Model Application

The original unadjusted base-case modal-split estimates of the model did not match average reported modal split. A set of regional adjustment factors for mode preference were applied to model utility values across the four modes to replicate reported modal split at the metropolitan-area level. The need for such adjustment factors is probably attributable to three problems:

1. Analysis of the summary utility results of the model suggests that respondents did not impart to the mode attribute all of their mode preferences not captured by the other attributes that were explicitly traded off. Some of the variations in mode preferences, based on comfort and other attributes not explicitly included in the trade-off questions, were evidently not expressed in utility scores for the four modes. Respondents' confusion as to what was being held constant and what was to be included as implied by a given mode was most likely responsible.
2. The expense-sharing assumptions used to simulate the base case may have been misleading. Dividing total vehicle expenses by the average number of occupants for the two car-pool modes probably overstates the degree to which cost sharing is perceived by commuters. Simulation assumptions used in future work should reflect this.
3. Car-pool modes were broken down into two submodes: driver and passenger. Because an assumption of proportionality was used to convert mode utilities to estimates of modal split, splitting a mode into two submodes tends, if everything else is equal, to give the resulting pair a greater total normalized utility proportion. This probably does not affect the model's accuracy in making relative impact estimates for different policies, but it does contribute to the need for base-case modal adjustments.

CONCLUSIONS

The trade-off model approach has been shown to be quite successful in its application to a rather complex problem of impact estimation. The strengths and the potential of the approach as an effective alternative to conventional modal-split techniques warrant further developmental work. Two major areas that would merit investigation in future research are (a) the possibility of expanding the size of a workable trade-off problem by splitting the answering task among several respondents who represent a single socioeconomic or travel group and (b) the feasibility of incorporating a soft factor in the trade-offs by using several more tangible component variables.

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Reductions in Automobile Use in Four Major Cities as a Result of Car Pooling and Improved Transit

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Voluntary car-pool matching programs and improvements in transit services are two transportation control policies that have received wide support from environmentalists, energy-conservation groups, and the public. This paper presents estimates of how these two policies would affect vehicle kilometers of travel and automobile emissions in Boston, Los Angeles, Chicago, and Washington, D.C. Because the four cities differ widely in terms of their spatial structure and their transportation systems, the estimates should cover the range of impacts expected in many large cities. The results indicate that car pooling will reduce vehicle kilometers of travel and automobile emissions by roughly 0.1 percent if pessimistic responses to employer-based car-pool matching programs are used and by as much as 1.5 percent if optimistic levels of participation are used. Improvement in transit performance, represented as a 20 percent reduction in travel time, is projected to reduce vehicle kilometers of travel by 0.5 to 1 percent and automobile emissions somewhat less. Crude cost-effectiveness analyses suggest that voluntary employer-based car-pool matching programs are attractive even if they only reduce vehicle kilometers of travel by 0.1 or 0.2 percent. The costs of improved transit service are difficult to estimate, but some bus-lane proposals are likely to be cost effective. However, savings that result from reductions in vehicle kilometers of travel attributable to improved transit performance are unlikely to justify investments in fixed-rail systems.

Much can be learned about the effects of various transportation control programs by analyzing their impacts in several large cities that have widely varying characteristics. The four cities included in this analysis—Boston, Chicago, Los Angeles, and Washington, D.C.—cover a wide range of employment and population densities, spatial organizations, transit use rates, and development paths. At one extreme is Boston—an old, high-density northeastern city with an extensive transit system. At the other is Los Angeles—a new, low-density southwestern city with an automobile-oriented development pattern.

Data given in Table 1 (8, 10) reveal pairwise similarities between Boston and Washington and Chicago and Los Angeles in terms of population, central-city share of the population of the standard metropolitan statistical area (SMSA), and central-city area. Population trends indicate that only the Los Angeles central city is still growing; the other three central cities peaked in 1950 and have since declined. Table 1 also gives the year when each city reached half its maximum population, a common way of measuring a city's age (4). By this definition Boston is the oldest and Los Angeles the youngest of the four cities. Measuring the age of a city is useful because it indicates when the city was laid out and provides information about the age of the housing stock and the type of transportation available. The two older cities, for example, have extensive transit systems whereas Los Angeles residents rely largely on automobiles.

