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Elasticity of Transit Demand With Respect to Price: A Case Study

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

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ABSTRACT

This report describes the methodology and the results of an empirical study of peak-period transit demand elasticity with respect to price (fare). The results suggest applying different pricing policies to different types of transit service.

Field observations were structured to capture the reactions of morning (inbound) commuters to a peak-period fare increase introduced on September 1, 1975. The study is limited to bus and automobile travelers on the Shirley Highway and to bus passengers on the Lee Highway, both in Northern Virginia. The Shirley buses provide express service on exclusive freeway lanes, whereas the Lee Highway buses provide traditional service on a signalized radial arterial. Typical fares ranged from \$.60 to \$.90 before the increase and from \$.75 to \$1.20 afterwards, resulting in increases of between 20 and 33 percent. Demand for service on the Shirley Highway Express buses proved less elastic (-0.301 to -0.243) than that for the traditional Lee Highway bus service (-0.843 to -0.671). There was little evidence of passengers on either service shifting travel outside the peak periods to avoid higher fares. The fare increase had no effect on auto travel.

Key Words: Elasticity; elasticity of transit demand; pricing; transit planning; transit pricing; transportation economics

I. Introduction

The board of directors of the Washington Metropolitan Area Transit Authority (METRO), after holding public hearings, raised "peak-period" bus fares on September 1, 1975. These fare increases applied only to the peak-period operations (6:30-9:30 a.m. and 3:30-6:00 p.m.); off-peak fares were not changed. The previous fares had been in effect for several years.

This pricing change provided an excellent research opportunity to study commuter reactions to fare increases. When confronted by a peak-period price increase, bus commuters have several options available: they may pay the increased fare and continue to commute by bus; shift their mode of commuting from bus to car or carpool; shift intertemporally from peak to off-peak commuting; or cease commuting.

The purpose of this study is to quantify these reactions for subsequent use in predicting the consequences of proposed peak-period transit fare increases.

The objectives of the research are fourfold:

- to observe and report the elasticity of peak-period transit demand with respect to price (fare)
- to identify and quantify the impact of a peak-period transit fare increase on auto usage and car pools
- to determine whether a peak-period transit fare increase caused any measurable shift in passenger usage from peak to off-peak times
- to compare the elasticities observed on the Shirley Express Buses with those observed on conventional bus service in the same metropolitan area, and to determine if elasticities observed for these two qualities of transit service are significantly different.

This report is organized as follows. The study area and its characteristics are described in Section II below. Procedures for data acquisition and refinements are presented in Section III, while the method of analysis employed is discussed in Section IV. Study results are presented in Section V, and conclusions in Section VI. Section VII is a list of references. This is followed by Appendices containing further references, data sources, special computations, and other supportive information.

The study was structured and implemented on extremely short notice. It could not have been completed to yield useful results without the cooperation and support of many individuals in a number of organizations within the Washington Metropolitan Area.[1]

[1] Significant contributions were provided by the following individuals: Ronald J. Fisher, Bert Arrillaga, and Vincenzo Milione of the Urban Mass Transportation Administration (UMTA), U.S. Department of Transportation, Washington, D.C.; Franklin F. Goodyear and Kenneth A. Brown, Metropolitan Washington Council of Governments, Washington, D.C.; Michael A. Bresnahan, M. F. Hewitt, and G. Perrie Nutwell, METRO, Washington, D.C.; Nathan Avins, and Abdul Sleemi, Department of Highways and Traffic, District of Columbia Government, Washington, D.C.; Robert H. Watkins, Principal, Rock Creek Associates, Washington, D.C.; James M. McLynn, Principal, DTM Inc., Bethesda, MD; Dr. Karla L. Hoffman, Eric Howe, and Cheng Ming Huang, National Bureau of Standards, Gaithersburg, MD; and John H. Mitton, Transportation Consultant, Washington, D.C.

II. Description and Characteristics of the Study Area

Historically, Northern Virginia has been a bedroom community for families of employees working in downtown Washington, D.C. Over the years, large employment centers have also developed within Northern Virginia itself, beginning with the Pentagon in the early 1940's and continuing with the Central Intelligence Agency in Langley, and later with massive office building developments in both Rosslyn and Crystal City.

This study quantifies the reactions of commuters living in the Northern Virginia suburbs who use bus service on Shirley Highway or Lee Highway, when confronted with an increase in peak period fares. Observations were made within the Shirley Highway and the Lee Highway Corridors, both of which are major radial traffic arteries carrying large volumes of automobile and bus transit commuters.

The Shirley Highway is a recently reconstructed radial freeway connecting the southwestern parts of Northern Virginia suburbs with employment centers at the Pentagon, and in Crystal City and downtown Washington. During peak commuter travel periods, an exclusive lane serves bus vehicles as well as car pools of four or more persons. Three regular lanes in each direction are available to serve other traffic.

The Lee Highway is a multi-lane signalized radial arterial connecting the northwestern parts of Northern Virginia suburbs with employment centers in Rosslyn and downtown Washington. As an uncontrolled access facility, Lee Highway serves the needs of local as well as through traffic. Observing and analyzing patronage on these lines permits a comparison of fare elasticities for two levels of bus service--the express service operated on the Shirley Highway, and the conventional bus service operated as the Route 2 and Route 3 lines on Lee Highway.

The census tracts which comprise the Shirley Highway Corridor and the Lee Highway Corridor are indicated in Figure 4 in Appendix B. Tables 11 and 12 in Appendix B list estimated 1974 median family income for census tracts adjacent to the Shirley Highway and the Lee Highway. The median income in the Lee Highway Corridor ($21,180) is higher than that in the Shirley Highway Corridor ($20,036). This may not be true for bus patrons, however. Median family incomes in census tracts adjacent to the Lee Highway bus lines could be weighted towards higher income values by the McLean residential area, whose southern border the lines traverse; the residents of these very high income areas may not, in general, commute by bus. On the other hand, the bottom quarter of the census-tract median family incomes in the Shirley Highway Corridor are notably lower than those for the Lee Highway Corridor.

Selected operating characteristics of the bus service observed in this study are given in Table 1.

TABLE 1: BUS ROUTE OPERATING CHARACTERISTICS, A.M. INBOUND PEAK PERIOD

	SHIRLEY HIGHWAY EXPRESS BUSES OPERATING ON EXCLUSIVE FREEWAY LANES FOR A PORTION OF TRIP						LEE HIGHWAY BUSES OPERATING ON ARTERIAL STREETS		
BUS ROUTE NUMBER[1]: / BUS TRIP CHARACTERISTIC	7A,B, E,F,F/ G,M,N, P,S, W,X	8A,B, E,F,P, S,W,X, Y,Z	17G,G/H H/,M, P,S,S/ Y,Z	18A,B, D,G,H, H/,K, M,P,X, X/	20E	27B,E, G,G/	3F,T,S	2F,T,M	3K,V
1. One-way Bus Route Trip Length in Miles	11.6	11.8	18.6	18.7	24.7	19.3	13.6	12.5	16.8
2. Number of Miles on Expressway	5.7	6.8	12.7	11.6[2]	16.5[2]	9.3	-	-	-
3. Ratio, Expressway Miles to Total Miles (2. ÷ 1.)	0.49	0.58	0.6	0.62	0.67	0.48	-	-	-
4. One-way Bus Route Travel Time in Minutes	37	48	63	57	67	59	74	71	74
5. One-way Bus Route Overall Minutes per Mile	3.2	4.1	3.4	3.1	2.7	3.1	5.4	5.7	4.4
6. Overall One-way Bus Route Speed, MPH	18.8	14.8	17.7	19.7	22.1	19.6	11.0	10.6	13.6

[1] A slash (/) indicates a peak-period variant of the route's service; this generally supplements (not replaces) the regular service during the route's peak-period.

[2] Some local mileage of these bus routes is traversed at expressway-like speeds. This is included in the figures of row 2., "Number of Miles on Expressway".

Prior to the September 1, 1975 fare increase, bus fares in both the Shirley Highway and the Lee Highway Corridors had been stable for a long time. The Shirley Highway Corridor bus service (Routes 7, 8, 17, 18, 20, and 27) was originally operated by the Alexandria, Bancroft, and Washington (A.B.&W.) Bus Co. This company last increased fares in July 1970. The Lee Highway Corridor bus service (Routes 2 and 3) was originally operated by the Washington, Virginia, and Maryland (W.V.&M.) Bus Company. This company last increased fares in October 1969. All privately-owned, Washington, D.C. metropolitan area commuter bus companies were consolidated under public ownership within METRO in January 1973.

METRO analyses indicated that A.B.&W. bus fares were higher than comparable W.V.&M. bus fares, and so in July 1973 METRO reduced A.B.&W. fares slightly to make them compatible with W.V.&M. fares.

Before the September 1, 1975 fare increase, typical bus fares from Northern Virginia to downtown Washington ranged from \$.60 to \$.90. After the fare increase, these fares ranged from \$.75 to \$1.20. The fare increase varied from 20 to 33 percent, increasing with length of trip. Northern Virginia bus fares before and after the September 1, 1975 fare increase are described in Appendix C, pg. 36. Fare zones are shown in Figure 5, pg. 37.

