Use of a Quantitative Marketing Model to Estimate Impacts of Car-Pooling Policies

Richard B. Rubin and Jeffrey M. Bruggeman, Peat, Marwick, Mitchell and Company
Frank Griffiths, Market Facts, Inc.

This paper discusses a quantitative marketing approach applied in a study designed to estimate the impacts on work travel of various proposed policies for encouraging car pooling. The decision to commute by car pool is influenced by a number of "soft" factors, such as comfort, safety, and midday mobility, that are not easily handled by traditional modal-split techniques. This study provided an opportunity to test the feasibility of adapting and applying quantitative marketing techniques to the projection of modal split under various car-pooling policies. A trade-off model, previously used primarily in traditional product market research, was adapted for modal-split estimation. The model estimates modal split on the basis of quantitative preference (utility) levels calculated for each of the competing modes, which distinguish between car pool and solo driver. The utilities are obtained from responses to paired-comparison questions on work-trip preferences asked of a representative sample of commuters. Modal split and other travel impacts were estimated for each of 14 proposed car-pooling policies. The marketing approach produced useful quantitative results. Additional efforts in the development of this approach are warranted, however, to improve the overall quality of the results and enhance the usefulness of the approach as a tool in transportation research.

This paper describes a quantitative marketing model used in a study of the impacts of car-pooling policies. A specially designed survey and a trade-off model developed to quantify traveler preferences were used instead of a traditional modal-split model to estimate the likely impact of proposed policies for encouraging car pooling. Bruggeman, Rubin, and Griffiths present the specific policy-impact findings of the study in a paper in this Record.

QUANTITATIVE MARKETING METHODOLOGY

Marketing approaches have traditionally been used to evaluate consumer preferences and estimate likely reaction to products. Surveying a sample of the relevant market is usually required. The more sophisticated quantitative marketing methodologies are designed to provide hard numbers, from comparatively "soft" survey response data, on likely market shares for products.

Relatively little use has been made of marketing approaches in transportation for estimation or prediction purposes. Certainly, numerous transportation data are obtained through surveys (such as home interview and screenline surveys). However, these surveys are primarily intended to collect objective data rather than travel-preference data. Applying quantitative marketing tools to a transportation task such as the estimation of modal split is far from straightforward but does offer several advantages:

1. Direct perceptions and preferences of travelers, rather than those inferred from observed behavior, are used to predict behavioral response to changes in policy or environment.
2. Sensitivity to other than traditional predictive factors can be achieved by incorporating in the survey questions on perception and preference that relate to these factors. Because almost all data come from a specially conducted survey, they are recent and internally consistent.
3. Calibration on the level of the individual respondent can be meaningfully achieved for a marketing model. Characteristics and preferences of individual survey respondents can be used directly or can be partially aggregated to impose policies and estimate their impacts on specific target groups.

SELECTION OF METHODOLOGY

The study required the estimation of fuel consumption and related travel impacts of various proposed policies to encourage car pooling. Any such investigation of impacts requires estimates of changes in modal split and vehicle occupancy that are likely to result from implementing the proposed policies. One of the traditional modal-split models would be an obvious choice for this task. However, the fact that the decision to car pool is rather subjective and complex tends to accentuate the inherent limitations of traditional modal-split models. Three considerations significantly reduce the usefulness of traditional modal-split models in dealing with car-pooling tendencies:

1. The almost emotional nature of the decision to car pool strengthens trip-maker perceptions and weakens objective measures of change associated with government policies as reliable predictors of travel response.
2. A number of significant factors other than travel time and cost are prominent in the decision on whether or not to car pool. Gasoline availability and ease of midday transportation for commuters are examples of important factors that could be influenced by policy but are not easily handled by traditional modal-split models.
3. Both the impact of and travel response to policies for encouraging car pooling are likely to be highly individual. If accurate impact estimates are to be achieved, greater disaggregation is needed than that typically available from modal-split models.

