transportation service to the facilitation of all public transportation options. The role of the RTA should be shifted from an entrepreneurial one of preserving the bus company to a mission-oriented one of serving various public transportation needs. Until the RTA boards and executives recognize the difference between the entrepreneurial role of preserving specific transportation service and the public mission to solve a specific problem, it will be difficult to implement alternative solutions. To implement a mission-oriented approach, there is need to separate the rules, liability, funding, and guidelines that apply to the entrepreneurial operation of the traditional services and the promotion and procurement of alternative services. For example, if a transit authority finds it more cost effective to promote carpooling than to add additional buses into low-density suburbs, the carpool efforts should not extend the common-carrier liability standard, Section 13(c) labor protections, public hearings over route and fare changes, and noncompetitive requirements to cover all carpools that develop.

Tax Issues

The IRS should resolve the tax issues and decide whether ridesharing is a business. The goal of ridesharing is to accomplish public goals through the cooperative effort of individuals (employers, employees, public officials, administrators, neighbors, friends, schoolmates, and other groups) who voluntarily decide to ride together. By making some vans tax-deductible and others highly taxed and by being unable to define when a vanpool is a business and thus which laws are applicable, the tax mechanism is a strong force to artificially structure the form vanpools take.

Currently, discussions are under way to subsidize employers to assume a large legal responsibility for their employees' transportation to work or to support transit authorities to do something they are ill-equipped to do, whereas individuals who can easily do it are discouraged by the uncertainty of liability and tax issues.

Federal tax law should recognize the following points:

1. Ridesharing is a cooperative area of activity and not subject to the traditional business or personal accounting and tax principles.
2. Employer efforts to promote ridesharing are a public service activity and should not necessarily be limited to employees only. For example, the investment tax credit should apply regardless of whether the pools include nonemployees, because this restriction encourages the destruction of pools involving neighbors or spouses who may work for nearby employers.
3. Individual pools are cooperative efforts and should have well-defined accounting and tax procedures without reference to whether or not the driver considers it to be a business.

Federal and state legislatures should explicitly recognize that it is in the national interest for government to permit individual citizens to cooperatively resolve their own transportation problems at their own expense and that these solutions should not be restricted to promote government-subsidized solutions, such as mass transit, the National Railroad Passenger Corporation (Amtrak), rail commuter services, subsidized intercity bus runs, or employment programs for drivers under the Comprehensive Employment and Training Act.

SUMMARY

Government seldom faces such a logical, inexpensive, and acceptable solution to a major national problem. Unfortunately, both state and federal government must make major legal and policy changes if the full potential of the ridesharing solution is to be realized. This paper has attempted to illustrate how government has unintentionally inhibited ridesharing by first making it illegal and then, after it was legalized, by applying archaic, inappropriate legal structures that did not recognize its cooperative, public service orientation. Seldom has government been faced with such a productive, low-cost situation requiring such a redirection in regulatory, tax, liability, insurance, and funding philosophy.

Demand Analysis for Ridesharing: State-of-the-Art Review

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The methods that are currently used to estimate demand for ridesharing for the work trip are reviewed. These techniques are categorized by the basic approach used, and models within each category are described, reviewed, and summarized. The first category consists of those techniques developed from the perspective of the formation of ridesharing units and includes the assessment of areawide ridesharing potential by estimation of possible matches and the identification of characteristics of the population that shares rides. The second category includes the techniques that view ridesharing as an individual or household decision. These include utility maximization models and household travel decision simulations. The third category includes those models concerned with estimating changes in ridership by various modes, including ridesharing, that result from the implementation of high-vehicle-occupancy treatments. These models consider demand and supply effects to obtain equilibrium traffic flows.

Ridesharing, the transportation of persons in a motor vehicle where such transportation is incidental to the purpose of the driver, did not generate much interest on the part of transportation analysts prior to 1973-1974. Until then, traditional transportation demand methodology developed in the 1950s and 1960s did not directly concern itself with ridesharing, and the sharing of rides entered into the planning process only through the automobile occupancy model. The objective of the automobile occupancy model was to convert person trips into vehicle trips for the purpose of planning highway facilities. Although the possibility of affecting vehicle occupancy by deliberate public policy did occur to planners in the 1960s, it appeared at that time to be beyond the realm of practicality (1).

The energy crisis of 1974 and the subsequent concern with transportation system management (TSM) called for transportation-planning techniques, which included ridesharing specifically. Those responsible for contingency planning wanted to know how much of the urban travel could be diverted to ridesharing in times of emergency. Those responsible for TSM wanted to know the impacts of strategies to increase automobile occupancy. Employers and other agencies considering ridesharing programs wanted to know what results to expect from their promotional and organizational efforts. These needs led to the development of techniques for estimating demand for ridesharing and also generated basic research into the motivation for ridesharing behavior and its effects on the overall travel patterns. Thus, a growing body of knowledge is becoming available for ridesharing applications.

Ridesharing includes the arrangements of carpooling, vanpooling, and buspooling. The obvious difference among these is the type of vehicle used. Carpools use private automobiles and although privately owned vehicles are used in some vanpools and buspools, such vehicles are usually supplied by employers, third-party providers, or transit companies. The number of persons in each arrangement is obviously a function of the capacity of the vehicle. In all cases the routes followed by the vehicles are tailored to the convenience of the rider group and can be modified to reflect rider needs. Collection and distribution arrangements also vary; a common collection point is popular for large groups. Payment arrangements range from no monetary exchange in shared driving arrangements to payments by pool members to the driver and, in some employer-organized vanpools, through payroll deduction. Since most of the ridesharing promotional efforts have been concentrated to encourage the solo driver to change to ridesharing during the work trip, most research on ridesharing behavior and forecasting techniques has also been concerned with the work trip.