The spatial distribution of activities within urban areas can be an important determinant of how effective transportation control programs are. Table 2 gives summary information about population and employment distributions within the four cities (8). Data are shown for the central business district (CBD), the central city other than the CBD, and the metropolitan area other than the central city. These areas roughly comprise the center and two concentric rings. Population distributions given in Table 2 mirror the numbers in Table 1: In all four areas more than half the population lives outside the central city and very small proportions live in the CBD. Employment is nearly as suburbanized as population; only in Chicago does the suburban ring contain less than half of SMSA employment. These distributions suggest that urban workers are likely both to live and to work in the suburbs.

The CBDs in the four cities contain a large number of jobs in absolute terms, but only in Washington does the share of metropolitan-area employment exceed 10 percent. The popular misconception that most jobs are in the CBDs undoubtedly stems from observation of high CBD employment densities, which, as shown by data given in Table 2, are always an order of magnitude larger than for the rest of the central city. Employment and population densities in Washington and Boston are very similar for the CBD and the central city; Chicago has very high CBD employment densities whereas the Los Angeles CBD has the lowest employment density of the four cities.

Table 1. Population and area of four urban areas studied.

Item	Boston	Los Angeles	Chicago	Washington
SMSA population in 1970	2 754 000	7 041 000	6 978 000	2 862 000
Central-city population in 1970	641 000	3 169 000	3 367 000	757 000
City's percentage of SMSA population	22.1	45.1	48.2	26.0
City's percentage of SMSA area	3.6	11.2	6.0	2.2
Area, km^2				
SMSA	3 578	11 302	10 330	7 811
City	128	1 264	617	169
Date central city reached half of maximum population	1885	1936	1903	1918

Note: 1 km^2 = 0.386 $mile^2$.

Table 2. Employment and population distributions.

Location	Employment			Population		
	Percentage	Jobs	Jobs/km^2	Percentage	Persons	Persons/km^2
Boston						
CBD	7.6	91 000	253 000	0.1	3 700	10 300
Rest of central city	29.3	351 000	22 000	23.1	637 000	39 320
SMSA other than central city	63.1	757 000	1 690	76.7	2 113 000	4 725
Total	100	1 199 000		100	2 754 000	
Los Angeles						
CBD	4.3	143 000	144 000	0.3	22 150	22 290
Rest of central city	43.9	1 446 000	8 900	44.7	3 147 000	19 330
SMSA other than central city	51.8	1 707 000	1 300	55.0	3 872 000	2 975
Total	100	3 296 000		100	7 041 000	
Chicago						
CBD	8.3	252 000	453 000	0.1	4 826	8 650
Rest of central city	46.4	1 413 000	17 800	48.2	3 364 000	42 380
SMSA other than central city	45.3	1 379 000	1 095	51.7	3 609 000	2 870
Total	100	3 044 000		100	6 978 000	
Washington						
CBD	11.7	147 000	296 000	0.2	5 105	10 280
Rest of central city	33.8	424 000	19 750	26.3	752 000	35 045
SMSA other than central city	54.5	683 000	690	73.5	2 105 000	2 125
Total	100	1 254 000		100	2 862 000	

Note: 1 km^2 = 0.386 $mile^2$.

Table 3 gives the interactions between residential locations and workplaces in terms of a trip table (8). Ring-to-ring trips comprise the largest share of work trips in all four cities although only in Boston does this category represent a majority of work trips. The trip tables for Boston and Washington are similar, as are the tables for Los Angeles and Chicago, reflecting the data given in Table 1 on the size of their central cities.

The importance of the trip table becomes apparent when the journey-to-work mode choice, which varies significantly by workplace as well as by the residence-workplace combination, is examined. In most metropolitan areas, the transit system has a strong radial orientation to the CBD; this often makes transit service between points outside the central city nonexistent or circuitous and time-consuming. The poor service caused by such circuitous routing often means that very few trips originating at and destined for the suburban ring will be made by transit. Moreover, it is often difficult to use transit to make work trips from the city center to outlying areas because of scheduling problems or poor transit service to suburban workplaces.

Work trip mode choices by workplace, taken from data in the 1970 Census, are given in Table 4. Data for persons per automobile have been calculated by dividing the sum of automobile drivers and passengers by the number of automobile drivers. Across the four cities studied, transit's share uniformly declines and the share of automobile-driver trips increases with workplace distance from the CBD. Walking is one mode often overlooked by transport planners, and Table 4 reveals its importance: In Los Angeles, walking is only slightly less popular than transit as a mode to work.

