TRANSIT FARE ELASTICITIES AND FREE FARE PROGRAMS

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This paper presents a review and discussion of the sensitivity of transit ridership to fare changes, based on research results and observations in transit systems in North America. The principal concept for capturing this sensitivity is that of elasticities. The first section of the paper will review this concept, and discuss some general issues associated with the measurement and subsequent interpretation of elasticities. The second section summarizes available findings on the values of fare elasticities in various systems, and their systematic dependence on the characteristics of the population as well as of the transit system itself. Of particular interest are elasticities associated with fare free demonstration projects, which are summarized in section three. Elasticities with respect to service characteristics and trip quality attributes are presented in section four. Finally, the market segments are defined for analysis purposes in section five, followed by concluding comments.

1. Conceptual Background

1.1. Definition

Elasticities capture the sensitivity or response of demand to changes in the values of the attributes or characteristics of the transportation system. Because the principal attribute of interest in this study is the fare, the focus of this discussion is on fare elasticities. The fare elasticity of demand, or ridership, can be defined as the percent change in ridership in response to a one percent change in fare. The mathematical definition of elasticity is given in reference to a demand function, which expresses the dependence of ridership on fare, as well as on other pertinent attributes, primarily level of service characteristics (such as frequency of service, travel times and reliability). Thus, given the demand function shown in Figure 1, the point elasticity (so called because it is defined at a particular point along the demand curve) is given by

point elasticity: $\varepsilon_0 = \frac{\partial V}{\partial F} \cdot \frac{F_0}{V_0}$

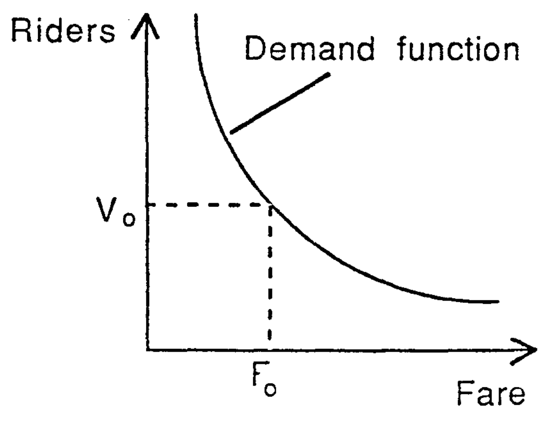

Figure 1

In this equation, F_0 is the prevailing fare and V_0 is the corresponding ridership. To calculate the point elasticity, one must take the partial derivative ("∂") of the demand function, with respect to the fare variable, multiply it by the original fare, F_0 and then divide by the original number of riders, V_0.

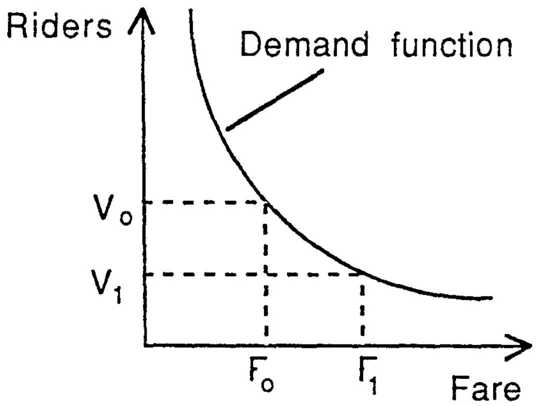

Figure 2

When data on ridership before and after a fare change are available, but the demand function is not known, on can calculate the arc elasticity as follows (V_0 is the ridership before the change, V_1 after the change; F_0 and F_1 are the corresponding fares):

arc elasticity:

$$\varepsilon_{arc} = \frac{\Delta F}{\Delta F} \cdot \frac{F_0}{V_0} = \frac{(V_1 - V_0)/V_0}{(F_1 - F_0)/F_0} \iff \frac{\text{\% change in ridership}}{\text{\% change in fare}}$$

The arc elasticity can thus be interpreted as the <u>% change in ridership per 1% change in fare</u>, so when the ridership is known before and after a fare change, we can simply divide the percent change in ridership by the percent change in fare to calculate the corresponding arc elasticity. If an elasticity is equal to -0.3, then a 3% loss in ridership would result from a 10% increase in fare.

In some cases, particularly when the fare or ridership change is large, a so-called midpoint elasticity is computed, by dividing the change by the average of the before and after values, i.e. the "midpoint" value of the change:

midpoint elasticity: $$\varepsilon_{midpoint} = \frac{(V_1 - V_0)/(V_1 + V_0)}{(F_1 - F_0)/(F_1 + F_0)}$$

The absolute value of the elasticity indicates whether the demand is elastic or inelastic to fare. When the absolute value is less than one (i.e., the elasticities between

+1 and -1), the demand is said to be "inelastic" with respect to fare changes. In this case, an increase in fare will cause an increase in revenues. Even though there is a decrease in ridership, it is a lower percentage than the increase in fare, such that the additional fare collected from the remaining riders still results in a net increase in revenues. Similarly, a decrease in fare will cause a decrease in revenue. However, when the absolute value of the elasticity is greater than one, the demand is said to be "elastic" with respect to fare changes. In this case, an increase in fares will cause a decrease in revenues, whereas a decrease in fares will cause an increase in revenues. In the special case of the absolute value of an elasticity being equal to one, the demand is said to be "unit elastic" with respect to fare changes. That is, the revenues will remain constant regardless of whether the fare is increased or decreased. The evidence collected over many years and from many different systems has firmly established that the demand for transit is inelastic with respect to fares. In other words, a decrease in fares will never generate enough additional riders to compensate for the lost revenues.

1.2. Basis for Estimation

The magnitude and practical implications of calculated elasticities depend on the manner in which these were estimated and the source of information or data on which they are based.

There are two principal sources for determining elasticities: 1) travel demand <u>models</u>, and 2) actual experiments or implemented changes, i.e. <u>before and after studies</u>. Elasticities based on models use the mathematical definition of "point elasticity" given earlier. Before and after studies allow us to calculate arc or midpoint elasticities.

Two types of models can be distinguished for the purpose of estimating elasticities:

- The most common are <u>cross-sectional models</u>, which are developed and estimated based on a cross-section of the population, at a given time. A typical example would be a mode choice model based on a home interview survey conducted in a particular week. The elasticity can be calculated from the coefficients of the cost or fare variable in the utility function in the commonly used logit mode choice model.
- In some cases the elasticity may be based on <u>time-series models</u>, which are developed and calibrated using a sequence of observations taken at different time periods. However, these observations are typically not obtained under controlled conditions, and thus may not be able to separate the effect of the variable of interest (fare in this case), to the same extent as before and after studies.