Two characteristics of the study situation complicate interpretation of the empirical results. The particular date (September 1) selected for the fare increase to become effective was not ideal from the standpoint of studying price elasticity: significant changes in travel patterns normally occur at the end of the summer when people return from vacations and autumn school terms begin. Thus it was necessary to adjust observed modal travel demands carefully for monthly (seasonal) variation, prior to studying the interrelationship of price and patronage. Additional ambiguity can be attributed to the rapid growth of Northern Virginia: new apartment and office buildings are opening continually. Since this study dealt with bus patronage by route during intervals of time stretching over two months, it is likely that some data were affected by changes in demand unrelated to price.[1] Although obviously incorrect data points were eliminated (see Section V below) and the aggregate elasticities were probably not overly affected, there is no way be certain that the demand changes used in the calculations are solely the result of fare increases.

The observational phase of the study consisted of observing and recording bus patronage on selected bus routes in the two corridors, both before the fare increase, and then long enough afterwards to expect patronage patterns to have stabilized. During the same observation periods, auto vehicle volumes and auto occupancies were recorded at a previously established screenline on the Shirley Highway.[2] (Auto vehicles and auto

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[1] See references [1] and [2] in Section VII.

[2] See Figure 1, pg. 8, and [3], pg. 99.

passengers were not counted on Lee Highway.) After adjustments were made in passenger and vehicle flows to account for seasonal variation, the effects of the fare increase on patronage and travel patterns were analyzed, and measures of elasticity were estimated. This outline of procedures is elaborated in Sections III and IV.

III. Data Acquisition and Refinement

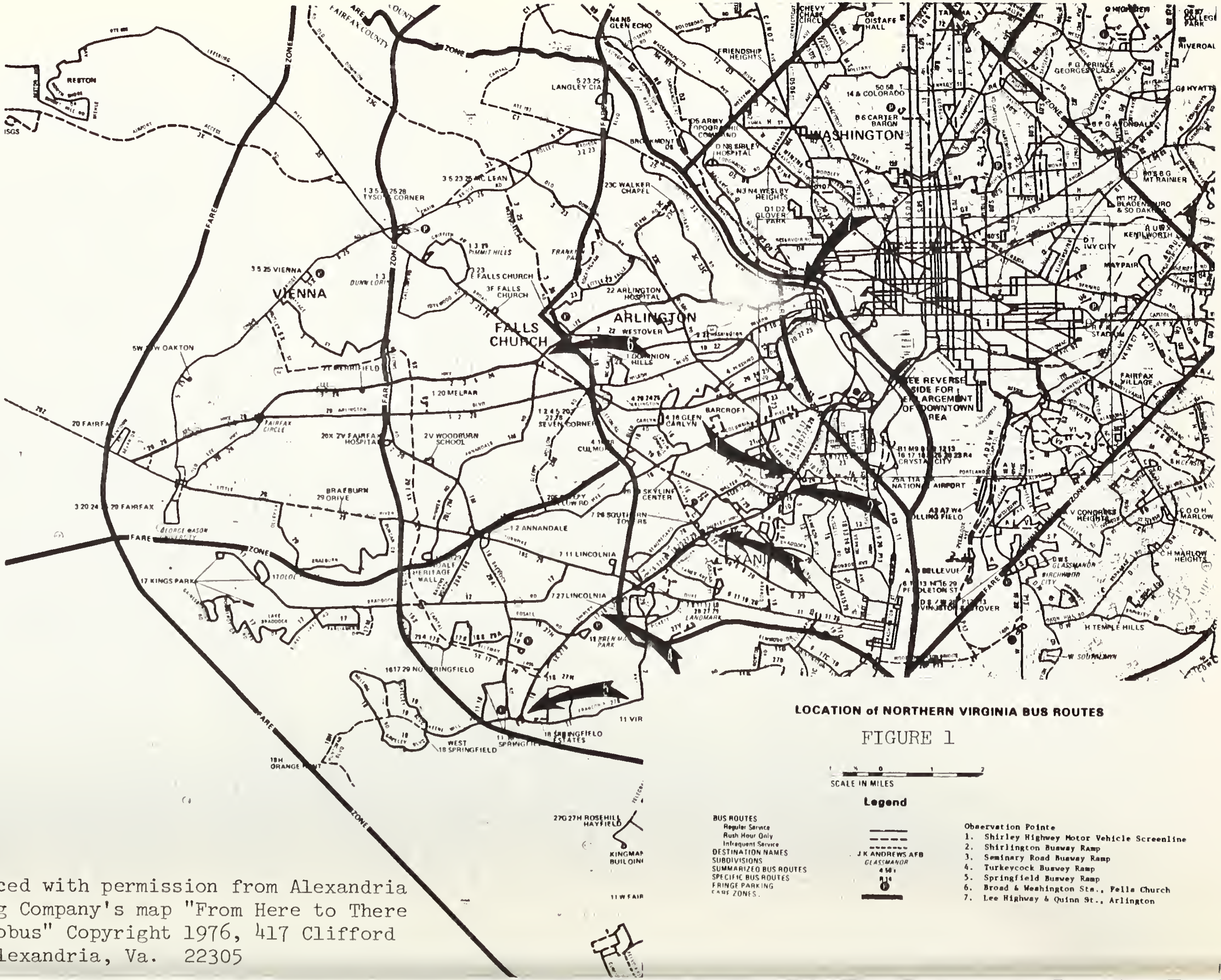
As stated earlier, the purpose of this study is to quantify intermodal and intertemporal changes in commuting patterns resulting from an increase in peak-period transit fares. In general, data collection procedures were as follows: bus patronage was observed, both before and after the fare increase, on selected routes in the Shirley Highway corridor and the Lee Highway corridor. (Table 6 contains a list of the selected bus routes.) During the same period, automobile traffic volumes were observed on Shirley Highway and recorded by person occupancy classification. Bus patronage was observed during peak and off-peak time periods, whereas only peak-period Shirley Highway auto traffic was observed and recorded. Adjustment factors were developed to correct for seasonal variation. Fare data were obtained from METRO and were aggregated. The remainder of this section describes the specific data-gathering techniques employed. Section IV discusses the techniques used in analyzing the data.

Field data were collected on August 19 and 20 and on October 7 and 8, 1975. (The 19th and the 7th, and the 20th and the 8th, were Tuesdays and Wednesdays respectively.) The weather was clear on all four of these days, which were not contiguous with legal holidays. Mean volumes for the two "before" days and the two "after" days were used in all subsequent analyses. The former period was immediately prior to the fare increase, and the latter was believed to be sufficiently long afterward for patronage patterns to have stabilized.

On Shirley Highway, METRO field personnel recorded the numbers of bus passengers by route number on all Shirley Highway buses between 6:00 a.m. and 7:00 p.m. as they entered the freeway segment of their trip. Locations where field data were collected are shown in Figure 1. Automobile usage on Shirley Highway was observed at an established screenline location near 20th Street in Arlington, Virginia. Field personnel recorded the number of autos by passenger occupancy classification from 6:30 a.m. to 9:00 a.m.

In the Lee Highway corridor, bus patronage was observed on two bus lines (route numbers 2 and 3) at two locations, shown in Figure 1. These two bus lines, serving North Arlington and Falls Church, Virginia, were observed between 6:00 a.m. and 7:00 p.m. on the aforementioned dates.

Since seasonal variation in traffic flows between August and October is significant, it was necessary to correct for this factor before quantifying the effects of the fare increase. Data to compensate for seasonal variation in transit demand were obtained from METRO. Seasonal variation data were available for the Shirley Highway for both bus patronage and automobile traffic. Comparable data for the Lee Highway were not available and had to be deduced from a broader data set. Separate seasonal patronage adjustment factors were derived for the Route 18 Shirley Express Buses, the other Shirley Express buses, and the Lee Highway conventional buses, as described below. Average weekday bus patronage was



LOCATION of NORTHERN VIRGINIA BUS ROUTES

FIGURE 1

SCALE IN MILES

Legend

BUS ROUTES
Regular Service
Rush Hour Only
Infrequent Service
DESTINATION NAMES
SUBDIVISIONS
SUMMARIZED BUS ROUTES
SPECIFIC BUS ROUTES
FRINGE PARKING
FARE ZONES

Observation Points
1. Shirley Highway Motor Vehicle Screenline
2. Shirlington Busway Ramp
3. Seminary Road Busway Ramp
4. Turkeycock Busway Ramp
5. Springfield Busway Ramp
6. Broad & Washington Sts., Falls Church
7. Lee Highway & Quinn St., Arlington

Reproduced with permission from Alexandria Drafting Company's map "From Here to There by Metrobus" Copyright 1976, 417 Clifford Ave., Alexandria, Va. 22305 obtained for August and October 1974 for the Shirley Highway bus routes, and is shown in Table 2. Table 3 summarizes the new bus service which was added between August and October 1974. Table 4 shows estimates of average weekday patronage by month for 1974 for the Arlington and Alexandria Divisions of WMATA.

