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Contents

Foreword

Horowitz examines errors in forecasts that can occur through reductions in numbers of zones—the principal means of saving computer time and memory. Using results from the highway network for Wausau, Wisconsin, general procedures and relationships are developed for determining the amount of error that can occur from subarea focusing.

Takyi discusses a household trip rate analysis that uses the cross-classification method and applies to a developing country. Trip rates, expressed as the average number of person-trips per household classified by purpose of trip and mode of travel, were established for four variables of the household (income, size, car ownership, and number of employed persons). Household income and size were each classified into six groups, and car ownership and number of employed persons were classified into four and three groups, respectively. The results indicate that large household sizes reflecting the extended family system in developing countries significantly affect trip making.

Lindquist presents a method to modify existing traffic analysis zone (TAZ) systems to account for passenger access to specific transit routes in systemwide mass transit ridership forecasting. Three problems are identified. The first concerns how the zone system can be modified to account for passenger access but retain both the basic structure of the TAZ system and a TAZ-based trip table through the four-step process. The second problem concerns how data may be efficiently and accurately reformatted within the framework of the modified zone system. The third problem concerns the adaptation of the four-step urban transportation modeling process for execution within the modified zone system.

Hartgen and Casey describe how a TV-based traffic mitigation campaign was used to encourage shifts in transportation behavior. The authors conclude that cooperative ventures between the media and government can be an important component of transportation mitigation strategies in metropolitan regions.

Murakami and Watterson discuss the first application of a general-purpose urban travel panel survey in the United States. It follows the Dutch National Mobility Panel and responds to needs for direct data on the effects of demographic characteristics and transportation conditions on household travel behavior in an urban area.

Goulias et al. describe a model system of trip generation and trip chaining that is developed by integrating concepts from activity-based analysis. The structure of the model system is recursive, depicting a sequential decision-making mechanism.

Mahmassani et al. present the results of a survey of commuters in Austin, Texas. Models of commuters' propensity to switch route and departure times for both the a.m. and p.m. commutes are developed. The models relate switching to geographic and network condition variables, workplace characteristics, individual attributes, and use of information (radio traffic reports).

Chu suggests the need for a dogit distribution formula in the construction of a combined trip distribution and assignment model. The new version of the combined model can be reformulated as an equivalent mathematical programming problem so that the equilibrium conditions on the network and the dogit distribution demand functions can be derived as the Kuhn-Tucker conditions of the proposed programming problem. The advantages of this method are discussed.

Bradley and Gunn discuss work undertaken on behalf of the Dutch Ministry of Transportation and Public Works. The focus was on travelers' valuations of savings or losses in travel time. The study provided monetary values of time changes that vary simultaneously along several household, personal, and situational dimensions, including the level of traffic congestion and the amount of free time and income available.

Tacken discusses teleshopping as a supplement and alternative to transportation that may have effects on traffic and physical planning. These ideas are presented and various outcomes are presented.

Keklikian reports how Canada's National Capital Commission is dealing with telework as a planning issue. A 1988 survey of the attitudes of senior federal managers toward telework in the capital region is described. The public policy environments for telework are examined, a number of key transportation and planning issues interacting with telework are identified, and opportunities for improved understanding and application of telework are suggested.

Kitamura et al. use travel diary survey results to evaluate the effect of home telecommuting. The data indicate that telecommuting reduces work trips, and no indication is present that telecommuting induces new nonwork trips. The analysis offers support for telecommuting as a way to mitigate traffic congestion and improve air quality.

Valdez and Arce present the findings of a survey of ridesharers, solo drivers, and the general commuting population of Orange County, California. Among the findings was that travel time was the most important mode selection factor for all three groups. Whereas the availability of a car at work was the second most important factor for commuters in general and solo drivers, ridesharers rated commuting costs as the second most important factor. Ridesharers were more likely to believe that high-occupancy vehicle (HOV) lanes encourage ridesharing than solo drivers, and there was more support among ridesharers than solo drivers for a sales tax increase to build HOV lanes.

Williams et al. discuss the results of a survey of vanpool operators in the Washington metropolitan area during the spring of 1989. Study areas include trip length, travel time, membership, occupancy, collection and distribution, insurance, and equipment. Among the strongest incentives for vanpool formation were HOV lanes linked to employment areas with a significant parking cost.

Subarea Focusing with Combined Models of Spatial Interaction and Equilibrium Assignment

ALAN J. HOROWITZ

Subarea focusing is a means of reducing computational requirements of large transportation networks when only a small portion of the region is affected by a project. Relatively unimportant links are eliminated from the network and distant zones are aggregated, whereas full detail is retained in the area of greatest impact. Errors in forecasts that can occur through reductions in numbers of zones—the principal means of saving computer time and memory—are examined. On the basis of results from the highway network for Wausau, Wisconsin, general procedures and relationships are developed for determining the amount of error that can occur from subarea focusing.

The recent development of software for the analysis of transportation impacts in small areas (i.e., SubArea Focusing and Quick Response System II) has raised some important methodological issues. First, it is not known whether subarea focusing is a valid concept for a meaningfully broad class of transportation problems. Second, if the concept is valid, there is little information about when and how it can be applied. And third, subarea focusing needs further testing with the newest generation of travel forecasting models—those that join a spatial interaction model to a traffic assignment model to find a combined equilibrium solution.

Subarea focusing is primarily a way to reduce the data preparation costs and computation requirements of travel forecasting with large transportation networks. It applies to transportation projects that affect only a small portion of the region. The network is redrawn so that the area of primary impact is shown in considerable detail (small zones and many links) and distant sections of the network are shown in much less detail (large zones and only the most important links). If a comprehensive network is already available for a region, computer programs, such as the SubArea Focusing package (*1*), can be used to automate the process. Otherwise, the planner must exercise judgment in selecting zone sizes and link densities.

The key assumption of subarea focusing is that forecast errors will be small if their sources are spatially distant from the area of primary impact. For example, a study of single-route transit ridership (*2*) indicated that zones on connecting routes could be quite coarse without affecting the forecast. This result stemmed from peculiarities of the structure of transit networks and may not apply to other types of travel.

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If it can be applied properly, subarea focusing has important advantages. It can reduce (perhaps only slightly) data preparation time and it can considerably reduce computation requirements. Large networks could fit into smaller computers and most of the computation time could be eliminated.

Two rules of thumb apply to computation time. First, it is approximately proportional to the number of links in the network; second, it is approximately proportional to the square of the number of zones. Both rules have important exceptions; for instance, the spatial interaction model described later has computation times that are nearly proportional to the cube of the number of zones. If computation time were the only issue, then planners should be much more interested in eliminating zones than links.

In deciding whether subarea focusing is beneficial, the planner must keep in mind that any modification to an unfocused network will cause an error in the forecast—the bold assumption is that the unfocused network approximates truth. Of course, forecasts with unfocused networks are themselves rampant with errors (*3,4*). A 30 percent average root-mean-square (RMS) error in highway link volumes is not unusual. If the errors in highway link volumes caused by subarea focusing are small relative to the errors already inherent in the forecast, then subarea focusing makes sense. If subarea focusing noticeably distorts the forecast, then it should be avoided.

As will be shown later, determining the error caused by subarea focusing is a major undertaking. If planners were required to ascertain the error before performing their forecast, any value of subarea focusing would be lost. A more efficient strategy would be to first develop general relationships that could be used to estimate errors due to subarea focusing. Ideally, these relationships should be specific to the particular unfocused network. A second solution would be to adopt relationships developed for other networks, such as the relationships derived in this paper.

In order to better understand errors from subarea focusing, simulations were run on a network from Wausau, Wisconsin. The simulations were performed using the Highway Land Use Forecasting Model II (HLFM II). HLFM II simultaneously produces both a land use forecast and a traffic forecast. HLFM II was selected over traditional travel forecasting models (e.g., UTPS or QRS II) because its spatial interaction step is more sensitive to variations in zone size and shape. Errors measured from HLFM II should be larger than errors from models that only provide a traffic forecast.

OVERVIEW OF THE SIMULATION STEPS

The spatial interaction step in HLFM II is a version of the Lowry-Garin model (*5,6*) of land use. The Lowry-Garin model remains one of the most popular methods of land use forecasting because of its consistency with economic base theory, its similarity to traditional theories of travel demand, and its straightforward method of solution. The Lowry-Garin model states that workers will locate their residences proximate to their workplaces and that services will locate proximate to their markets. Two service categories are defined: services for residences and services for businesses. The important exogenous variables in the model are the zonal locations of basic employment (e.g., factory workers), the travel times between all pairs of zones in the region, and measures of the ability of any zone to attract population or service employment. HLFM II's specific implementation of the Lowry-Garin model is briefly described in the Appendix.

HLFM II also forecasts traffic by estimating the numbers of trips between each pair of zones and assigning the trips to the network. HLFM II implements several forms of traffic assignment, some of which can produce a combined equilibrium solution. A network is considered to be in equilibrium when (*a*) numbers of trips between pairs of zones are consistent with travel times between those zones, (*b*) link volumes are consistent with link travel times, and (*c*) all trips are assigned to a shortest path between the origin zone and the destination zone. The method of traffic assignment adopted for this study is a hybrid of the Evans algorithm of elastic-demand traffic assignment (*7*) and a form of incremental assignment that has been derived from Frank-Wolfe decomposition (*8–10*). Tests of this algorithm on several networks have shown that it consistently converges to the equilibrium solution in about the same time as Frank-Wolfe decomposition (*11,12*). This algorithm is referred to as elastic-demand incremental assignment.

It has been shown (*11*) that the error in link volumes from insufficient iterations with the Frank-Wolfe decomposition family of algorithms varies approximately with the reciprocal of the number of iterations. In an elastic-demand assignment each iteration consists of a complete pass through the spatial interaction step, an all-or-nothing assignment, and a step in which the model finds an average of traffic volumes from all previous iterations. Thus, a convergence error of less than 0.5 percent could be achieved with approximately 250 iterations. This number greatly exceeds common practice. However, the convergence error must be kept small if the effects of zone restructuring are to be accurately measured.

FOCUSING THE WAUSAU NETWORK

As shown in Figure 1, the Wausau network is already focused on the central business district (CBD). All streets within the CBD are represented, and zone sizes in the CBD are about 0.2 mi^2. The remaining zones become larger with increasing distance from the CBD; the largest zones range from 3 to 10 mi^2. The Wausau network contains just 36 zones and 9 external stations. The network simulates the p.m. peak hour.

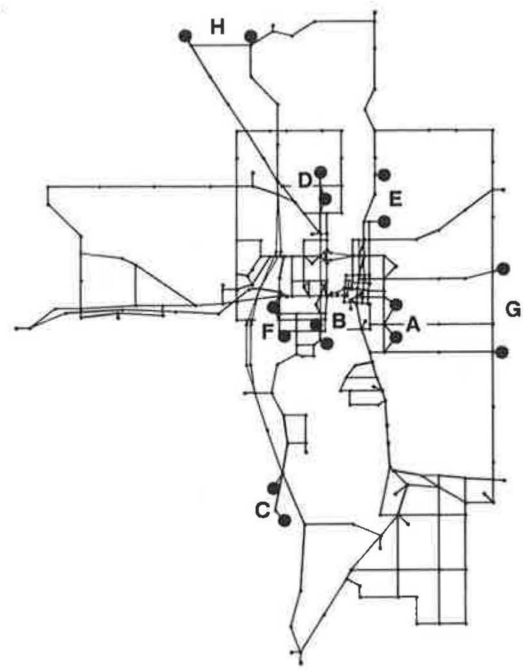

FIGURE 1 Base Wausau network showing the eight zone pairs.

Obtaining Base Networks

A complete understanding of errors due to zone restructuring requires both equilibrium and all-or-nothing assignments. Consequently, it was necessary to prepare a base network that would give results between the two assignment methods that were reasonably compatible. The base network was obtained by running the original Wausau network through 20 iterations of elastic-demand incremental assignment. The near-equilibrium link travel times from this simulation were used as the starting point for all remaining simulations.

It was expected that simulations involving elastic-demand incremental assignment would require 250 iterations to eliminate the problem of convergence error. This assumption was checked by comparing two separate assignments on the base network, one at 250 iterations and one at 1,000 iterations. Convergence error from the 1,000-iteration assignment can be considered insignificant. The RMS difference in link volumes between the two assignments was 0.6 vehicle/hr, or about 0.14 percent—better than expected.