In addition to the distinction between model-based elasticities and those derived by experimental or quasi-experimental methods, it is useful to distinguish between static versus dynamic approaches to estimate elasticities. A static approach does not involve observations over time, e.g. cross-sectional mode choice models. On the other hand, a dynamic approach can be either model-based or experimental (or quasi-experimental) and is characterized by observations of actual changes over time. Elasticities based on a dynamic approach provide a more appropriate and desirable basis for forecasting the effect of changes in fares (or other attributes). Elasticities derived from a static approach are not based on observations of actual changes and responses thereto, and are therefore more questionable as a basis for forecasting the response to fare changes. To illustrate the effect of the estimation approach on the magnitude of the resulting elasticities, the table below gives the average and standard deviation of elasticities based on different approaches from a variety of cities in North America.

Source	Avg. elasticity ± standard deviation
Dynamic;	
before and after experiments	-0.28 ± 0.16 (67 cases)
Time-Series models	-0.42 ± 0.24 (28 cases)
Static; cross-sectional models	-0.53 ± 0.35 (28 cases)

Source: Lago, Mayworm & McEnroe (1981)

Several points can be noted in connection with the above table:

a. The well-known Simpson Curtin rule (established in the 1950's and 1960's as an industry rule of thumb) states that transit ridership elasticity with respect to fare is approximately -0.3, which is remarkably close to the average elasticities for the "before and after" cases (itself based on data over the last several decades). This implies that -0.3 is probably still a reasonable estimate for the fare elasticity when no other information is available.

b. The source and estimation approach appears to have a systematic effect on the resulting elasticities. For instance, the average magnitude of elasticities obtained from cross-sectional models is approximately twice that obtained from experiments or quasi-experiments. In other words, elasticities based on static models will tend to overpredict the ridership impact of a given fare change by about a factor of two.

c. The implication of the above is that if a mode choice model is calibrated for Austin, for example for TCAP purposes, then the elasticities based on that model ought to be divided by a factor of two in order to provide a realistic basis to study the effect of fare policies.

Another important distinction in the source of data on which elasticities might be based is between revealed preference and stated preference data. Revealed preference data generally consist of observations of actual behavior, from which tripmakers' preferences can be inferred. On the other hand, stated preference data consist of responses to questions on what a tripmaker might do if some hypothetical changes were to be implemented, or if some new service were to be offered. Research has established that what individuals say they might do and what they actually do are not always the same. Nevertheless, stated preference data may be the only practical approach available to assess what user response might be prior to the development and/or introduction of major service changes and new policies for which no historical record is available. Most of the elasticities available in the literature (and discussed in this report) are based on revealed preferences, or observations of actual behavior, using either static or dynamic approaches. However, the past few years have seen increased selective use of stated preference methods in the transit industry, e.g., in a recent study conducted by the Chicago Transit Authority, as well as in several systems in the U.K. and the Netherlands. Such careful and properly controlled use of stated preference methods may be the only practical approach available to gain insight into user preferences and predict responses to innovative fare policies and fare-related programs

1.3. Asymmetries in response to fare increases vs. decreases

Some studies have revealed asymmetries in ridership response to fare changes. These arise because ridership responds differently to a fare increase than to a fare decrease. A fare decrease is not as likely to attract as many new riders as a fare increase of the same magnitude is to lose riders. This is reflected in the absolute value of the elasticity of ridership with respect to a fare decrease being smaller than that corresponding to an increase. There are several possible explanations for this phenomenon. One is that fare decreases may not be sufficient to compensate for the perceived inconvenience of transit service by non-riders (especially staunch non-riders). Another is due to information diffusion and awareness considerations: current riders immediately become aware of fare increases, thereby possibly seeking alternative modes, whereas information about fare decreases may not spread adequately to non-riders to induce them to ride.

Shown in the table below is a summary of elasticities with respect to an increase as well as to a decrease in two of the very few cities where such information is available for both increases and decreases. In addition, average elasticities for increases versus decreases are also reported.

Elasticity

City	Fare Decrease	Fare Increase
Atlanta	-0.18 (1972)	-0.60 (1971)
Madison		2 - 3 times larger than that for a fare decrease

Action	Average Elasticity ± Standard Deviation
Fare Increase	-0.34 ± 0.11 (14 cases)*
Fare Decrease	-0.37 ± 0.11 (9 cases)*

Source: Lago, Mayworm & McEnroe (1981)

* The fare increase value is an average of: Cincinnati (1957), San Francisco (1952), Chicago (1957 & 1970), Atlanta (1963 &1971), Cleveland (1973), York (1948), Jacksonville (1970), Springfield (1949), Portland (1958), Hartford (1958), and 2 values from Boston (1955). The fare decrease value is an average of Atlanta (1972), Seattle (1973), Cincinnati (1973), Kent (1967), Richmond (1973), and 2 values each from St. Louis (1973) and San Diego (1972).

Note that when values are averaged, erroneous interpretations may result. For instance, data from the two cities where elasticities are available for both increase and decrease clearly indicate that the elasticity with respect to fare increase is about 3 times greater than that for a decrease. However, the average values taken over many cities indicate essentially equal values. The reason is that these averages are taken over different cities and different years in each case. Therefore, no proper basis exists for comparing the average values.

In the next section, some general trends in reported values of elasticities are discussed. In particular, the sensitivity of different market segments, defined on the basis of time of travel, trip purpose, trip length, route type and income, are examined. Unfortunately, much of the reported data does not differentiate between elasticities estimated from cross-sectional (static) models and those based on experimental or quasi-experimental methods. Nevertheless, the resulting patterns and insights are valuable for purposes of the Capital Metro fare study.

2. Elasticities for Various Market Segments

2.1. Time of Day

Time Period	Average Elasticity ± Standard Deviation
Peak	-0.17 ± 0.09 (5 cases)
Off-Peak	-0.40 ± 0.26 (5 cases)
All Hours	-0.29 ± 0.19 (5 cases)

Source: Lago, Mayworm & McEnroe (1981)

Peak ridership is much less elastic with respect to fares than off-peak ridership. Most peak trips are work trips, i.e. required, whereas off-peak trips tend to be more discretionary in nature, such as shopping and recreational trips. Therefore a fare change is likely to have a greater effect on off-peak trips.

2.2. Trip Purpose

Trip Purpose	Average Elasticity ± Standard Deviation
Work	-0.10 ± 0.04 (6 cases)
School	-0.19 (1 case)
Shop	-0.23 ±0.06 (5 cases)

Source: Lago, Mayworm & McEnroe (1981)

As expected, work trips exhibit the least elasticity with respect to fares. Though only based on one case, school trips appear to be slightly more elastic than work trips, even though the school trip is in principle not optional to the student. However, students and their families may arrange for alternative transportation involving other members of the household or neighbors. The shopping trip is the most discretionary, and therefore would have the highest elasticity.

