Use of Disaggregate Travel Demand Models to Analyze Car Pooling Policy Incentives

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Increased emphasis is being placed on short-range transportation options as a means of reducing energy consumption, air pollution, and traffic congestion. The research presented evaluates potential car pooling incentives and analyzes the direct and indirect effects of such policies. The travel analysis is based on three disaggregate travel demand models that predict mode choice for the work trip (including drive alone, transit, and the car pool alternative); frequency, destination, and mode choice for the nonwork trip; and household automobile ownership level. The analysis is conducted in a case study framework by using data from Washington, D.C. For each of many randomly selected households, the travel response to a candidate policy is simulated probabilistically by sequentially proceeding through the three models. By predicting the results at the level of each individual household, the models can stratify areawide travel impacts by any socioeconomic or geographic characteristic, e.g., income groupings. Results indicate that most policies result in modest reductions in travel for the work trip but that this may be partially offset by increased nonwork trip making induced by the increased number of automobiles left at home. When a policy influences both work and nonwork trips (gasoline price increases, for example), nonwork travel decreases significantly more than work trip travel, which confirms the more discretionary nature of nonwork travel.

Significant changes in both the scope and the emphasis of transportation planning have occurred in recent years. Where the former forcus was almost exclusively on long-range (1990 or 2000) forecasts of travel demand for use in major facility planning, now more and more transportation policy making is being directed at current problems of air quality, traffic congestion, energy consumption, noise pollution, and social equity. The objective is to develop solutions to these problems that can be implemented immediately, i.e., to make more effective and desirable use of existing facilities.

In this context, the Federal Energy Administration is examining various transportation policy incentives and disincentives that could be used to encourage car pooling with the general objective of reducing overall fuel consumption. To fully evaluate car pooling policies, though, one must go beyond the indirect effects, i.e., the shift to car pooling as the mode used for the work trip. For example, to what extent will the increase in trip circuity and vehicle weight associated with car pooling influence overall fuel consumption? What will happen with the increased number of automobiles left at home as a result of increased car pooling for work trips? Will this increase in automobile availability result in a corresponding increase in the number and length of nonwork trips such that the reduction in fuel consumption achieved by car pooling will be partially offset? Will the policy itself, for example, gasoline price increases, also directly affect nonwork trip making? Will a particular car pooling policy affect all segments of the population, or will certain groups be affected significantly more than others?

RESPONSE OF TRAVEL DEMAND TO CAR POOL INCENTIVES

Traditional aggregate models of travel demand have proved inadequate for this kind of short-range policy planning. Such aggregate models, based on existing relationships between zonal averages, tend to be correlative in nature rather than causal or behavioral and often are completely insensitive to proposed changes in transportation policy. Also by dealing in zonal averages, zonal totals, and zone centroids, aggregate models lose or blur much of the individual household information that sets one household apart from another in terms of travel behavior. Clearly, such models are inappropriate for analyzing the complex and often subtle interrelationship of variables that influence an individual's decision to car pool and are incapable of dealing with the appropriate issues.

Two basic requirements must be satisfied to properly analyze the effectiveness of various policy options related to car pooling (4). First, the models must be sensitive to changes in attributes of transportation alternatives that would result from the policies being analyzed (i.e., the models must be policy sensitive). Second and equally important, the models must be structured in such a way that they accurately reflect the choice process of an individual traveler deciding between travel alter-

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natives based on the attributes of each (i.e., the models must be behavioral). If a model does not meet these two conditions, it cannot be expected to predict with any degree of accuracy the effects on travel behavior of implementing a given policy.

Recently developed disaggregate models are calibrated at the household level by using observations of individual travel behavior, and they have several distinct advantages over aggregate models, including the following.