Formally, the Route 18 Shirley Highway Express Bus seasonal adjustment factor (the factor by which to multiply August observations to obtain "corresponding" October figures) is 2551 passengers ÷ 2460 passengers = 1.04. However, the additional 3 buses on the Route 18 line constituted a 4% service increase which in all likelihood both induced new travel and diverted some travel from the auto mode, so that the August-to-October change in Table 2 does not reflect only seasonal variation. The actual seasonal variation is thought to lie between 1.00 and 1.04.

Similarly, for the Shirley express bus service other than the Route 18 line, the apparent relationship between August and October demand is 11155 passengers ÷ 10255 passengers = 1.088. However, the additional 10 buses during the peak-period resulted in a similar service increase which in all likelihood both induced new travel and diverted some travel from the auto mode. Thus the calculated 1.088 probably does not reflect only the seasonal variation. The actual seasonal variation is thought to lie between 1.05 and 1.09.

Data for estimating seasonal variation for the Lee Highway bus lines were obtained from Table 4 since line-specific information was not available. On a Division-wide basis for 1974, the apparent relationship between August and October demand is 31,015 passengers ÷ 28,697 passengers = 1.08, for the Arlington Division which includes the Lee Highway Bus lines. The comparable relationship for the Alexandria division which includes the Shirley Bus service is 64,884 passengers ÷ 60,526 passengers = 1.07. Recall that the comparable figure for the Shirley express bus service other than the Route 18 line, from Table 2, is 1.088. From these figures the range 1.05 - 1.09 for the seasonal patronage variation factor, October with respect to August, as determined in the "rest of the Shirley buses excluding Route 18 service," appears reasonable for use on the Lee Highway Bus lines as well.

These results are summarized in Table 5 below, which indicates the range of values for the ratio of October to August peak-period bus patronage which were selected for use in this research.

Bus routings, service frequencies, travel-time data, and fare and fare-zone data were obtained from schedules, published tariffs, and a large-scale system map furnished by METRO. Since passengers boarded the buses in a number of fare zones prior to observation and recording of patronage, it was necessary to estimate an average fare "before" and an average fare "after" the fare increase.

TABLE 2: AVERAGE WEEKDAY BUS PATRONAGE, SHIRLEY HIGHWAY[1]

Bus Service	August 1974	October 1974
Route 18 Shirley Highway Express Buses	2,460 passengers	2,551 passengers
Shirley Highway Express Buses except Route 18	10,255	11,155

TABLE 3: NEW BUS SERVICE ADDED BETWEEN AUGUST AND OCTOBER 1974[1]

Bus Route Designation	Number of Bus Trips
16G[2]	3 in AM Peak Period, 3 in PM Peak Period
18H	3 in AM Peak Period, 3 in PM Peak Period
27B	3 in AM Peak Period, 3 in PM Peak Period
29Z[2]	4 in AM Peak Period, 4 in PM Peak Period

[1] Source: telephone communication with John Fularz, Office of Planning, METRO.

[2] These two bus routes do not figure in the main study, but their 1974 patronage data were combined with those of other Shirley Highway bus routes in estimating seasonal adjustment factors.

TABLE 4: ESTIMATED AVERAGE WEEKDAY BUS PATRONAGE[1]

Year	Division	August	October
1974	Arlington	28,697	31,015
1974	Alexandria	60,526	64,844

Notes for TABLE 4:

1. Virginia divisions of METRO did not carry significant numbers of public school students, so the impact of school trips was neglibible.

2. METRO developed these daily patronage estimates by recording daily deposits of fares collected by operating Division; estimating average fares by Division; and dividing (daily) fare deposits by the estimated average fare.

3. The Arlington Division is the former W. V. & M. Bus Co. The Lee Highway Routes are a part of this division. The Alexandria Division is the former A. B. & W. Bus Co. The Shirley Highway Express-Bus Routes are a part of this division.

[1]Source: telephone communication with John Fularz, Office of Planning, METRO.

TABLE 5: RANGE OF SEASONAL PATRONAGE VARIATION FACTORS USED

Bus Service	Ratio of October to August Peak Period Bus Patronage	
	Lower Bound	Upper Bound
Route 18 Shirley Highway Express Buses	1.0	1.04
Shirley Highway Express Buses except Route 18	1.05	1.09
Lee Highway Bus Lines 2 & 3	1.05	1.09

Individual bus lines and established fare-zone boundaries were located on a large-scale map of the existing street system. Based on the distribution of destinations on individual bus lines (e.g. those along Route 18), and the path length and relative intensity of development within each of the fare zones traversed prior to observation of patronage, a high estimate and a low estimate were obtained for the average fare paid on each route, both before the fare increase and after the fare increase occurred. For most bus lines a "best" judgemental estimate of the average fare "before" and "after" the fare increase was also made. Thus the fare data by bus line could be arrayed as follows: (illustrative figures):

	Before Fare Increase	After Fare Increase
Lowest Fare Estimate	$.70	$ .90
Highest Fare Estimate	.90	1.05
"Best judgemental" Estimate	.71	.93

Subsequent elasticity computations (see Section IV-(a)) involve only <u>relative</u> (i.e., percentage) fare increases; the "high" estimate of the relative fare increase would be selected in this illustrative example as the larger of

$$\frac{.90-.70}{.70} \quad \text{or} \quad \frac{1.05-.90}{.90}$$

and similarly for the "low" estimate.

This choice, avoiding the "super-high" extreme of (1.05-.70)/.70, in effect assumes that the distribution of passengers by origin/destination fare zones did not change significantly after the fare increase. The estimated fares paid by passengers observed at the counting locations are presented in Table 6.

TABLE 6: ESTIMATED AVERAGE PASSENGER FARES BY TRANSIT ROUTE

Bus Route Number	New Peak Period Fare After Sept. 1, 1975			Old Peak Period Fare Before Sept. 1, 1975			Remarks	Off Peak Fare
	High Est.	Low Est.	Best Est.	High Est.	Low Est.	Best Est.		
7A, B, E, F, F/, G, M, N, P, S, W, X	.75	.65	.72	.60	.50	.57	Observed at Shirlington and Seminary Rd. Ramps	.60
8A, B. E, F, P, S, W, X, Y, Z	.75	.65	.73	.60	.50	.58	Observed at Shirlington and Seminary Rd. Ramps	.58
17, G, G/, H, H/, M, P, S, S/, Y, Z	1.05	.90	.94	.80	.70	.72	Observed at Turkeycock and and Seminary Rd. Ramps	.58
18A, B, D, G, H, H/, K, M, P, X, X/	1.05	.90	.93	.90	.70	.71	Observed at Springfield and Turkeycock Ramps	.55
20E	1.05	1.05	1.05	.80	.80	.80	Observed at Turkeycock Ramp	no off peak service
27B, E, G, G/	.90	.80	.84	.70	.60	.65	Observed at Seminary Rd. Ramp	.60
3 F, T, S	1.20	.95	1.08	.92	.70	.81	Observed at Broad & Washington Streets, Falls Church, VA	.55
2 F, T, M	.80	.50	.65	.60	.40	.50	Observed at Broad & Washington Streets, Falls Church, VA	.55
3 K, V	.95	.90	.93	.70	.70	.70	Observed at Broad & Washington Streets, Falls Church, VA	.55

NOTE: These are estimated average fares paid by passengers who were counted on the bus vehicles at the observation location noted.

IV. Method of Analysis

This section describes the method used to quantify the impact of the increase in the peak-period bus fare upon: (a) peak transit patronage for express transit service (on Shirley Highway) and for conventional transit service (on Lee Highway); (b) off-peak transit demand; and (c) auto usage and carpools.

(a) Elasticity of Peak-Period Transit Patronage with Respect to Price.

The changes in transit demand with respect to increase in price will be described by the use of demand elasticities. The elasticity of transit demand with respect to fare (price) is the proportional change in demand divided by the proportional change in price; i.e.

$$e_i = dQ_i/Q_i \div dP_i/P_i = \frac{P_i}{Q_i}\frac{dQ_i}{dP_i}, \tag{1}$$

$$Q_i = F_i(P_i)$$

where e_i is the elasticity for the i^{th} route, P_i is the fare, and Q_i is the demand function. It is well-known that if $e_i>(-1)$ then a small increase in P_i will increase gross revenue, P_iQ_i, and if $e_i<(-1)$, a small increase in P_i will decrease gross revenue.