2.3. Transit Mode

Transit Mode	Average Elasticity ± Standard Deviation
Bus	-0.35 ± 0.14 (12 cases)
Rapid Rail	-0.17 ± 0.05 (10 cases)
Commuter Rail	-0.31 (1 case)

Source: Lago, Mayworm & McEnroe (1981)

For systems where more than one transit modal alternative is available, e.g., bus and rail, reported elasticities exhibit higher values for bus trips. Note that there is only one case for the commuter rail elasticity, so this value may not be representative.

This data is not directly applicable to the Capital Metro service area since only bus service is available. However, it might suggest that ridership on the "premium" services (e.g., express buses) may be less elastic to fare changes (read increases) than regular service. This is corroborated by the next set of results for different route types.

2.4. Route Type

Route Type	Average Elasticity ± Standard Deviation
Radial arterial (routes)	-0.09 ± 0.02 (3 cases)
Intrasuburban (routes)	-0.31 ± 0.05 (3 cases)
System-wide (all routes)	-0.24 ± 0.08 (3 cases)

(The 3 cases are: Bus, Rapid Rail and Commuter Rail in London, [1977])

CBD oriented (routes)	-0.40 ± 0.04 (3 cases)
Non-CBD oriented (routes)	-0.62 ± 0.09 (3 cases)
System-wide (all routes)	-0.55 ± 0.08 (3 cases)

(2 of these cases are: San Diego, peak [1972 - 1975] and Minneapolis/St. Paul, peak [1976].)

Intra-CBD (routes)	-0.52 ± 0.11 (4 cases)

(The 4 cases are: Portland, all hours [34 months, before 1980]; Albany, off-peak [6 months, before 1979]; Seattle, all hours [10 months, before 1980]; and Knoxville, all hours [18 months, before 1980].)

System-wide (all routes)	-0.43 ± 0.08 (3 cases)

(The 3 cases are: Portland, all hours [34 months, before 1980]; Albany, off-peak [6 months, before 1979]; and Seattle, all hours [10 months, before 1980].)

Source: Lago, Mayworm & McEnroe (1981)

The radial trip often corresponds to a CBD work trip and would therefore be less elastic than the intrasuburban trip. Intrasuburban trips could be more evenly divided between work or shopping purposes. Even if it is a work trip, it would be sensitive to fares because suburban offices generally do not have the parking limitations associated with CBD destinations. The system-wide average would, of course, be somewhere in between. For the same reason, one would expect the CBD oriented trip to be less elastic than the non-CBD trip, as reflected in the above table. The intra-CBD trip would be more elastic than the average trip because it tends to be a short trip, competes with walking and may be given up altogether.

2.5. Trip Length

Trip Length	Average Elasticity ± Standard Deviation
London: Bus	
• trips less than 1 mile	-0.55 (1 case)
• trips between 1 and 3 miles	-0.29 (1 case)
London: Rapid Rail	
• trips between 1 and 3 miles	-0.25 (1 case)
• trips greater than 3 miles	-0.60 (1 case)

Source: Lago, Mayworm & McEnroe (1981)

In general, short trips are more elastic than long trips. The bus is competing against walking (a free, but sometimes inconvenient alternative) for the short trips. A reason the opposite appears true for the case of London rapid rail is that the more circuitous surface street layout, compared to the directness of the rail system, may actually be masking the true length of a trip by competing modes.

2.6. City Size

City Size	Average Elasticity ± Standard Deviation
Populations greater than 1 million	-0.24 ± 0.10 (19 cases)
Populations 500,000 to 1 million	-0.30 ± 0.12 (11 cases)
Populations less than 500,000	-0.35 ± 0.12 (14 cases)

Source: Lago, Mayworm & McEnroe (1981)

As one would expect, cities with larger populations exhibit lower elasticities than smaller cities. In general, larger cities have more traffic congestion and less parking (and hence more expensive).

3. Elasticities Associated with Free-Fare Demonstrations

This section summarizes available findings regarding the response of different ridership groups to partial or total free fare experiments conducted in Denver, Trenton, Portland and Seattle. It should be noted in connection with the reported values that elasticities can be a misleading indicator of tripmaker response to such experiments. Elasticities are calculated relative to existing ridership levels before the introduction of the free fares, and do not as such capture information of the relative size of the potential market of non-users. In addition, because the demonstration projects in question may have involved simultaneous major service increases or improvements, the measured response cannot be attributed solely to the fare element of the changes.

Fare Change to Fare-Free	Average Elasticity ± Standard Deviation
Within CBD only	-0.52 ± 0.11 (4 cases)
(3 of these cases are: Portland, Albany, and Knoxville)	
System-wide	-0.30 ± 0.17 (6 cases)
(5 of these cases are: Madison; Auburn; Rome, Italy; Denver; & Trenton)	

Source: Lago, Mayworm & McEnroe (1981)

The elasticity associated with fare-free travel in the CBD only is generally higher than that for systemwide free travel. This parallels the earlier finding that intra-CBD trips are more elastic than the average system trip. For many intra-CBD trips, walking is a viable alternative, which competes with transit. The higher elasticity of these trips is the result of individuals choosing to ride for free rather than walk. It is noteworthy that the average systemwide elasticity associated with a change to free-fare is virtually identical to the average fare elasticity calculated from less extreme fare changes. As such, it suggests that no significant additional impact on ridership can be attributed to free fares beyond that associated with the reduction in the monetary amount of the fare.

Given the objectives of the present study, a more detailed examination of elasticities associated with free fares is useful. The following income-based elasticities were derived from the free fare demonstrations in Trenton and Denver:

Household Income (1978 $)	Denver's Off-Peak Elasticity	Trenton's Off-Peak Elasticity
Under $5,000	-0.28	-0.09
$5,000 to $9,999	-0.24	-0.10
$10,000 to $14,999	-0.25	-0.41
$15,000 to $24,999	-0.28	-0.08
$25,000 or more	-0.31	-0.43

Source: Lago, Mayworm & McEnroe (1981)

When two other cases (unknown, and not stated whether free fare or not) are included the following average elasticities are obtained:

Income Group	Average Elasticity ± Standard Deviation
Less than $5,000	-0.19 ± 0.10 (2 cases)
$5,000 to $14,999	-0.25 ± 0.11 (4 cases)
More than $15,000	-0.28 ± 0.13 (4 cases)

Source: Lago, Mayworm & McEnroe (1981)

Given the large standard deviations associated with the above values, it is not clear that the apparent numerical differences in the average values are really significant, especially since they are based on so few cases. For instance, the results in Denver and Trenton do not suggest any consistent trend. Note that the elasticities given for Denver and Trenton are for off-peak trips and are therefore more likely to be discretionary. Surprisingly, the impact of the free fares on the low-income ridership in Trenton is relatively low. The following elasticities for various trip purposes were determined from the Trenton demonstration:

Trip Purpose	Off-Peak Fare Elasticity
Work	-0.11
School	-0.19
Shop	-0.25
Medical	-0.32
Recreation	-0.37
Social	-0.25
Other	-0.19
Aggregate Value	-0.19

Source: Lago, Mayworm & McEnroe (1981)

As expected, the work trip is the least elastic, while recreational trips are the most elastic. Note, however, that the work trip is probably not well represented among off-peak trips.