1. Because disaggregate models are not tied to any particular zonal system, they can be used at any geographical level; i.e., they can be aggregated to any level and are applicable for both areawide and subregional planning.
2. Because disaggregate models are behavioral or explanatory rather than correlative, they are more easily transferred from one situation or area to another. Geographic and temporal transferability of disaggregate models has been substantiated (2).
3. Disaggregate models make more efficient use of available data. A large portion of the variation in any data set is intrazonal rather than interzonal (5). Disaggregate models do not group data but preserve information about each individual household, and hence actually use intrazonal variation in a data set to estimate model parameters. Each individual becomes an observation rather than a zonal total being an observation unit.

INTERRELATIONSHIP OF AUTOMOBILE OWNERSHIP AND WORK AND NONWORK TRAVEL

From the viewpoint of an individual household, three groups of travel-related decisions can be distinguished (Figure 1). First are the long-range or major land use and locational decisions. These include choice of work place location for primary workers in the household and choices of residential location and housing type. These long-run decisions are assumed to be fixed for purposes of short-run policy analysis. Second are the medium-range decisions, which include automobile ownership and usual choice of mode to work decisions. The decisions on automobile ownership and work mode choice, it can be argued, are not typically independent of one another, at least not for the primary worker trips, and should be modeled simultaneously. A change in one would require a reconsideration of the other. A change in automobile ownership may require 1 to 3 years to actually take place, however. The third group of household travel decisions is short-range or nonwork trip decisions. These trips tend to be more discretionary and not to be planned very far in advance. Moreover, one does not decide to make a nonwork trip (shopping, for example), then decide where to make the trip, and then decide by what mode to make the trip in three sequential, independent steps as traditional aggregate models usually suggest; the frequency, destination choice, and mode choice decisions for nonwork trips should be considered simultaneously as alternative travel possibilities available to the household.

Given this basic travel behavior philosophy, three separate disaggregate travel demand models were integrated into a single model system:

1. A joint automobile ownership-work mode choice (for the head of household only) model (3),
2. A work trip mode choice model for all workers (3), and
3. A simultaneous frequency, destination, and mode choice model for nonwork trips (1).

Each of these models is of the multinomial logit form and was calibrated on observed travel decisions of individuals by maximum likelihood estimation. Logit is a specific mathematical form that has properties that match actual travel behavior, both empirically and theoretically, and is tractable computationally; maximum likelihood estimation is a technique for curve fitting or calibration, like least squares or regression but more sophisticated and compatible with the nonlinear logit form.

Each of the models is hypothesized as the probability of an individual or household choosing one of a set of alternative choices; for example, the work mode choice model is the probability of choosing each of three alternative modes—driving alone, sharing a ride, or riding transit—although a given individual may not necessarily have all three alternatives available to him or her. In the automobile ownership model, the choices are 0, 1, or 2+ automobiles owned; and in the nonwork model, the choice is a particular combination of destination and mode plus the option of no trip at all.

In each of the models, an alternative choice is described by its utility, or attractiveness, to the individual decision maker. This utility is an appropriately weighted combination of level-of-service attributes of the alternative, socioeconomic characteristics of the individual or household, and locational attributes such as employment density (which affect the probability of shared ride) given in Table 1. The appropriate weights are the relative weights a homogeneous group of individuals or households would assign to each of these attributes in making trade-offs among them; the weights or coefficients of each of the utility function terms are determined by the calibration or estimation process (maximum likelihood estimation, in this case) based on observed behavior and observed values of each of the variables or attributes of the alternative. (SI units are not given for the variables in these models inasmuch as their operation requires that values be in U.S. customary units.)

The variables represent known characteristics of travel demand. For work trips (Table 2), we know for instance that (a) as the ratio of available automobiles to licensed drivers increases, the probability of a drive alone trip increases; (b) the primary worker, or person of highest personal income, generally is given preference in use of an available automobile; and (c) the existence of more than one worker within a household creates the opportunity for family car pooling.

Locational variables are used in the work model to help define the probability of choosing the shared ride travel mode. For example, employment density at the work zone (employees per commercial acre) is multiplied by the one-way trip distance (miles); as this product increases, the probability of shared ride mode also increases. That is, the greater the density is at the destination zone, the higher the probability will be of finding someone to carpool with, and the longer the trip is, the more incentive there is to join a car pool or the greater the attractiveness of the shared ride mode will be.