In this study, data were not sufficient to estimate the functions $Q_i = F_i(P_i)$, so it was necessary to choose an approximation to Equation (1). Among many possible approximations, the following were chosen:

$$\hat{e}_i = \frac{\Delta Q_i/Q_{i1}}{\Delta P_i/P_{i1}}, \tag{2}$$

$$\tilde{e}_i = \frac{\ln Q_{i2}-\ln Q_{i1}}{\ln P_{i2}-\ln P_{i1}}. \tag{3}$$

Here subscripts "1" and "2" refer to "before" and "after" respectively, while $\Delta Q_i = Q_{i2}-Q_{i1}$ and $\Delta P_i = P_{i2}-P_{i1}$. The ratio $\hat{e}_i$ has been called the <u>shrinkage ratio</u> and is a measure frequently used by transit operators in the United States to forecast the impact of a price change on revenues and patronage. The <u>shrinkage ratio</u> describes the relative change in patronage with changed fares.[1] The ratio $\tilde{e}_i$, which is also frequently employed, is known as the <u>arc elasticity</u> of demand with respect to fares.

[1] See [9], pg. 2-4 and [6], pg. 26-28.

For very small fare changes, $\tilde{e}_i$ will be very close to $\hat{e}_i$. For larger changes, the arc elasticity $\tilde{e}_i$ will be larger than $\hat{e}$ for fare increases and smaller for fare decreases. Both measures are defined so that price elasticities are negative for typical demand schedules.

In this research, demand has been measured in transit passenger trips. Demand could also have been quantified, at least conceptually, in terms of passenger miles. For demand elasticity measurements on the Shirley Highway buses where trip length is relatively constant, the choice of demand measure would have less impact than for the Lee Highway buses where passenger-trip length is much more variable.

Equation (2) follows from Equation (1) by replacing differentials with finite differences; Equation (3) follows in the same manner after Equation (1) is rewritten in the equivalent form $e_i = d(\ell n Q_i)/d(\ell n P_i)$. Sample calculations are given in Appendix D.

As noted, one goal of this study was to compare the elasticity of express bus service (operating on the Shirley Highway) with that of conventional bus service (operating on the Lee Highway). It was therefore necessary to aggregate separately the individual elasticities of the bus routes traversing the Shirley Highway, and those traversing the Lee Highway.

Unfortunately, there is no uniquely "correct" formula for such aggregate elasticities. The particular formula used[1], refers to the quantities

$$Q = \text{total demand} = \Sigma Q_i$$

$$R = \text{total revenue} = \Sigma R_i = \Sigma P_i Q_i$$

and is given by

$$e = R\, dQ/[Q\, dR - R\, dQ]. \tag{4}$$

Relative to the "composite price"

$$P = \Sigma(Q_i/Q)P_i$$

obtained as the demand-weighted average of the fares on the individual lines, this formula has the advantage that the customary equations employing elasticities to predict the consequences of price changes, namely,

$$dQ = e(Q/P)dP \quad , \quad dR = (1+e)Q\, dP,$$

remain valid. On the other hand, the aggregation method given by Equation (4) lacks the theoretically desireable "consistency principle" that when all e_i have the same value, e should also have this value.

[1] Suggested by J. M. McLynn.

The shrinkage-factor and arc-elasticity approximations obtained from (4) are

$$\hat{e} = R_1 \Delta Q / [Q_1 \Delta R - R_1 \Delta Q], \tag{5}$$

$$\tilde{e} = [R_1 \Sigma Q_{i1} \ell n(Q_{i2}/Q_{i1})] \div [Q_1 \Sigma R_{i1} \ell n(R_{i2}/R_{i1}) - R_1 \Sigma Q_{i1} \ell n(Q_{i2}/Q_{i1})]. \tag{6}$$

The summations were taken only over routes exhibiting negative elasticities. As discussed in section (b), positive elasticities were attributed to exogenous changes unrelated to the fare increase.

(b) Shifts in Transit Demand from Peak to Off-Peak Periods

Chi-square tests were used to determine whether there was a significant shift from peak to off-peak transit usage. One-tailed Chi-square tests were performed both on individual bus routes and in combinations comprising (1) the total Shirley Highway express buses and (2) the Lee Highway conventional bus service.

The choice of a one-tailed test over a two-tailed one (for a change in the pattern of utilization) may be questioned. After all, economic theory admits the existence of the "Giffen effect," where an increase in peak bus fares might increase the demand for peak bus service.[1] With some trepidation, we adhere in this study to the customary assumption that transit price elasticities are negative. Thus, if the increase in the peak fare of a route corresponded to an increase in peak patronage (relative to off-peak), this was attributed to the exogenous forces discussed earlier in Section II.

(c) Shifts in Automobile Usage

Chi-square tests were performed to see whether there was a significant increase in use of autos or carpools relative to bus service. As in section (b), these were one-tailed tests. As discussed in section III, the data used applied to the Shirley corridor alone, since data on auto usage were not collected along the Lee Highway.

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[1] See [7], page 115. The Giffen effect occurs when an increase in the price of a good, all other prices held fixed, results in an increase in the demand for that good. In some situations this is consistent with utility-maximizing behavior by consumers.

V. Results

A. Elasticity of Peak-Period Transit Demand

The elasticities of demand estimated for individual routes are shown in Table 7.

As discussed in Section III, reasonable extrema of both seasonal variation factors and the increase in average bus-route fares were selected to bound a plausible range for each variable. A "best judgemental estimate" of the average fare change was also prepared, and an associated estimate of elasticities made. One would naturally expect observed elasticities with respect to demand to carry a negative sign, since patronage should decrease with increase in fare. However, in this study the data for some bus routes which operate on the Shirley Highway indicated positive elasticities; several bus routes exhibited elasticities whose signs change from positive to negative within the bounds of seasonal adjustment factor extremes. As noted earlier, we do not believe these were instances of the Giffen effect;[1] it seems more likely that the increases were caused or brought about by other variables which were not "tracked" during this research.[2] Such variables might include changes in employment centers, and/or the opening of large apartment house facilities. The positive elasticities were assumed to be caused by "experimental error", and are not reported by bus route nor considered in preparing aggregate elasticities.

The aggregate elasticities for the Shirley Corridor and the Lee Corridor routes are indicated in Table 8. The estimated arc elasticity for the Shirley express bus service (ranging from -.301 up to -.243) is substantially different from that for the conventional Lee Highway bus service (which ranges between -.843 and -.671). This result tends to support the hypothesis that elasticities of transit demand with respect to price are smaller for premium-type express bus service than for conventional bus service.[3]

Table 9 permits a comparison of the findings of this study with peak-period transit elasticities estimated in other studies.

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[1]See footnote 1, pg. 17.

[2]Other studies of transit elasticities have also reported occasional instances where positive elasticities have been observed. For an example see Section VII of [11], Table 7, page 5.

[3]See [10] for one researcher's hypothesized distribution of <u>shrinkage ratios</u> by type of service offered.

TABLE 7: PEAK-PERIOD ELASTICITY ESTIMATES

BUS ROUTE		LOW SEASONAL NORMALIZATION			HIGH SEASONAL NORMALIZATION		
SHIRLEY HIGHWAY EXPRESS BUSES		HIGH EST. OF % FARE INCREASE	LOW EST. OF % FARE INCREASE	BEST EST. OF % FARE INCREASE	HIGH EST. OF % FARE INCREASE	LOW EST. OF % FARE INCREASE	BEST EST. OF % FARE INCREASE
7A,B,E, F, F/, G,	Arc Elasticity				-0.076	-0.089	-0.085
M,N,P,S ,W,X	Shrinkage Factor				-0.066	-0.079	-0.085
8A,B,E,F,P,	Arc Elasticity	-0.077	-0.091	-0.088	-0.219	-0.257	-0.250
S,W,X,Y,Z	Shrinkage Factor	-0.067	-0.086	-0.078	-0.186	-0.223	-0.216
17G,G/,H,H/,M,	Arc Elasticity	-0.614	-0.664	-0.626	-0.751	-0.812	-0.766
P,S,S/,Y,Z	Shrinkage Factor	-0.492	-0.538	-0.503	-0.591	-0.646	-0.604
		Note: For the 18A,B,G,H/ Buses only, the Bracketing Seasonal Normalization Factors are =1.0			=1.04		
18A,B,D,G,H,H/,	Arc Elasticity				-0.055	-0.089	-0.051
K,M,P,X,X/	Shrinkage Factor				-0.048	-0.082	-0.044
20E	Arc Elasticity	-	-	0	-	-	-0.129
	Shrinkage Factor	-	-	0	-	-	-0.111
27B,E,G,G/	Arc Elasticity	-0.030	-0.034	-0.034	-0.160	-0.184	-0.180
	Shrinkage Factor	-0.026	-0.030	-0.029	-0.135	-0.158	-0.154
LEE HIGHWAY BUS SERVICE (Observed at Broad & Wash. Sts.)							
3F,T,S	Arc Elasticity	-0.259	-0.298		-0.382	-0.439	
	Shrinkage Factor	-0.213	-0.250		-0.346	-0.361	
2F,M,T	Arc Elasticity	-1.189	-1.153		-1.324	-1.707	
	Shrinkage Factor	-0.869	-1.159		-0.950	-1.267	
3K,V	Arc Elasticity	-0.673	-0.817		-0.792	-0.963	
	Shrinkage Factor	-0.520	-0.650		-0.602	-0.752	