These considerations suggested that estimating the impacts of car-pooling-incentive policies would be an excellent opportunity for adapting a quantitative marketing approach to transportation research. A trade-off model was adapted to estimate modal split, vehicle kilometers of travel, and related impacts of proposed policies for encouraging car pooling. The core model generates estimates of relative preference among modal alternatives on a person-by-person basis from responses to paired-comparison survey questions. These estimates, under various policy conditions, are then converted to modal split, vehicle kilometers of travel, and related policy impacts by using travel data also collected by the survey.

TRADE-OFF MODEL THEORY

Trade-off analysis is a variety of conjoint measurement developed to overcome the shortcomings of the conventional attitude research study (1, 2), which probes people's desires when alternatives are not interrelated and without reference to cost. Such studies almost never force the respondent to consider and choose between realistic alternatives. Trade-off analysis is fundamentally a method of solving problems of relative priorities that are not solved by straightforward attitude studies. It deals with preferences among different competing combinations of circumstances.

The trade-off model produces utilities (quantitative preference levels) for various products from responses to questions in matrix or paired-comparison formats. In this study, the products are work trips by a given mode under conditions set by the various government policies to be tested. Each matrix or paired-comparison trade-off question is expressed in terms of two of the several attributes used to characterize the work trip.

EXAMPLE

An example can be constructed by using two of the attributes used to describe the work trip: (a) weekly travel cost and (b) one-way riding time. Since the number of specific trade-offs that can reasonably be asked of a respondent is limited, a small number of discrete levels spanning the typical range of values must be chosen for each attribute. Typical levels might be $5, $10, and $15 for weekly travel cost and 30 percent less, same as now, and 30 percent more for riding time. All other attributes (such as mode and parking cost) are held constant, and the respondent expresses relative preferences among different levels of each of the two attributes of the work trip.

In the matrix format, which is shown in Figure 1, the respondent would be asked to place the integers 1 through 9 in the nine cells in order of his or her preference for the situations defined by the attribute levels corresponding to the cells. The normal respondent would always rank the first and last cells 1 and 9 respectively. The rank order of the other cells depends on the relative importance of the two attributes to the respondent. By ranking these cells in order of preference, the respondent reveals relative preferences among levels of travel cost and riding time.

The respondent is then asked to fill out analogous trade-off matrixes corresponding to other pairs from among the total set of attributes used to describe the work trip. If the number of attributes is small (three or four), the respondent may be requested to express preferences for all possible pairs of attributes. But when the number of attributes is larger, such a task becomes overwhelming. Under such conditions, the respondent is asked to fill out only a selection of all possible matrixes. The pairs of attributes are chosen so that each attribute appears in at least two or three matrixes, and a tight linkage is maintained among the attributes so that relative preferences among attributes not directly compared can be inferred from those that are. The model is then used to convert the trade-off responses to quantitative utility estimates for each specified level of each attribute by means of an algorithm that searches for those sets of utility numbers that best preserve the rank orderings of the respondent.

Figure 2 shows a typical response. Each cell has been split diagonally. The rank-order preferences of the respondent are in the upper left corner. The trade-off model produces utility values for each level of the two attributes; these values appear in parentheses with the corresponding row and column headings. They are normalized to sum to one for each attribute and thus best preserve the respondent's expressed rankings across all matrixes. The match for the matrix shown in Figure 2 is excellent. The products of the row (riding time) and column (travel cost) utility levels (shown in parentheses in the lower right portion of each cell) are in the same rank order as the respondent's expressed preferences.

USING THE MODEL TO ESTIMATE MODAL SPLIT

Once the utility values have been generated for each level of each attribute, a respondent's utility for any work-trip situation (expressed as the collection of levels for each attribute) can be estimated as the product of the corresponding component utility values. For this study, modal-split estimates were made by using an assumption of proportionality. Under any given policy condition, a respondent's utility for each mode was estimated. Because each respondent in a sample represents many similar people in the general population and because this study was concerned with average trends, the probability of choosing a mode was assumed to be proportional to the utility for that mode. Thus, the estimated utilities were normalized to sum to one (100 percent) over all modes. The resulting values were modal-split estimates for the population group represented by the sample respondent.