Comparison Networks

Comparison networks were created to determine the sensitivity of the model to small amounts of zonal restructuring and to determine how errors increase as larger numbers of zones are eliminated. A total of 15 comparison networks were created; all were small variations on the base network. Each of the first eight networks combined a single pair of adjacent zones, thereby eliminating one zone from the total for the network. The pairs of zones are shown in Figure 1 and are labeled A through H. All were outside but at varying distances

TABLE 1 RMS ERRORS (VEHICLES PER HOUR) OF ELIMINATING A SINGLE ZONE FROM THE WAUSAU BASE NETWORK

	Elastic-Demand Incremental		All-or-Nothing	
Network	All Links	CBD Links	All Links	CBD Links
A	20.7	30.1	25.6	40.1
B	42.2	6.5	44.2	6.9
C	17.2	0.6	17.5	0.4
D	30.2	5.9	45.8	6.1
E	55.9	5.1	44.6	3.5
F	30.3	6.7	33.1	14.1
G	4.5	6.1	5.1	6.9
H	26.3	0.4	26.3	2.6

from the CBD. Two of the zone pairs, G and H, were sets of external stations.

The next four networks (identified here as Networks AB, CH, EG, and DF) were combinations of the previous eight. Each of these networks eliminated two zones from the base network. For example, Network AB collapsed both Zone Pair A and Zone Pair B.

Two networks (ABCH and EGDF) were combinations of the previous four. Both of these networks eliminated four zones. The last network was a combination of the previous two. It eliminated eight zones and is referred to as ABCHEGDF.

Determining the Error

The base network and all the comparison networks were each run twice—once through 250 iterations of elastic-demand incremental assignment and once through all-or-nothing assignment. The RMS errors in directional link volumes were computed for each comparison network. Only links that represented real streets were included; centroid connectors and other artificial network elements were ignored.

The RMS difference between the two base assignments (all-or-nothing and elastic-demand incremental) was 114 vehicles/hr, or about 26.5 percent. This difference was smaller than expected, perhaps because the base network had already been processed through 20 iterations of elastic-demand incremental assignment.

The RMS errors for the first eight comparison networks are shown in Table 1. The errors are reported for both assignment methods and for the set of all links and for the set of links within the CBD. As expected, there was a substantial difference between the RMS errors across all links and the RMS errors for only the CBD links. In general the RMS errors were less for the CBD links; the major exceptions were Zone Pair A (immediately adjacent to the CBD) and Zone Pair G (relatively small external stations).

An unexpected result, but a highly useful one, is the similarity between errors from the elastic-demand incremental assignment and errors from the all-or-nothing assignment. This similarity suggests that it is unnecessary to perform lengthy equilibrium assignments solely to determine the errors from subarea focusing. All-or-nothing assignments will suffice, provided that the network has been prepared with near-equilibrium link travel times.

Eliminating a single zone from a network introduces a disturbance to every link with positive volumes. Some links are affected more than others, particularly links that are near the eliminated zone. If two spatially separated zones are eliminated, it could be surmised that the two disturbances would behave as if they were independently distributed random variables. Because the nature of the disturbance is essentially unknown, this hypothesis must be verified empirically.

Table 2 shows the results from the remaining seven networks, each of which collapsed multiple zone pairs. Listed in Table 2 are the actual RMS errors and the estimated RMS errors, calculated by assuming that the disturbances from eliminating a single zone are independently distributed random variables. For example, the estimated error for Network AB was found from the errors measured in Network A and Network B; the estimated error for Network ABCH was found from the measured errors in Networks A, B, C, and H.

TABLE 2 RMS ERRORS OF ELIMINATING MULTIPLE ZONES FROM THE WAUSAU BASE NETWORK

	Elastic-Demand Incremental		All-or-Nothing	
Network	Measured	Expected	Measured	Expected
Across All Links				
AB	45.2	47.0	48.9	51.1
CH	31.4	31.4	31.9	31.6
EG	43.2	56.1	45.0	44.9
DF	42.4	42.8	56.2	56.5
ABCH	55.0	56.5	58.6	60.1
EGDF	60.6	70.6	72.0	72.2
ABCHEGDF	82.5	89.9	93.1	93.9
Across CBD Links				
AB	30.4	30.8	37.7	40.7
CH	0.6	0.7	0.6	2.6
EG	5.9	8.0	7.0	7.7
DF	8.1	8.9	15.2	15.4
ABCH	30.4	30.8	37.6	40.8
EGDF	10.2	12.0	19.5	17.2
ABCHEGDF	32.2	33.1	45.4	44.3

NOTE: Data are in vehicles per hour.

The estimated errors agree closely with the measured errors. This agreement holds for both assignment methods and for the set of all links and the set of CBD links. The ability to make the assumption of independence is important. It permits estimation of the effect of eliminating an arbitrary number of zones from knowledge of the effect of eliminating a single zone.

PATH DEPENDENCE

The elimination of a single zone affects a large number of paths. Each path will carry the disturbance, but the paths are not assigned as if they were independently distributed random variables. Links closest to the eliminated zone are assigned more paths than links farther away; some links (e.g., those with high capacity) are unusually attractive to paths. Thus, some links are consistently affected more than others—disproportionately influencing the RMS error. The probabilistic dependence of path assignment is important to the concept of subarea focusing.

Tables 3 and 4 illustrate the levels of path dependence in the Wausau base network with all-or-nothing assignment. Statistics are provided for six zones, one zone from Pairs A through F. (Zone Pairs G and H were external stations; HLFM II could not generate path dependence data for external stations.) For each zone, Table 3 shows the standard deviation of the number of paths that are assigned to any link. The zones were treated as being origins only, so there were 44 paths in each case. Any given link could be assigned as many as 44 paths or as few as 0 paths. This standard deviation is calculated separately for the set of all links and for the set of CBD links. Table 3 also indicates the mean number of paths that are assigned to each link.

The number of paths on a link would be binomially distributed if paths were randomly and independently assigned to the links (they are not). Take, for example, the assignment of paths from one of the zones in Pair A to CBD links. With a mean assignment of 1.901 paths, the probability that a link would be randomly and independently assigned any given path is 0.0432 (i.e., 1.901/44). Consequently, the standard deviation from the binomial distribution is 1.349, much smaller than the actual value of 6.016 from Table 3. The difference can be attributed to the dependence between paths.

A useful measure of this dependence is the covariance between paths. Assuming paths are identically (but not independently) distributed, the covariance can be found from the following relationship:

$$\sigma^2_{\text{measured}} = \sigma^2_{\text{binomial}} + m(m - 1)C \qquad (1)$$

where

C = the covariance,
$\sigma^2_{\text{measured}}$ = the measured variance,
$\sigma^2_{\text{binomial}}$ = the variance from the binomial distribution, and
m = the number assigned paths.

TABLE 3 STANDARD DEVIATIONS AND MEANS OF NUMBERS OF PATHS ASSIGNED TO LINKS IN THE WAUSAU NETWORK FOR A SINGLE ORIGIN ZONE

Represented Zone Pair	All Links St. Dev.	All Links Mean	CBD Links St. Dev.	CBD Links Mean
A	3.232	0.858	6.016	1.901
B	1.863	0.608	1.492	0.656
C	3.119	0.750	1.107	0.590
D	2.506	0.682	1.398	0.508
E	3.041	0.860	1.641	0.721
F	1.945	0.636	1.988	0.984

TABLE 4 PROBABILITIES AND COVARIANCES OF PATHS ASSIGNED TO LINKS IN THE WAUSAU NETWORK FOR A SINGLE ORIGIN ZONE

Represented Zone Pair	All Links Probability	All Links Covar.	CBD Links Probability	CBD Links Covar.
A	0.0195	0.0051	0.0423	0.018
B	0.0135	0.0015	0.0149	0.00084
C	0.0170	0.0048	0.0134	0.00034
D	0.0155	0.0030	0.0115	0.00077
E	0.0195	0.0044	0.0164	0.0011
F	0.0145	0.0017	0.0224	0.0016
All	0.0169	0.0036	0.0203	0.0039
All Except A	--	--	0.0157	0.00091

Applying Equation 1 to the previous example yields a covariance of 0.018. The probability of a path being assigned to a link and the path covariances are shown in Table 4. The covariances vary greatly from zone to zone. For example, among CBD links the covariance for paths from Zone A is about an order of magnitude larger than the others—demonstrating that Zone A, which is quite close to the CBD, would be a poor choice for elimination.

As discussed in the next section, the path covariance is particularly helpful in estimating errors in new networks.

ESTIMATING ERRORS IN EXISTING NETWORKS

Every network has unique error characteristics. Ideally, the following procedure should be followed:

1. Obtain an unfocused network for the region.
2. Run this network through a sufficient number of iterations of the chosen assignment method to ascertain near-equilibrium link travel times.
3. Develop a base forecast by running an all-or-nothing assignment on the network with the near-equilibrium link travel times.
4. Choose a sample of zone pairs that are suitably distant from the impact area.
5. Collapse each zone pair to a single zone and run an all-or-nothing assignment.
6. Measure the RMS error on the links in the impact area by comparing their volumes with the base assignment.
7. Find an average RMS error for the sample of zones with

$$\varepsilon^S = \left(1/n \sum_{i=1}^{n} \varepsilon_i^2\right)^{1/2} \tag{2}$$

where n is the number of samples.

8. Determine the effect of the subarea focusing with

$$\varepsilon^R = q^{1/2}\, \varepsilon^S \tag{3}$$

where q is the number of zones to be eliminated.

9. Eliminate the desired number of zones and eliminate links that had zero assigned volumes in Step 2.

Experience with the Wausau network suggests that the error estimates obtained from this procedure should be good. Although time consuming, this procedure could be simultaneously performed for many potential subareas, thereby satisfying all future subarea focusing needs.

EXTRAPOLATING ERRORS TO OTHER NETWORKS

The procedure in the previous section requires an unfocused network of reasonable quality, but focused networks are often developed from scratch. In such cases, it is impossible to determine an average error before the network is built. The only option is to extrapolate errors from networks developed elsewhere.

Some simple relationships can be derived to help anticipate the amount of error caused by subarea focusing in a nonexistent network. To do this, the following assumptions can be made.

1. Zones are identical.
2. The elimination of any zone causes the same disturbance to the subset of links.
3. The magnitude of that disturbance is proportional to the number of trips in a single path.
4. For any path, the assignment of paths to a given link is a random Bernoulli process.
5. The number of links in any path for a given network is a constant.
6. The path covariance is a constant.

Each of these assumptions could be made more realistic, but it is unlikely that extremely precise relations would be beneficial given the limited knowledge of subarea focusing errors.

The number of assigned paths from any zone, m, is one less than the number of zones, z. From Equation 1

$$\sigma^2_{zone} = (z - 1)p(1 - p) + (z - 1)(z - 2)C \tag{4}$$

where

σ^2_{zone} = the variance of paths from a single zone assigned to a link,
p = the probability that a path is assigned to a link, and
C = the path covariance.

The error from a single zone reduction would be

$$\varepsilon^S = k\, T/z^2\, \sigma_{zone} \tag{5}$$

where T is the total number of vehicle trips in the network and k is an empirical constant. Substituting Equation 4 into Equation 5 produces

$$\varepsilon^S = k\, T/z^2\, [(z - 1)p(1 - p) + (z - 1)(z - 2)C]^{1/2} \tag{6}$$

The effect of a reduction in q zones is

$$\varepsilon^R = k\, T/z^2\, \{q[(z - 1)p(1 - p) + (z - 1)(z - 2)C]\}^{1/2} \tag{7}$$

The value of k can be determined from Equations 1 and 6 and from data similar to those in Tables 1 and 4. For example, k can be computed for the Wausau network on CBD links. On the basis of the all-or-nothing assignment for Zone Pairs B through F, Equation 1 yields an average error from a single zone reduction of 7.7. The covariance for these same zone pairs is 0.00091 (Table 4), and the probability of a path being assigned to a link is 0.0157. The Wausau network has 45 zones and external stations, and it has about 24,700 vehicle trips in the p.m. peak hour. Substituting into Equation 6 and solving for k gives a value of 0.41.

Extrapolating the results between networks requires an assumption about the value of k and the value of the path covariance. These values can be ascertained from any other network by repeating the same procedure that was carried out on the Wausau network. The probability that a path is assigned to a link can be found from the whole path length (as measured in links) and the total number of links:

p = (path length)/(number of links)

The path length can be conveniently approximated by dividing the sum of volumes on all links in the network by the total number of vehicle trips.

For example, a 50-zone reduction of the East Brunswick network (*11*) is contemplated. This network has 129 zones, a total of 939 one-way equivalent links, 25,600 vehicle trips in the a.m. peak hour, and a total link volume of 540,000 vehicles. Therefore, the average path length is 21.1 links, and the probability of a path being assigned to a link is 0.0225. Adopting the values of k and the path covariance from the Wausau CBD and substituting into Equation 7 gives an RMS error of 19 vehicles/hr, or about 3 percent of the average directional volume.

The path covariance is strongly related to the distance between the subarea and the eliminated zones. The adopted path covariance should be extracted from a network as similar as possible in size and structure.

Although not addressed in this study, it would be particularly helpful if path covariance for a single link could be expressed as a function of distance to any given zone. With this information, simple guidelines could be established (e.g., do not eliminate zones within x mi of the subarea), and the need for sensitivity analysis could be reduced.