Fundamental changes in the level of service of a transportation system, such as in cost, travel time, or modal availability, will lead to changes in automobile ownership over time. These changes may involve, for example,

1. Purchasing or selling a vehicle (frequently a second or third vehicle);
2. Postponing the sale or purchase of a new vehicle to a later time; or
3. Changing to a smaller, more fuel-efficient vehicle.

Figure 1. Travel choice hierarchy.

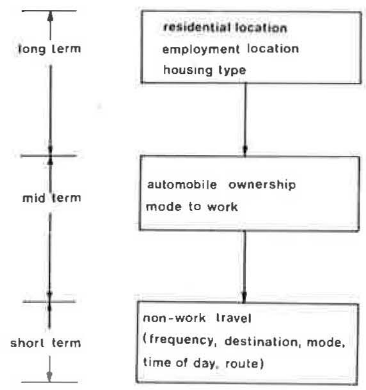
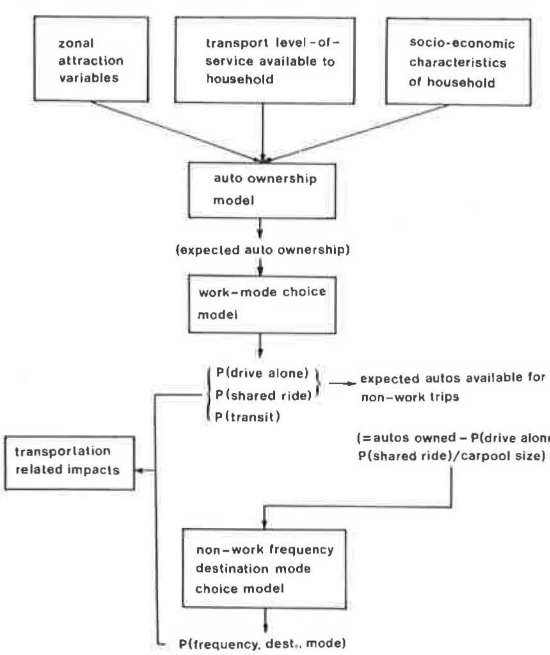


Table 1. Variables included in utility function of disaggregate travel demand models.

Variable	Automobile Ownership	Work Mode	Nonwork Frequency Destination and Mode
Socioeconomic			
Income	X	X	X
Automobile availability	X	DA, SR	X
Primary worker		DA	
Number of workers	X	SR	
Household size	X		X
Number of licensed drivers	X		
Residence type	X		
Level of service			
In-vehicle travel time	X	X	X
Out-of-vehicle travel time	X	X	X
Out-of-pocket travel cost	X	X	X
Locational			
Distance	X	X	X
CBD	X	DA, SR	X
Employment density	X	SR	
Employment type	X	SR	
Retail employment			X

Note: DA = drive alone mode (only), SR = shared ride mode (only), and X = all alternatives.

Figure 2. Model linkage.



The automobile ownership model includes transport level-of-service characteristics for both peak and off-peak travel, socioeconomic attributes of a household, and other locational factors that may influence automobile ownership and mode choice. The model actually is a joint model of automobile ownership and work mode choice, where each combination of automobile ownership level and mode to work is represented by a single alternative. The model, therefore, resolves the interdependency of automobile ownership and usual choice of mode to work by assuming the two decisions are made simultaneously.

FORECASTING CHANGES IN TRAVEL BEHAVIOR

The linkage of the three behavioral travel demand models into a single system is shown in Figure 2, which illustrates the sequence of calculations for a single household. In this way, the required information, such as automobile availability, is passed from model to model, and each model is conditional on any previous calculations for a given household. The computations follow the hierarchy of decisions shown in Figure 1, starting with automobile ownership and proceeding to work and nonwork trips. For predictions of only immediate or short-run impacts, the automobile ownership estimate is bypassed and the process starts with the work mode choice model for each of the household's workers. Only effects on daily travel activity are examined in this case, assuming automobile ownership remains constant. Running all three models, however, is more representative of an intermediate (1 to 3-year) impact time frame.