Ridesharing, and therefore demand estimation for ridesharing, can be considered from several approaches. One approach is consideration of the group who will travel together in a common vehicle. Of interest here is the process of formation of the group as well as the conditions for its existence as a unit. Another way of viewing ridesharing is in the context of household travel decisionmaking and under what circumstances ridesharing is an option for households. Still another way to look at ridesharing is from its influences on the movement of traffic in an urban area, especially on the capacity and level of service of traffic corridors.

Although this categorization of approaches is not unique, most ridesharing demand estimation methods can be broadly classified under one of these three approaches. This paper reviews the methods currently used to estimate demand for ridesharing. The techniques are categorized by the basic approach used, and the models within each category are described and reviewed.

RIDESHARING UNIT FORMATION

The first approach is based on the ridesharing unit formation process and stems from the concern of identifying and matching people into such units. A set of conditions necessary for the formation of a ridesharing unit requires that

1. The origins and destinations of the trips of the potential pool members be spaced in such a way that the travel between them is acceptable to all the potential pool members,
2. The time interval in which the trip occurs be acceptable to all potential members of the pool,
3. The potential ridesharers be aware of each other,
4. There be sufficient incentive (economic, social, etc.) to travel together, and
5. The group be adequately compatible so that the ridesharing arrangement will be maintained over a period of time.

Consideration of ridesharing group formation leads to the issues of the target population, the matching process, and the characteristics of the resulting ridesharing units. The types of ridesharing estimation techniques that come from the consideration of the formation process are the ridesharing-potential models and the technique of identifying characteristics of users and potential users and applying these in an expansion process to the population under consideration.

Models of Ridesharing Potential

The objective of these models is to estimate the ridesharing potential of an area. There are two categories of these models--the maximum-potential models and the economic-incentive-potential models. The objective of the maximum-potential model is to give a practical upper limit of the ridesharing potential of an area. Results from such a model would be used to plan for emergencies and crises such as energy shortages or transit strikes in large cities and can also be used as a reference for evaluation of ridesharing programs. The economic-incentive-potential models, on the other hand, give estimates that could be used for planning long-term ridesharing programs.

An early maximum-potential model was developed by Kendall (2) and was used to estimate the carpooling potential of the eastern Massachusetts metropolitan area.

The model matched origins and destinations in zones the boundaries of which had been established a priori. An assumed maximum allowable time interval in terms of inconvenience to commuters was also set a priori. Thus, all workers with common origins and destinations who depart the zones within the same time interval were candidates for carpooling. The need for the car during the day as well as the consideration that a portion of the population does not travel to work during the peak periods were included as adjustment factors in the model. There was no consideration of economic incentives, user preferences, or the compatibility of the ridesharers.

By using trip tables developed from a 1963 home interview survey and matching time intervals of 30 min and average origin and destination sectors of 1 mile each, the ridesharing potential was estimated to be approximately 60 percent of the morning commuter trips.

Another type of maximum-potential estimation was carried out by Lee and Glover (3) by using 1976 Michigan driver data. It was assumed that the maximum potential for ridesharing was reached when the automobile occupancy for all trips more than 10 min long commencing between 6:00-9:00 a.m. and 3:00-7:00 p.m. was at least three persons. Considering only trips in the Standard Metropolitan Statistical Areas in Michigan, they calculated that this level of ridesharing would result in an annual 10 percent reduction in gasoline consumption. Although Lee and Glover did not estimate ridesharing potential directly, Cheslow, in a comparison of the two potential models (4), reports that when their analysis is carried further, it yields an estimate very similar to that of Kendall.

The automobile occupancy of at least three persons per car seems arbitrary and Cheslow suggests that using the automobile occupancy rates of nonwork group travel in maximum-potential estimates would reflect capacity and reasonable physical comfort inside vehicles. The average size of groups for social and recreational travel, the most frequent type of group travel, is 2.8 persons/car. Since it includes children in many cases, Cheslow suggests that applying the average group occupancy of other nonwork travel of 2.55 persons/car to commuter work trips would give an estimate of maximum potential for ridesharing for the work trip.

When the Kendall and the Lee and Glover models are compared against the general necessary conditions for ridesharing unit formation, it can be seen that the first two conditions, concerned with spatial locations of origins and destinations and with the common time interval, are satisfied. It can also be assumed that in emergencies there is an incentive to travel together, and although compatibility of the members of the ridesharing units is not addressed, it is implicitly assumed that people accept inconveniences during such times.

The consideration of how far people are willing to deviate from their routes in order to rideshare, in terms of their valuation of time, is the basis of another class of models of ridesharing potential. Such maximum deviations are applied to computer or manual matching programs and used for defining areas where ridesharing efforts are expected to be successful. The basic assumption here is that potential pooling trips are only those trips with common destinations that are adequately clustered, so that the cost of pooling, considering the users' value of time, is less than the cost of driving alone.

Berry (5) developed such an economic-incentive model for carpooling potential by assuming that a carpool unit will form if, for all the members of a pool, the marginal savings exceed the marginal costs of pooling for the work trip. The marginal costs are a function of the value of time for each member of the pool as well as of the out-of-pocket travel expenses. He derived the maximum economic circuity--the difference in length of the one-way trip (including the collection of members of the pool) and the average length of the trip for each of the members driving alone--as a function of costs and travel time. This maximum circuity increases as line-haul distance increases, as the value of time decreases, and as the costs associated with commuting (such as parking) increase.