Because respondents filling out a matrix tend to simplify their task by placing the integers 1 through 9 across the rows or down the columns, it is sometimes desirable to replace the matrix with a number of simple paired comparisons. Each paired comparison essentially asks the respondent to choose between two cells of the matrix. There is usually an assumed order of preference along each row and down each column (low cost is always better than high cost, if travel time remains constant); thus, it is possible to obtain virtually all of the preference information of a matrix from a limited number of diagonal cell-comparison questions and a transitivity assumption. This format does not have the patterning bias of the matrix format. Otherwise, the trade-off methodology is identical to that used with the matrix format.

APPLICATION OF THE MODEL

The analytical framework of the study was built around a detailed survey for measuring attitudes on and perceptions of work-trip mode choice in general and car pooling in particular. Model requirements and the characteristics of the analytical marketing approach provided a framework for the design of the survey. Representative cities were selected, and the survey was administered in each. After model calibration and validation, the selected car-pooling policies were simulated to produce estimates of effects on modal split. Finally, vehicle kilometers of travel, fuel consumption, and related impacts were estimated for each policy.

Presurvey Selections

The survey was the primary input to the trade-off model and the estimation of policy impacts. Specific capabilities had to be incorporated, and it was necessary to decide well in advance on (a) the specific policies to be tested and (b) the specific attributes to be used in defining the modal alternatives.

Test Policies

Nine generic travel-time sensitivity tests and 14 specific policies were chosen for simulation. The sensitivity tests were included to permit evaluation of the impact of discriminatory travel-time changes, which was difficult to measure with the specific realistic policies being considered. The policies that were to be tested included (a) gasoline rationing, (b) four different adjustments to parking rates, (c) two levels of gasoline surcharge, (d) a surcharge on tolls, (e) a tax rebate for car-pool members, (f) three kinds of car-pool matching programs, and (g) two kinds of improvement in midday transportation for commuters. These policies applied to specific target groups and were defined at levels representative of administratively feasible programs.

Simulation Attributes

The trade-off model approach requires that a work trip by a given mode under a test policy be defined in terms of a set of selected trip attributes. The attributes must adequately discriminate among modes under a given policy and among policies for a given mode, and the set of attributes must span the major dimensions of commuter trip preferences but not be so large as to impose an unreasonable burden on the typical respondent in the form of trade-off questions. The following attributes

Figure 1. Trade-off problem in the matrix format.