TABLE 8: SUMMARY OF PEAK-PERIOD ELASTICITY BY TYPE OF SERVICE

	Low Seasonal Normalization			High Seasonal Normalization		
	HIGH EST. OF % FARE INCREASE	LOW EST. OF % FARE INCREASE	BEST EST. OF % FARE INCREASE	HIGH EST. OF % FARE INCREASE	LOW EST. OF % FARE INCREASE	BEST EST. OF % FARE INCREASE
IIRLEY HIGHWAY EXPRESS BUSES						
c Elasticity	-.301	-.290	-.298	-.289	-.243	-.249
rinkage Factor	-.266	-.253	-.263	-.258	-.211	-.217
E HIGHWAY BUS TRADITIONAL SERVICE						
c Elasticity	-.671	-.712	-.679	-.795	-.843	-.804
rinkage Factor	-.622	-.656	-.627	-.754	-.795	-.760

TABLE 9: COMPARISON OF PEAK-PERIOD TRANSIT ELASTICITIES WITH THOSE FROM OTHER STUDIES

Observed Peak-Period Arc Elasticity of Demand with Respect to Price (Fare)	Comments
-0.2	Urban buses, London, England, c1973. See [9], Section 6.1.
-0.27	Stevenage Superbus Experiment, Great Britain, c1973. See [9], Section 6.1.
-0.27	Urban buses, London, England, 1969. See Section VII, [9], Section 12.1.
-0.51	Urban buses, Chicago, 1969. See [12], page 140.
-0.12	N.Y.C. Subway 1966 Fare Increase. See [11], page 5 and Appendix D.
-0.29	Shirley Highway Autumn 1974 Data. Cross-sectional model-derived elasticity (Model II) calculated at the means of all variables. See [13], pg. III-20.
-0.27	Shirley Highway Data collected "before" and "after" 1975 fare increase. (Mean value of "Best" estimates of % fare increase for "Low" and for "High" seasonal normalization factors.)
-0.74	Lee Highway Data collected "before" and "after" 1975 fare increase. (Mean value of "Best" estimates of % fare increase for "Low" and "High" seasonal normalization factors.)

Examination of the limited set of peak-period price elasticities estimated in other city studies seems to support the hypothesis that demand elasticities vary with the type of transit service offered. Demand for conventional bus transit service operating over arterial streets, as in the first four studies, tends to be more elastic than demand for premium rapid rail service operating on a separate right-of-way, such as in the fifth study.

On the other hand, there are much more limited travel options to and from the financial district of New York City (the scene of the fifth study). It should be noted that the first three studies were all made at least five years ago in Great Britain, where travel options might also have been more limited than in the United States. Thus these results might not be comparable with observations in the U.S.

The sixth estimate was calculated by evaluating a closed-form theoretical expression for elasticity using mean values of data collected in a survey of Shirley Highway Corridor travelers in the autumn of 1974. This particular mathematical formula predicting elasticity was obtained from one variant of J. M. McLynn's "fully competitive mode choice model".[1] The close agreement of the theoretically-derived elasticity evaluated with 1974 data, with the (independent) empirical estimate from data before and after the 1975 price-increase, lends support to the validity of both results.

B. Shifts from Peak to Off-Peak Transit Usage

There was little evidence of a shift from peak to off-peak use of bus services. Of the fourteen bus routes which were analyzed, only two showed a shift significant at the five percent level upon application of the Chi-Square test. These were routes 2M and 2T (westbound) and 2F, 2M, and 2T (eastbound) in the Lee Highway corridor. Since the 2 route offered the slowest service of all routes studied, we may speculate that individuals using these routes (prior to the change in fare) had more intertemporal flexibility than is the norm.

Three combinations of bus routes were tested for intertemporal shifts: all routes in the Shirley corridor; all routes in the Lee Highway corridor; and all routes together. None of these aggregates showed a shift from peak to off-peak usage at the 5% level of significance.

C. Shifts of Peak-Period Commuters from Bus to Auto Mode

In addition to the above tests for intertemporal shifts of commuters, analyses were made to detect shifts in travel mode. The distributions of inbound peak-period commuters using the Shirley Highway, by vehicle occupancy and by mode, are indicated in Table 10. Application of the Chi Square test to these modal data indicates there was no significant shift from bus to auto after the fare increase.

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[1] See [13], Chapter III.

TABLE 10 DISTRIBUTION OF AUTO PERSON TRIPS BY CARPOOL SIZE
SHIRLEY HIGHWAY 6:30-9AM PEAK PERIOD INBOUND

CAR POOL SIZE		BEFORE FARE INCREASE (Aug. 19-20, 1975)	AFTER FARE INCREASE (Oct. 8-9, 1975)
		REGULAR LANES AND EXPRESS LANE COMBINED	
1 (driver)		8488 persons	8612 persons
2 persons		5261	3801
3 persons		1433	893
4 persons		2468	3574
5 persons		1613	3188
6 persons		477	690
≥7 persons		210	144
	Total	19950 persons	20902 persons
	Vehicle Occupancy	1.58 persons per vehicle	1.67 persons per vehicle
		REGULAR LANES	
1(driver)		8488 persons	8612 persons
2 persons		5261	3801
3 persons		1433	893
≥4 persons		598	408
	Total	15780 persons	13714 persons
	Vehicle Occupancy	1.34 persons per vehicle	1.26 persons per vehicle
		EXPRESS LANE	
4 persons		1870 persons	3166 persons
5 persons		1613	3188
6 persons		477	690
≥7 persons		210	144
	Total	4170 persons	7188 persons
	Vehicle Occupancy	4.63 persons per vehicle	4.59 persons per vehicle
	SHIRLEY HIGHWAY BUS PASSENGERS	13944 persons	14675 persons

NOTES: These data were collected at the Shirley Highway Screenline Station near 20th Street in Arlington, VA.

These data are raw; they have <u>not</u> been seasonally adjusted.

Bus passenger figures cover all observed commuter buses using the express lanes, including some low-volume routes not considered in the elasticity computations.

Since there was no significant shift of commuters from the bus to the auto mode after the fare increase, the impact of the fare increase on the carpool mode would be expected to be negligible. Surprisingly, the number of persons per car increased slightly, from 1.58 persons per car before the fare increase to 1.67 persons per car after. Figure 2 shows the distribution of peak-period auto person travelers by size of carpool for all inbound Shirley Highway Lanes. Although these data are not seasonally adjusted, there is a substantial decrease in two and three-person carpools and a substantial increase in four, five and six-person carpools. With substantially the same number of auto person commuters before and after the fare increase, this suggests a slight drop in the number of auto vehicles using the Shirley Highway. This actually was the case, with 12648 autos before and 12479 autos after the fare increase traveling inbound during the 6:30-9AM peak period. Had these data been seasonally adjusted, the modified figure for this decline would have been greater.

Figure 3 shows the distribution by carpool size of peak-period auto person travelers using the Shirley Highway express lane. Again one observes a dramatic increase in the number of four, five, and six-person carpools. There was also a substantial increase in the number of automobiles using the Shirley Highway express lane during the peak-period, from 901 vehicles before the transit fare increase to 1566 vehicles after. On the regular Shirley Highway lanes, the number of automobiles traveling inbound during the peak period dropped, from 11,747 vehicles before to 10,913 after the transit fare increase.

The change in the distribution of travelers among the various sizes of car pools is probably totally unrelated to the transit fare increase, instead resulting from commuters returning from vacations and joining or rejoining carpools.

It should also be noted that the Shirley Highway Corridor is not a totally isolated corridor. There are several alternative highway routings, and even alternative bus routes for some commuters within the corridor. However, since disruption to commutation by external phenomena such as construction was minimal during the periods of observation, it is believed that the observations utilized herein truly reflect conditions within the study area at the time.