The fare elasticities by age group were also determined in the Denver and Trenton free fare demonstrations. These are reported below:

Age Group	Denver	Trenton	Average Elasticity ± Std. Dev.
1 to 16 years	-0.32	-0.31	-0.32 ± 0.01
17 to 24 years	-0.30	-0.24	-0.27 ± 0.03
25 to 44 years	-0.28	-0.08	-0.18 ± 0.10
45 to 64 years	-0.18	-0.12	-0.15 ± 0.03
65 and more years	-0.16	-0.12	-0.14 ± 0.02

Source: Lago, Mayworm & McEnroe (1981)

In general, older riders tend to be less elastic to fares, with respect to either increases or decreases, than younger riders. One explanation is that older persons may already be in the "transit habit," and because the very old are less likely to drive and in some cases may be transit-dependent, whereas non-riders may be more reluctant to experiment. Furthermore, in the free fare demonstrations, older riders may have been discouraged from further use of the system by the higher level of crowdedness and discomfort induced by large numbers of teenagers (the group with the largest response to the free fare).

Available examples of free fare elasticities for different cities are shown below followed by a discussion of the corresponding schemes and related findings:

Location	Elasticity
Portland's Fareless Square	≈ -7.2 to -8.0 (CBD area only)
Seattle's Magic Carpet	-2.0 (CBD area only)
Denver's Off-Peak Demonstration	-0.52 (off-peak)
	-0.32 (overall)
Trenton's Off-Peak Demonstration	-0.46 (off-peak)

Sources: Colman (1979[1]); Colman (1979[2]); Donnelly, Ong, and Gelb (1980); Spear and Doxsey (1981).

Some pertinent information regarding the above cases is summarized hereafter.

Portland's Fareless Square *(Source: Colman,1979a):*

- Begun in January 1975, over an area of 280 square blocks.
  Expanded in 1977 to an area of 350 square blocks, which includes offices, retail establishments, high rise condominiums/apartments, an urban renewal area and Portland State University.
- All bus trips within the CBD are free during all hours, seven days per week. In the CBD, passengers may board and exit the bus from the front or rear door. When the passengers board outside the CBD, they pay as they get on the bus. If going through the zone, they ask for transfers when boarding and return them when getting off (so that the driver knows they have paid). When transferring buses in the CBD to an eventual destination outside the CBD, the transfer is returned when getting off

the second bus. Any applicable zone fees will be paid at that time. When the passengers get on the bus in the CBD and ride beyond the Fareless Square boundary, they pay all fares and transfers when getting off the bus. If a transfer is needed to another non-CBD bus, it is requested when getting off the bus. Outside the CBD, only the front door of the bus is used for boarding and alighting.

- Ridership on the downtown shuttle was estimated to be between 900 and 1000 trips per day before the introduction of the Fareless Square promotion. A ridership survey in November, 1977 indicated 8200 trips per day in the Fareless Square. This yields an elasticity of between -7.2 and -8.0. ((8200-1000)/1000 = 7.2% increase in ridership with a 100% decrease in fare, for an elasticity of 7.2%/-100% = -7.2). Two factors contribute to this distorted and misleadingly high value: 1) service coverage was significantly increased in the zone, and 2) the initial level was quite low, thereby yielding rather high relative increases.
- The "Shop Hop" operated in the CBD prior to the Fareless Square. This service charged 10¢ per ride. Two buses operated at 10 minute headways from 10 a.m. to 4 p.m. Monday - Friday on only two streets.
- Between 1975 and 1977, overall Tri-Met service was increased by 17%, thereby precluding the attribution of the observed ridership exclusively to the free fare.
- 4% of the trips in Portland are made by transit; 28% of the CBD trips are transit trips.
- When the Fareless Square began, the 35/75¢ zone charge was changed to a 35¢ flat fare, and monthly passes were introduced. In September 1978, a 45/65¢ zone charge was put into effect.
- Fareless Square start-up costs: $5300 for a rider's contest to name the free fare zone; $5900 for promotion in January and February 1975 (art production, printing, etc.); and $910 for 200 signs.
- The free service costs Tri-Met $218,000 per year (0.4% of their operating budget), which are paid out of the regular operating budget (there is no special funding for the service). Thirty additional vehicle hours per day were required during the P.M. peak (0.6% of the "current" service). [See chart in Fig. 3 "Estimated Costs and Operating Results of Fareless Square, FY 1978/79"]
- Two-thirds of the new trips were made between 9 a.m. and 4 p.m.
- An increase in boarding speed was noticed due to the elimination of fare collection. However, this may have been offset overall by the increase in the number of