The model system also includes a variety of intermediate computations or submodels that are not shown in Figure 2, including shared ride automobile occupancy, automobile operating cost, and fuel consumption. These are performed, by household, on a trip-by-trip basis. For example, the probable size of a car pool is estimated as part of the work trip model and is based on the relevant socioeconomic, level-of-service, and locational variables. Fuel consumption is estimated as a function of trip length and vehicle weight, such that the effects of cold starts and increased automobile occupancy are taken into account.

MODEL REPRESENTATION OF POLICIES

Estimates of areawide impacts are projected from individual household impacts by repeating the model calculations for a suitable number of randomly selected households. This approach, called the random sample enumeration method, is free from any aggregation bias and, because the basic household level home interview survey data are used as a representative sample of areawide households, all the household-specific locational, level-of-service, and socioeconomic information can be preserved. The random sample of households needs to be large enough to be representative of the distribution of areawide households, to an acceptable level of accuracy. For Washington, D.C., a sample size of 800 households was found to be statistically sufficient for drawing areawide conclusions.

When a particular car pool incentive is analyzed, the household variables that would be directly affected by the incentive (e.g., work trip parking cost) are altered to reflect superimposition of the new incentive (Table 3). Then the models are used to simulate the travel choice probabilities of individual households, initially in the absence of a candidate incentive to provide a base case and then under the assumption that the incentive is in place. Areawide total changes are predicted by an

Table 2. Washington work trip mode choice model.

Variable	Car	Shared Ride	Transit	Standard Error	t-Statistic
Drive alone constant	-3.24			0.473	-6.86
Shared-ride constant		-2.24		0.401	-5.60
Out-of-pocket travel cost divided by income	-28.8	-28.8	-28.8	12.7	-2.26
In-vehicle travel time	-0.015 4	-0.015 4	-0.015 4	0.005 7	-2.67
Out-of-vehicle travel time divided by distance	-0.160	-0.160	-0.160	0.039	-4.08
Automobile availability (drive alone only)	3.99			0.395	10.08
Automobile availability (shared ride only)		1.62		0.305	5.31
Primary worker (drive alone only)	0.890			0.186	4.79
Government worker (shared ride only)		0.287		0.161	1.78
CBD work place (drive alone only)	-0.854			0.311	-2.75
CBD work place (shared ride only)		-0.404		0.298	-1.36
Disposable income (drive alone and shared ride only)	0.000 071	0.000 071		0.000 02	3.46
Number of workers (shared ride only)		0.098 3		0.095	1.03
Employment density (shared ride only)		0.000 65		0.000 49	1.34

Table 3. Examples of car pooling incentives and their representation.

Policy	How Represented in Model System
Car pool matching and promotion	Based on empirical data, modify government worker (car pool incentive) dummy variable to indicate matching assistance
Van pools	Extend alternative set to include this option with the appropriate travel times and costs
Preferential traffic control	Decrease car pool and increase drive alone travel times by appropriate amount, iterate for congestion effects
Area restrictions	Eliminate alternatives that require parking in that area or increase car out-of-vehicle time if have to park farther away
Gasoline rationing	Add shadow price to car travel cost, iterate for convergence
One-day/week driving ban	Decrease automobile ownership for each household by one for selected day per week
Preferential parking	Decrease car pool and increase drive alone excess time
Car pool parking subsidies	Decrease car pool travel cost
Parking tax surcharges	Increase car travel cost
Area of facility tolls	Increase car travel cost for selected trips
Gasoline tax	Increase car travel cost
Vehicle purchase or registration taxes	Increase ownership costs in automobile ownership model

Table 4. Example results of car pool policies for Washington, D.C.