ERRORS IN ESTIMATES OF POPULATION

The major purpose of an HLFM II simulation is to obtain estimates of the spatial distribution of population and employment. Table 5 gives the RMS errors in population for each of the Wausau comparison networks. The RMS errors were computed for the 24 zones that were not touched by any of the zone reductions. The errors were quite small (less than 1 percent of the average zonal population of 1,885), and the RMS error does not appear to be strongly related to the number of zones eliminated. Population forecasts for almost any subarea can be expected to be insensitive to zone size and structure in the remainder of the region.

TABLE 5 RMS ERRORS IN POPULATION FOR 24 ZONES IN THE WAUSAU NETWORK

Network	RMS Error
A	4.3
B	6.0
C	1.4
D	8.2
E	14.9
F	2.8
G	0.8
H	0.9
AB	8.1
CH	1.3
EG	1.0
DF	7.9
AGCH	7.8
EGDF	8.4
ABCHEGDF	10.9

CONCLUSIONS

The major advantage of subarea focusing is a reduction of computer requirements when handling large networks. The greatest reductions can be achieved by aggregating zones within the network; eliminating links offers little advantage, considering the potential for damage to the forecast. Zones can be successfully aggregated, depending on the unfocused zone structure, the nature of the links within the subarea, the relationship between the subarea and the rest of the network, and the intended use of the forecast. Before subarea focusing is attempted, planners must determine how it will affect the quality of the forecast. This impact can be ascertained by performing trial simulations on the unfocused network or by extrapolating information about subarea focusing errors from networks of similar structure.

Subarea focusing offers considerable promise for land use simulations. Forecasts of demographic variables within subareas are relatively insensitive to the structure of the zones in the remainder of the region. Furthermore, subarea focusing overcomes two serious problems with land use models: (*a*) the requirement that the whole region be included within the zone system and (*b*) the extreme computer requirements of networks with large numbers of zones.

APPENDIX—IMPLEMENTATION OF LOWRY-GARIN MODEL

The model used for this research has been implemented as HLFM II. This program runs on MS-DOS and OS/2 microcomputers. HLFM II contains a wide variety of options for data preparation and execution, which were not invoked in this study. The following description of the Lowry-Garin model is confined to those features actually used. Provisions in HLFM II for expanded capabilities are noted as appropriate.

The Garin version of the Lowry model is a series of matrix equations that forecasts the distribution of population and employment in an urban area. The Lowry-Garin model recognizes only four land use activities: residential, basic industries, service industries for population, and service industries for businesses. Basic industries (i.e., industries that receive their income from outside the urban area) are assumed to be fixed at known locations. The Lowry-Garin model attempts to maintain proximity of workers' residences to their workplaces and to maintain proximity of service industries to their respective markets (either residences or other business, depending on the type of service activities).

The Lowry-Garin model is derived here by constructing an employment conservation equation. Let E be a vector of total employment (each element, e_i, of E being the total employment of the ith zone), E_B be a vector of basic employment, E_R be a vector of service employment required by residences, and E_W be a vector of service employment required by workers (i.e., businesses). Total employment is the sum of its three components:

$$E = E_B + E_R + E_W \tag{A-1}$$

Each of the three vectors on the right-hand side of Equation A-1 represents the spatial distribution of a sector of employment in the urban area. Basic employment, E_B, is the only explicit exogenous variable in the Lowry-Garin model. Employment serving residences, E_R, and employment serving workers, E_W, are dependent on trip-making patterns, the transportation system, and existing land use.

Employment in industries that serve workers, E_W, is calculated by distributing service employees around all employment locations as given by the vector E. Define h_{ij} as the conditional probability that an employee in Zone j is served by another employee in Zone i. Denote this matrix of conditional probabilities as H. Also define f as the number of service employees required for each employee, averaged across the whole urban area. Then

$$E_W = fHE \qquad \text{(A-2)}$$

HLFM II permits specifying a different f at each zone, but this was not done for the tests in this paper.

A similar relation can be constructed for employees serving the entire population. Define b_{ij} as the conditional probability that an individual who lives in j is served by an employee in i. This conditional probability matrix is B. Also define g as the number of employees that serve each individual, averaged across the whole urban area. Then, as in Equation A-2,

$$E_R = gBP \qquad \text{(A-3)}$$

where P is the population vector containing elements, p_i, each of which is the population in Zone i. The variable g could have been set separately for each zone but was not. Population distribution is computed from total employment. Define a_{ij} as the conditional probability that an individual working in j lives in i. Let A be the matrix of these conditional probabilities. Also define q_i as the ratio of population to employees in residental Zone i. Furthermore, let

$$Q = [\delta_{ij}\, q_i] \qquad \text{(A-4)}$$

where δ_{ij} is the Kronecker delta. Note that Q is a diagonal matrix. Populations of all the zones are found from

$$P = QAE \qquad \text{(A-5)}$$

Consequently, from Equations A-3 and A-5,

$$E_R = gBQAE \qquad \text{(A-6)}$$

Substituting Equations A-2, A-3, and A-6 into Equation A-1 reduces the employment conservation equation to one with terms for only total employment, E, and basic employment, E_B.

$$E = E_B + gBQAE + fHE \qquad \text{(A-7)}$$

Equation A-7 can be solved for the spatial distribution of total employment (E) in terms of basic employment.

$$E = (I - gBAQ - fH)^{-1}\, E_B \qquad \text{(A-8)}$$

The spatial distribution of population can be computed from Equation A-5, and the spatial distributions of employment in the two service sectors, E_R and E_W, are directly computed from Equations A-2 and A-6.

The three conditional probability matrices (A, B, and H) are computed from singly constrained trip distribution equations with an exponential deterrence function. For example, the A matrix can be found by

$$a_{ij} = w_i \exp(-\beta c_{ij}) / \sum_i w_i \exp(-\beta c_{ij}) \qquad \text{(A-9)}$$

where

c_{ij} = the generalized cost of travel between Zones i and j,
w_i = the attractiveness for residential Zone i, and
β = a calibrated parameter.

The model uses residential-developable area for w_i. The generalized cost of travel is computed as if trips followed the shortest path between pairs of zones in the urban area. That is,

$$c_{ij} = (1 + y/v)\, t_{ij} + t_{ij}^z \qquad \text{(A-10)}$$

where

t_{ij} = the portion of shortest travel time that occurs on streets,
y = the monetary cost per minute,
v = the value of time, and
t_{ij}^z = the portion of shortest travel time that occurs on centroid connectors.

Adjustments to Residential Attractiveness

Land area does not formally appear in either the Lowry-Garin model or in the trip distribution equations. Nonetheless, land area has been introduced into the model by making residential attractiveness (w_i in Equation A-9) equal to residential-developable area and by making service attractiveness equal to service-developable area. The same parcel of land may be included in both measures of attractiveness. The trip distribution equations will assign activities to zones roughly in proportion to these developable areas. If a zone is almost fully occupied by service activities, then only a few people should be able to live there. The model can be instructed to reduce residential trip attractiveness in response to large allocations of service employees to a zone. This adjustment is handled iteratively. The residential attractiveness at iteration n (after the first iteration) is based on the amount of service allocated at iteration $n - 1$. Specifically,

$$W^n = W^1 - z(E_R^{n-1} + E_W^{n-1}) \qquad \text{(A-11)}$$

where

W^n = the vector of residential attractiveness at iteration n,
W^1 = the vector of residential attractiveness at the first iteration as specified in the data input step,
z = area per service employee,
E_R^{n-1} = the vector of the number of employees that serve residences as calculated on iteration $n - 1$, and
E_W^{n-1} = the vector of the number of employees that serve other employees as calculated in iteration $n - 1$.

Residential attractiveness at any iteration (W^n) is constrained to be greater than or equal to zero. In addition, the adjustment to residential attractiveness (the second term of Equation A-11) cannot exceed the service-developable area. This procedure for adjusting residential attractiveness effectively incorporates the notion of land capacity into the forecasts. HLFM II permits a different value of area per service employee in each zone.

In addition, HLFM II can be forced to allocate a specific population to any given zone. This constraint is satisfied by making adjustments to residential attractiveness in the trip distribution equations.

Adjustments to Service Attractiveness

The Lowry-Garin model does not provide for agglomeration even though Lowry did recognize that certain zones would attain high levels of service activities. The original Lowry model permitted the planner to set the minimum amount of service employment that could occur in a zone.

Agglomeration can be partially handled by making upward adjustments of service attractiveness from those set by the planner. The underlying assumption is that agglomeration will occur in zones that have the highest potential to attract a disproportionately large share of customers. These zones will tend to be central to the region or near large concentrations of population. At least two iterations of the Lowry-Garin model are required—the first iteration establishes the "potential" and the second iteration distributes the residence-serving and employment-serving trips according to this potential. The measure of potential is continually updated as the number of iterations is increased. The method is somewhat complex and was not invoked in the assignment tests.

HLFM II can be instructed to allocate a specific number of service employees to any given zone. This constraint is satisfied by making adjustments to service attractiveness within the trip distribution equations.

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Trip Generation Analysis in a Developing Country Context

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A household trip rate analysis that uses the cross-classification method and applies in a developing country context is presented. The importance of choosing, defining, and classifying variables and using an appropriate analytic technique related to the socioeconomic values and travel behavior of residents in developing countries is stressed. Trip rates, expressed as the average number of person-trips per household classified by purpose of trip and mode of travel, were established for four variables of the household (income, size, car ownership, and number of employed persons). Household income and size were each classified into six groups, and car ownership and number of employed persons were classified into four and three groups, respectively. The standard cross-classification method was used to determine which household characteristics, given limited data, most influence trip making. The results indicate that large household sizes reflecting the extended family system in developing countries significantly affect trip making. Together with car ownership and the number of employed persons in the household, household size as a variable performs significantly better than household income for work, school, and shopping trips, which make up more than 60 percent of total household trips.

The growing volume and complexity of urban travel in developing countries should be a major concern to transportation planners, service sponsors in urban areas, and policy makers. One component that seems to have been neglected or taken for granted in the planning of cities in the developing world is travel demand analysis. There is no systematic analysis of established relationships between various forms of land use and attitudes of trip makers to guide planning of major developments and activity centers. This deficiency limits the effectiveness of transportation policies and actions in meeting the needs of expanding urban populations in the developing world.

In contrast, travel demand analysis has been a major component of transportation planning in the developed world for many decades (*1*,*2*). In the 1950s and 1960s, most transportation planning studies focused on developing person-trip production models using zonal variables such as residential density, type of dwelling unit, and number of employed residents. The primary method of analysis of these models was linear regression (*3*,*4*). However, in the 1970s and 1980s a more disaggregate trip generation model based on household variables such as income, car ownership, and family size was developed. Regression analysis was (and is) used in most household trip generation studies. In early 1970, in response to the need for greater disaggregation in trip rate analysis, an alternative, the cross-classification method (also referred to as category analysis), was developed (*5*). This method uses categorized variables, such as household size, car ownership, and income, as integer values to describe individual households. For instance, integer values of household size could be 1 to 2 persons per household, 3 to 4 persons per household, 5 to 6 persons per household, and more than 6 persons per household. The definition and classification schemes must be based on the nature of residential living arrangements and the concepts of family and household. These concepts vary in meaning and scope from one place to another. Analysis of variance (ANOVA) is sometimes used to determine which groups or variables of households are better classification schemes for modeling (*6*). Recently, multiple classification analysis (MCA) has been used to determine interaction effects, comparative analysis of alternative models, and cell rates for small samples (*7*). The desire for further disaggregation of trip generation analysis has led to the development of the person category models as an alternative to the household models (*8*). Another variation of the disaggregated household models is the household structure concept (*9*). Although the person level of data aggregation has been found to be useful for travel demand analysis based on demographic factors, it does not incorporate household structure and interaction effects or household money and budget costs into the analysis. These models, however, use the cross-classification and the regression methods to analyze the data.

The primary advantages of the cross-classification method over the regression method are as follows: (*a*) it does not require a linear or monotonic relationship between the variables and (*b*) it permits a more comprehensive analysis of trip making by showing the relationships among different classes of households. It may also be a better method when the data are insufficient because of large standard errors and uncertainty in model parameters associated with small sample sizes. On the other hand, the regression method allows results of trip generation models to be used for prediction beyond the calibrated data.

Because trip generation studies have been well documented in the developed countries, most of the established practices, such as the choice of an analytic technique and the selection and specification of variables, are based on travel behavior and demographic characteristics of residents in developed countries. This paper examines these issues in the light of conditions in developing countries. The results of a trip generation study carried out in Kumasi, Ghana, are presented. Kumasi, the second-largest city in Ghana, is a rapidly expanding urban center (population 700,000) with a growing demand for travel.

An earlier version of this study used linear regression analysis (*10*). The cross-classification method is used here because

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it deals with the nonlinearities observed between some of the variables and the average number of person-trips per household. It also allows more detailed analysis of the variables.