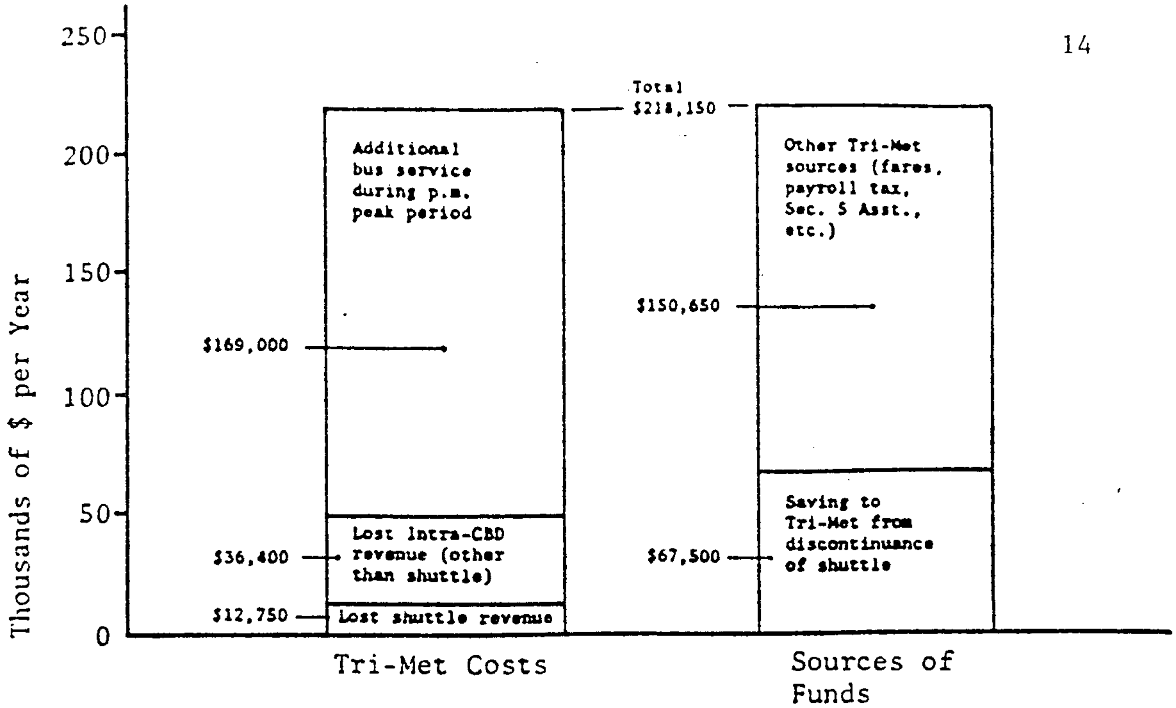

Figure 3
ESTIMATED COSTS AND OPERATING RESULTS OF FARELESS SQUARE, FY 1978/79

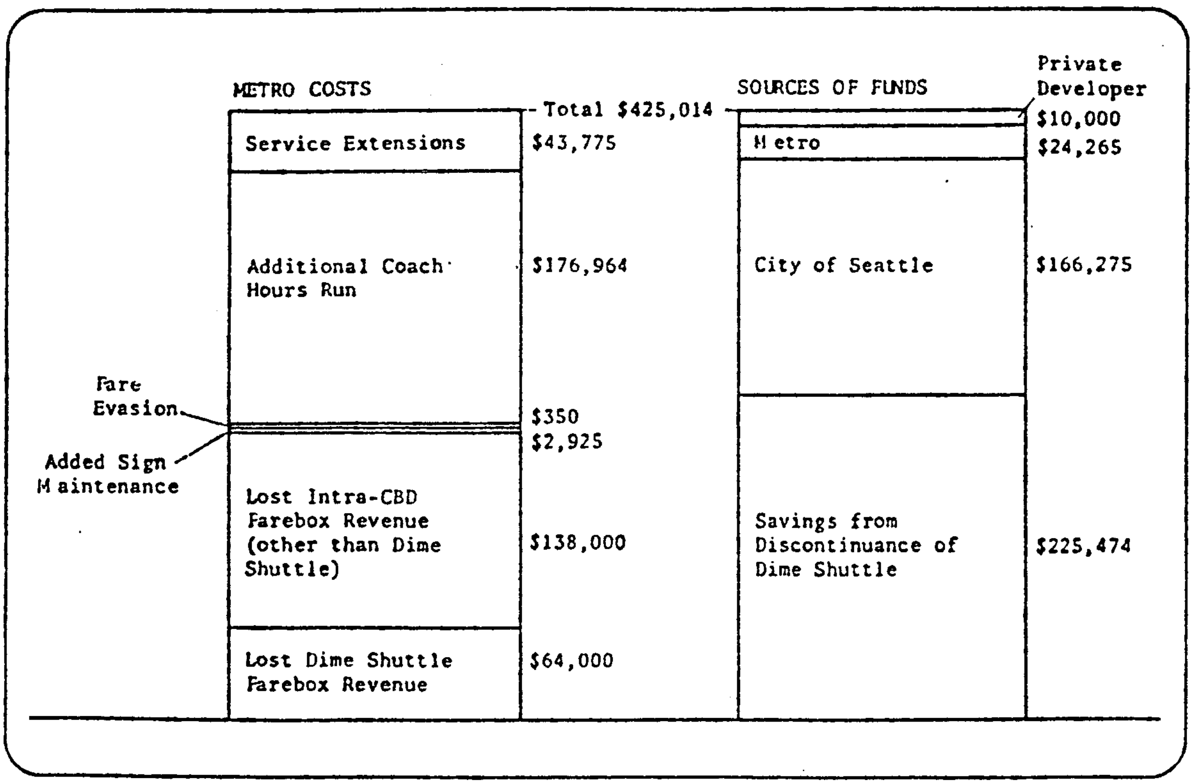

Figure 4
MAGIC CARPET COSTS ESTIMATED BY METRO FOR 1978

Source: METRO Transit Planning Department passengers and the pay-on-exit system. No estimates of the net effect are available.

- A slight though probably insignificant increase in retail sales was noted.
- Riders in the Fareless Square appear to have a slightly higher average income than the average Tri-Met passenger.

Seattle's Magic Carpet *(Source, Colman, 1979b):*

- Began in 1973 in a 1/2 square mile area of the CBD, consisting mostly of retail, tourist and office centers, it has been expanded twice (1974 & 1978) to an area of 2/3 square mile. In 1974, four bus stops were added. In 1978, urban renewal and some residential areas were added to the free fare zone including most of the Regrade residential area. Previously, a downtown shuttle system charging 10¢ per ride and called the Dime Shuttle provided service with 5 minute headways between 10 a.m. and 3 p.m., Monday - Friday.
- Intra-CBD ridership increased from 4100 to 12,250 trips per day. This represents an elasticity of -2.0. However, as noted, this cannot be interpreted as a fare elasticity since service coverage and other service attributes changed as well.
- Most new trips are made between 11 a.m. and 2 p.m. Of the people who made these trips before, most had walked (45%) or ridden the bus (41%).
- Previous riders appear to have increased the frequency of their use.
- Seattle uses a similar pay-when-exit system as in Portland.
- Boarding time was reduced by about 20% in the CBD, though longer deboarding times were noted outside the CBD during the peak hours.
- Riders in the free-fare zone appear to have a slightly higher average income than the average passenger on the system as a whole.
- The City of Seattle paid from its general fund for most of the incremental costs of the free fare service. [See chart, in Fig. 4, of "Magic Carpet Estimated by Metro for 1978"]

Denver's Free Off-Peak Demonstration *(Source: Donnelly, Ong, and Gelb, 1980; and Studenmund, Swan and Connor,1979):*

- The demonstration took place between February 1978 and January 1979. It was begun as "transit Awareness Month" in February 1978, and was subsequently extended several times until the local and federal agreement to make it a one-year demonstration project. Its primary purpose was to reduce the massive air pollution problems that the city was facing at the time. All buses on all routes were free, except between 7 and 9 a.m. and 4 and 6 p.m., Monday - Friday. The morning peak was redefined on May 1, 1978, to 6-8 a.m.