FIGURE 2

DISTRIBUTION OF 6:30-9AM PEAK-PERIOD INBOUND SHIRLEY HIGHWAY AUTO PERSONS BY CARPOOL SIZE BEFORE AND AFTER TRANSIT FARE INCREASE. ALL SHIRLEY HIGHWAY LANES

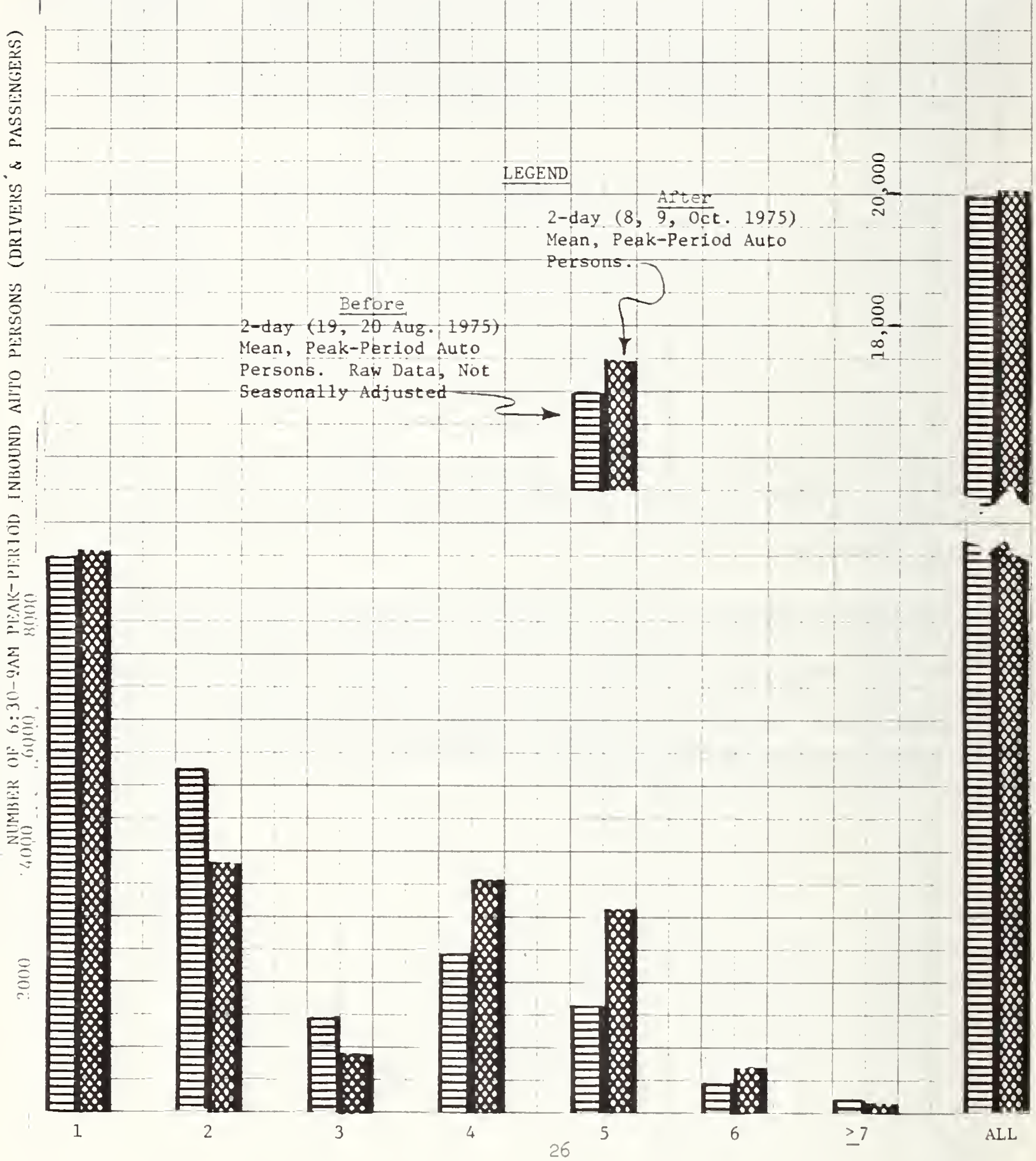
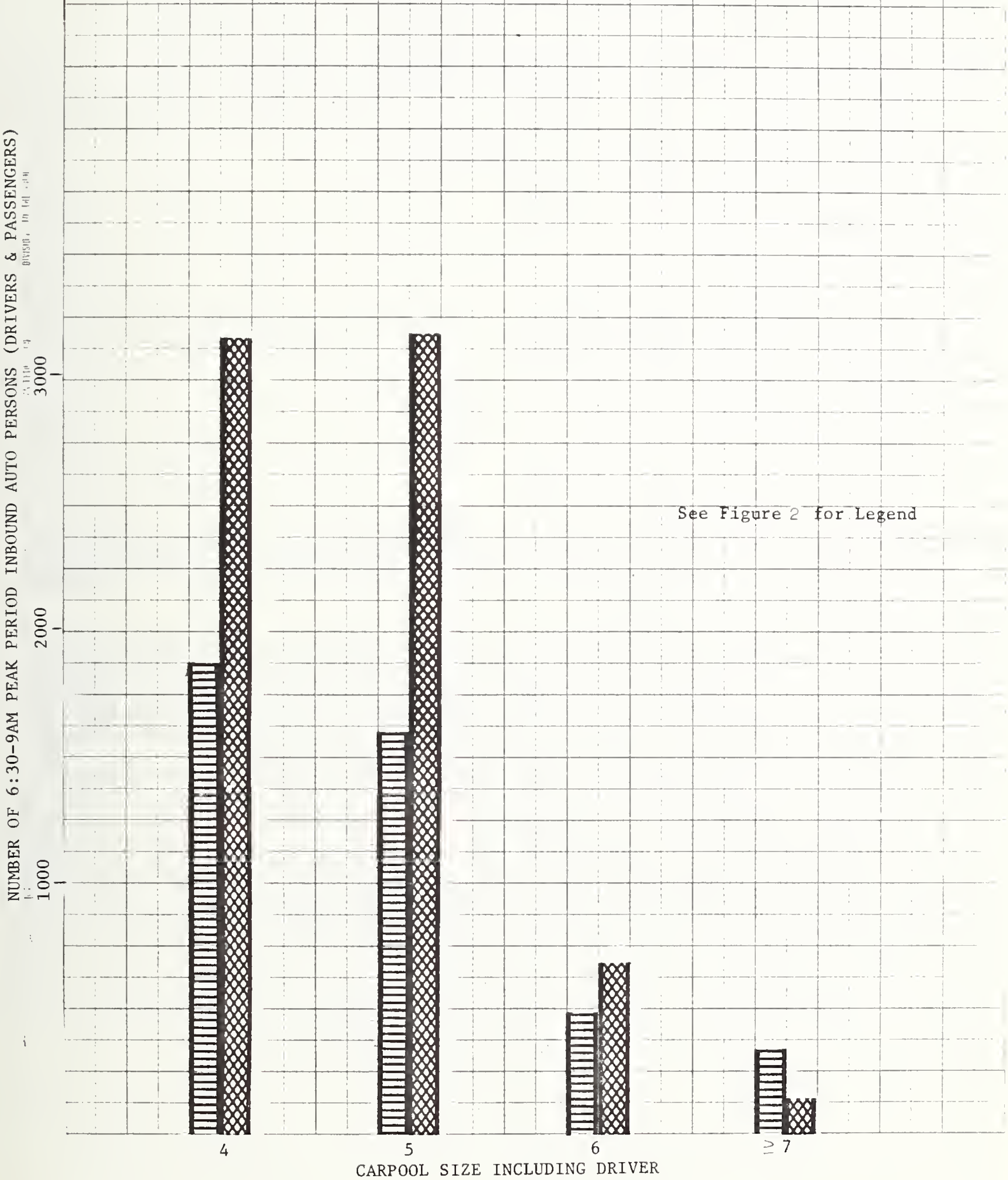


FIGURE 3

DISTRIBUTION OF 6:30-9AM PEAK-PERIOD INBOUND SHIRLEY HIGHWAY AUTO PERSONS USING EXPRESS LANES BY CARPOOL SIZE BEFORE AND AFTER TRANSIT INCREASE. EXPRESS LANE AUTOS ONLY



VI. Conclusions

This study, which was conducted in Northern Virginia, began with four objectives: To observe and report on the elasticity of peak-period transit demand with respect to price; to identify and quantify the impact of a peak-period transit fare increase on auto usage and carpooling; to determine whether a peak-period transit fare increase caused any measurable shift in passenger usage from peak to off-peak times; and to compare the elasticities observed on the Shirley Express Buses with those observed on conventional bus service in the same metropolitan area and determine if elasticities observed for these two qualities of transit service are significantly different.

These objectives have been fulfilled.

Peak period arc elasticities were determined as follows:

Shirley Highway Express Buses	-0.301 to -0.243
Lee Highway Conventional Buses	-0.843 to -0.671

Comparable shrinkage ratios are as follows:

Shirley Highway Express Buses	-0.266 to -0.211
Lee Highway Traditional Buses	-0.795 to -0.622

In both instances, values for the Shirley Highway Express Bus service are considerably different from those for the conventional bus service operating on the Lee Highway.

No noticeable impact of the transit fare increase on the number of travelers by auto was observed. The seasonally unadjusted (raw) numbers for peak period inbound auto persons traveling on the Shirley Highway were 19,950 persons in August, and 20,902 in October after the transit fare increase. Application of a seasonal adjustment would likely indicate a decrease in auto person trips after the transit fare increase. At the same time, an overall increase in vehicle occupancy was observed on the Shirley Highway: from 1.58 persons per vehicle before the transit fare increase to 1.67 persons per vehicle after the increase. This increase in persons per car came from other auto passengers, since the total number of inbound autos traveling on the Shirley Highway during the peak-period dropped from 12,648 vehicles before the transit fare increase to 12,479 after the increase. These data again are not seasonally adjusted. The decrease in auto vehicle trips would be more pronounced had seasonal adjustments been applied. The increase in vehicle occupancy was probably caused by the return of workers from vacation.