In all four cities the automobile occupancy rate for work trips declines with increasing workplace distance from the CBD. High automobile occupancy rates in the Washington CBD undoubtedly reflect the impact of the federal employee car-pooling program that has been encouraged there for many years. An interesting contrast is the workplace-related change in automobile occupancy rates and share of work trips made by automobile passengers. The automobile passenger share, a measure of car-pooling activity, increases with distance from the CBD in Boston and Chicago but decreases in Los Angeles and Washington. The low share of automobile passenger trips made to the Boston and Chicago CBDs is probably attributable to the presence of extensive transit systems, which suggests that car-pooling and transit are competing modes.

Table 3. Percentage of total work trips from residence to workplace.

Residence Location	Percentage of SMSA Work Trips: Workplace: CBD	Non-CBD Central City	Ring	Total
Boston				
Central city	3.0	13.5	4.5	21.0
Ring	4.3	13.3	50.1	67.7
Outside SMSA	0.3	2.5	8.5	11.3
Total	7.6	29.3	63.1	100
Los Angeles				
Central city	2.4	28.2	12.2	42.8
Ring	1.8	15.3	37.8	54.9
Outside SMSA	0.2	0.5	1.8	2.5
Total	4.4	44.0	51.8	100
Chicago				
Central city	5.3	35.0	7.4	47.7
Ring	3.0	11.0	36.7	50.7
Outside SMSA	0.1	0.5	1.2	1.8
Total	8.4	46.5	45.3	100
Washington				
Central city	4.7	16.8	4.7	26.2
Ring	6.7	15.6	46.4	68.7
Outside SMSA	0.3	1.4	3.3	5.0
Total	11.7	33.8	54.4	100

VOLUNTARY CAR-POOL MATCHING PROGRAMS

Car pooling and other high-vehicle-occupancy policies have aroused great enthusiasm as techniques for reducing vehicle kilometers of travel in urban areas. These policies have many strengths: (a) They use existing fa-

Table 4. Work-trip mode split and automobile occupancy by workplace.

Workplace Location	Mode Split (%): Automobile Driver	Automobile Passenger	Transit	Walk	Taxi	Other	Persons per Automobile
Boston							
CBD	29.0	7.6	57.4	4.8	0.6	0.6	1.26
Rest of central city	49.2	11.3	25.6	10.7	1.5	1.8	1.23
SMSA other than central city	65.6	13.1	7.4	9.4	0.7	3.9	1.20
All	58.0	11.6	17.0	9.5	1.0	2.9	1.21
Los Angeles							
CBD	62.2	13.1	22.2	1.2	0.0	1.3	1.21
Rest of central city	76.8	8.4	6.4	4.4	0.0	3.9	1.11
SMSA other than central city	80.5	8.9	2.5	4.2	0.1	3.8	1.11
All	78.2	8.6	5.2	4.1	0.1	3.8	1.11
Chicago							
CBD	18.8	3.7	75.6	1.1	0.5	0.4	1.20
Rest of central city	49.8	9.5	30.3	8.3	0.3	1.9	1.19
SMSA other than central city	70.6	13.4	5.8	5.7	0.3	4.1	1.19
All	57.0	10.8	22.6	6.5	0.3	2.8	1.19
Washington							
CBD	39.0	18.0	35.4	4.0	1.9	1.3	1.46
Rest of central city	54.2	14.1	22.6	5.0	1.4	2.7	1.26
SMSA other than central city	72.0	11.5	5.8	5.2	0.8	4.6	1.16
All	62.2	13.1	14.9	5.0	1.2	3.6	1.21

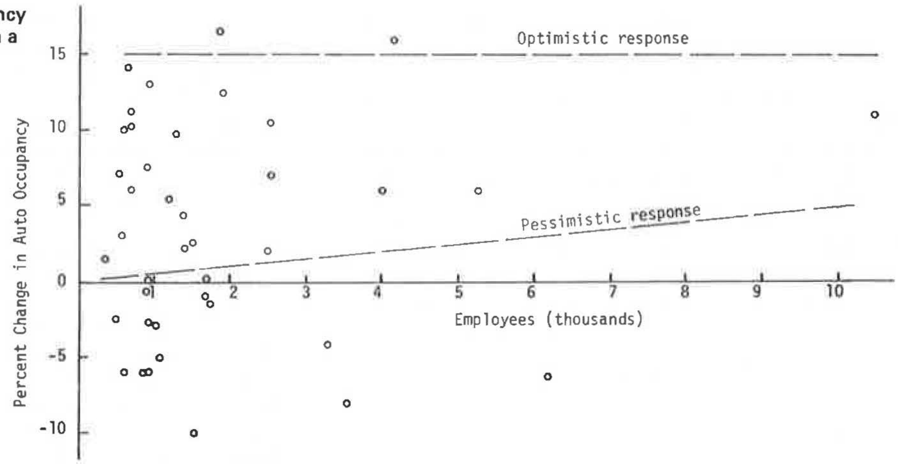

Figure 1. Change in automobile occupancy for New Jersey firms that participated in a car-pool matching program.

cilities and do not call for massive public or private investments, (b) they can be as efficient as some higher occupancy modes such as buses, (c) they involve few public employees, and (d) they can serve almost any location presently accessible by automobile. The major difficulty with high-vehicle-occupancy policies is their service characteristics. Car and van pools have particularly inflexible schedules: The service is offered once a day to a member, and changes in trip times generally require the consensus of all members.