Berry proposed that commuter response to various ridesharing incentive strategies be assessed by calculating the changes these have on circuity and weighing these changes by the proportion of commuter population in each value-of-time category.

Johnson (6) developed a vanpool-planning model in which the costs of travel, including time and the adequate clustering of origins and destinations, were considered. She derived a maximum deviation of pool collection to line-haul distance, which varies with speed, vehicle occupancy, and the value of time.

Johnson calculated the regional potential for the van share mode by using a computer algorithm that searches an origin-destination matrix for trips of more than 10 miles to zones with large employers. She assumes that only half of the commuters eligible to vanpool will do so and that a minimum van occupancy for vanpool formation is 10 people. Thus, 20 such trips must be clustered in a service area for one potential vanpool.

Soot and others (7) further developed these concepts into a planning tool known as the Service Area Identification Method (SAIM), which can be used to calculate the areawide demand for ridesharing. Aggregate origin-destination data are used in a simple algorithm that compares the travel costs and travel times of each of the trips by carpool or vanpool with travel costs and travel times of driving alone. The objective of SAIM is to identify those trip patterns that would be best served by each of these modes. The output of SAIM gives maps of the service areas for each mode, summary tables of regional information on number of users, trip lengths, etc., and zone-by-zone listings for both origin and destination of total trips and number of trips that can be considered to potentially use the mode considered.

The potential models with economic incentives differ from the maximum-potential models in that they are intended for more than just contingency planning and are designed to explore ridesharing potential under different conditions that affect the cost and travel time of the work trip. The SAIM model is intended as a complete planning tool for ridesharing. Examining this model for the general necessary conditions for formation of a ridesharing unit shows that the model addresses the spatial requirements, i.e., the adequate clustering of trip ends, and also provides a motive for ridesharing based strictly on costs and value of travel time. The compatibility of the poolers is not addressed. The model is, however, useful for identifying areas of ridesharing potential where ridesharing matching and promotional programs could be attempted.

Identification of Ridesharers

The existence and knowledge of a set of characteristics of ridesharers and potential ridesharers would be extremely useful in identifying incentives for ridesharing and in organizing and coordinating ridesharing programs. The knowledge of the distribution of the characteristics of potential ridesharers and the levels of incentives at which they respond could be an estimation technique in itself or could be used for market-segment identification for other estimation procedures.

Since most ridesharing programs publish statistical summaries that include information about the participants, attempts have been made to find significant differences between ridesharers and solo drivers from this information (8-15). The search has been directed toward sociodemographic, locational, attitudinal, and employment variables.

Attempts to identify a simple set of sociodemographic characteristics of ridesharers have generally been unsuccessful. Income does not appear to be a discriminating factor. Table 1 shows some of the results of sociodemographic comparison of ridesharers and solo drivers from several studies. No clear-cut differences in sociodemographic characteristics are immediately obvious. There is agreement in the literature that any existing relationships between demographic and work-trip ridesharing behavior are very weak.

Locational differences between ridesharers and solo drivers have been found to be significant in a number of studies. There is general agreement (8,9,11,16,17) that those who rideshare to work tend to have longer commuting times and distances than the rest of the population. This is supported by an investigation of the interaction of locational and demographic factors carried out at the New York State Department of Transportation (NYSDOT) (18) in which it was found that the best discriminator between ridesharers and solo drivers was the distance to work and travel time. Household size and licensed drivers per household were the only demo-

Table 1. Sociodemographic characteristics of ridesharers.

				Sociodemographic Characteristics									
Source	Year Data Collected	Place	Sample	Age	Income	Automobile Availability	Sex	Workers per Household	Marital Status	Occupation	Household Size	Licensed Drivers per Household	Salary Level
Voorhees (16)	1972	Los Angeles, CA	1896 freeway drivers	Younger	Slightly lower	Low							
Kendall (2)	1973-1974	United States	2084 automobile commuters	18-24	Lower	Low	Female						
Heaton (8)	1974	Boston, MA	4293 participants and 6288 nonparticipants in commuter computer program	Higher			Male			Professional managearial			
Davis (12)	1975	Knoxville, TN	Commuters to high employment areas			Yes			Married				
Peat, Marwick, Mitchell, and Co. and Market Facts (27)	1975	Chicago, IL; Pittsburgh, PA; Sacramento, CA	100 in each of 3 concentric rings in each city		No difference		Male						
Horowitz and Sheth (9)	1975	Chicago, IL	822 commuters to 43 large firms	Older	No difference	No difference	No difference		Married	No difference	Large		
Margolin and Misch (11)	1977	Washington, DC	20 panels and survey of 500 commuters	30+		No difference	Male	2+			No difference		
Dobson and Tischer (14)	1977	Los Angeles, CA	889 central-business-district commuters		Lower			2+					
Brunso, Kocis, and Ugolik (19)	1979	Albany, NY	901 commuters	No difference			No difference				Minor interactive effect	Minor interactive effect	No difference
Cambridge Systematics, Inc. (15)	1980	Minneapolis, MN	Choice-based sample of 200 commuters to 2 sites	No difference	No difference	No difference	-[a]			Production worker			

[a] One site in this study showed a higher percentage of female commuters carpooling than male commuters.

graphic variables that entered interactively into the discrimination, but only in a minor way. It is interesting to note that in a recent similar investigation of nonwork ridesharing (19), these same demographic characteristics were a much stronger discriminator between ridesharers and nonridesharers than they were for the work trip.