Few studies have been made of travel demand in Ghana, as is true of other parts of the developing world. Some studies, however, have been made of traffic generation of commercial areas, hospitals, and industrial establishments (*11–13*). One study of trip generation that deserves mention is an analysis of urban travel characteristics in Accra (*14*). Although the study recognizes the importance of the household unit in the generation process, it confuses residential zonal treatment with household treatment in the selection and measurement of variables. The study also attempts to derive conventional trip generation models for residential zones by making the convenient simplifying assumption that all trips by households in a residential zone are home-based and single-destination trips. The study reported here seeks to correct the shortcomings of those traditional assumptions of urban travel analysis and to eliminate the error that might be introduced into forecasts of future urban travel in Kumasi.

Data collection procedures, selection of variables, and definition of a classification scheme are discussed. Four household variables—income, size, car ownership, and the number of members employed—are analyzed. Household income and household size are each grouped into six categories, and car ownership and the number of employed persons are grouped into four and three categories, respectively. Trip rates are established for specific household categories in terms of the average number of person-trips per household classified by purpose and mode of travel. The standard cross-classification method is employed to determine which variables and categories have the strongest relationships to trip making. To explore further variations in the data, a one-way ANOVA was performed. This allowed two-way tabulations of specific variables to be included and discussed.

DATA COLLECTION

Field Survey

Data were obtained largely through a home interview survey of travel patterns of household residents in Kumasi. The survey was conducted during April and May 1979. The data were updated in 1983. The survey usually started around 4:30 p.m. and ended around 7:30 p.m. each weekday.

Using the Kumasi City Council's 1978 property rating, 6 residential zones out of a total of 50 were selected for the home interview survey. The selected zones consisted of two high-income residential zones (Nhyiaeso and the U.S.T. Ridge), two medium-income zones (Kwadaso Estate and Menhyia Extension), and two low-income zones (Old Tafo and Asawasi). To account for the influence of differences in distance from the central business district (CBD) on trip frequency, a zone closer to the CBD and another further away were selected for each group. Figure 1 shows the six selected zones in relation to the CBD of Kumasi.

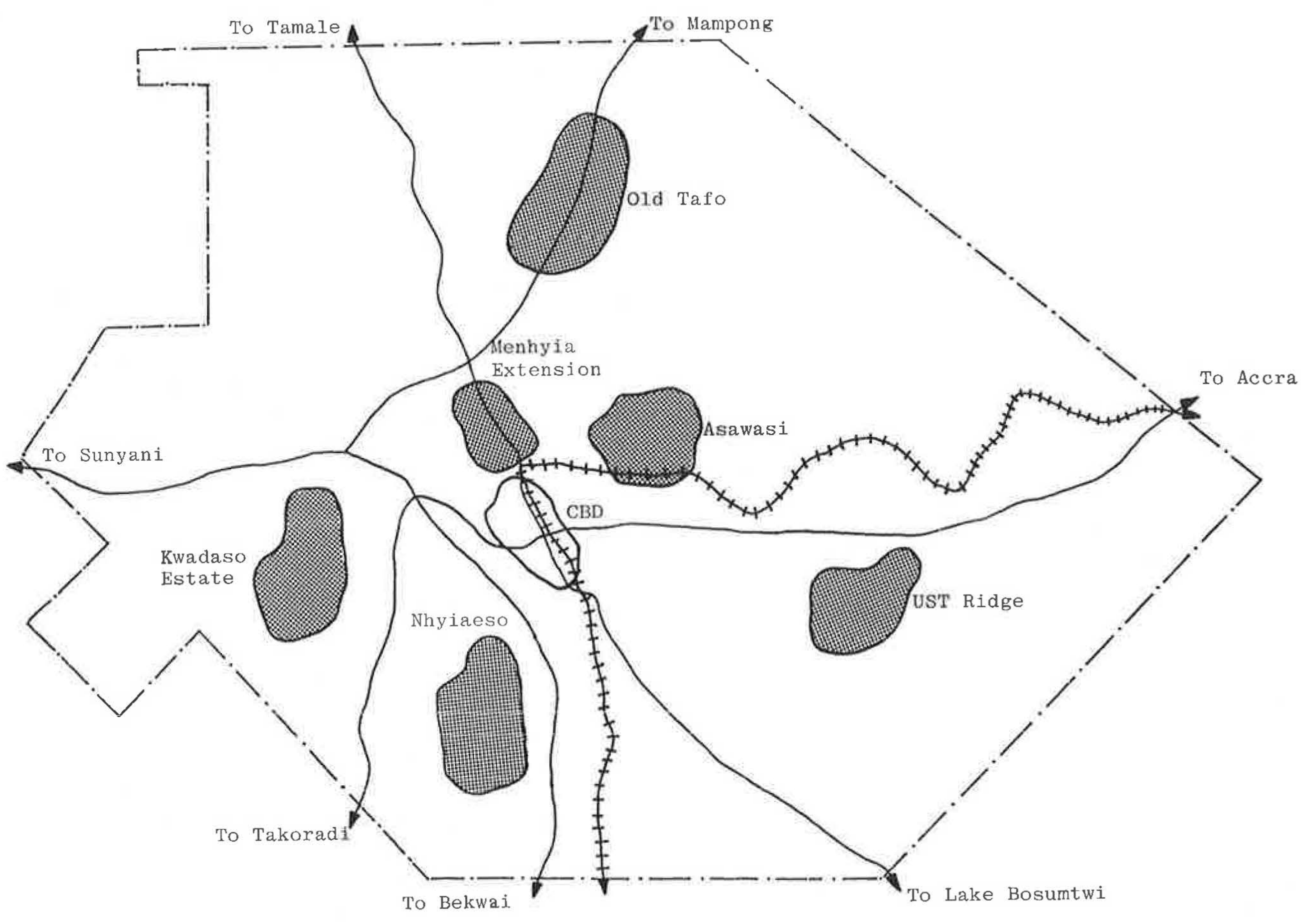

FIGURE 1 Kumasi City Council area showing six selected zones in relation to the CBD.

The selected zones are purely residential areas. As a result, trip attraction rates from other areas to the selected zones were negligible. Most trips are CBD-oriented because all major commercial work and other trip-generating activities are located in the CBD.

Households in the six residential zones were selected for interviews on the basis of the stage sampling technique and minimum standards recommended by Bruton (*15*). Stage sampling is a technique that allows samples to be chosen randomly from a stratified population. The minimum standards recommended by Bruton were modified to account for differences in residential family structure and household densities between Great Britain and Ghana. For instance, a minimum sample of 1:70 or a recommended sample of 1:20 is required for a population between 500,000 and 1,000,000. However, to achieve a greater level of accuracy, a sample of 1:20 was applied to residential areas with high household densities (such as Old Tafo) and a larger sample of 1:10 was applied to zones with smaller household densities and dwelling units (such as Nhyiaeso). In all, 673 households were interviewed from a sample of 188 houses.

In the Ghanaian residential system a number of individual households who may or may not belong to the same family live in the same house. Of the households interviewed, the average household size ranged from 1.31 in U.S.T. Ridge to 5.10 in Old Tafo. The average household size of the total sample was 3.19. However, 72 percent (484) of all households had four or more persons.

Variables and Categories

Trip generation analysis of residential land use employs a number of independent variables that are known to influence trip making, including family income, car ownership, household size, type of dwelling unit, household composition, land use factors, accessibility, and level of public transportation service (*16*). The intensity, character, and location of land use, measured by dwelling units per acre, land area of nonresidential uses, and distance from the CBD, are important in explaining some of the variations in trip making. Similarly, the level of accessibility and transportation service, characterized by route structure, spacing and coverage, congestion levels, and level-of-service quality criteria, are useful explanatory variables.

In applying these variables to trip generation analysis in developing countries, differences between developed and developing countries need to be considered. For example, compared with developing countries, developed countries have more working-parent households and nuclear family living arrangements, greater use of the telephone system, and other communication devices such as fax machines. These characteristics can reduce personalized trips and lessen concentration and centralization of commercial activities, producing multiple trip purpose patterns and more convenient use of the public transportation system for urban trips. Selection, definition, and classification of variables in this study took into account these differences.

Four independent variables were selected on the basis of two factors: (*a*) their expected influence on trip production and attraction rates in developing countries and (*b*) their measurable characteristics as household variables. The selected independent variables were

1. Household income,
2. Household size,
3. Number of cars owned per household, and
4. Number of employed persons per household.

Each variable, together with its expected effects on trip production, is described briefly.

Household income is defined as the average annual disposable income of the head of the household, measured in cedis (₵). In Ghana and in other parts of the developing world where a strong extended family system is practiced, the income of the head of the household is recognized as the only legitimate source of support for the entire family. This contrasts with the nuclear family system in the developed countries where the income of other family members can be counted as part of the household income. In general, income represents the ability of a family to pay for its travel. Thus, trip making is expected to increase as the income of the household increases because the money available to satisfy previously unsatisfied travel demands increases.

Household income was grouped into six categories: low (₵0 to ₵1,200 and ₵1,201 to ₵2,400), medium (₵2,401 to ₵3,600 and ₵3,601 to ₵4,800), and high (₵4,801 to ₵6,000 and more than ₵6,000). The categories represent the socioeconomic status of the household at the time of the survey. For an equivalent household today, each range should be multiplied by six to account for inflation and devaluation of the Ghanaian cedi.

Household size is defined as the number of persons in the household. The number of persons counted in a household includes not only the members of the nuclear family (sons, daughters, etc.) but also other family members (nephews, cousins, nieces, etc.) who reside and eat with the nuclear family members from the same income. Even within the nuclear family structure there could be sons and daughters from different wives of the male head of household because of the polygamous marriage system practiced in some parts of developing countries. This situation usually makes the size of households in developing countries higher than in developed countries that do not practice the extended family system. Larger household size is expected to cause increases in trip making because, with more people in the household, more trips are likely to be made, although the trip purposes may differ.

Household size was grouped into six categories: 1 to 2, 3 to 4, 5 to 6, 7 to 8, 9 to 10, and more than 10. This grouping allowed all types of household sizes in the extended family culture to be covered in the analysis.

Car ownership is measured by the number of automobiles, vans, and lightweight trucks owned by the household and available for use by members. Exclusive use of an automobile by the owner or immediate family members is discouraged by the living arrangements and the extended family system. The ownership of a car, therefore, offers the entire household an opportunity to satisfy its travel needs, especially for motorized trips. The problem is that there is usually only one driver (the owner) for the entire household. Generally, a car-owning household is expected to generate more trips than a non-car-owning household.

The number of cars owned was classified into four groups: zero, one, two, and three or more. This grouping reflects the disparity in affluence in developing countries, which is represented in part by the number of cars owned.

The number of employed persons in the household represents the number of full-time or part-time workers living in the household. Usually, in households of more than one employed person, the workers are self-employed artisans or traders who do not earn steady incomes. Their trip-making behavior is influenced by the nature of their work, and often it is difficult to document such trips. Clearly, the number of workers will be in direct proportion to and is causative of the number of household work trips.

The number of employed persons in the household was grouped into three categories: one, two, and three or more workers.

Definitions

Trip rate analysis classified by purpose and mode of travel was performed for each household variable (i) and category (j) using the following formula:

$$t_{ij}^{p/m} = T_{ij}^{p/m}/H_{ij}$$

where

$t_{ij}^{p/m}$ = trip rate for purpose p or mode of travel m for category j of variable i,
$T_{ij}^{p/m}$ = observed trips for purpose p or mode m for category j of variable i, and
H_{ij} = observed number of households for category j of variable i.

To compute trip rates, households in the survey were grouped into the individual cells represented by the observed trips by purpose or modal group. The trip rate was then the total trips in a cell by purpose or mode of travel divided by the number of households in that cell. The purposes of trip makers were grouped into six categories: work, school, shopping, sports and entertainment, social, and other. Social trips were trips made to visit relatives or to take part in a funeral service. The "other" category covers trips made to transfer from one mode to another, to seek medical attention, or for a business-related purpose such as a trip to the bank. The trip-purpose classification applies to all trips, home-based and non-home-based.

Modes for making the trips were classified into six groups: car, trotro, bus, taxi, motorcycle, and walking. "Trotro" is the name of the paratransit or jitney system in Ghana. Vehicles used as trotros are usually 12- to 20-passenger minibuses or large bedford trucks (sometimes with wooden benches) operating along a fixed or semifixed route by private entrepreneurs (*17*). Walking was included as a mode because in small cities of the developing world many trips are made on foot—residences are often near activity centers and there may be a lack of adequate, efficient, and affordable intracity transportation services.

Two other independent variables were used in the study design and data collection: the distance of the household from the CBD and the average ratable value of residential property. The dependent variable used in the analysis was the average number of trips per household per day.

TRIP RATE ANALYSIS

Trip rates were established for the household variables and were classified according to the purpose of the trip, mode of travel, and total trips reported by each household. This method of classification incorporates different trip distribution and modal split characteristics in the trip generation analysis.

Trip Purpose

The influence of household size, household income, and the number of employed persons per household on trip purpose is shown in Table 1 and Figures 2–4.