The difficulty of finding potential car poolers has been significantly reduced in many metropolitan areas by publicly supported, voluntary car-pool matching programs that solicit information from commuters and match groups by origin, destination, and time of travel (2, 3). Perhaps the major service of such programs is their lowering of car-pool "transaction costs." The number of successful car pools formed by areawide voluntary programs has been very small, however. Car pooling has been much more successful when it involves employees from a single firm; these individuals are less likely to be strangers and typically share workplace and work hours, and so residential location is the major dimension requiring commonality. As a result, most metropolitan car-pooling programs are now employer based.

Theoretical work suggests that the proportion of successfully matched applicants in a car-pool program will increase with the number of applicants (3). This observation has led designers of employer-based programs to solicit potential car poolers only from large firms. The Massachusetts Mass Pool program, for example, deals only with firms that have 250 or more employees.

Estimating the impacts that a voluntary employer-based car-pool matching program would have in the four selected cities requires three major steps:

1. Presentation of data on the "dose-response" relation between car-pooling programs and increases in car pooling,
2. Definition of the pool of potential candidates in terms of employment distribution by firm size (number of employees), and
3. Application of the dose-response relation to the pool of potential candidates to determine how a voluntary matching program affects vehicle kilometers of travel in each of the four metropolitan areas.

Automobile Occupancy Rates

Because relatively few of the early matching programs were employer based, data that link changes in car-pooling rates to the application of voluntary, employer-based car-pool matching programs are relatively rare. Data from 42 New Jersey firms that participated in a car-pool matching program begun in the winter of 1973-1974 measure changes in car-pooling activity in terms of the percentage change in each firm's automobile occupancy rate over 18 months.

Figure 1 relates the change in automobile occupancy rates to firm size and reveals that firm size has no strong effect. The decline in automobile occupancy rates for many firms is attributable to employment reductions that disrupted car pools and to the high level of voluntary car pooling during the 1973-1974 energy crisis. Given the wide distribution of data in Figure 1, two extreme responses to an employer-based car-pool matching program are hypothesized. An optimistic response, defined by the upper bound of points, is approximately a 15 percent increase in automobile occupancy rates independent of firm size. A pessimistic response, defined by the lower bound of positive changes, increases linearly from zero at a firm size of zero to 5 percent at a firm size of 10 000. These responses serve to bound the experience of firms in other areas.

Distribution of Employment by Size of Firm

Many analysts believe that increases in car pooling vary with firm size. Although the data in Figure 1 do not support such a relation, they are certainly not the final word on this matter. Furthermore, the smallest firm shown in Figure 1 has 350 employees. Because some employer-based programs have a minimum firm-size requirement, the distribution of employment by size of firm will show what proportion of workers will be eligible as the minimum size is varied.

Table 5 gives the cumulative distribution of employment by firm size based on 1973 county business patterns and the 1970 Census. There are obvious differences among the four metropolitan areas: Chicago has many large firms and Washington many small companies. In the suburbs of Washington only 30 percent of private employment is in firms with 250 or more employees, whereas in Chicago roughly 44 percent of suburban employment is in such firms. In all four cities about 15 percent of employment is in firms with 100 to 249 employees; thus, from 45 percent (Washington suburbs) to 60 percent (Chicago) of private employment is in establishments with more than 100 employees. Obviously, therefore, the minimum required firm size for employer-based car-pooling programs must be carefully selected because moving that minimum point from 250 down to 100 can have such a large impact on the percentage of

Table 5. Cumulative percentage distribution of employment by firm size.