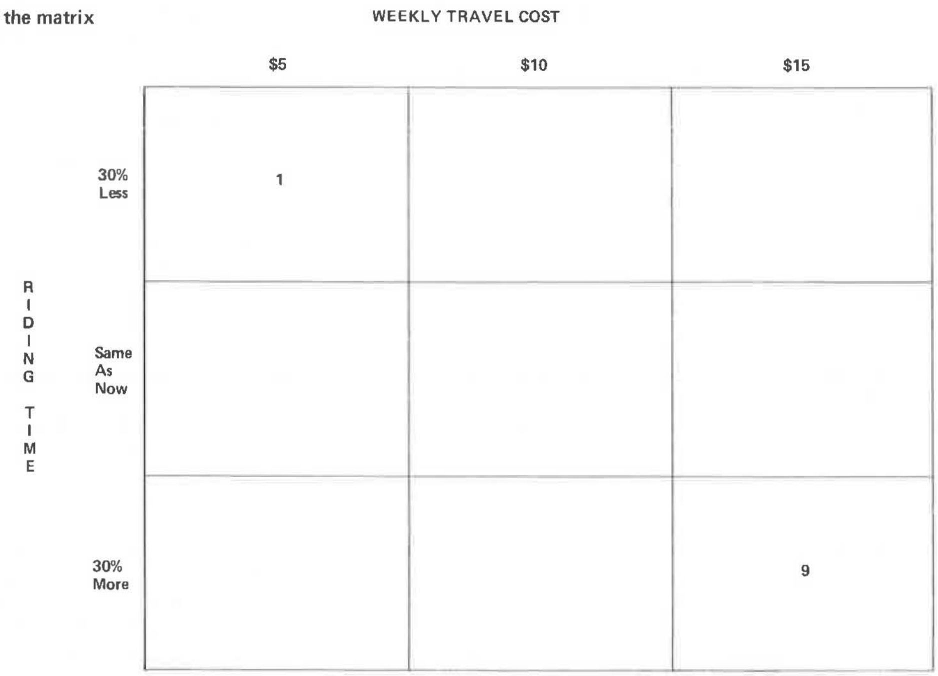
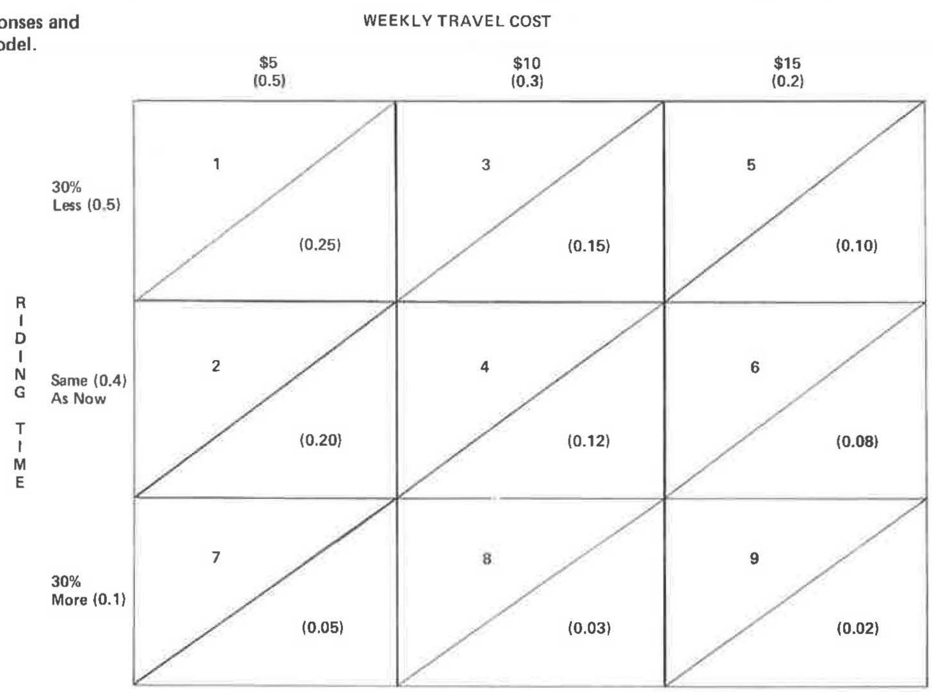


Figure 2. Possible trade-off responses and utility levels estimated by the model.



were chosen for use with the model:

1. Mode used (drive alone in an automobile, drive with passengers in an automobile, be driven by another in an automobile, ride public transportation);
2. Travel cost (including gasoline and tolls or transit fare as appropriate);
3. Parking cost;
4. Extra time (time spent walking, waiting for others or for public transportation, and picking up or dropping off others);
5. Riding time (line-haul time or total elapsed door-to-door time minus extra time);
6. Number of people in the vehicle;
7. Ease of finding others to share a ride;
8. Ease of finding transportation during the day for personal business; and
9. Supply of gasoline available for consumption.

The mode attribute was included to reflect unique modal characteristics not reflected in the remaining attributes.

The Survey

The survey that was central to the marketing approach adopted for the study was specially designed to provide (a) basic preference data for the trade-off model, (b) the parameters and base condition values necessary to simulate the various car-pooling policies, and (c) trip characteristics and socioeconomic and attitudinal data useful in evaluating the various policies.

Limitations on time and funds dictated the selection of three representative metropolitan areas for survey sampling: Chicago, Pittsburgh, and Sacramento. No three cities could possibly span all combinations of conditions that might influence modal choice and car-pooling potential but, for study purposes, these three cities were reasonably representative. The actual survey was conducted during the period from July 18 through August 3, 1975. Respondents were commuters selected from sampled households. In each of three approximately concentric "rings" in each region, 100 interviews were conducted for a total of 300 interviews in each city. The employed population of each ring, based on 1970 census data, was used to factor the sample results to total area figures.