There was little evidence of a pronounced shift from peak to off-peak-period after the peak-period transit fare increase. Of the fourteen bus routes which were analyzed, only the Route 2M and 2T westbound and the 2F, 2M, and 2T eastbound operating over the Lee Highway showed a significant shift at the 5% level of significance. Three combinations of bus routes were studied for intertemporal shifts: all Express Buses operating on the Shirley Highway; all bus routes operating on the Lee Highway; and all bus routes combined. None of these combinations indicated a significant shift to off-peak usage.

The overall impact of the peak-period fare change (an increase ranging from 20% to 33%) is quite minimal. This is to be expected. The last fare increases on the bus lines investigated in this study were instituted at the beginning of the decade. During this same period gasoline and oil costs increased by approximately 62%, according to a recent edition of the Survey of Current Business (U.S. Department of Commerce). Thus even with a peak-period fare increase of from 20 to 33%, transit fares remained a great bargain in transportation.

The differences in the elasticities exhibited by the two types of bus service considered in this study - express buses operating on exclusive freeway lanes, and conventional bus service operating on a signalized radial arterial street - tend to confirm that different segments of the public transit market have different elasticities.[1] Translating this into rudimentary pricing policy, one might consider raising fares more on premium transportation services than on traditional services. This would tend to relate user charges more systematically to the services received. As long as the aggregate transit demand elasticity with respect to fare remains greater than -1, the net increase in revenues due to higher fares will exceed the net loss in revenues attributable to lost patronage.

Additional studies should be directed at a comparison of peak-period and off-peak-period transit elasticities. These results will provide a factual basis for development of a comprehensive transit fare policy.

Difficulties were encountered in this study in determining values for (route) average fares and for seasonal variation factors, and in identifying exogeneous phenomena which affected transit patterns. These data problems could have been avoided at high cost, by interviewing individual travelers and keeping track of these travelers (and identifying new ones) before and after the transit fare increase. This would have yielded a more precise estimate of transit elasticity with respect to price. However, it would be of little use to a transit operator considering the revenue impacts of a possible fare increase, since he is not likely to spend the money necessary to collect the data on his system that would be needed to apply such results with comparable precision.

[1] See [10].

VII. List of References

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Appendix A: Supplemental Data Sources

A. BUS SCHEDULES:

Published by the Washington Metropolitan Area Transit Authority (WMATA), defining service immediately before and after the fare increase of September 1975 for the following routes:

(1) Route 1
(2) Routes 1, 3, 20 & 25
(3) Routes 1, 2, 3, 4, 20 & 24
(4) Route 2
(5) Route 3
(6) Route 3Z
(7) Route 4
(8) Route 5 & 25
(9) Route 5-X
(10) Route 6
(11) Route 7
(12) Route 8
(13) Route 16
(14) Route 17
(15) Route 18
(16) Route 19G, Y
(17) Route 20E
(18) Route 27
(19) Route 28G
(20) Route 29
(21) Route 29Z

B. MAPS:

1. From Here to There by Metrobus, January 1, 1976, published by the Washington Metropolitan Area Transit Authority (WMATA).

2. Northern Virginia Metropolitan Area 1976-77, published by the American Automobile Association (AAA).

C. OTHER WMATA PUBLICATIONS:

Operators Guide. Fares-Fare Zones & Proper Issuance & Acceptance of Transfers effective Sept. 1, 1975, Washington Metropolitan Area Transit Authority (WMATA).

Tariff of the Washington Metropolitan Area Transit Authority on Metrobus Lines within the Washington Metropolitan Area including Intrastate and Interstate operations, effective Sept. 1, 1975. Regular Route Tariff Number 2 issued by Jackson Graham, General Manager, WMATA.

Appendix B: Northern Virginia Census Tracts, Populations, and Incomes

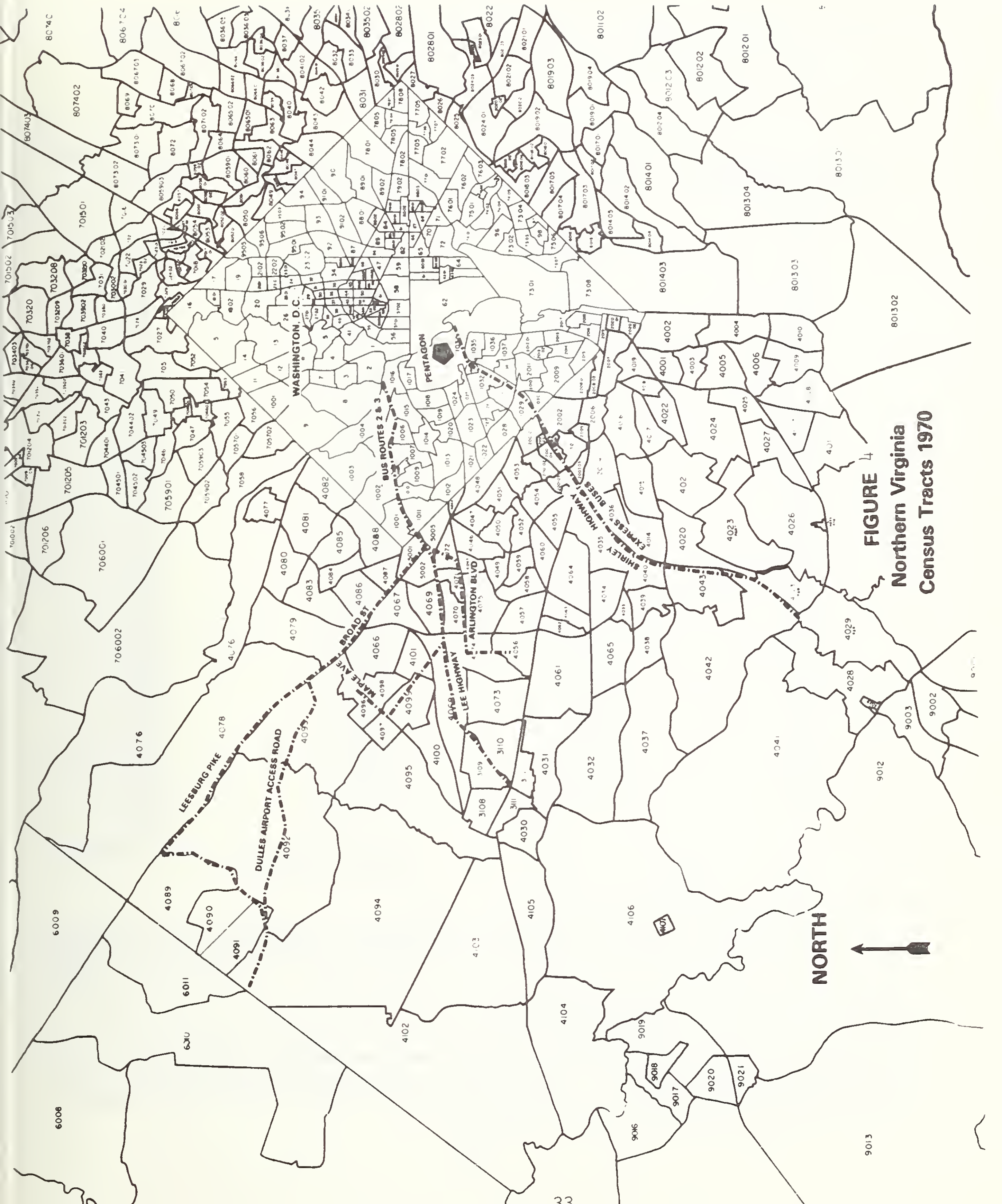

FIGURE 4
Northern Virginia
Census Tracts 1970

TABLE 11

Estimated[1] 1974 Population and Median Income in Census Tracts Adjacent to

Shirley Highway Bus Lines

Census Tract Number	Population	Median Income Measure[2]	Ranking
4064	5594	$24125	7
4055	3908	20032	15
4054	2399	24833	4
4053	6118	12293	25
4043	1917	13361	22
4042	15385	24233	6
4040	5564	21523	12
4039	3066	23310	8
4038	9045	22715	10
4036	2906	14336	20
4035	6154	13629	21
4034	7115	21221	13
4033	1429	26949	1
4023	6611	21809	11
4021	3419	17194	19
4020	2036	22796	9
4015	2535	20719	14
4014	3310	25991	3
2015	3511	11417	26
2010	3727	9025	28
2009	4321	24431	5
2008	5765	18441[3]	16
2006	3951	17373	18
2005	5364	8760	29
2004	6011	8591	30
2003	9563	18057[3]	17
2002	4594	26532	2
2001	10929	9683[3]	27
1030	2529	13119	23
1029	5940	12944	24

Unweighted average income = $18,315.
Median = $20,036.

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[1] International Data Development Corporation, "Estimates of Population and Income for Tracts in Washington, D.C. SMSA(1974)", National Technical Information Service Document PB 245 331.

[2] Income measure treats unrelated individuals in a household as separate units, but combines the incomes of family members.