Number of Employees in Firm	Employment Distribution (%)							
	Boston		Los Angeles		Chicago		Washington	
	Central City	Ring	Central City	Ring	Central City	Ring	Central City	Ring
1 to 49	31.36	36.60	36.28	37.66	29.43	31.34	34.66	42.77
50 to 99	42.87	48.07	47.40	49.05	39.89	41.71	45.99	55.23
100 to 249	58.54	61.83	61.71	63.46	54.74	55.99	60.12	70.11
250 to 499	69.53	71.87	70.97	73.15	65.82	67.79	71.22	79.01
500 to 999	78.37	80.54	79.10	81.00	74.99	76.71	77.60	85.42
1000 to 1499	83.67	85.65	83.28	84.96	80.51	81.98	82.98	90.78
1500 to 2499	88.76	90.34	86.62	87.89	85.66	86.63	88.82	93.48
2500 to 4999	93.32	94.52	91.22	91.96	91.54	91.99	96.81	97.49
5000	100	100	100	100	100	100	100	100

Note: Excludes workers in the public administration category.

Table 6. Percentage change in automobile occupancy for various responses to car-pool matching program.

Item	Boston	Los Angeles	Chicago	Washington
Persons per automobile				
Average	1.40	1.39	1.4	1.4
Work trip	1.21	1.11	1.19	1.21
Elasticity of total with respect to work trip	0.368	0.339	0.388	0.368
Work-trip share of vehicle kilometers of travel, %	0.38	0.35	0.40	0.38
Increase in automobile occupancy for various car-pool responses, %				
Work-trip estimates				
Pessimistic	0.363	0.583	0.599	0.358
Optimistic				
≥250 employees	6.03	5.72	6.74	5.32
≥100 employees	8.10	7.98	8.92	7.97
Overall estimates				
Pessimistic	0.138	0.203	0.239	0.136
Optimistic				
250 employees	2.21	1.93	2.59	1.96
100 employees	2.93	2.66	3.39	2.89

eligible workers. Accordingly, estimates of car-pool response have been calculated for minimum required firm sizes of 100 and 250 employees.

The firm-size distributions exclude public administration workers, a group that comprises from 6 to 8 percent of the work force in Boston, Los Angeles, and Chicago but 36 percent of central-city workers and 26 percent of suburban workers in Washington. Because of a lack of comparable data for the four cities on firm size for public administration workers, the distribution of public administration employment by firm size is assumed to be similar to that in the private sector. If this proves to be a poor assumption, it will clearly produce the largest biases in Washington.

Reductions in Vehicle Kilometers of Travel

Given the dose-response relations derived from Figure 1 and the distribution of employment by firm size, a range of car-pool-induced changes in automobile occupancy rates can be calculated for each city (Table 6). The basic data on overall automobile occupancy rates for Boston and Los Angeles were obtained from 1963 and 1968 home interview surveys; rates for Chicago and Washington are estimates based on the Boston and Los Angeles figures. The work-trip automobile occupancy figures for the four cities are 1970 Census-based rates reported previously in Table 4. The work-trip shares of vehicle kilometers of travel for Boston and Los Angeles are based on Boston and Los Angeles survey data, and the Washington figure is from a paper by Horowitz and Pernela (5). The work-trip share of vehicle kilometers of travel for Chicago is an estimate based on the work-trip share of total trips.

The elasticity of the overall automobile occupancy rate, derived elsewhere (7), equals the proportion of vehicle kilometers of travel times the proportional change in the work-trip automobile occupancy rate. Because the elasticity varies with the change in work-trip automobile occupancy rates, Table 6 reports the elasticity for a 5 percent proportional increase in the work-trip automobile occupancy rate. This elasticity and the following calculations assume that increases in work-trip automobile occupancy rates result only from redistributing automobile travelers among vehicles and that no travelers on other modes are diverted to car pools. Because a matching program is, in fact, likely to divert some CBD or central-city workers from transit to car pools, the calculations presented may overstate the reduction in vehicle kilometers of travel.

Table 6 also gives the increase in work-trip automobile occupancy rates for the hypothesized responses to a car-pool matching program. The pessimistic estimate assumes that work-trip automobile occupancy rates will increase by 0.0005 percent times the number of employees in a firm. This calculation is done for firms with 250 or more employees and provides a lower bound for the impact of a matching program. The optimistic estimates for firms having ≥250 or ≥100 employees assume that work-trip automobile occupancy rates will increase by 15 percent for these firms. Differences in the estimated change in work-trip automobile occupancy rates among the four cities are caused by differences in employment distribution by firm size. For example, the optimistic estimate for Boston for firms with ≥250 employees is 6.03 percent because only about 40 percent of Boston employment is in firms of that size.

The overall increase in automobile occupancy rates given in Table 6 is obtained by multiplying the change in

Table 7. Percentage reductions in areawide vehicle kilometers of travel and mobile-source HC emissions for various responses to car pooling.