Another factor considered to be related to ridesharing behavior is the individual's employment characteristics. A widespread method of estimating ridesharing potential at an employment site is to multiply the number of employees in firms over a certain size by a factor transferred from a ridesharing program at a similar site.

Suhrbier and Wagner (20) report that a literature review of vanpooling contained estimates of the vanpool modal share that ranged from 25 to 50 percent of those employees eligible to vanpool and that, within individual companies, vanpool shares of about 10 percent of all employees are common. Carpooling shares are often estimated to be about 30 percent.

The problem with this transfer procedure is that the ridesharing programs, especially vanpool programs, differ greatly from one area to another. Thus, care must be taken when using this method for predicting demand.

In attempts to get at differences between ridesharers and solo drivers, several studies have sought to identify attitudinal and perceptual differences between the two groups with respect to ridesharing. Horowitz and Sheth (9), in a psychosocial analysis of ridesharers, identified the primary difference between the ridesharers and solo drivers as their perception of the time convenience, reliability, comfort, and saving of travel time. The Margolin and Misch investigation into the profiles of carpooling perceptions (11) of the two groups shows that the greatest differences were time-related (risk of being late, arriving home when expected, travel and wait time), comfort (crowding), and convenience (difficulty of making arrangements and space for packages).

In Heaton's study (8), the features of carpooling that carpoolers reported as being most appealing were cost savings, alleviation of congestion and pollution, and relief from driving. The features least liked by the carpoolers were reduced independence and mobility. Difficulties of adhering to schedules, other people's driving habits, inconvenience, responsibility to others, and increased travel time were of secondary importance. Reasons given by nonpoolers for not pooling were the need for a car at work, irregular working hours, and reduced mobility and independence.

A semantic differential analysis of attitudes of poolers and nonpoolers (16) showed that poolers liked to drive with others, whereas solo drivers did not, and poolers perceived a real cost savings whereas nonpoolers felt that the amount of savings was not worthwhile. Another difference was in reliance on others. Poolers were not averse to relying on others or having others depend on them, whereas nonpoolers disliked both options. It was concluded that the reasons given for not pooling are in fact excuses and that the real reasons involved personal independence, privacy, and freedom from others.

Social interaction emerged as the primary consideration in decisions to share rides in the Margolin and Misch study of ridesharing behavior (11). Distrust of computer matching was expressed by insistance on meeting people before arranging a carpool. Carpooling with strangers was ruled out by 39 percent of their sample. Women more than men and white- and blue-collar workers more than members of the managerial-executive-professional group were concerned about ridesharing with strangers. This finding is also reported by Levin and Gray (21), who in an analysis of interpersonal factors found that acquaintance was an important factor in carpooling and that the desirability of carpooling for an individual decreased as the number of nonacquaintances in the pool increased.

Status, a sensitive issue in our culture, also emerged as a consideration in the social interaction (11). It was found that, in general, people are wary of carpooling with others somewhat different from themselves. There was concern about intrapool behavior, i.e., talking, eating, and smoking. Since there are no established rules of etiquette or codes of behavior for ridesharing, rules of ridesharing (even rulemaking itself) were a source of anxiety. Margolin and Misch point out that smoking was an especially "hot" issue and that, although it was a legitimate issue in itself, it seemed to become a surrogate for other sources of dissatisfaction.

To date, the search for a set of identifying characteristics of ridesharers and potential ridesharers has not yielded a simple set. The only common characteristic of ridesharers across the studies reviewed is a long distance to work. However, there is evidence from these studies that the set of characteristics that defines ridesharer profiles consists of interactions of demographic, locational, and employment characteristics. Furthermore, it is reasonable to expect that these interactions vary across different segments of the population as well as with the incentives offered for ridesharing.

No study to date has systematically explored the carpool or vanpool as a unit of behavior and examined the similarities and differences of the characteristics of the individual members of pools.

DISAGGREGATE TRAVEL CHOICE

The second category of ridesharing estimation techniques is based on the disaggregate approach, which considers the choice to rideshare in the context of household travel behavior. Included in this are model sequences based on the assumptions of utility-maximization methods based on simulations of household activity and travel behavior.

Methods Based on Utility Maximization

The methodology that has had widespread influence on the estimation of ridesharing impacts was developed by Cambridge Systematics, Inc. (CSI) in a series of projects for the Federal Energy Administration and the U.S. Department of Transportation (22-25). It links together several models of household transportation choices to predict automobile ownership, work-trip mode choice, and nonwork travel (frequency, destination, and mode). Aggregated, it provides information for estimating changes in demand for travel under various TSM strategies as well as in energy use.

It has been adapted to be compatible with the Urban Mass Transportation Administration (UMTA) Urban Transportation Planning System, a set of computer programs in widespread use by metropolitan planning organizations for highway and transit network supply and equilibrium analysis, and has also been adapted for manual sketch planning (26).

The model sequence for a single household includes automobile ownership models for households with at least one worker and with no workers and work mode-choice models with a possible choice among three modes--driving alone, sharing a ride, and using transit. Since some of the level-of-service variables in this model depend on the number of people in the shared-ride arrangement, a separate submodel determines the size of carpool the person would be in if he or she shared a ride to work.