It can be observed from Figure 2 and Table 1 that, in general, the household trip rate increased steadily as the size of the household increased. This trend was more pronounced in the work, school, and shopping trips. For example, households of one to two persons made 0.85 and 0.66 work and school trips, respectively. The corresponding trip rates for households of 9 to 10 persons were 2.30 and 1.25 trips. Typically, larger households had greater proportions of children; hence, the practical concavity of the school purpose trip curve in Figure 2. Similarly, sports and entertainment trips tended to increase with household size. In contrast to the general trend, trip rates for social purposes increased with household size only up to seven- to eight-person households and then flattened out. This suggests that an increase in household size beyond the average of seven to eight persons has no significant influence on the rate of social trips made. The reason for this is that trips to satisfy social needs are normally made by adults; because larger households contain higher proportions of children, social trips are not largely represented in such households.

The influence of household income on trip purpose rates as shown in Figure 3 and Table 1 was similar to that of household size except that the variation of increase in trip rates was smaller in higher-income households as compared with that in larger household units. Whereas households with incomes below ₵3,601 enjoyed higher trip rates for all purposes, those with incomes above ₵3,601 had proportionately smaller increases in trip rates. It is interesting to note that shopping, social, and school trips tended to be independent of income for households with income ranges of ₵4,801 to ₵6,000 and more than ₵6,000. There was also no significant influence on work trips. Sports and entertainment trips and those classified as "other" were particularly influenced by household income because there was a steady increase in trip rates for all household income categories. This is because shopping, school, and work trips are basic trips that each household must undertake irrespective of its financial circumstances. However, this is not true for entertainment and sports, social, and "other" trips.

The level of household employment had a similar effect on trip rates (see Table 1 and Figure 4). In general, all trips except shopping trips varied with the number of employed persons in the household. Shopping trip rates decreased from 3.12 for households with two employed persons to 3.07 for households with three or more employed persons. Despite this slight deviation, a significant number of trips were made to satisfy shopping and entertainment needs. The total for

TABLE 1 HOUSEHOLD TRIP RATES BY PURPOSE OF TRAVEL

Household Category		Work	School	Shopping	Social	Sport and Entertainment	Other
Household Size	1 - 2	0.85	0.66	0.69	0.51	0.28	0.14
	3 - 4	0.81	0.78	0.75	0.62	0.42	0.18
	5 - 6	1.73	0.92	0.98	0.78	0.56	0.20
	7 - 8	1.88	0.99	1.17	1.05	0.73	0.22
	9 - 10	2.30	1.25	1.42	1.06	1.01	0.23
	11 +	2.36	1.87	1.69	1.06	1.24	0.36
Household Income (in Cedis)	0 - 1,200	0.79	0.64	0.46	0.34	0.62	0.19
	1,201 - 2,400	0.82	0.80	0.76	0.49	0.78	0.24
	2,401 - 3,600	1.64	0.94	1.32	0.71	0.82	0.30
	3,601 - 4,800	2.10	1.09	1.38	0.67	0.85	0.34
	4,801 - 6,000	2.13	1.00	1.38	1.33	0.89	0.50
	6,000 +	2.16	0.98	1.39	1.31	0.93	0.72
Number Employed In Household	1	2.81	1.52	2.08	0.20	1.45	0.26
	2	3.64	1.58	3.12	0.66	2.68	0.29
	3 +	3.91	2.31	3.07	0.75	2.93	0.50

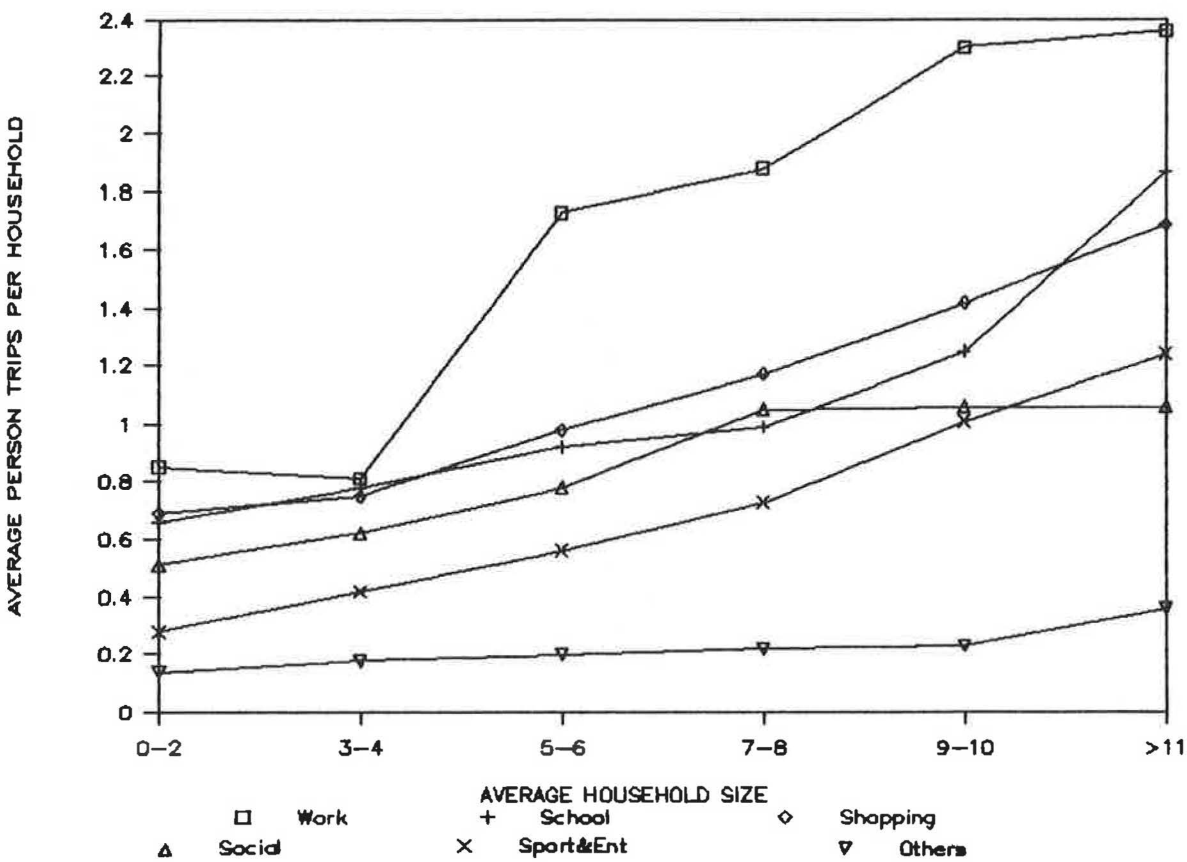

FIGURE 2 Household trip rate by household size and trip purpose.

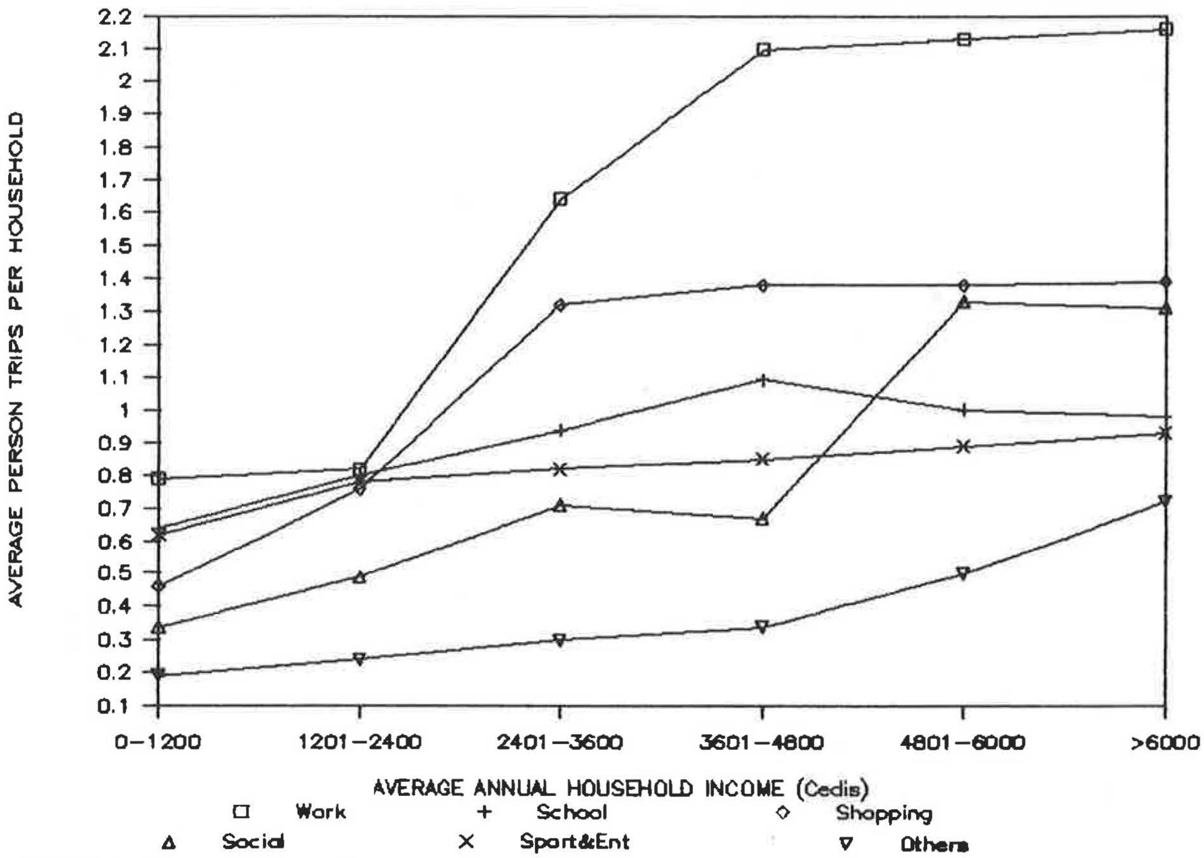

FIGURE 3 **Household trip rate by household income and trip purpose.**

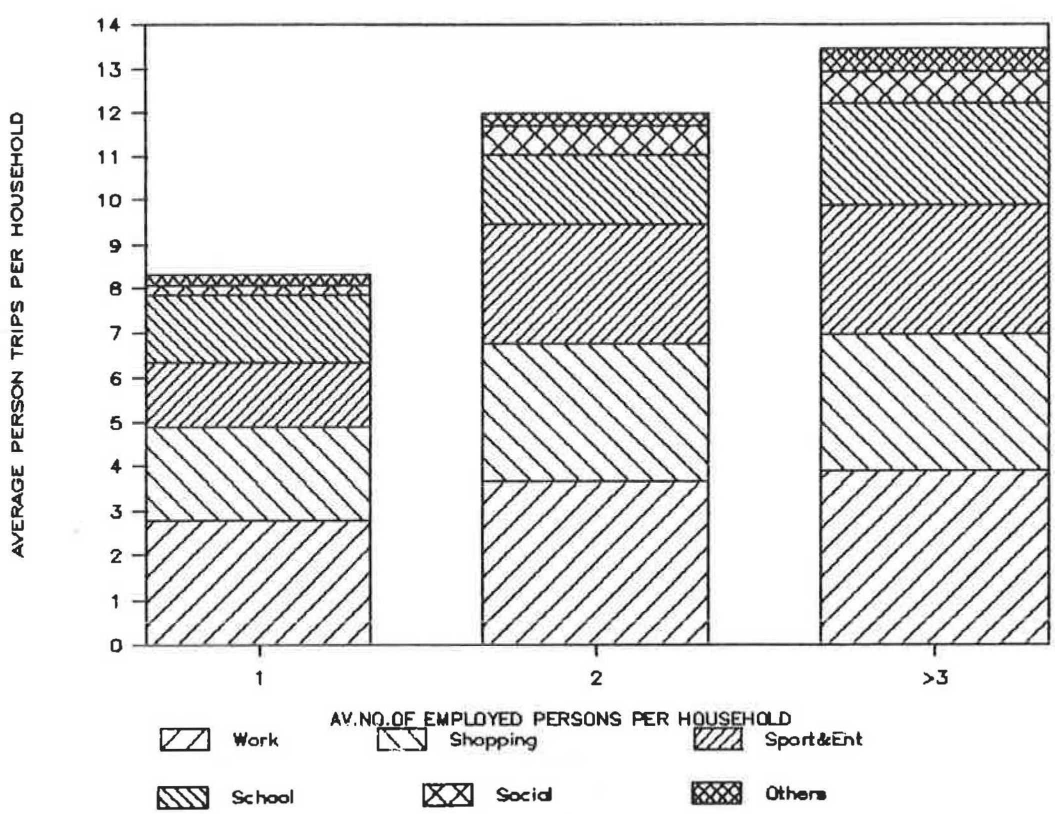

FIGURE 4 **Household trip rate by number of employed persons per household and trip purpose.**

shopping trips was 8.27 and the total for sports and entertainment trips was 7.06. Because incomes earned by employed members of the household, other than the head of the household, are not usually considered to be part of the "legitimate" household income, there is a tendency to use such incomes to satisfy personal wants; hence, the increase in shopping and sports and entertainment trips. Social trips were underrepresented because such trips are linked to trips undertaken to satisfy sporting and entertainment needs. An example is calling on a friend to go to a movie or to a soccer match.