Calibrating and Validating the Model

The model was calibrated by establishing the numerical utility values for each level of each attribute for the individual respondent. A computational algorithm, based on the model theory discussed previously, was applied to the respondents' trade-off answers to obtain these utility values. The model was validated by using the trade-off model to simulate the base case (conditions prevailing during the survey period) and comparing the estimated modal split with the modal split calculated from the actual responses for "mode currently used." Survey responses were used to define for each respondent the value of each attribute that best characterized his or her work trip by each competing mode for the base case.

Mode-specific adjustment factors were calculated as the ratios of the actual reported mode shares to the values estimated by the model. These factors were applied to all subsequent model estimates to ensure the best fit of the model to reality. They represent mode-specific adjustments that should not vary significantly with the policy being tested. Thus, modal-split estimates for various policies, relative to base-case values, should not be affected by these adjustments.

Policy Simulations

The trade-off model was used directly to simulate all cost-related policies and the various time-related sensitivity tests. Modifications to attribute levels were computed separately for each individual based on his or her work-trip situation. In some cases, only a portion of the total population was affected by the policy and the adjustments were made only for this group. The remaining respondents kept their base-case attribute levels.

Simulation of a gasoline rationing policy required special treatment because it involved a basic change in the modal choice faced by the respondent rather than a simple change in attribute levels. A procedure was developed by which the responses to a series of special survey questions were used to adjust the base-case modal splits. These questions asked respondents to indicate the percentage of time they would continue to use their current travel mode and the percentage of time they would switch to the other modes for the work trip when they were faced with a specified decrease in gasoline supply for total travel. The individual base-case modal splits were adjusted on the basis of these mode-change percentages to obtain modal-split estimates under rationing conditions.

Policies that affect the ease of finding a car-pool match and the availability of midday transportation also change the basic car-pool environment. To simulate policies in these areas, several special trade-off questions were asked of each respondent to determine his or her utility values under an assumed change in the car-pool environment. A revised set of utility values was computed for each respondent under the altered conditions. The various car-pool-matching and midday-transportation policies were then simulated by using the appropriate set of modified utility values in the same way as they are used for the other policies.

Impact Estimates

The trade-off model runs produced estimates of modal split for the simulated case or policy. Three other types of policy impacts were estimated from the modal-split results (3):

1. Vehicle kilometers of travel—Vehicle kilometers of travel associated with work trips were estimated by applying respondents' specific work-trip frequency and trip-length factors and average mode-specific vehicle occupancy factors to each respondent's estimated mode-split distribution. These estimates of vehicle kilometers of travel were then expanded by using the appropriate sampling rate factors to permit aggregation of the estimates by group and for the metropolitan area as a whole.
2. Fuel consumption—By using available transportation planning data from the region and responses to survey questions, a matrix was developed for converting vehicle kilometers of travel by origin and destination in the sampled ring to vehicle kilometers of travel by average speed and road type. This made it possible to apply speed-specific and facility-type-specific average fuel-consumption rates to estimated vehicle kilometers of travel to obtain fuel-consumption estimates.
3. Air Pollution—Estimates of three types of automotive air-pollutant emissions (carbon monoxide, hydrocarbons, and nitrogen oxides) were made. The procedure was analogous to that used for the fuel-consumption estimates. Speed-specific emission rates were applied to the estimates of vehicle kilometers of travel by average speed.

OBSERVATIONS ON USE OF THE TRADE-OFF METHODOLOGY

Adapting the trade-off methodology to modal-split estimation and applying it to estimating the impact of car-pooling policies revealed both major strong points and problem areas.

Survey

Work-Trip Map Tracings

One of the more unusual aspects of the survey was the map tracing each respondent was asked to make of the actual route to work. Minor logistical problems arose in supplying the appropriate maps for all respondents to use, but the results were generally good. Although map tracings are not generally appropriate as a data-collection method, their use in this survey proved to be a reasonably accurate and effective procedure for obtaining data on length of the work trip, home and work-place location, and similar work-trip parameters.