- The average off-peak fare prior to the demonstration had been 25¢, while the peak fare remained 50¢. [See Table 1 for fare structures before, during and after the demonstration.]
- Because of a lack of pre-implementation data, the "before" data came from surveys (i.e. stated usage) rather than being observed, and is therefore of questionable reliability.
- A large number of new motor coaches were put into service in early 1978. Major route restructuring was also implemented during the demonstration, which limits one's ability to separate and assess the effect of the fare elimination.
- Relatively large increases in weekday off-peak ridership (50%), Saturday ridership (50%), and Sunday ridership (100%) were observed.
- Approximately 34.3 million trips were made during the demonstration (about 8.2 million more than projected without the free off-peak, or ≈31% increase). This is approximately 118,500 trips per weekday (about 26,000 more than without the free off-peak, or ≈28% increase).
- 70% of the weekly trips during the demonstration were made during the off-peak.
- The bus mode share of the intra-regional trips was 2.4% before the demonstration and 3.1% during the demonstration.
- For CBD trips, the bus carried less than 9% before the demonstration, and ≈11% during.
- The ridership gain was rapid: 85% of the maximum impact was attained shortly after the first month.
- Five months after the reinstatement of the 25¢ off-peak fare, the ridership was an estimated 7% higher than if there had not been the demonstration. However, it should be noted that when the free fares were discontinued, tokens and passes were promoted more heavily in order to dampen the ridership loss due to the termination of the demonstration.
- Attitude surveys indicated that passengers became more negative about overcrowding, late buses and security problems. A significant number of users switched to the peak or stopped bus use entirely.
- Approximately one-half of the nearly $7 million needed to fund the project for one year came from a Federal UMTA grant.
- RTD experienced a 40% reduction in fare revenues, or 6% of the total operating budget.

Table 1
DENVER RTD FARE SCHEDULES: 1977, JANUARY 1978, AND 1979 AFTER FREE FARE

Type of Service	1977 Peak	1977 Off-Peak	January, 1978[a] Peak	January, 1978[a] Off-Peak	1977 & 1978 Monthly Pass	1979, After Free-Fare[a] Peak	1979, After Free-Fare[a] Off-Peak	1979, After Free-Fare[a] Monthly Pass
Local								
Regular	$.35	$.25	$ .50	$ .25	$15.00	$ .50	$ .25	$15.00
E&H[b]	.25	.15	.50	.25	12.50	.50	free-.10[c]	12.00
Students	.20	.20	.50	.25	12.50	.50	.25	12.00
Express								
Regular	.50	.50	.75	.75	25.00	.75	-	25.00
E&H	.40	.40	.75	.25	22.50	.75	.25[d]	22.50
Students	.35	.35	.75	.25	22.50	.75		22.50
Circulator								
Regular	.25	.25	.25	.25	7.50	.25	.25	7.50
E&H	.15	.15	.25	.25	5.00	.25	free-.10[c]	5.00
Students	.20	.20	.25	.25	5.00	.25	.25	5.00
Transfer[e]	.05	.05	free	free		free	free	
Intercity								
Medium Distance	-	-	1.00	1.00	32.00	.75-1.00	.75-1.00	35.00
Long Distance	-	-	1.25	1.25	40.00	1.25	1.25	40.00[f]
E&H	-	-	.50	.50	28.00-35.00	1.75-1.25	free-.50[c]	35.00

[a]The off-peak free-fare program began February 1, 1978 and continued through January 31, 1979.

[b]Elderly (over 65 years) and handicapped.

[c]Elderly ride free during off-peak hours; handicapped persons ride at reduced fares.

[d]Express buses do not serve off-peak hours. Should elderly or handicapped persons board an express bus completing a run after the peak period has ended, they receive their off-peak reduction.

[e]Transfers are free since 1978; patrons transferring from a lower to a higher grade of service, however, are required to pay the difference in fares.

[f]Reduced monthly pass rate is also available to students.

- Additional bus service (about a 1% increase) was added to help ease the overcrowding problems.
- 60% of the metropolitan area residents never used the free service.
- Researchers have concluded that free fare can be effective as a short-term marketing instrument, though reduced or low fares during the off-peak may produce similar results.

Trenton's Free Off-Peak Demonstration *(Sources: Knight, 1978; Spear and Doxsey, 1981; and Studenmund, Swan and Connor, 1979):*

- The population of Trenton, New Jersey was decreasing at a rate of almost one percent per year at the time of the demonstration. The population was around 104,000. Most of the population was low-income, elderly and/or carless. Mercer County was approximately twice the size of Trenton and was growing at that time. Most of the residents of the county were fairly affluent.
- One objective of the demonstration, aside from learning more about free fares, was to help revitalize Trenton's CBD.
- The demonstration was from March 1978 - February 1979.
- All trips on all buses within Mercer County, New Jersey were free (a few routes to special locations outside the county were not included in the demonstration) during the off-peak. The off-peak was defined as all day Sunday and holidays, and from 10 a.m. to 2 p.m. and after 6 p.m. Monday - Saturday.
- Most off-peak trips charged a fee of 15¢, with transfers charging an additional 5¢, before the demonstration. The longest intracounty trips charged fares of 20¢ and 25¢ during the off-peak. The peak fares remained at 30¢, 40¢, and 50¢, respectively.
- It is claimed that extensive planning before the demonstration produced relatively reliable "before" data. Several surveys were conducted before and during the demonstration, including phone and on-board surveys, as well as interviews with patrons in a major shopping mall.
- In order to maintain better experimental control, no other major service changes were made at the time.
- The demonstration was funded by a $500,000 grant from UMTA. The total cost was estimated to potentially reach $750,000 not including evaluation.
- Off-peak weekday ridership increased an average of 56% during the demonstration. This impact is lower than the one observed in the Denver demonstration. Some possible reasons include the simultaneous service

improvements in Denver, shorter off-peak period in Trenton, and the lower pre-demonstration fare in Trenton.

In summary, the free fare demonstrations have yielded mixed results. On one hand, there have been increases in ridership on the affected portions of the system and during the affected times of the day (or day of the week); on the other hand, these increases were either unsustained, did not achieve the broader societal role of transit of attracting auto driver trips (instead picking up mostly otherwise walking trips), or not exclusively due to fare elimination per se. The mixed record nevertheless points to the fact that free fares can be most effective as a promotional device for major service improvements. The successful demonstrations were accompanied by such service coverage or quality changes. This leads to a fundamental question facing a transit operator contemplating fare reductions as an inducement to ridership: what is the relative impact on ridership of fare changes compared to that of service improvements. This is especially important because all available evidence indicates that ridership is inelastic to fares, in that decreasing fares will always lead to losses in revenues. Had these lost revenues been invested instead in service improvements, would the impact be greater or smaller than that of the fare decrease?