The household nonwork travel is modeled by trip-generation and joint-destination and mode-choice (automobile and transit) models for social and recreational trips and other nonwork home-based trips. The structure of the mode-choice model is logit with a linear additive utility function with level-of-service, locational, and socioeconomic variables.

Since carpools of various sizes cannot be treated as separate alternatives without violating a basic assumption of the logit model, a carpool-size submodel precedes the mode-choice model in the model sequence. Thus, the model predicts the size of a carpool that the individual would join, assuming that the individual would choose to rideshare, and the level-of-service variables based on carpool size are generated for the individual's ridesharing alternatives. The carpool-size submodel is structured with a linear specification and was calibrated by standard linear-regression techniques. The CSI set of models treats the vanpooling option by introducing it as a new mode only in circumstances where it was available to a worker (by having that information in a data set or by making assumptions about employer sizes in destination zones) and if the work journey was over some minimum trip length.

The household results are aggregated to give areawide estimates by using a random-sample enumeration method. The joint distribution of independent variables is represented by an appropriate random subsample of households from the original home interview survey. The choice probabilities are forecast for each sampled household and expanded to the entire population. Advantages of this method are that no assumptions on the distribution of the independent variables are required and impacts of policies aimed at particular identifiable groups can be estimated by using larger appropriately weighted samples from such groups. Furthermore, as more knowledge is gained about the identification of market segments of carpoolers, it could readily be applied in this aggregation procedure.

Another model for ridesharing based on utility theory developed by Peat, Marwick, Mitchell, and Company (PMM) and Market Facts, Inc. (27), used a trade-off approach in assessing the multiattribute utility functions of a set of individuals for various modes to work. Trade-off analysis is a type of conjoint measurement that attempts to answer the question of which combinations of circumstances are preferred to other circumstances by a set of subjects. A set of attributes, preselected by the researchers to represent what the researchers perceived to be relevant to the choice, were the mode used (e.g., driving alone in a car, driving with passengers in a car, being driven by another in a car, riding public transportation); travel costs (including gasoline and tolls or transit fare, as appropriate); parking cost; extra time (e.g., the time spent walking, waiting for others or for public transportation pickup, or dropping off others); riding time (e.g., the line-haul time); the number of people in the vehicle; the ease of finding transportation during the day for personal business; and the supply of gasoline available for consumption.

A special survey instrument was then designed to provide basic data for the trade-off model and to supply the parameters and base condition values necessary for simulating various carpool strategies. The survey also elicited information on trip characteristics and socioeconomic and attitudinal data. The subjects to which this survey was administered were from three urban areas (Chicago, Pittsburgh, and Sacramento), stratified by location from three concentric rings about the central business district (CBD) (100 for each ring in each city), and selected for their socioeconomic status.

The model yields a utility function for each subject that can be evaluated for each alternative for various levels of the attributes as determined by carpooling incentives. The aggregate modal split was estimated from the proportionality of the calculated utilities for the modes of each individual. Since each subject was taken to represent a group of people similar with respect to sociodemographic and locational characteristics, the proportionalities were used to estimate the aggregate shares.

This demand-estimation procedure uses a very powerful tool from the field of decision theory and has made progress in the development of the type of demand model that is policy-sensitive and can handle modes such as ridesharing. The study concludes with observations on methodology with the recognition that it did not incorporate the "soft" variables such as comfort and convenience and reliability. Nor did it include any social-interaction variables that are being identified by recent work (11) as being important.

Microsimulation

A microsimulation model sequence that uses the logit specification was developed by Bonsall (28) for the prediction of ridesharing. This computer model generates a set of commuters and simulates their decision process with respect to ridesharing. The sample of commuters is generated by a process designed to replicate the socioeconomic and locational characteristics of the population under consideration; it maintains the intercharacteristic probabilities revealed in a household survey and within a control total derived from published census material. The model allows applications for up to seven types of ridesharing schemes, which range from carpooling to giving or receiving rides in the morning or in the evening or both. A filtering process is used to establish a feasible set of alternatives for each actor.

A series of binary logit models is calibrated and used to calculate the probability that each commuter will join a carpooling arrangement. This is converted to a likelihood of submitting an application, checked against a threshold of interest, and determines whether the commuter submits an application. A submodel simulates the processing of applications and matches ridesharing interests, times, and locations.

The model further simulates the decision of each person; it considers a list of potential traveling companions supplied by the organizers. The expected utility to a given person of a given arrangement is assumed to be a function of the personal characteristics of that person, of personal characteristics of the proposed partners in the arrangement, and of the operational consequences of the arrangement such as delays and diversions. The parameters are calibrated on a series of regression equations by using data from a field survey.

The model user defines the scale and location of the ridesharing scheme to be tested by defining a target population in terms of their residential location, work location, or some combination of the two. The user also specifies a threshold of interest, which may be taken to represent the intensity of an advertising campaign conducted among the target population.

The model maximizes this utility for each individual. For any arrangement that has positive net expected utilities, the one with the maximum net expected utility to the applicant is selected, and a match is designated as successful. Since the decision to match was based on expected utility, which in reality may be revised, the next submodel simulates the survival of the match.

The last feature of the model is the output of system performance indicators. These include the summary statistics, information on work-journey public transit patronage lost, and information on private vehicle use changes in automobile occupancy.

