; = 1.43 minutes,

The off-peak period effect of no fare transit with service improvements was estimated as follows:

- Reduction in the Out-of-Pocket Cost of a Transit Trip = 31.96¢
- Reduction of Transit Wait Time = 2.9 minutes
- Net Reduction in the Disutility of an Off-Peak Period Transit Trip = 31.96 × .0133 + 2.9 × .09 = .687
- T′/T from Equation (with α =.93) = 1.86
- Percentage Increase in Off-Peak Period Transit Ridership = 8670

As with the peak period, the off-peak reduction in the out-of-pocket cost of transit travel was assumed to be 31.96d, the average fare in 1974.

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The reduction in off-peak wait time of 2.86 minutes was estimated assuming that vehicles added to the transit fleet to cover peak period ridership increases would be used also to expand off-peak transit vehicle miles of operation by 40 percent and that the average off-peak wait time is 10 minutes. i.e.:

$$10 \times \frac{.4}{1.4} = 2.86 \text{ minutes.}$$

No reduction of in-vehicle time during the off-peak period was estimated since the time savings associated with the elimination of fare collection were not viewed as significant under the less congested conditions of off-peak travel.

Table 47 shows an analysis of the effect on energy consumption by automobiles of no fare transit and related service improvement in the peak and off-peak periods. The combined effect is a savings of 55,000 barrels/day.

A 507₀ Increase in the Price of Gasoline

Estimates of gasoline price elasticities were made by Data Resources Inc.[7] using a dynamic consumption function. The dynamic consumption function enables the short term effects of a gasoline price increase to be estimated separately from those effects which occur over a longer time period. The usefulness of this procedure is characterized as follows:

> "In the first time period after a price increase consumers can make only marginal adjustments, such as cutting the number of trips to the store, re-arranging the use of autos to save gasoline, and forming of car pools. As time passes, however, more opportunities for conservation appear. Large inefficient cars can be replaced by small, more efficient ones, families can relocate so as to minimize the mileage traveled to work and the store, more housing near modes of mass transit can be constructed, and conservation habits become more refined. "[8]

7*A Study of* the Quarterly Demand *for Gasoline* and impacts *Of* Alternative *Gasoline* Taxes, Data Resources, Inc., Lexington, Mass., Preliminary Report, December 5, 1973.

8*Ibid.*, page `1.22.

TABLE 47

ESTIMATES OF THE EFFECT OF NO FARE TRANSIT AND RELATED SERVICE IMPROVEMENTS ON ENERGY CONSUMPTION BY AUTOMOBILES

	Peak	Off-Peak	Total
(I) 1974 Annual Transit Ridership (Millions)	2803	2803	5606
(2) Estimated Increases in Transit Ridership	1233	2410	3643
(3) Average Length of a Diverted Auto Driver Trip	8.4 miles	6.4 miles	—
(4) Average Fuel Efficiency of a Diverted Auto Driver Trip	11 mpg	13 mpg	—
(5) Fraction of Transit Ridership Increase Associated with the Diversion of Auto Drivers	.5	.3	—
(6) Barrels/Day Reduction in Automobile Energy Consumption	● 3071 o	● 2321 8	53928

$$\bullet(\#6) = \frac{(\#2) \times (\#3) \times (\#5)}{(\#4) \times 365 \times 42}$$

This study estimated that the short term price elasticity (short term is defined as 3 months) ranges from ,07 to .14 depending on the definition of gasoline consumption and the long term price elasticity (which requires roughly ten quarters to be fully achieved) ranges from .26 to .30.

If it is assumed that the short term price elasticity is due to a reduction in vehicle miles of travel and the difference between the short and long term elasticities is due to more fuel-efficient automobiles, then a 50 percent increase in the price of gasoline would result in a **3.5-7. o** percent reduction in vehicle miles of travel (since the short term price elasticity of gasoline is **.07-.14).**

The regression analysis of the effect on transit ridership of energy and economic conditions described previously led to the following relationship between transit ridership and highway vehicle miles of travel:

$$\frac{T'}{T} \text{ is proportional } \left(\frac{VMT'}{VMT}\right)^{-.86}$$

Applying this relationship to a 5 percent reduction in highway vehicle miles associated with a 50 percent increase in the price of gasoline leads to an estimated 4.5 percent increase in transit ridership.

Alternatively, the effect of a 50 percent increase in the price of gasoline can be estimated by:

- estimating the additional cost per trip by auto associated with the gasoline price increase
- using the equation for T'/T to calculate the effect on transit ridership of a fare reduction equal to the additional cost per trip by auto
- canceling out that portion of the ridership increase which would not be diverted from autos.