The next section attempts to provide an answer to this question by reviewing available evidence on the elasticity of transit ridership with respect to changes in the level of service characteristics.

4. Elasticities with Respect to Service Changes

This section reviews available elasticities with respect to changes in overall supply (vehicle-miles of service), route characteristics (headway for frequency), as well as individual trip attributes (total trip time, in-vehicle travel time, walk time, transfer time and number of transfers).

4.1. Overall Supply

Overall supply is measured in terms of vehicle miles of service, which could represent changes in coverage (spatial and temporal), routing or frequency (or any combination thereof). Below is a summary of reported demand elasticities with respect to vehicle miles.

Vehicle-miles	Elasticity ± Standard Deviation	
Bus (quasi-experimental)		
All hours	+0.63 ± 0.24	(3 cases)
Bus (non-experimental)		
Peak	+0.33 ± 0.18	(3 cases)
Off-peak	+0.63 ± 0.11	(3 cases)
All hours	+0.69 ± 0.31	(17 cases)
Rapid Rail (non-experimental)		
Peak	+0.10	(1 case)
Off-peak	+0.25	(1 case)
All hours	+0.55	(1 case)

Source: Meyer and Miller (1984)

These elasticities are of course positive since more vehicle-miles represent an improvement to the system, which would be expected to increase ridership. The average of the reported elasticities for the peak trips is less than for the off-peak trips (approximately one-half the value). Note that the peak average is based only on 3 cases, and has a rather high associated variability (as measured by the reported standard deviation). Furthermore, to the extent that the peak values are based on non-experimental methods (i.e., inferred from static models), their reliability and validity are dubious because vehicle miles is not a commonly used explanatory variable in travel demand models, and the model specification is likely to have included variables that correlate with it (so that its effect may not be properly captured by the associated coefficient value in the estimated model).

An interesting aspect of the data presented in the above table is that the average elasticities based on quasi-experimental approaches are about equal to those based on non-experimental approaches, unlike the fare elasticities discussed earlier. More importantly, this value is about twice as large as the elasticity with respect to fares, meaning that a 1% increase in supply results on average in twice as much ridership increase than a 1% fare reduction.

4.2. Route Characteristics

Headway	Average Elasticity ± Standard Deviation
Bus (quasi-experimental)	
Peak	-0.37 ± 0.19 (3 cases)
Off-peak	-0.46 ± 0.26 (9 cases)
All hours	-0.47 ± 0.21 (7 cases)
Commuter rail (quasi-experimental)	
Peak	-0.38 ± 0.16 (5 cases)
Off-peak	-0.65 ± 0.19 (5 cases)
All hours	-0.47 ± 0.14 (5 cases)
Commuter rail (non-experimental)	-0.47 ± 0.11 (4 cases)

Source: Meyer and Miller (1984)

As one would expect, the headway elasticity is negative, indicating a loss of ridership in response to longer headways (which imply longer waiting times). The headway elasticities are also somewhat lower for the peak trips, though there is no indication of whether the values are based on increases or decreases in headway. The smaller elasticities may reflect either an already well-served market segment (peak work trips), or a less flexible group of commuters. There appears to be no significant difference between the elasticities for bus and commuter rail, regardless of method of calculation, with the exception of off-peak trips (which exhibit a rather higher degree of variability).

4.3. Individual Trip Attributes

These elasticities are with respect to the attributes of individual trips rather than those of a route or of the system. As such, these values come closer to capturing the riders' preferences and attitudes towards the service as it affects the quality of particular trips. These elasticities are based almost exclusively on non-experimental approaches, relying primarily on discrete choice models of individual mode choice behavior, usually calibrated using a cross-section of tripmakers.

The first attribute considered is the total travel time for a trip, which includes the walking and waiting times in addition to the in-vehicle travel time.

Total Travel Time	Average Elasticity ± Standard Deviation
Bus (non-experimental)	
Peak	-1.03 ± 0.13 (2 cases)
Off-peak	-0.92 ± 0.37 (2 cases)
Bus and rapid rail (non-experimental)	
Off-peak	-0.59 (1 case)

Source: Meyer and Miller (1984)

The elasticities reported indicate that riders are more sensitive to total travel time than to comparable percent changes in any other feature. The absolute values of the travel time elasticities may actually exceed 1, indicating that a percentage point improvement in total travel time induces more than a 1% increase in ridership.

Next, the in-vehicle component of the total travel time is considered.

In-Vehicle Time	Average Elasticity ± Standard Deviation
Bus (quasi-experimental)	
Peak	-0.29 ± 0.13 (9 cases)
Off-peak	-0.83 (1 case)
Bus (non-experimental)	
Peak	-0.68 ± 0.32 (7 cases)
Off-peak	-0.12 (1 case)
Rapid rail (non-experimental)	
Peak	-0.70 ± 0.10 (2 cases)
Bus and rapid rail (non-experimental)	
Peak	-0.30 ± 0.10 (2 cases)
All hours	-0.27 (1 case)
Commuter rail (non-experimental)	
All hours	-0.59 ± 0.28 (9 cases)

Source: Meyer and Miller (1984)

As expected, riders are less sensitive to improvements in in-vehicle travel time than they are to total travel time. In-vehicle travel time is generally much better tolerated than waiting time. The limited number of cases make any general conclusions regarding the differences between peak and off-peak, bus and rail, or non- and quasi-experimental calculation methods difficult. The values are nevertheless relatively high, especially when compared to the fare elasticities.

In the case of walk-time, the person's reaction is greater during the peak hours. This may be because people traveling during the peak have less flexibility in their schedules and are therefore more sensitive to changes in this attribute. However, it is not appropriate to generalize on the basis of just one case.

Transfer-time	Average Elasticity ± Standard Deviation
Bus and rapid rail (non-experimental)	
Peak	-0.40 ± 0.18 (3 cases)
Number-of-transfers	
Bus (non-experimental)	
Off-peak	-0.59 (1 case)

Source: Meyer and Miller (1984)

The above values indicate that travelers appear to be more sensitive to relative changes in the number of transfers than in the transfer time. Such information is however difficult to obtain because it has not been adequately addressed in past studies.

In general, it appears that riders are less sensitive to fare changes than to changes in the level of service provided by the transit system. While fare changes do affect ridership, a transit agency would realize a larger impact by improving the overall service.