	Reduction (%)			
	Work-Trip Travel		Induced Nonwork Travel[a]	
Estimate	Vehicle Kilometers	HC Emissions	Vehicle Kilometers	HC Emissions
Boston				
Pessimistic	0.124	0.121	0.074	0.073
Optimistic				
250 employees	1.99	1.95	1.19	1.17
100 employees	2.64	2.59	1.58	1.55
Los Angeles				
Pessimistic	0.185	0.183	0.111	0.110
Optimistic				
250 employees	1.76	1.74	1.06	1.05
100 employees	1.43	2.40	1.46	1.44
Chicago				
Pessimistic	0.22	0.22	0.13	0.13
Optimistic				
250 employees	2.4	2.4	1.4	1.4
100 employees	3.1	3.1	1.9	1.9
Washington				
Pessimistic	0.12	0.12	0.07	0.07
Optimistic				
250 employees	1.8	1.8	1.1	1.1
100 employees	2.6	2.6	1.6	1.6

Note: 1 km = 0.62 mile.
[a] Net reductions.

work-trip automobile occupancy rates by the elasticity of the overall occupancy rate with respect to work-trip occupancy rates. Changes in overall automobile occupancy rates vary from nearly zero to 3 percent, a range that seems fairly small. Clearly, however, this is the right order of magnitude because 40 percent of travel is for work trips, 40 percent of the workers are affected, the change is 15 percent, and 0.4 x 0.4 x 0.15 = 0.024.

The next step in the analysis is to translate the increase in automobile occupancy rates into a reduction in vehicle kilometers of travel and automobile emissions. This was done by using a transportation and air shed simulation model (TASSIM) (6) calibrated to Boston and Los Angeles; for this analysis the results were extrapolated to Chicago and Washington. Reductions produced by the various hypothetical car-pooling responses are given in Table 7. Data for vehicle travel and hydrocarbon (HC) emissions for each city show the direct impact on travel, assuming that a reduction in work trips is not accompanied by an increase in nonwork trips. It is likely, however, that the increased availability of automobiles to household members may induce more nonwork travel. Estimates using TASSIM suggest that about 40 percent of the reduced work-trip travel may be replaced by nonwork travel, and this estimate has been supported by others (1). Work-trip car-pool programs might reduce areawide vehicle kilometers of travel by up to 2 percent, although a reduction between 0.1 and 1 percent seems more likely. The adjusted figures for induced nonwork travel may still overstate the reduction in vehicle kilometers of travel because the calculations assume that no transit riders are diverted to car pools.

Diversion of transit riders to car pools interferes with the simple relation assumed so far between automobile occupancy rates and vehicle kilometers of travel. For example, if car-pooling programs only turn transit passengers into car-pool passengers, automobile occupancy rates (and the mode share of automobile passengers) would increase but vehicle kilometers of travel would be unaffected. Furthermore, the data in Table 4 suggested that car pools and transit may be viewed as substitutes, and so some adjustment in projected vehicle kilometers of travel may be called for.

Preliminary estimates have been made of the relation between car pooling and transit ridership for a sample of 159 firms participating in the Massachusetts Mass Pool program. The sample was compiled by Alan M. Voorhees and Associates, Inc. The regression analysis for the entire sample is as follows [numbers in parentheses are t-ratios, and locations of firms are identified by a system of 2.6-km² (1-mile²) grids]:

$$\begin{aligned} PUBTR = {} & 0.198 - 0.30CP - 0.012LFS + 0.04STN1 + 0.013STN2 \\ & (1.8) \quad (2.8) \quad (9.7) \quad (5.9) \quad (4.2) \\ & - 0.016SUB \quad R^2 = 0.66 \\ & (0.3) \quad N = 159 \end{aligned} \quad (1)$$

where

PUBTR = proportion of the work force that commute by transit,
CP = proportion of the work force that commute in multioccupancy vehicles,
LFS = log of firm size (number of employees),
STN1 – number of subway stations located in the same 2.6-km² grid as the firm,
STN2 = number of subway stations in the eight grid squares that surround the grid square in which the firm is located, and
SUB = dummy variable (1 for suburban location and 0 for central city).