Bonsall and Kirby (29) used this model to predict ridesharing for the city of Leeds under various scenarios and to examine policy implications on the transportation network. This model is offered as a predictive tool for estimating areawide ridesharing and employer-based ridesharing under various conditions. It differs from the other utility-maximizing models of ridesharing in that the interpersonal nature of ridesharing is considered. The model not only captures the necessary commonality of origins, destinations, and time intervals and considers the levels of service for carpooling, but also addresses the compatibility of the commuters by simulating the match survival. Some of the insight gained by the various behavioral investigations into who rideshares and why and when is being applied to the ridesharing estimation process. Since the procedure is a simulation, i.e., one observation of an experiment, trustworthy results can only be obtained from many repetitions.

Household Activity Simulation

Interaction simulation games, a recent development in transportation planning, have been applied to ridesharing. These simulation games chart through time and space the activities and travel decisions of households. By using boards that represent time and space, an analyst asks members of a household to arrange their activities and travel and to rearrange them for various scenarios. The model simulates different situations but, unlike the microsimulation model, uses the actual decisionmakers as actors in the decision process. Thus, the method does not seek to model the decision process itself but observes reactions in a simulated environment.

This process yields much insight into the adaptations in activities, scheduling, and travel made by households faced with changes in the transport environment. It is computationally cumbersome and thus somewhat restrictive as a prediction tool; however, it is extremely useful in obtaining behavioral insight that could be useful in the prediction procedures.

The Response to Energy and Activity Constraints on Travel (REACT) (30) game has been developed by NYSDOT's Planning Unit and is currently being further developed as a planning tool. The initial application of REACT explored the responses of a small sample of households to various policies intended to reduce automobile fuel consumption. Policies tested were a 20 percent reduction in travel on weekdays, on weekends (a possible result of gasoline rationing), and a no-drive day on weekdays and on weekends. Preliminary results indicated that two-car households cut discretionary travel in response to the no-drive day policy. One-car households, however, carpooled and shifted schedules and destinations to adjust to both policies.

REACT and other such interactive games cannot be used as planning tools alone. However, they can identify direct and indirect public responses for assessment of policies with which there has been no previous experience. They provide first-cut analyses for many types of policies and can be used with other planning tools to estimate travel changes, including ridesharing.

TRAFFIC-EQUILIBRIUM MODELS

Another perspective from which ridesharing has been considered is that of traffic flow equilibrium. Encouragement of ridesharing by high-occupancy-vehicle (HOV) strategies such as priority ramps and exclusive lanes on congested facilities has a significant effect on the levels of service of all modes that use these facilities. Consideration of such strategies involves the assessment of their effects on traffic flow, including travel time and congestion, and involves the merging of demand relationships with those of supply or service.

A review of modal-shift models for HOV priority strategies (31) has identified several models that are capable of treating ridesharing in terms of equilibrium in traffic corridors. These models are the pivot-point logit model (CSI) (24), the economic-simulation model for priority lanes on urban radial freeways (32), the planning model for transportation corridors (33), the FREQ6PL freeway priority lane simulation model (34), the TRANSYT6C (35), and the JHK/Shirley Highway carpool mode-shift model (36,37).

The CSI model discussed previously can be used in the assessment of HOV strategies in traffic corridors. Application of the model requires the user to determine the distinct user groups that will be affected by the change. The changes in the level-of-service measures such as in-vehicle and out-of-vehicle times and out-of-pocket costs must be specified for each group. The incremental-logit model is then used to predict changes from the existing travel behavior. The predicted volumes are used to obtain new travel times, which are compared with those from the first estimate. If necessary, additional iterations can be made to reach equilibrium. The merit of the CSI model in this application is its extremely low computational requirements. It is also applicable to a large set of HOV strategies.

The economic simulation model for priority lanes on urban radial expressways combines the conventional logit demand model with a simple traffic-flow model. The demand model includes level-of-service variables such as transfers, in-vehicle and out-of-vehicle waiting and walking times, and travel cost and socioeconomic variables such as income, age, number of children, and length of residence in the neighborhood. The modes considered are car (with one or two occupants), carpool (three or more occupants), bus with walk access, and bus with car access. The travel speeds are obtained by a deterministic queuing model of traffic flow and the demand-and-supply models are iterated to equilibrium.

The planning model for transportation corridors also uses a logit demand model with level-of-service and socioeconomic variables. In this case, data for a representative sample of households in the study area are used to calculate modal choices for driving alone, ridesharing local bus, and express bus and/or rapid transit with various access modes. The choices with various access modes are carefully defined to avoid possible violations of assumptions of the logit model. The change in the level of service for both the access and line-haul portions of the trip is determined by supply-side relationships and a simultaneous solution to the demand-and-supply equations determines the equilibrium modal volumes.

The JHK/Shirley Highway model is based on the assumption that current carpools will choose the fastest path and that modal shifts will occur as the relative travel times between carpools and other modes change for any origin-destination combination. Modes considered are bus, single-occupant automobile, two-occupant automobile, three-occupant automobile, and carpool, which is defined as an automobile with four or more occupants. Diversion curves developed from empirical findings about modal shifts from the Shirley Highway demonstration project are used in this approach. The method consists of defining an origin-destination zonal system and a coarse network for the corridor of interest, identifying minimum time paths for every origin-destination pair, and obtaining average times and speeds for each link for the base and forecast period. The modal shares for each zonal pair before implementation of the HOV strategy are also required. The diversion factors from the Shirley Highway modal shifts are used to obtain changes to carpool modal shares. This method has no supply-side feedback. Its main merit is that it uses information from an actual observation of shifts to ridesharing.