Cross Tabulations

The survey was conducted primarily to provide the raw preference data for the trade-off model. However, tabulations and cross tabulations of the survey responses were also generated, and these proved to be valuable adjuncts to the results obtained by the trade-off model in adjusting model estimates and evaluating policy potential. The special tabulation on the alternate use of a vehicle left at home, an example of the first type of side benefit, provided data for adjusting the estimates of first-order savings in vehicle kilometers of travel. This adjustment is necessary to account for other household members' use of a vehicle left at home by a commuter who is projected as switching to car pool or transit.

Ambiguity of Questions

Despite careful design and pretesting of questions, survey results indicated a number of areas in which ambiguity remained or respondents otherwise experienced difficulty in giving accurate answers. For example, the analysis of survey answers indicated that, despite instructions to the contrary, respondents were including non-work-trip as well as work-trip fuel consumption in their estimates. Probable causes were a lack of emphasis in the question or the inability of the respondent to make such an estimate. Such sources of survey errors can be identified and largely remedied or circumvented in subsequent applications. More intensive interviewer training would also help to reduce this problem.

Trade-Off Model

Use of Soft Variables

One of the major advantages of a marketing technique such as the trade-off model is the ability to deal with so-called soft variables. Car pooling is clearly an area of transportation in which less easily quantified trip attributes such as comfort, dependability, and midday mobility are important considerations. The more traditional modal-split techniques can only indirectly and inadequately deal with such attributes.

Adaptation of the trade-off model was proposed as an approach that could handle these soft variables. Perceptions, opinions, and preferences with respect to any possibly significant attribute could be asked of a respondent in a survey. But for an attribute to be incorporated into application of a trade-off model, the various levels of the attribute must be presented unambiguously and consistently to all respondents. The attribute and its levels must also be such that any policy that is to be simulated can be associated with a specific change in the level of the attribute for a given individual and mode. In designing the survey instrument and the specifications for policy simulation, it was found that these requirements are difficult to satisfy for some attributes.

For example, if comfort were chosen as a work-trip attribute, the levels chosen to express that attribute in the trade-off questions might be very comfortable, somewhat comfortable, and not comfortable. Does any given respondent know how much comfort is meant by very comfortable? Just as important are questions on the use of such an attribute in policy simulation. For example, a respondent reports a certain comfort level in using public transportation. A policy is implemented that calls for installing more comfortable seats in all public transportation. Even if it can be assumed that the respondent experiences an increase in comfort, how is the new comfort level estimated for purposes of policy simulation?

These problems do not mean that the trade-off model cannot address the attribute of comfort. They do suggest that treatment of such soft attributes will be more complex than that of easily quantifiable attributes. Most likely, comfort would have to be disaggregated into more specific attributes such as level of temperature control, the exclusion of smokers, and leg-room, which do meet the above requirements. However, the resulting increase in the respondent's burden in the trade-off task must be carefully balanced against the desirability of explicitly treating such a soft attribute.

Environmental Factors

In the application of the trade-off model to the problem of estimating the impacts of car-pooling policies, some factors important in the mode-choice decision turned out not to be true trade-off attributes. For example, factors such as gasoline availability, the ease of finding a car-pool match, and the ease of obtaining midday transportation were more environmental in nature than characteristic of a specific work trip. These background factors could influence the modal decision but could not really be treated as attributes of the work trip itself and thus could not be directly traded off. Special procedures were used for incorporating these characteristics into the simulations, as discussed earlier. However, the procedure used for the car-pool-matching and midday-transportation factors did not deal satisfactorily with the problem. Further work is necessary on incorporating such factors into the trade-off model approach.

Disaggregate Nature of the Model

One of the greatest strengths of the trade-off model was found to be its ability to deal with the preferences, characteristics, and circumstances of respondents on an entirely individual basis. This capability was used extensively in the study application. Two examples are (a) the use of the respondent's reported transit availability in policy simulations and (b) the use of the reported home-to-work distance for the work trip in the estimation of vehicle kilometers of travel.

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

Gregory K. Ingram, Department of Economics, Harvard University

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.