The regression for the stratified sample is as follows:

$$\begin{aligned} PUBTRC = {} & 0.207 - 0.66CPC - 0.009LFS + 0.034STN1 \\ & (1.1) \quad (2.9) \quad (0.3) \quad (3.7) \\ & + 0.016STN2 \quad R^2 = 0.44 \\ & (3.2) \quad N = 76 \end{aligned} \quad (2)$$

$$\begin{aligned} PUBTRS = {} & 0.204 - 0.047CPS - 0.023LFS + 0.150STN1 \\ & (1.9) \quad (0.6) \quad (1.4) \quad (3.8) \\ & + 0.002STN2 \quad R^2 = 0.36 \\ & (0.6) \quad N = 83 \end{aligned} \quad (3)$$

where

PUBTRC = PUBTR for central-city firms,
PUBTRS = PUBTR for suburban firms,
CPC = CP for central-city firms, and
CPS = CP for suburban firms.

The table below gives the means for the work-force variables used in the analyses:

Variable	Mean
CP	0.217
CPC	0.181
CPS	0.251
PUBTR	0.240
PUBTRC	0.428
PUBTRS	0.069

The regression for the entire sample indicates that 30 percent of new car-pool riders will be drawn from transit. Stratification of the sample by employment location reveals that the extent of this diversion from transit differs dramatically: In the central city, 66 percent of new car poolers may be drawn from transit but, in the suburbs, 5 percent. Other studies have also found that transit and car pools are substitutes. Atherton, Suhrbier, and Jessiman (1) estimate that in Washington approximately 25 percent of new car-pool riders attracted

Table 8. Reductions in areawide vehicle kilometers of travel and related savings as result of car pooling and transit improvement.

Item	Boston	Los Angeles	Chicago	Washington
Approximate daily vehicle kilometers of travel, 000 000s	32[a]	210[a]	85[b]	35[c]
Daily vehicle kilometers of travel × 365, 000 000 000s	11.8	76.6	31.1	12.9
1.0 percent of annual vehicle kilometers of travel, 000 000s	118	766	311	129
Value of 1 percent reduction at $0.04/km, $	4 380 000	28 500 000	11 500 000	4 800 000
Value of 0.1 percent reduction at $0.04/km, $	438 000	2 850 000	1 158 000	480 000
Approximate cost of present car-pooling program, $	600 000	1 000 000	270 000[d]	150 000

Note: 1 km = 0.62 mile.
[a] Scaled to the metropolitan area from TASSIM estimates for the air quality control region.
[b] Scaled from Washington vehicle kilometers of travel by population.
[c] From Wickstrom (9).
[d] Costs for a program operated by a radio station.

by an employer-based program would be diverted from transit. If a diversion rate of one-quarter to one-third is applied to the other three cities in Table 7, the maximum reduction in vehicle kilometers of travel from the most optimistic program would be less than 1.5 percent.

From the point of view of designing car-pool-incentive programs, the diversion of commuters from transit can be reduced significantly by not offering a computer matching program to firms if a large proportion of their work forces commute by transit. The mode-split figures in Table 4 suggest, for example, that employees of firms located in the Chicago and Boston CBDs are heavy users of transit and that relatively little would be gained by offering them car-pool matching services.

IMPROVED TRANSIT PERFORMANCE

Improved transit performance has also been suggested as a policy to reduce vehicle kilometers of travel and automobile emissions, but improvements in the form of new transit systems are very costly. Of course, other low-cost alternatives are also available, such as transferring existing highway lanes from automobile to bus use. But such a policy improves performance only where highways are presently congested and is thus likely to benefit high-density central cities more than suburban areas.

The evaluation of improved transit performance as a technique for reducing vehicle kilometers of travel and automobile emissions was carried out for Boston and Los Angeles by using the TASSIM model. In both cities the model was used to simulate the impacts of a hypothetical (and extremely optimistic) 20 percent decrease in transit travel times; vehicle kilometers of travel are reduced because improved transit service induces more travelers to use transit for all or part of their trips. The results of the TASSIM simulations are given in the table below:

	Reduction (%)			
Item	Boston	Los Angeles	Chicago	Washington
Vehicle kilometers of travel	0.50	0.62	0.4	1.1
HC emissions	0.39	0.46	0.3	0.9

Overall vehicle kilometers of travel are reduced by about 0.5 percent in Boston and Los Angeles. The reduction in HC emissions is less because many commuters drive to the transit station and cold-start emissions constitute a large share of total emissions from urban automobile trips.