Mode of Travel

The influence of household size, income, and car ownership on mode of travel was analyzed. The results are shown in Table 2 and illustrated in Figures 5–7. Generally, trotro or bus trips and walking trips increased with household size. Trotro trip rates increased steadily from 1.51 to 2.84 trips per household as household size increased from 1 to 2 persons to 11 or more persons. A similar trend is observed in bus trip rates. The majority of households interviewed live in low- and middle-income residential units, so this finding indicates the importance of public transportation services (i.e., trotro and bus) in Kumasi and their impact on the daily travel patterns of the majority of household members. For large households, taxi and car trips tended to decrease. The decline indicates that resources for travel in larger families influenced modal choice in favor of the cheaper and more available modes (trotro, bus, and walking) and against the more expensive ones (taxi and car). Figure 5 shows this trend.

As can be seen from Figure 6, which illustrates the relationship between household income and modal choice, more car trips were made as household income increased. However, trotro trips decreased for households with income levels of ₵2,401 or more. For low-income households earning ₵2,400 or less there was a general increase in household trip rates, but as the level of income increased, trotro and motorcycle trip rates tended to decrease.

Surprisingly, bus trip rates increased and taxi trip rates dropped for households earning more than ₵4,800. In most developing countries, taxis are operated not for individual rides as they are in the developed countries but for shared rides. In fact, in most cities, the number of available and operative taxis is few relative to the number of riders, so riders are willing to share and pay separately for the same taxi ride. In this situation, taxis are operated like jitneys following a fixed or semifixed route and schedule and charging the same fare. The only difference is that taxis usually charge a higher fare and carry a maximum of 5 persons at a time, whereas jitneys carry 10 or more persons depending on the type of chassis. The bus is usually cheaper and sometimes cleaner and more comfortable than the taxi. This may be why higher-income households in Kumasi used the bus more than the taxi system at the time of the survey. Nevertheless, the trend depicted in Figure 6 indicates the relationship existing between household income and mode of travel. The study indicates that households prefer to use the mode of travel charging fares that are consistent with their levels of income.

Figure 7 shows household trip rates stratified according to the number of cars owned. Generally, the proportion of daily trips by car, bus, and taxi varied according to the number of cars owned. Trotro trips were stable with increasing car ownership. Contrary to what may exist in developed countries, car trips were made by households that did not own cars; in

TABLE 2 HOUSEHOLD TRIP RATES BY MODE OF TRAVEL

Household Category		Car	Trotro	Bus	Taxi	Motorcycle	Walk
Household Size	1 - 2	0.64	1.51	0.75	0.36	0.09	0.11
	3 - 4	0.48	1.89	0.81	0.42	0.18	0.24
	5 - 6	1.31	1.59	1.39	1.12	0.37	0.53
	7 - 8	1.42	1.85	1.52	1.16	0.31	0.59
	9 - 10	0.85	2.32	1.65	1.19	0.18	0.49
	11 +	0.22	2.84	1.93	0.58	0.11	0.58
Household Income (in Cedis)	0 - 1,200	0.41	1.57	0.82	0.30	0.03	0.16
	1,201 - 2,400	0.40	1.69	0.96	0.46	0.08	0.17
	2,401 - 3,600	0.59	1.95	1.41	1.23	0.29	0.13
	3,601 - 4,800	1.16	1.78	1.29	1.34	0.32	1.10
	4,801 - 6,000	2.44	1.52	1.30	1.82	0.19	0.15
	6,001 +	2.95	1.34	1.57	1.72	0.02	0.10
Car Ownership	0	2.08	1.23	1.31	0.91	0.39	0.96
	1	2.50	1.39	1.81	1.01	0.82	1.23
	2	2.52	1.36	1.89	1.02	0.86	1.32
	3 +	2.45	1.36	1.91	1.07	0.87	1.45

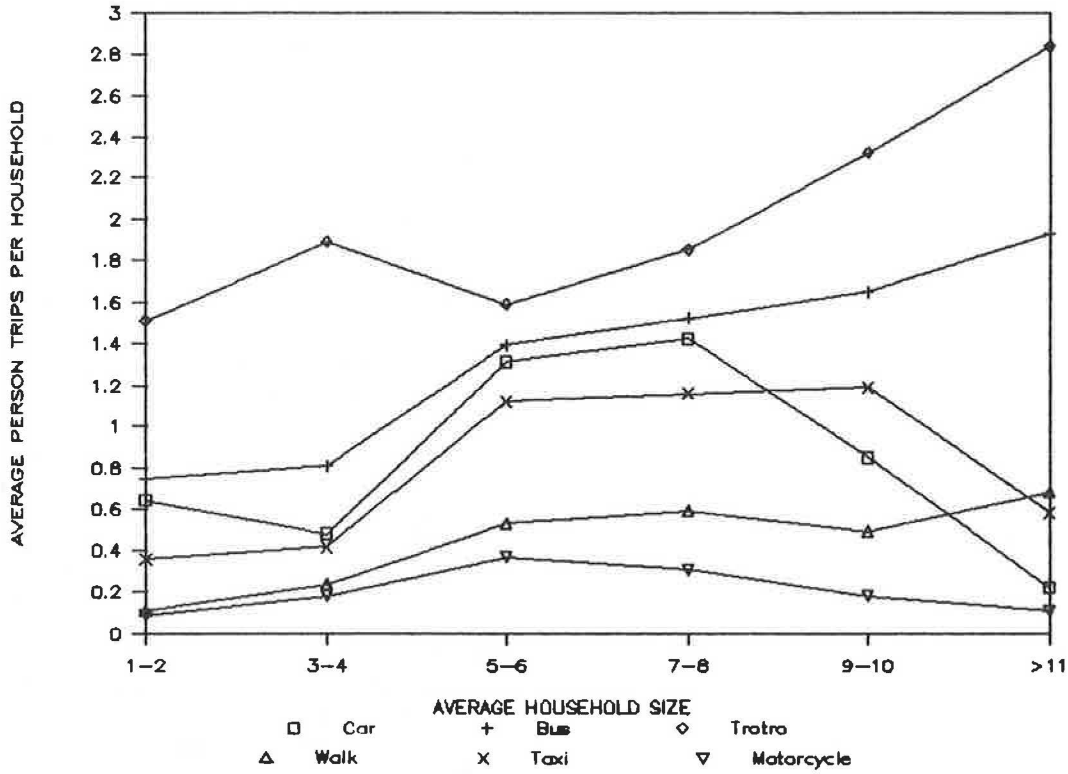

FIGURE 5 Household trip rate by household size and mode of travel.

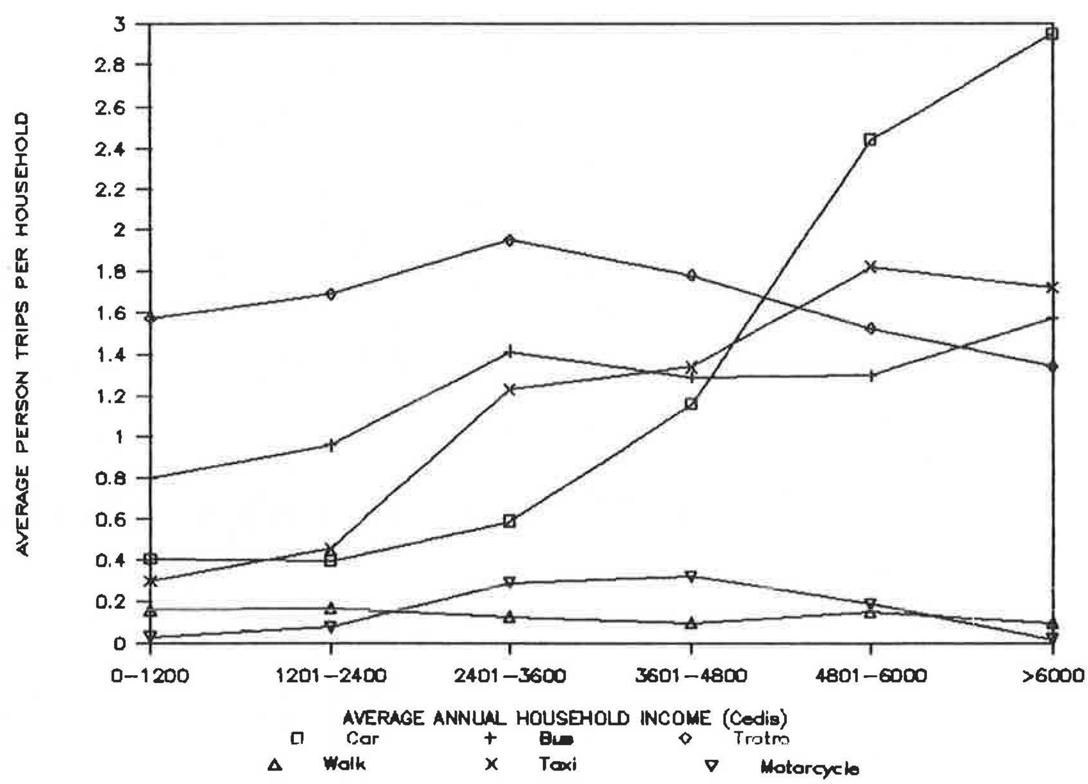

FIGURE 6 Household trip rate by household income and mode of travel.

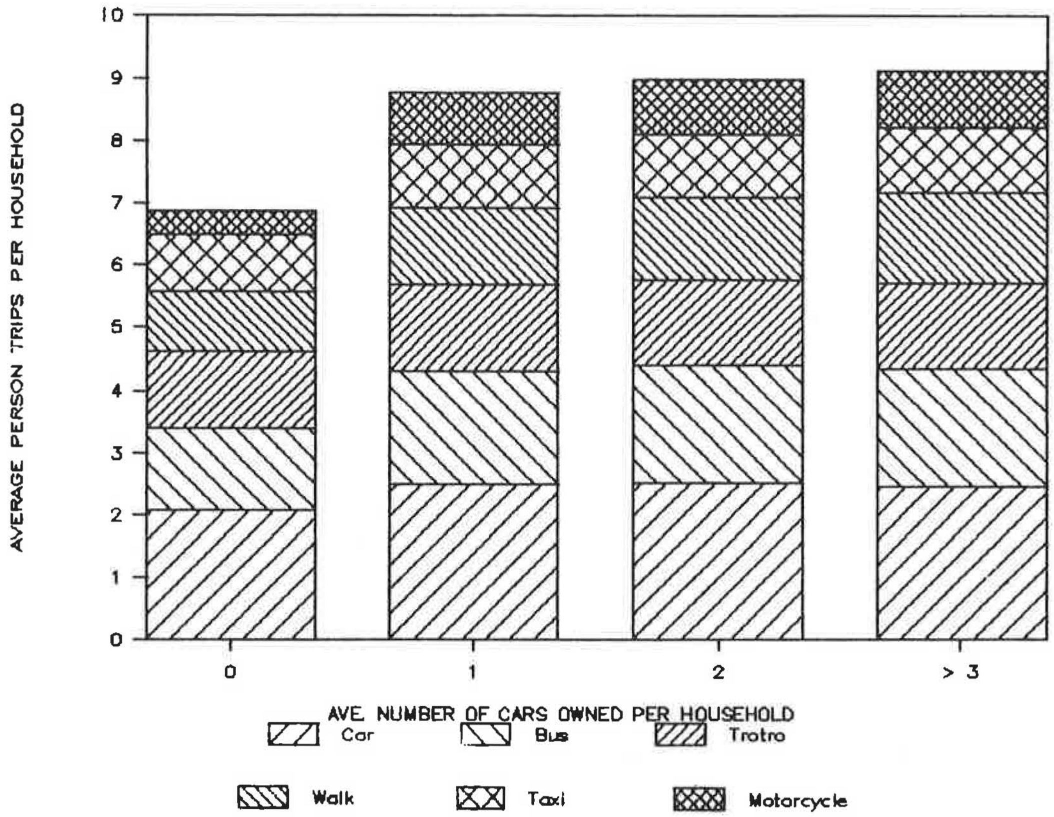

FIGURE 7 Household trip rate by car ownership and mode of travel.

fact, car trips were relatively greater in number than trips made by other modes of travel with the possible exception of walking trips. One possible explanation is that these households have been enjoying the use of cars owned by other households living in the same house. In other words, non-car-owning household members get lifts from car owners living in the same house. Although car-owning households made more car trips, a significant proportion of the members also used bus, trotro, and taxi services.