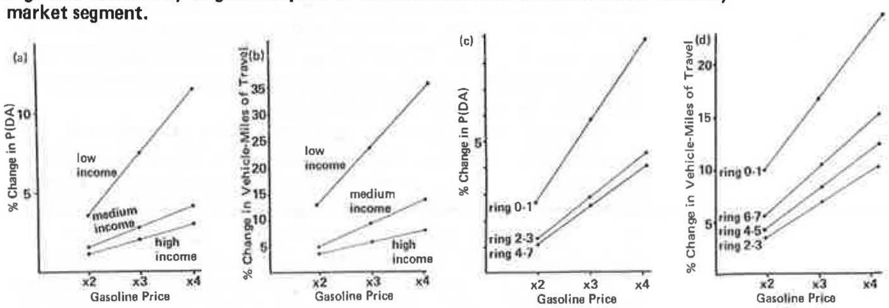
Policy	Percentage Change in Work Trip Mode Shares			Percentage Change in Vehicle-Miles Traveled			Percentage Change in Fuel Consumption
	Drive Alone	Car Pool	Transit	Work	Nonwork	Total	
Base value	52.9	25.4	14.5				
Parking incentives	-10.7	22.1	0.4	3.4	1.0	-0.6	-0.6
Parking incentives and parking costs	-22.3	43.8	4.6	-9.8	2.5	-2.2	-1.8
Base parking cost + $1 (areawide)	-5.1	4.6	10.6	-3.3	0.7	-0.8	-0.7
Base parking cost + $3 (areawide)	-15.6	13.9	32.6	-10.2	2.3	-2.5	-2.1
Base parking cost + $1 (CBD only)	-2.2	1.0	6.3	-1.4	0.3	-0.3	-0.3
Employer incentives	-3.9	16.7	-5.0	-1.8	0.5	-0.4	-0.2
200 percent gasoline price increase	-1.4	1.6	2.4	-1.4	-6.6	-5.12	-4.7
300 percent gasoline price increase	-2.9	3.2	4.9	-2.6	-12.4	-9.7	-9.0
Gasoline rationing	-9.3	8.2	12.6	-9.1	-22.4	-19.1	-17.4

Table 5. Base values against which data in Table 4 are compared.

Base Value	Vehicle-Miles Traveled			Fuel Consumption (gal/day)
	Work	Nonwork	Total	
Excluding weekend travel	10.4	16.7	27.1	2.58
Including weekend travel	10.4	27.6	38.0	3.68

Notes: 1 vehicle-mile = 1.6 vehicle-km; 1 gal/day = 3.8 liters/day.

Figure 3. Sensitivity to gasoline price of mode choice and vehicle-miles of travel by market segment.



appropriate summation of the individual household results; the households analyzed are grouped by homogeneous classes or market segments to examine differential impacts or to determine inequities that would result if the incentive were implemented. For each of the car pool strategies analyzed, the following specific market segments were examined:

1. Income (low, middle, and high),
2. Distance from central business district (three rings), and
3. Automobile ownership (0, 1, or 2+).

Several resource constraint policies impose a limitation on available supply (e.g., parking spaces or gasoline rationing) or result in significantly altered congestion effects, and require a calculation of supply-demand equilibrium; for example, if a gasoline rationing policy is to be implemented as a household-specific limitation (i.e., based on the number of licensed drivers, persons over 16, or full-time workers), the first iteration for a particular household would determine the amount of fuel consumed by that household under no resource constraint. If that figure is greater than the amount that would be available to the household, a shadow price or penalty for using a constrained resource would be estimated and added to the per gallon price of gasoline for that household. This resulting new fuel price would then be used in a second iteration to predict adjusted travel behavior of the household. This iterative process would continue one household at a time until the amount of fuel consumed by each household is in equilibrium with the amount of fuel allocated. The final value of the shadow price represents the price that each household would be willing to pay for one more unit of fuel. For a reduction in the supply of parking, the same basic logic would apply except that the iteration would proceed to equilibrium over the entire sample rather than for each household individually.

RESULTS OF POLICY ANALYSES

The results for nine of the policies analyzed are given in Table 4. The average household base values with and without weekend travel are given in Table 5. (The values in Tables 4 and 5 and Figure 3 are not given in SI units because operation of the model requires that they be in U.S. customary units.) The shifts in mode choice probabilities for work trips; work, nonwork, and total vehicle-miles traveled; and fuel consumed resulting from these policies are tabulated as percentage changes from the base values. Several findings are apparent from these data.