5. Definition of Market Segments

The above fare elasticities can be used to explore the ridership impacts of alternative fare changes and policies in connection with appropriately defined market segments. At this stage, a detailed set of market segments has been defined for this purpose. These are intended primarily to provide a conceptual framework for the analysis. However, it should be noted that the data is not presently available to support such fine differentiation across segments. The market segments are defined on the following criteria:

a. Service Type: regular fixed route service, Park & Ride, 'Dillo and STS
b. Socio-Demographic Characteristics: students, senior citizens, mobility-impaired and "regular" (the latter corresponding to those that currently pay full fare, whereas the first three receive half-price discounts).
c. Transit Status: riders who possess a valid driver's licence and have access to a car (choice rider); riders who have a valid driver's licence, but no access to a car; and riders who do not have a valid driver's licence (captive riders).
d. Pass Usage: Pass, no pass
e. Time-of-Day: Peak, off-peak
f. Trip Length: Long trip, short trip.

Figure 5 lists all the combinations for each service type in this study. An explanation of the rationale for including or excluding certain categories is presented hereafter for each service type.

Regular Fixed Route Service For "regular" and mobility impaired riders, all combinations of the levels of factors c-f above are considered. Because students' trips do not exhibit the concentrated patterns of commuters, time-of-day is not considered for that group. Pass usage is also not considered for students because they do not receive the one-half price discount for passes (as they do with cash fares), and student passes will apparently be phased out upon the acquisition by Capital Metro of the Laidlaw-operated UT Shuttle Bus System. Therefore, the only market segments considered for student trips, on regular routes, are defined on the basis of captive status and trip length. Time-of-day is also not considered for senior citizen trips. However, all other combinations will be considered for senior citizens' trips on regular routes.

Park & Ride Routes The majority of the service provided by the Park & Ride routes takes place during the peak hours, and corresponds to long trips. Therefore, only one level of each of the trip length and time-of-day factors are considered. All combinations of the levels of captive status and pass usage are considered for all user types of Park & Ride, with the exception that pass usage is not included for students (for the same reasons mentioned earlier).

'Dillo Most of these trips are short, therefore only this level is considered for the trip length factor. Because all riders currently pay the same fare, 'Dillo riders are not partitioned on the basis of sociodemographics. All possible combinations of captive status, pass usage, and time-of-day are considered.

The above segmentation is deliberately very detailed in order to provide a flexible basis for analysis and evaluation. The classes defined can be easily aggregated into classes compatible with the available data and the purposes of any particular analysis.

6. Concluding Comments

The elasticities reviewed in this report provide a distillation of the transit industry's experience. However, several important cautionary comments must be kept in mind when trying to interpret this data:

1) There is considerable variability across systems and over time in the reported elasticities; this is compounded by the differences in the sources for and the

manner in which the elasticities were computed. Therefore, extreme caution must be exercised in trying to apply the results locally.

2) The elasticities reported are in most cases aggregate measures for a whole system or portions thereof. The documented variation of the elasticities across market segments and service types further suggests that it is dangerous to take such aggregate values and apply them to very specific localized proposals.

3) Fare decreases will never attract sufficient riders to compensate for the loss in revenues. In subsequent analysis, we will examine cost trade-offs between alternative actions for a given ridership impact, and compare such actions and policies on the basis of subsidy per additional rider.

4) Major limitations in using transferred fare elasticities for policy analysis are that issues of service quality are ignored (i.e., the same response to fare changes is predicted regardless of whether the service is convenient or not), and that no provision is made for the effect of information dissemination and promotional activities. Both of these factors can be critical in the Capital Metro situation.

5) Information on user response is critically needed at the local level for future Capital Metro planning activities. Such information could be obtained using stated preference approaches (successfully tried elsewhere) and possibly small-scale targeted experimentation.

REGULAR ROUTES

FULL FARE
LNC-P-PK-ST
LNC-P-PK-LT
LNC-P-OPK-ST
LNC-P-OPK-LT
LNC-NP-PK-ST
LNC-NP-PK-LT
LNC-NP-OPK-ST
LNC-NP-OPK-LT
LC-P-PK-ST
LC-P-PK-LT
LC-P-OPK-ST
LC-P-OPK-LT
LC-NP-PK-ST
LC-NP-PK-LT
LC-NP-OPK-ST
LC-NP-OPK-LT
NL-P-PK-ST
NL-P-PK-LT
NL-P-OPK-ST
NL-P-OPK-LT
NL-NP-PK-ST
NL-NP-PK-LT
NL-NP-OPK-ST
NL-NP-OPK-LT

1/2 FARE--STUDENTS
LNC-ST
LNC-LT
LC-ST
LC-LT
NL-ST
NL-LT

LEGEND
LNC=LICENSED/NO CAR
LC=LICENSED/CAR
NL=NO LICENSE

P=PASS
NP=NO PASS

PK=PEAK
OPK=OFF-PEAK

LT=LONG TRIP
ST=SHORT TRIP

1/2 FARE--SENIOR CITIZENS
LNC-P-ST
LNC-P-LT
LNC-NP-ST
LNC-NP-LT
LC-P-ST
LC-P-LT
LC-NP-ST
LC-NP-LT
NL-P-ST
NL-P-LT
NL-NP-ST
NL-NP-LT

1/2 FARE--MOBILITY IMPAIRED
LNC-P-PK-ST
LNC-P-PK-LT
LNC-P-OPK-ST
LNC-P-OPK-LT
LNC-NP-PK-ST
LNC-NP-PK-LT
LNC-NP-OPK-ST
LNC-NP-OPK-LT
LC-P-PK-ST
LC-P-PK-LT
LC-P-OPK-ST
LC-P-OPK-LT
LC-NP-PK-ST
LC-NP-PK-LT
LC-NP-OPK-ST
LC-NP-OPK-LT
NL-P-PK-ST
NL-P-PK-LT
NL-P-OPK-ST
NL-P-OPK-LT
NL-NP-PK-ST
NL-NP-PK-LT
NL-NP-OPK-ST
NL-NP-OPK-LT

PARK AND RIDE

FULL FARE
LNC-P
LNC-NP
LC-P
LC-NP
NL-P
NL-NP

1/2 FARE--STUDENTS
LNC
LC
NL

1/2 FARE--SENIOR CITIZENS
LNC-P
LNC-NP
LC-P
LC-NP
NL-P
NL-NP

1/2 FARE--MOBILITY IMPAIRED
LNC-P
LNC-NP
LC-P
LC-NP
NL-P
NL-NP

'DILLO
LNC-P-PK
LNC-P-OPK
LNC-NP-PK
LNC-NP-OPK
LC-P-PK
LC-P-OPK
LC-NP-PK
LC-NP-OPK
NL-P-PK
NL-P-OPK
NL-NP-PK
NL-NP-OPK

STS
SENIOR-NON IMPAIRED
SENIOR-IMPAIRED
NON SENIOR-IMPAIRED

Figure 5