Total Reported Trips

The total trips reported in this study are summarized under two classifications—trip purpose and mode of travel. Figures 8 and 9 provide these summaries. Figure 8 indicates that the order of importance of trip purpose in the household trip generation process was work, shopping, school, sports and entertainment, social, and other. Work trips contributed 28.8 percent of the total household trip rate, shopping contributed 20 percent, and school trips contributed 17.1 percent. Whereas almost every household made trips to satisfy work and shopping needs every weekday, not all did so for school, social, and sports and entertainment. On the whole, trips were fairly distributed among the various purposes of travel.

Figure 9 indicates that trotro trips accounted for 32 percent of the total household trip rates, followed by bus (23 percent), car (19.5 percent), and taxi trips (17 percent). Walking and motorcycle trips contributed 4.9 and 3.2 percent, respectively. The high percentage of trips made with trotro is partly explained by the availability, convenience, and affordability of trotro service to a majority of the urban population. The choice of mode is influenced not only by ability to pay but also by the purpose of the trip.

CROSS-CLASSIFICATION ANALYSIS

A one-way ANOVA was performed to determine the variables that appear to have the strongest relationships to trip making by purpose and mode of travel. The results were used to determine the best grouping of data for the cross-classification analysis. Details of the runs of the ANOVA by trip purpose are presented in Table 3. From the table, the following conclusions were drawn.

Household size performed better than household income and number of employed persons for all trip purposes except work and sports and entertainment trips. It was a significant variable for all modes of travel. It ranked first in significance across most travel modes.

Household income did not perform satisfactorily across a majority of trip purposes. It was significant for unclassified trips and sports and entertainment trips. Similarly, it was only significant for taxi and bus trips.

Number of employed persons was a consistently significant variable for most trip purpose groups. It was significant for work, shopping, and sports and entertainment trips.

The results of the ANOVA by mode of travel are not provided here because they were used primarily to explore further variations in the analysis of variables. From the analysis, household size was found to be significant across all trips (both

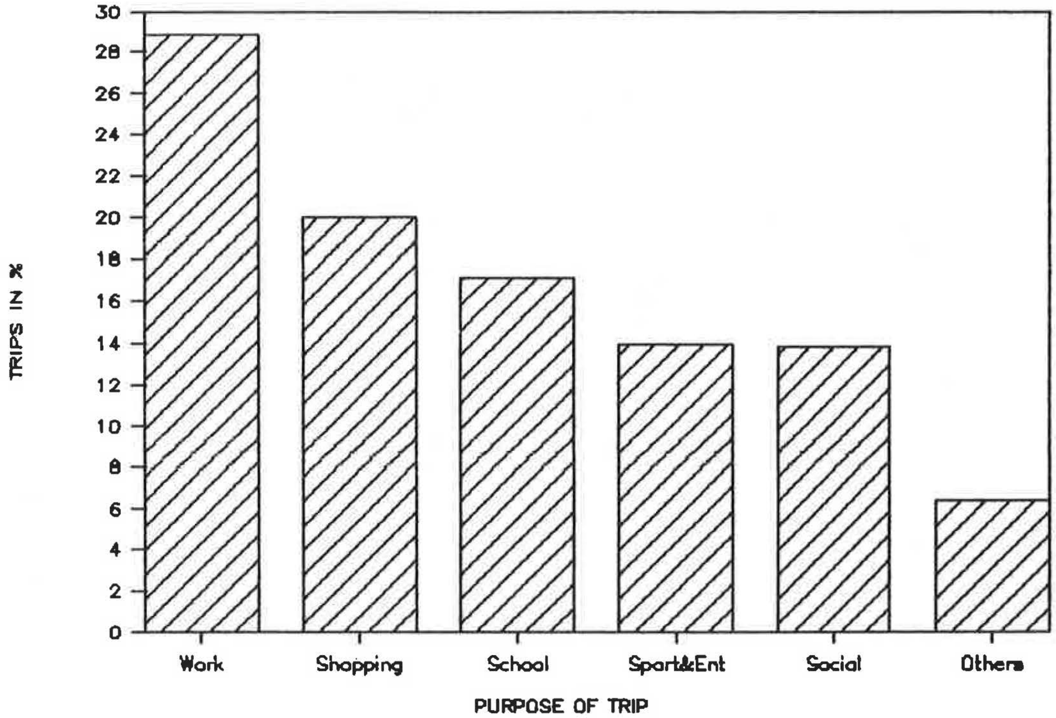

FIGURE 8 **Total reported trips by trip purpose.**

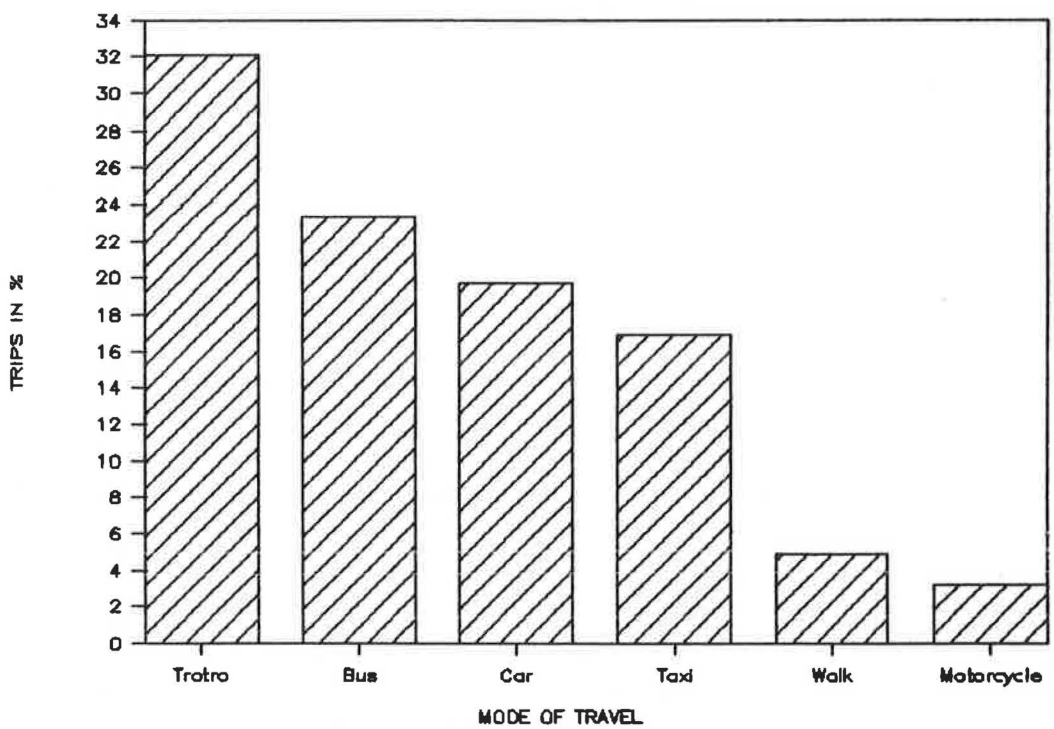

FIGURE 9 **Total reported trips by mode of travel.**

TABLE 3 ANOVA RESULTS BY TRIP PURPOSE

Variable	Categories	Statistic	Purpose of Trip: Work	School	Shopping	Social	Sport and Entertainment	Other
Household Size	6	F	2.1	6.5	6.9	7.5	2.2	3.0
		df						
		SS (Between)	5	5	5	5	5	5
		SS (Within)	668					
		Significance	*b*	*a*	*a*	*a*	*b*	*a*
Household Income	6	F	2.1	1.9	2.0	2.1	3.4	4.7
		df						
		SS (Between)	5	5	5	5	5	5
		SS (Within)	646					
		Significance	*b*	*b*	*b*	*b*	*a*	*a*
Number of Employed Persons	3	F	6.8	2.0	5.2	2.1	5.1	2.2
		df						
		SS (Between)	2	2	2	2	2	2
		SS (Within)	659					
		Significance	*a*	*b*	*a*	*b*	*a*	*b*

F = F score SS = Sum of Squares, and df = degrees of freedom

[a]significance at 95 percent or beyond; [b]not significant at 95 percent or beyond.

motorized and nonmotorized). Household income was less significant than car ownership for all trip modes.

A comparison of the levels of significance of the variables in Table 3 indicates that household size and number of employed persons are the most significant variables for trip making. In addition, car ownership was found significant in the ANOVA analysis by mode of travel. Thus, they were chosen for further trip rate analysis. Household income was not significant compared with the other three variables because most of the trips were made to satisfy school, shopping, and work purposes. It was also not significant when acting simultaneously with car ownership. One reason for the low performance of household income when used simultaneously with car ownership is that, in the Ghanaian culture, owning one or more cars is a strong indicator of the economic status of a household. Other trip generation studies, carried out in a culture in which ownership of a car is not related strongly to level of income, indicate contrasting results (*7,8*). This is because in the latter case a large market for used cars of varying conditions and price ranges usually exists, whereas in the former case primarily new or remodeled automobiles are sold at prices far above the means of the average worker. One way to improve the significance of the household income variable would be to use the total household income or per capita income.

The simple cross-classification rates shown in Tables 4–6 provide a comparative analysis of trip rates of the most significant variables. Table 4 indicates that high trip rates were associated with large households that own two cars and have seven or more members.

There were empty cells for one- or two-member households with two or more cars. The same observation applies to households with three or more employed persons, as indicated in

TABLE 4 SIMPLE CROSS-CLASSIFICATION TRIP RATES: CAR OWNERSHIP VERSUS HOUSEHOLD SIZE

Car Ownership	Household Size: 1-2	3-4	5-6	7-8	9-10	≥ 11
0	0.51	0.61	1.39	1.72	1.59	1.60
1	0.01	0.25	1.95	2.00	1.08	0.98
2	--	0.71	1.89	2.20	2.51	2.39
≥3	--	0.03	1.45	2.40	1.99	1.84

TABLE 5 SIMPLE CROSS-CLASSIFICATION TRIP RATES: NUMBER OF EMPLOYED PERSONS VERSUS HOUSEHOLD SIZE

No. of Employed Persons	Household Size 1-2	3-4	5-6	7-8	9-10	≥ 11
1	0.81	1.21	1.08	0.87	0.45	--
2	0.19	3.18	2.82	3.11	1.71	0.94
≥3	--	--	1.56	2.14	1.12	1.04

TABLE 6 SIMPLE CROSS-CLASSIFICATION TRIP RATES: NUMBER OF EMPLOYED PERSONS VERSUS CAR OWNERSHIP

No. of Employed Persons	Car Ownership 0	1	2	≥ 3
1	1.41	2.10	2.09	0.41
2	1.98	3.11	3.23	2.42
≥3	2.00	2.99	3.04	1.82

Table 5. This indicates that large households (with three to eight members) are a feature of the household structure in Ghana. These households had the highest trip rates. A household size larger than eight did not significantly influence trip frequency, so further evidence is needed before household size groupings above eight can be used.

Table 6 indicates that trip rates were higher in households with one or two workers who own one or two cars. The rates vary from 2.09 to 3.23.

CONCLUSION

Trip generation procedures adopted in developed countries may not apply to developing countries because the factors influencing trip-making behavior of household members are different. The type of variables, how they are defined and structured for trip rate analysis, and the limitations of the analytic technique in relation to socioeconomic values must be examined for study results to be useful.

The analysis indicates that owing to the extended family system in Ghana, household sizes were found to be large and influential in trip generation, although trip rates were not significantly increased for household sizes larger than eight. The prevalent household trips were found to be work, shopping, and school trips. The trip rate for such trips increased with increasing size of household. Similarly, the larger the household, the greater the trotro, bus, and walking trips. The two other significant variables were number of employed persons and car ownership. Trips for sports and entertainment, social, and other reasons such as to transact personal business increased with income. However, when household income was included in the same model with car ownership, its influence on trip making was significantly reduced. As urbanization increases and household travel patterns become more complex, a wider income classification that includes incomes of other household members will be needed in the analysis of nonbasic trips.

Because household size is the strongest determinant of trip making, the influence of the structure (i.e., number of dependent nieces, cousins, etc., working dependents, and number of dependent children and adults) of large household sizes (between four and eight members) on trip frequency must be explored. The usefulness of ANOVA is demonstrated in this kind of analysis, and if a higher level of sophistication is needed, the MCA technique can also be employed.

The results of the earlier version of this study using linear regression corroborate some of the findings of this analysis when the cross-classification method is used. For instance, household income had low significance levels in both cases, and car ownership and the number of employed persons were both found to be significant variables. However, the cross-classification method used here improves significantly the influence of the household size variable, which earlier showed a nonlinear relationship to the average number of trips per household. This method also allows a comparative analysis of selected household variables to be made. Therefore, it holds much promise for future trip generation studies in developing countries.