Computerized traffic-simulation models such as FREQ and TRANSYT have also been used to assess the impacts of HOV strategies. These models, which have undergone several rounds of refinement at the University of California at Berkeley, can be used to assess demand shifts and travel-flow characteristics resulting from implementation of HOV strategies on expressways and arterial streets at the micro level. The modal shifts between automobiles and ridesharing and automobiles and bus are obtained by using demand relationships from a previously calibrated logit model, and the differences in travel time by various modes are calculated by a detailed supply-side algorithm. The demand shifts, however, are sensitive only to in-vehicle travel time. No access time changes are considered.

Use of aggregate before-and-after data coupled with the simultaneous consideration of demand and supply is the important feature of a technique developed by Charles River Associates (CRA) (38) to predict travel-volume changes in urban corridors resulting from implementing HOV priority strategies. This method, intended to be used as a first-cut estimate, does not need origin-destination data or the socioeconomic characteristics of the area. Supply relationships between travel time and travel volume were obtained from speed-volume relationships for various facilities from the Highway Capacity Manual. Traffic volumes were measured in 12 corridors before and after implementation of HOV treatments to assess the sensitivity of travelers to levels of service for various modes and to estimate elasticities and cross-elasticities for various modes.

The basic underlying assumption in models of this third category is that commuters respond to changes in transportation level of service. There is no concern for the matching of commuters into workable ridesharing units. With the exception of the JHK/Shirley Highway model and the CRA models, the demand model specification is a multinominal logit with level-of-service and, in most cases, socioeconomic variables, and the main difference among the models is in the treatment of the supply side and equilibrium. The treatment of demand in the traffic-simulation models is extremely simple and demand is assumed to be sensitive only to changes in the in-vehicle travel time. The JHK/Shirley Highway model and the CRA model use information from observed modal shifts to ridesharing after the implementation of HOV strategies.

SUMMARY

The knowledge about ridesharing has increased significantly since 1973-1974 and the national recognition of its possible benefits. Estimation techniques have also progressed from near nonexistence to the wide variety described in this report. The following tables present an overview and summary of those techniques. The estimation techniques vary not only by the purpose for which they are intended, but also by their degree of readiness for application. Some are offered as complete planning tools;

others can only provide a basis from which a planner can make judgments and others are starting points for more research.

Table 2 summarizes the models that can be considered complete methodologies. These include Kendall's maximum-potential model, SAIM, the CSI model, Bonsall's microsimulation, the set of traffic-equilibrium models, and the PMM and Market Facts trade-off model.

Table 3 summarizes the methods that, although not complete ridesharing estimation methodologies, have been used or have been proposed to estimate ridesharing. These methods include those characterized by the transfer of information from a known situa-

Table 2. Summary of ridesharing estimation methodologies.

Model	Ridesharing Application	Basic Approach	Model Type	Ref.	Past Application	Data Required	Computational Requirement	Merits	Limitations
Maximum potential	Contingency planning	Formation of ridesharing unit	Matching origins, destinations, and time	Kendall (2)	Tested with data from Boston, MA	O-D trip tables for automobile home-based work trips	Computer required	Benchmark for evaluation of ridesharing programs	Does not consider user preferences, compatibility of group, enroute matching or off-peak travel
Service-area identification	Identifies areas of ridesharing potential	Formation of ridesharing unit	Matching origins, destinations, and time	Soot and others (7)	Tested with data from Chicago, IL	O-D information	Computer required	Considers economic incentives; identifies travel patterns that can be served by ridesharing	Does not consider user preferences or compatibility of group; vanpool and carpool service areas estimated separately
CSI	Areawide ridesharing demand; demand at employment sites; modal shifts from HOV strategies	Household decision, equilibrium	Demand—logit; carpool size—regression; equilibrium—iteration	CSI (22)	Tested with data from Washington, San Francisco, Minneapolis	Socioeconomic, transportation LOS information, need base modal shares for manual method	Manual recalibration requires computer	Well documented; minimal data requirements for manual method; considers effects on other trip purposes	Does not consider user preferences or compatibility of group
JHK/Shirley Highway carpool modal shift	Estimates modal shifts from HOV treatments	Traffic equilibrium	Diversion curves	JHK (36)	Applied to data from Shirley Highway and Metro K line and I-66 corridor in northern Virginia	Specification of transportation analysis zones, routes, and number of work trips for all O-D pairs, travel times, and speeds	Manual	Based on observed modal shifts to carpools	No further interaction with supply
PMM and Market Facts trade-off	Estimates areawide ridesharing demand	Household decision	Trade-off	PMM (27)	Applied to data from Chicago, Pittsburgh, and Sacramento	Conjoint measurement data about modes used, time, cost, automobile occupancy, socioeconomic data, existing modal shares	Computer required	Gives much information about commuters' preferences by socioeconomic groups and location in city	Does not consider comfort, convenience, reliability; long, tedious method
Economic simulation for priority lane on urban expressway	Estimates modal shifts from HOV treatments	Traffic equilibrium	Demand—logit; supply—LOS function of V/C; equilibrium—iteration	Small (32)	No application in actual environment	Socioeconomic, LOS information at household level	Computer required	Workable equilibration process	Experienced analyst required; does not consider user preferences
University of California, Berkeley, traffic simulation	Estimates modal shifts from HOV treatments	Traffic equilibrium	Traffic flow microsimulation demand from nomograph derived from multinomial logit	Cilliers, May, and Cooper (34)	Case studies on Santa Monica Freeway and Wilshire Boulevard	Detailed network information, travel time by modes, signals	Computer required	Gives microeffects on traffic corridors	Demand sensitive only to changes in in-vehicle travel time
CRA-HOV travel-volume change	Estimates travel-volume changes from HOV treatments for sketch planning	Traffic equilibrium	Demand—incremental product and exponential; supply—volume and delay relationship; equilibrium—simultaneous equations	CRA (38)	Currently being tested	Existing modal volumes and LOS characteristics	Manual	Does not need socioeconomic data; calibrated on observed changes in travel volumes	Provides only first-cut estimates
Car-sharing microsimulation	Areawide demand; demand at employment site	Household decision	Microsimulation with logit demand	Bonsall (28)	Applied to data from Leeds, England	Household travel survey, socioeconomic, LOS data, census data	Computer required	Considers compatibility of group	Extensive data requirements
Planning for transportation corridors	Estimates modal shifts from HOV treatments	Traffic equilibrium	Demand—logit; supply—bottleneck method; equilibrium—simultaneous solution	Talvitie (33)	Prediction of HOV lane in I-580 corridor, San Francisco	Socioeconomic, LOS information at household level, free-flow speeds, bottleneck capacities	Computer required	Workable equilibration procedure; access and line-haul mode choices considered separately	Modal shares of representative households may not represent mode shares in corridor