Existing levels of private ride sharing for work trips are already fairly high, 25.4 percent in Washington, based on total person work trips. The use of car pool pool incentives, therefore, reflects an effort to increase the use of ride sharing, not the introduction of an entirely new mode.

The positive impact (i.e., reduced fuel consumption) of a policy affecting only the work trip may be offset by increased nonwork travel resulting from increased automobile availability. For example, increasing the areawide base parking cost by $1/day decreases work travel by 3.3 percent; however, nonwork travel increases by 0.7 percent. When both work and nonwork changes are expressed as a percentage of total vehicle-miles traveled (-1.2 and +0.4 percent respectively), the resulting change in total travel (-0.8 percent) is 65 percent of the expected reduction based on work trips alone; i.e., 35 percent of the potential reduction is lost because of increased nonwork trip activity. This increase in nonwork travel is induced by a 2.4 percent increase in the number of automobiles available for such trips. Almost all (90 percent) of the increase results from increased trip frequency or destination shifts; only 10 percent is due to a shift in mode from transit to automobile.

When a particular policy affects both work and nonwork trips (e.g., gasoline rationing and price increases), the reduction in nonwork travel is even greater than that predicted for work trips despite the increased automobile availability for nonwork trips. This is in agreement with other findings that nonwork trips, because they are more discretionary in nature, are more sensitive or elastic to changes in level of service (6). For example, tripling the base gasoline price decreases work trip travel 2.6 percent, but decreases nonwork travel 12.4 percent. This decrease occurs despite a 1.8 percent increase in automobile availability for these trips. Here again, changes in mode shares have little impact on the decrease in nonwork travel, which is brought about by a 5 percent decrease in average trip length, a 7.2 percent decrease in trip frequency, and only a 0.6 percent shift in mode from automobile to transit. These results emphasize the importance of considering all aspects of nonwork travel.

In cities having well-developed transit services, such as Washington, there is a potential for policies that act as car pool incentives to divert riders from transit as well as from the drive alone mode. For example, a comprehensive program of employer incentives applied to all firms increases car pooling by 16.7 percent, but at the expense of a 5.0 percent decrease in transit use. This implies that a program should be carefully designed to encourage transit ridership as well as car pooling and van pooling; for example, perhaps it should avoid offering car pool incentives to persons who are well served by transit.

Allowing for longer run changes in both automobile ownership levels and shifts to more fuel-efficient vehicles results in fuel savings that are considerably larger than the immediate short-run conservation effects given in Table 4. Doubling the price of fuel without accounting for changes in automobile ownership results in a 4.7 percent decline in fuel consumption. Considering both changes in the number of vehicles owned and the shift to more fuel-efficient cars shows a decline in automobile ownership of 0.06 percent but three times the fuel savings, 15.1 percent versus 4.7 percent. The increase in the shared ride mode, however, declines from +1.6 percent to +1.1 percent when changes in automobile ownership and vehicle type are taken into consideration.

The strategies examined, which can be characterized as being disincentives, have potential inequities in the distribution of their effects; in each case, low- and middle-income households are affected more than higher income households, and one-car households are impacted more severely than households with two or more cars. Figure 3 shows the effects of gasoline price increases by income and geographic market segments.

Although the analysis results focus on the travel and energy effects of various actions examined independently of one another, it is much more likely that a combination of individual actions would be implemented as a well-designed, coordinated program. As one would expect, the effects of such programs on fuel conservation are likely to be greater (and more equitable) than those of individual strategies implemented in isolation, although not necessarily in a linear additive manner. For example, the combination of preferential traffic treatment and an employer-based program consisting of promotion, van pooling, and preferential parking results in regionwide reduction in daily travel of 1.7 percent. If these incentives are then combined with fairly strong pricing and automobile restrictions, a travel reduction of more than 8 percent can be achieved.

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