Because transit serves CBD-destined trips especially well, the TASSIM extrapolations to Chicago and Washington were based on the current share of all CBD-bound automobile trips for the four cities. The results are given below:

	Automobile Work Trips by Workplace Location (%)			
City	CBD	Rest of Central City	Rest of SMSA	Total
Boston	4.0	25.5	70.8	100
Los Angeles	3.7	43.0	53.3	100
Chicago	2.8	41.8	56.4	100
Washington	8.9	30.7	60.5	100

In Boston and Los Angeles, roughly 4 percent of all automobile work trips are made to the CBD; in Chicago the proportion is lower, and in Washington it is higher. Reductions in vehicle kilometers of travel in the table above are based on the importance of automobile use for CBD-bound trips; improved transit is thus expected to have the largest impact in Washington and the smallest impact in Chicago. In both cities the forecast reduction in HC emissions is again less than the reduction in vehicle kilometers of travel because of cold-start emissions.

DISCUSSION OF RESULTS

It is easy to be disappointed by the relatively small reductions in vehicle kilometers of travel projected here for car-pooling and transit improvement policies: from 0.1 to 1 percent of daily areawide vehicle kilometers of travel, depending on the assumptions used. In absolute terms, however, the impact of these reductions is significant. Table 8 gives order-of-magnitude estimates of daily and annual vehicle kilometers of travel for the four case cities as well as the value of 1 percent of annual vehicle kilometers of travel calculated at $0.04/km ($0.06/mile) to approximate out-of-pocket operating costs for automobiles. This rather conservative valuation implies that a 1 percent reduction in annual vehicle kilometers of travel would produce annual savings of from $4 million in Boston to $28 million in Los Angeles. Moreover, the approximate costs of car-pool matching programs suggest that these programs will be cost effective even if they reduce vehicle kilometers of travel by as little as 0.1 percent.

Calculating costs for a transit improvement program that would reduce transit travel time by 20 percent in each of the four cities is difficult. Reserved bus lanes may have relatively low costs and be cost effective, but more detailed analysis on a corridor-by-corridor basis in each city is necessary to produce adequate estimates of improvement costs. The values of a 1 percent reduction in vehicle kilometers of travel suggest, however, that investments in extensive fixed-rail transit systems would probably not be justified in terms of reductions in vehicle kilometers of travel.

A final point worth emphasizing is that transit and car pools appear to be highly substitutable modes for many commuters. This finding suggests that car-pooling programs should not be vigorously promoted in areas where a large proportion of the work force uses transit. The data suggest that extremely high transit use occurs mainly in CBDs but that CBDs typically contain less than 10 percent of a metropolitan area's employment. Even so, car-pool matching programs appear to have a wide potential market.

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Abridgment

Integrating Transit and Paratransit

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The declining fit of radially oriented transit to today's more dispersed travel, the recognition of the role of taxis, and the growth of paratransit have led to strong interest in integrating conventional transit and paratransit. This interest has been based on the expectation that, by and large, these services complement each other—particularly that paratransit can serve markets for which conventional service is either unequipped or overly expensive. Policy statements by the Urban Mass Transportation Administration (UMTA), the American Public Transit Association, and the International Taxicab Association support service integration.

However, the emergence of paratransit has raised more options and issues than can be dealt with by using current information. For example, there are a bewildering variety of service options—choices between public and private operators, labor questions, regulatory changes, insurance issues, high costs, and requirements for special services, to name just a few. Moreover, although UMTA activities for specific modes, primarily dial-a-ride and its variations, have been in progress for over 5 years, research and demonstrations addressing the integration of paratransit and transit only began within the past 3 years. The Rochester, New York, demonstration began in April 1975; the UMTA areawide demand-responsive transportation projects are just now being started.

Definitive results are not yet available, but the lessons from previous experience and research point toward several general conclusions. This paper highlights such tentative results.

PARATRANSIT IMPACTS

The major impacts of expanded paratransit services appear to be the following:

1. Improved mobility for people permanently or temporarily without access to private automobiles or high-quality transit service;
2. Reduced total cost of transportation for commuters, taxi users, and other individuals; and
3. Reduced congestion or parking requirements at individual employment or activity centers.

Improved mobility might well be the single largest impact of paratransit service. The low demand densities, scattered trip patterns, and special service needs that characterize the travel of people who are currently without adequate transportation are often more appropriate for demand-responsive or local minibus service than for conventional transit. Almost invariably, these people are unable to drive or they find the cost of private automobiles too high; the availability of a private automobile would remove the limitation on their mobility.

Notably missing from the list of impacts are the major national concerns of energy and environmental protection. Improvements in vehicle technology would probably have a larger impact on reducing energy use and pollutant emissions than would any foreseeable effect of paratransit. The percentage of trips by public transportation, about 5 percent nationwide, is so small that the