Note: LOS = level of service, O-D = origin-destination.

Table 3. Other ridesharing estimation methods.

Method	Ridesharing Application	Description	Comments
Emergency automobile occupancy	Estimates ridesharing potential for contingency planning	Apply automobile occupancy rate to work trips with common origin and destination zones	Lee and Glover used minimum occupancy of 3; Cheslow suggests 2.55; no empirical validation
Aggregate share	Usually estimates ridesharing demand at workplace	Transfer of observed modal share for ridesharing from existing program to new site	Reported modal shares from ridesharing programs vary greatly from site to site; many differences among ridesharing programs
Identification of potential ridesharers in population	Estimates areawide demand; estimates ridesharing potential at workplace	Potential determined by comparing characteristics of population against known characteristics of ridesharers	No known simple set of sociodemographic characteristics describes ridesharers; only common characteristic appears to be long commute
Household decision simulation games	Identifies possible responses (including ridesharing) to various policies	Household rearranges travel patterns on game board in response to various scenarios	Administration of game to more than small sample time-consuming; gives insight to possible changes in travel and activity patterns for various scenarios

tion to a new situation and also include the household-interaction simulation games.

RESEARCH NEEDS

Estimation techniques for ridesharing still present a challenge to transportation analysts for several reasons. Ridesharing is not strictly a private mode of transportation nor is it public. Travelers' decisions to rideshare are more complex than decisions to use either public transport or private automobile in that coordination with other travelers is required. Depending on the nature of the ridesharing program, some or all of this coordination becomes the responsibility of the travelers themselves; this increases the relative effort necessary to use this mode. Innovative ridesharing arrangements and promotional efforts are introduced regularly and predicting demand for these new situations compounds the problem for the analyst.

The following two proposed studies are seen to have an immediate impact on the improvement of ridesharing estimation techniques. The first is a multivariate analysis of ridesharing at employment sites. Since many ridesharing estimates are made by transferring a known modal share from one place to another, it would be extremely useful to provide a good set of factors for such transfer. These could be obtained from a multivariate analysis of a data set from a national sample of employment sites that contains the following information about each site: type of industry, number of employees, incentives for ridesharing, incentives for driving alone, degree of ridesharing assistance, number of ridesharing units by type (carpool, vanpool, buspool), and pool composition (intracompany, intercompany, with household members, with neighbors). The second study would be to simply field test a set of estimation techniques at several sites so that an assessment of accuracy, strength, and limitations could be made.

ACKNOWLEDGMENT

This report was prepared while I was a Faculty Fellow in the Urban and Regional Research Division at the Transportation Systems Center, U.S. Department of Transportation.

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Activity Flexibilities of Rural Households: Implications for Ridesharing

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The research described in this paper deals with activity patterns and their relationship to travel needs in a rural area in eastern Connecticut during a typical weekday. It was part of a larger effort to determine the potential for dynamic ridesharing in a low-density area. Various types of activity flexibilities are examined based on the results of a home interview survey of 601 households in the 330-mile^2 Windham Planning Region. Activity flexibility in time was found to be very great except for work or school. With the exception of these two, it was found that 75 percent of all activities were judged to be not fixed in starting time. In fact, 37 percent of all activities could have occurred on a completely different day. Demands on the responsiveness of a ridesharing program should not be excessive since most activities are known well in advance. In the case of the sample households, only 5 percent of the recorded activities occurred with no advance notice and 75 percent were known 24 h in advance. The results indicate that an effective program to encourage ridesharing should recognize that activities occur with great regularity and hence can be scheduled far in advance or are quite flexible in time and can thus be rescheduled to be compatible with ridesharing.

There would appear to be little doubt that ridesharing is an effective strategy for conserving energy, increasing mobility, or achieving some favorable combination of the two.

For the most part, previous studies have focused on satisfying existing travel patterns that in turn are partly the result of habits gained during a period of cheap energy. The possibility of taking advantage of the underlying flexibility of the activities that give rise to the travel patterns has received little attention. It is suggested here that, within limits, not only can the transportation system adapt to travel patterns, but travel patterns can be adapted to the transportation system and that this adaptation can take place within the constraints established by our pattern of daily activities.