Carrying out these steps for the peak period:

- Increase in the Out-of-Pocket Cost of a Peak Period Auto Trip = 22.9¢
- Net Reduction in the Disutility of Transit Travel Relative to Auto Travel = .0133 × 22.9 = .305
- T'/T (with α = .667) = 1.212
- Fraction of Transit Ridership Increase Associated with Diversion of Auto Drivers = .5
- Percentage Increase in Peak Period Transit Ridership = .5 × 21.2 percent = 10.6 percent

and for the off-peak period:

- Net Increase in the Out-of-Pocket Cost of an Off-Peak Auto Trip = 14.7¢
- Net Reduction in the Disutility of Transit Travel Relative to Auto Travel = .01333 × 14.7 = .196
- T'/T (with α = .93) = 1.20
- Fraction of Transit Ridership Increase Associated with Diversion of Auto Drivers = .3
- Percentage Increase in Off-Peak Period Transit Ridership = .3 × 20 percent = 6 percent

The 22.9¢ increase in the price of a peak period auto trip assumes an average trip length of 8.4 miles, an average fuel efficiency of 11 miles/gallon and a price increase of 30¢/gallon. The 14.7¢ increase in the price of an off-peak period auto trip assumes an average trip length of 6.4 miles and an average fuel efficiency of 13 miles/gallon.

Combining the peak and off-peak increases, the net effect of a 50 percent increase in the price of gasoline using the above steps is an 8.3 percent increase in transit ridership. This is close to twice the 4.5 percent increase estimated using the results of the regression analysis. However, both are quite small, indicating the limited effect of gasoline price increases on transit ridership. Further, had the cost of the peak and off-peak auto trips been estimated with average fuel efficiencies of 17 and 19 mpg, such

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as might be the case in 1980 if the gasoline price increase is implemented, then the two methods would have produced a most identical results.

$1.50/Day Increase in the Price of Downtown Commuter Parking

This action is designed to provide a disincentive to auto use in the travel market best served by transit: travel to or from work places in downtown areas of SMSA'S with population greater than 250,000. Twelve percent of all work travel in these SMSA'S is by transit.[9] However, given the heavy downtown orientation of transit systems, it is estimated that about 90 percent of transit work travel is to a downtown area containing 25 percent of SMSA employment. It is in these areas, to which transit carries about half of the work trips, where the parking price increase would be implemented, About 93 percent of all transit travel occurs in SMSA'S with populations greater than 25,000,[10] Thus, noting that 60 percent of all transit travel is work travel, about half of all transit travel in the United States is work travel to the area affected by the parking price increase.

The analysis of the net effect on transit work trips of a $1.50/day increase in the price of commuter parking in downtown areas of large cities takes into account the following separate effects:

- the increased out-of-pocket cost of an automobile work trip
- the reduction in travel time by automobile resulting from lower levels of congestion as fewer people drive to work
- the reduction in time spent waiting for transit resulting from increases in the size of the transit fleet.

In order to calculate the transit ridership increase associated with these effects, it was assumed that the primary result would be the diversion of auto drivers (i.e., q = 0) to transit and that typical value of MS_T for transit work trips to the affected areas is .6. It should be recalled that in selecting a value of α for use in calculating T'/T, a typical value for *transit* travel, not for *all* travel, should be used. Thus, a value of α = .4 was used. The net effect was calculated as follows:

- Increase in the Out-of-Pocket Cost of a One-Way Auto Trip = 75cents
- Reduction in Auto In-Vehicle Travel Time = 10 minutes
- Reduction in Transit Wait Time = 1 minute
- Net Reduction in the Disutility of Transit Travel Relative to Auto Travel =(75) x (.01333) + (1) x (.09)+ (–10) x ~~~(.03) = .79.
- T'/T (with ~ = .4) = 1,28
- Percentage Increase in Transit Work Trips = 28 percent.

The increase in the out-of-pocket cost of an auto work trip is shown above as 75cents since the estimating equation pertains to one-way work trips, against which only half of the parking charge should be applied.

The 10 minute reduction in auto in-vehicle travel time is a result of the roughly 30 percent decrease in the volume of auto work trips to the area affected by the parking price increase. It corresponds to an increase in speed from 20 to 30 miles per hour for the 9.4 miles of an average work trip.

The 1 minute reduction in transit wait time is the result of a 25 percent increase in the transit fleet necessary to cover the 30 percent increase in transit work trips, since about 80 percent of peak period transit ridership is work travel.

Table 48 shows an analysis of the effect of the parking price increase and energy consumption by automobiles.

TABLE 48

ESTIMATE OF THE EFFECT OF A $1.50/DAY INCREASE IN THE PRICE OF DOWNTOWN COMMUTER PARKING ON TRANSIT WORK TRIPS TO THE AFFECTED AREA

1974 Transit Work Trips to the Affected Area	2803
Estimated Increase	784
Average Fuel Efficiency of a Diverted Auto Driver Trip	10 miles per gallon*
Average Trip Length of a Diverted Auto Driver Work Trip	9.4 miles
Barrels/Day Reduction in Automobile Energy Consumption	48073

* 1O mpg was used for the affected work trip because it was assumed that these work trips would be through the most congested parts of the urban areas, and thus have slightly less auto efficiency than the average auto work trip.