[3] Population and income estimates were given for subareas making up each of census tracts 2001, 2003, and 2008. In these cases, the tract median income was approximated by averaging the median incomes of the subareas comprising the census tract, weighted by the estimated populations of the subareas.

TABLE 12

Estimated[1] 1974 Population and Median Income in Census Tracts Adjacent to Lee Highway Bus Lines

Census Tract Number	Population	Median Income Measure[2]	Ranking
5002	6125	$15555	27
5001	3036	20964	18
4101	5717	26800	4
4099	9363	23115	11
4098	3238	20348	20
4097	2730	26241	7
4096	3934	27317	3
4093	4964	27462	2
4092	23610	21398	15
4091	4983	21247	16
4090	2457	18186	24
4089	450	18421	22
4087	1326	26666	5
4086	7040	18642	21
4079	3261	28379	1
4078	5268	26658	6
4075	6797	15935	25
4074	5369	15460	28
4073	7131	26155	8
4072	4156	15947	19
4071	4758	15633	26
4070	4091	10638	33
4069	6649	10868	32
4068	10685	21112	17
4067	5145	12018	31
4066	2427	21517	14
4046	2320	22632	12
4045	2628	18200	23
3112	2670	24118	10
3111	4684	13478	30
3110	3293	21533	13
3109	4548	24906	9
3108	4643	13804	29

Unweighted average income = $20,344
Median = $21,180.

[1] International Data Development Corporation, "Estimates of Population and Income for Tracts in Washington, D.C. SMSA(1974)", National Technical Information Service Document PB-245-331.

[2] Income measure treats unrelated individuals in a household as separate units, but combines the incomes of family members.

Appendix C: Northern Virginia Bus Fares

A. PEAK-PERIOD INTERSTATE FARES BETWEEN VIRGINIA ZONES AND DOWNTOWN WASHINGTON, DC :

Old Zone Number	New Zone Number	Fare Before 1 Sept. 75	Fare After 1 Sept. 75
1	G	$ .50	$ .60
2	1	.60	.75
3	2	.70	.90
4	3	.80	1.05
5	4	.90	1.20
6	4	$1.00	$1.20

B. PEAK-PERIOD INTRASTATE FARES-WITHIN AND AMONG VIRGINIA ZONES:

	Fare Before 1 Sept. 75	Fare After 1 Sept. 75
Trips within one zone	$ .40	$ .50
Trips crossing one zone boundary	.50	.65
Trips crossing two zone boundaries	.60	.80
Trips crossing three zone boundaries	.70	.95
Trips crossing four zone boundaries	.80	1.10
Trips crossing five zone boundaries	$ .90	$1.10

C. OFF-PEAK FARES :

Prior to September 1, 1975, there was no distinction between peak fares and off-peak fares. The fares indicated in A and B above as "Before 1 Sept. 1975" applied, based solely upon origin and destination of trip.

After September 1, 1975, zones are no longer applicable to the determination of off-peak fares:

All intrastate off-peak trip fares are $.40
All interstate off-peak trip fares are $.60

Note:

The peak period is defined in the tariff and on the published transit schedules as 6:30 am - 9:00 am and 3:30 pm - 6:00 pm weekdays. All other times are considered as off-peak travel periods.

D. WMATA FARE ZONES:

See Figure 5 on next page.

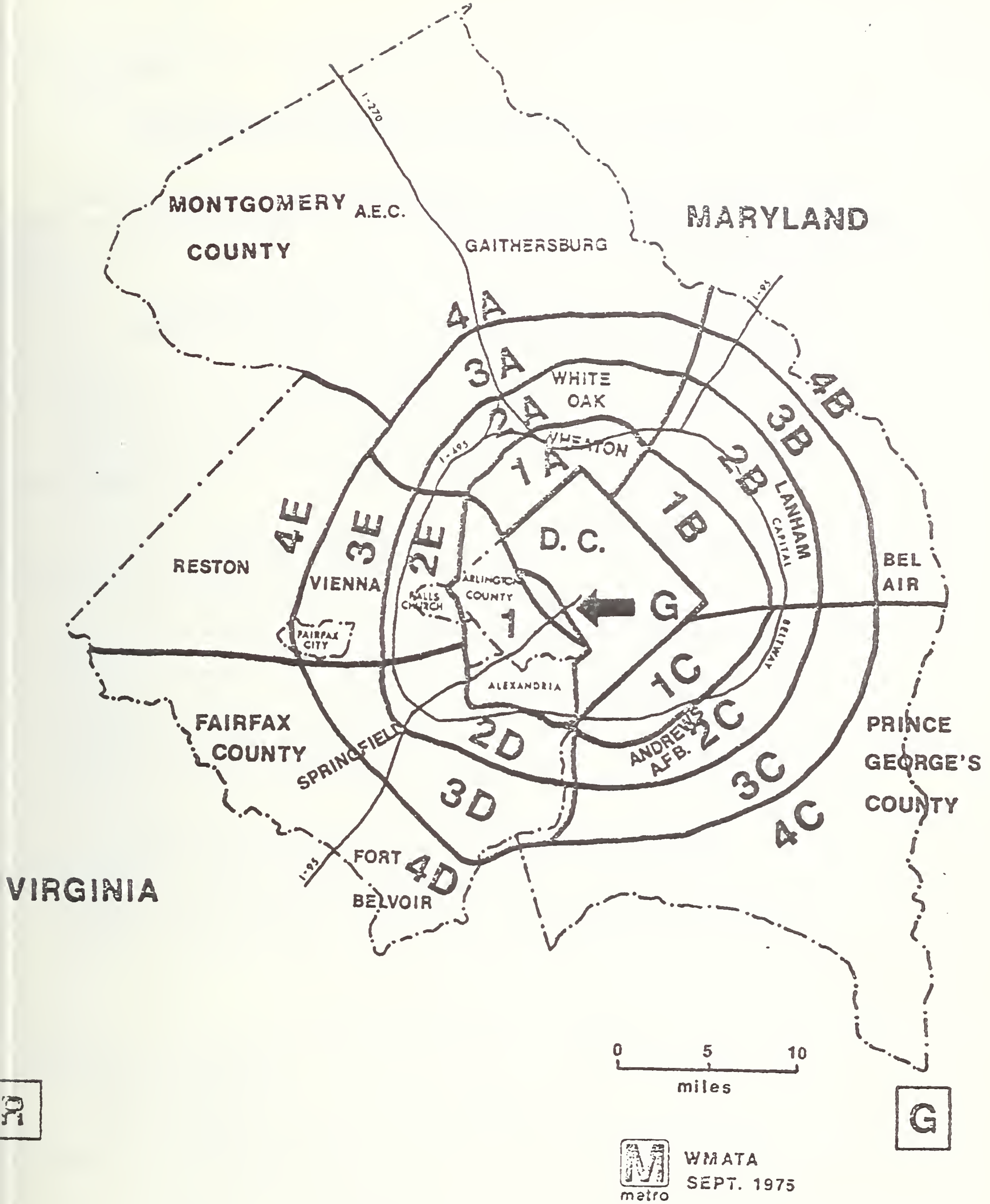

FIGURE 5
WMATA FARE ZONES

Appendix D: Illustrative Calculation of Approximate Elasticities

We illustrate the calculation of approximate elasticities using data observed before/after the 1966 fare increase from 15¢ to 20¢ in the New York City subway system.

Table 7 of [11], page 5. gives

Decline in turnstile registration from financial district stations in period 4 p.m. - 7 p.m. = 3.4%.

So: $\frac{\Delta Q}{Q} = -3.4\%$, $Q_2/Q_1 = 0.966$

Also: $\frac{\Delta P}{P} = \frac{5¢}{15¢} = 33\%$, $P_2/P_1 = 1.333$.

For shrinkage factor: $\hat{e} = \frac{\Delta Q}{Q} / \frac{\Delta P}{P} = \frac{-.034}{.33} = -0.103$

For arc elasticity (see Equation 7 of [9], page 15):

$$\tilde{e} = \ln(Q_2/Q_1)/\ln(P_2/P_1)$$

$$= \frac{\ln 0.966}{\ln 1.333} = -0.120$$

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To be published in outside journal.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes the methodology and the results of an empirical study of peak-period transit demand elasticity with respect to price (fare). Field observations were structured to capture the reactions of morning (inbound) commuters to a peak-period fare increase introduced on September 1, 1975. The study is limited to bus and automobile travelers on the Shirley Highway and bus passengers on the Lee Highway, both in Northern Virginia. The Shirley buses provide express service on exclusive freeway lanes, whereas the Lee Highway buses provide traditional service on a signalized radial arterial. Various impacts are identified, quantified and compared.

Demand for service on the Shirley Highway Express buses is less elastic (-0.274 to -0.218) than that for the traditional Lee Highway bus service (-0.535 to -0.273). There was little evidence of passengers on either service shifting travel outside the peak-periods to avoid higher fares. The fare increase had no effect on auto travel. These results suggest applying different pricing policies to different types of transit service.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Elasticity; elasticity of transit demand; pricing; transit planning; transit pricing

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