ACKNOWLEDGMENT

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Zone Modification Method for Systemwide Mass Transit Ridership Forecasting

PETER S. LINDQUIST

One of the major problems encountered in urban mass transit ridership forecasting is the incompatibility between traffic analysis zone (TAZ) boundaries and service areas for mass transit routes. This incompatibility results in limited sensitivity of many TAZ systems to passenger access to transit and often results in erroneous ridership estimates. A method to modify existing TAZ systems to account for passenger access to specific transit routes in systemwide mass transit ridership forecasting is documented. Three problems are identified and addressed in the application of this method to conventional forecasting methods that use the four-step modeling process of trip generation, trip distribution, mode split, and trip assignment. The first problem concerns how the zone system can be modified to account for passenger access but retain both the basic structure of the TAZ system and a TAZ-based trip table through the entire four-step process. The second problem concerns how model data may be efficiently and accurately reformatted in the framework of the modified zone system. The third problem concerns the adaptation of the four-step urban transportation modeling process for execution in the modified zone system—particularly in the stages of mode split and trip assignment.

One of the major problems encountered in urban mass transit ridership forecasting is the incompatibility between traffic analysis zone (TAZ) boundaries and the boundaries of service areas surrounding individual transit routes. Transit service areas are defined here as the catchment areas surrounding transit stops that are bounded by a maximum walking distance to the route.

Incompatible boundary alignment can significantly affect the performance of TAZ-based aggregate forecasting models, particularly in the mode split and trip assignment stages. Traditional TAZ-based forecasting methods are insensitive to the ability of riders to gain access to the transit system. As a result, it is difficult to identify the portion of the trip-making population in a given TAZ that can gain access to the network within the limits of transit service areas.

A number of studies have demonstrated that walking distance to the nearest stop is a critical factor influencing the rate of use of urban bus service. Generally, the rate of use drops sharply in most areas after 100 m (0.06 mi), and in most cases, few riders will walk beyond 600 m (0.36 mi) (*1–3*). In practice, 0.25-mi walking distance is often used as the maximum walking distance or service area radius.

Extending this concept to the route level, each stop along a transit route will form its own service or catchment area defined by the service area radius. With sufficiently close stop spacing, the service areas will converge to form a service corridor centered on the main axis of the route. The width of the corridor may vary among transit systems according to local ridership behavior in using the system.

It has been argued that the service corridor is a more realistic geographic unit of analysis than the TAZ for transit ridership forecasting (*4*), but the boundaries of service corridors rarely coincide with the boundaries of the TAZ system. As a result, serious problems arise in mode split and trip assignment modeling for transit ridership.

Trip assignment is particularly affected by this inconsistency because the proportion of trip makers truly having access to specific routes cannot be identified and loaded onto those routes. For example, difficulties are encountered in large TAZs with dimensions exceeding the service corridor width; the possibility exists for the overassignment of riders to routes that can serve only a portion of any given TAZ. Conventional methods cannot systematically exclude riders from being loaded onto inaccessible routes within a TAZ (*4,5*). This problem is compounded with the use of all-or-nothing trip assignment, which loads all trips to the shortest path between a given TAZ pair. As a result, trips may be overassigned to some routes and underassigned to others. This problem may be alleviated by multiple path trip assignment, but better zone definition on the basis of accessibility is still necessary to ensure that trips are loaded onto the correct routes (*4,6*).

Mode split estimates are difficult to obtain because existing methods cannot easily exclude trip makers located beyond the service area of any transit facility. The inability to isolate inaccessible trip makers will result in an overestimate of potential transit trips within TAZs whose dimensions exceed the given service corridor width.

The zone incompatibility problem has been overcome in single-route forecasting through the service corridor approach (*4,7,8*). However, these methods are limited in their application to systemwide forecasting because the specialized zone systems generated in these cases are focused strictly on the service corridor of the route under study. Each route must generate its own specialized zone system, which will inevitably conflict with the specialized zone system of another route. Therefore, it is difficult to simultaneously forecast ridership among several routes by using a highly specialized zone system focused on each route—particularly in transit networks with extensive circuitry. This problem has been discussed in previous work (*4,5*).

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This paper introduces a method to overcome the zonal incompatibility problem in systemwide ridership forecasting. The method described modifies the TAZ system to account for passenger access to transit and facilitates the execution of the four-step modeling process (i.e., trip generation, trip distribution, mode split, and trip assignment) in the modified zone system. Three critical problems are identified and addressed in meeting these objectives:

1. Construction of a modified zone system that preserves the structure of the TAZ system for execution of the four-step process yet accounts for passenger access to the transit system,
2. Modification of trip data in the TAZ system for execution of the four-step process in the modified zone system, and
3. Minimal modification of the four-step process for execution in the modified zone system.

The procedure described outlines the basic operation of the Zone Program, an experimental microcomputer program developed to modify the TAZ system and to allocate trips to specific routes within zones for use in mode split and trip assignment. This software was developed for execution with the Quick Response System II (QRS-II), a microcomputer-based modeling package for forecasting highway traffic and transit ridership. The software and the procedures described in this paper were developed concurrently with QRS-II.

METHOD

A major objective of the zone modification method is to preserve the TAZ system to the greatest extent possible. By preserving the TAZ system, it is possible to forecast transit ridership together with highway traffic and preserve a TAZ-based trip table. The approach seeks to refine the TAZ system rather than generate a separate, independent zone system as seen in previous single-route ridership models.

This approach makes unnecessary the complete transformation of the zone system, which results in a considerable saving of effort and expense in boundary realignment, data acquisition, and model execution. In addition, a single TAZ system ensures that trip generation and trip distribution need only be executed once for all modes of travel. This is particularly significant in trip distribution. Previous work has demonstrated that trip distribution models are highly sensitive to changes in zone structure (*9–11*).

An overview of the proposed zone modification procedure is presented in the framework of the four-step process in Figure 1. The left side of Figure 1 shows that the four-step process remains intact for both transit and highway traffic forecasting through the mode split stage. The right side of Figure 1 shows a parallel process, in which the TAZ system is modified and trip data are reformatted in the modified zone system for execution of mode split and trip assignment for transit. The zone modification procedure (shown in the right half of Figure 1) can be divided into three parts:

1. Modification of the TAZ system,
2. Identification of the distribution of combined trip productions and attractions (total trip ends) within each TAZ and the allocation of those trip ends to individual segments of zones for execution of mode split and trip assignment, and
3. Execution of modified mode split and trip assignment models for transit in the modified TAZ system.

Each of these parts is treated in detail in the following discussion. The procedure is described sequentially, beginning with the construction of transit zones and ending with the execution of mode split and trip assignment in the modified TAZ system.

Modification of the TAZ System

The TAZ modification procedure has two stages. In the first stage, the service corridor boundaries for every route in the network are simultaneously overlaid. Areas of intersection between corridors are identified and defined as "transit zones." Each transit zone is labeled and a list is made of the transit routes serving that zone.

In the second stage, the transit zone coverage is overlaid on the TAZ boundaries to partition each TAZ into "subzones." A subzone is defined as the area of intersection between a TAZ and a transit zone; each subzone is unique in its access to individual routes or a set of routes in any given TAZ. As a result, each modified TAZ is composed of subzones that represent refined areal units in each TAZ from which to load trips onto the network during mode split and trip assignment.

Figure 2 shows a hypothetical transit network and TAZ system used to illustrate the zone modification procedure. The first stage of zone modification is shown in Figure 3. The steps involved in this stage are summarized as follows:

1. Align corridor boundaries parallel to each transit route in the system and maintain parallel alignment when the main axis of the route changes direction (Figure 3A).
2. Identify areas of intersection between corridors and establish each as a separate and independent transit zone (Figure 3B).
3. Establish each transit zone as a separate areal unit and record the corresponding transit routes serving the zone (Figure 3B).

In this application, Pythagorean or air-line distance is the distance metric defining the service area radius.

This procedure produces a system of zones having irregular shapes and varying sizes; all transit zones in the system are unique in the access to their respective routes. "Sliver polygons," or exceedingly small polygons generated by this procedure, are added to the nearest intact transit zone that shares the largest contiguous boundary. Areas in the study region having no access to any route are labeled accordingly and eliminated from further analysis.

The procedure continues, as shown in Figure 4, in which the transit zone system is overlaid on the TAZ system to partition each TAZ into subzones. Subzones in each TAZ are numbered and a record is kept of individual routes serving each subzone. The intersection of TAZs 3 and 12 (from Figure 2) and the transit zones created in Figure 3B results in TAZ 12 being composed of six subzones and TAZ 3 being composed of five (see Figure 4).

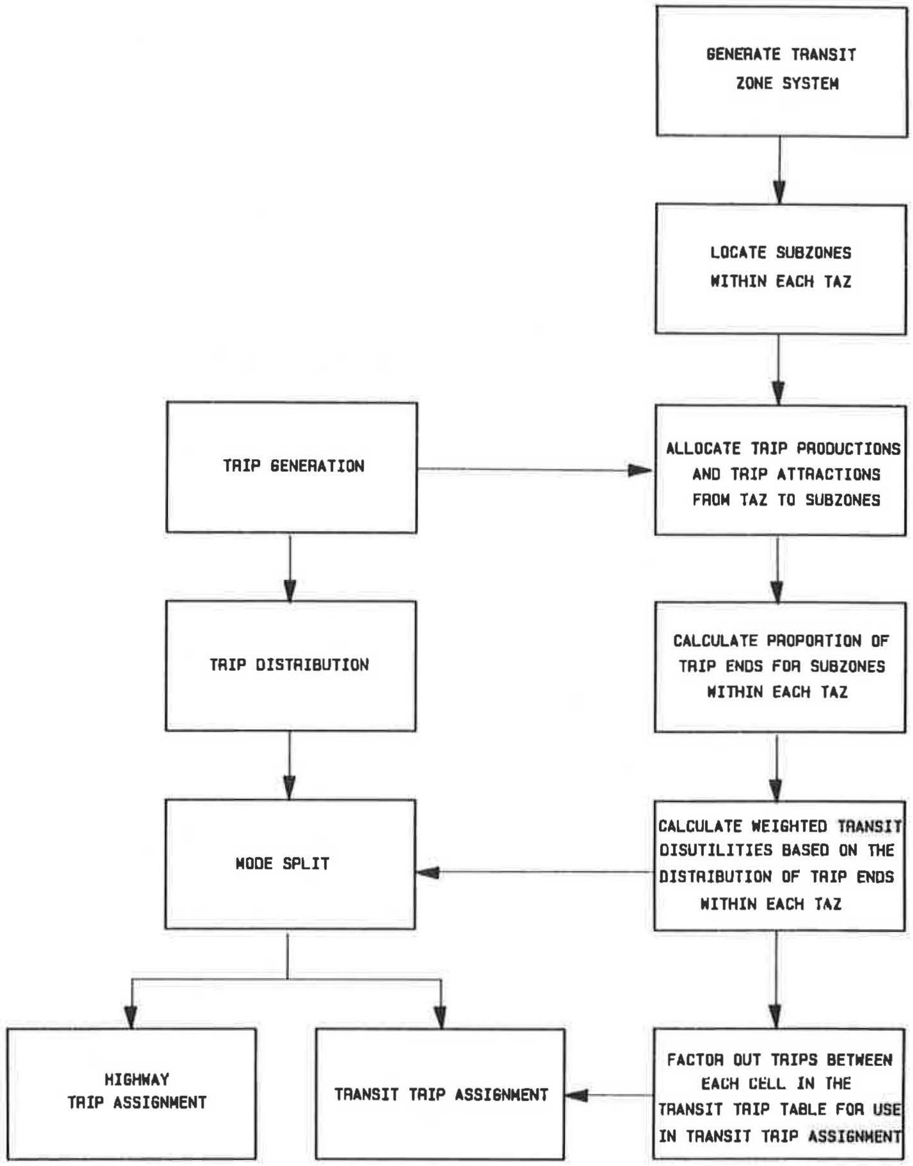

FIGURE 1 Overview of the zone modification method.

Modification of Trip Data in the Modified TAZ System

The system of partitioned TAZs provides the new framework for the execution of mode split and trip assignment. As a result, it is necessary to allocate trip productions and trip attractions to the subzones composing each TAZ before mode split and trip assignment are carried out. This intermediate step is needed to identify the proportion of trip makers having access to specific routes and in turn to restrict trips from being loaded onto routes beyond the service area radius in any given TAZ. In this procedure, trip productions and attractions are summed within each subzone to obtain the "total trip ends," which represent a composite weight of the portion of trips loaded onto specific routes from each subzone on a roundtrip basis for most trip purposes.

For accuracy, the most desirable alternative for allocating total trip ends to individual subzones is to allocate trip generation input data from its raw disaggregated form to each subzone and carry out trip attraction and trip distribution calculations in each subzone before summation of total trip ends. With current geographic information systems, this procedure is possible provided that data are available in disaggregate (or at least minimally aggregated) form. However, the costs of data acquisition, encoding, and analysis may be prohibitive when equipment, funds, personnel, and time are limited.

A more efficient alternative is areal interpolation. Automated volume-preserving areal interpolation methods can be used to transfer area-based data from one set of geographical boundaries to another without the loss of individual observations during transfer. A comprehensive review of areal

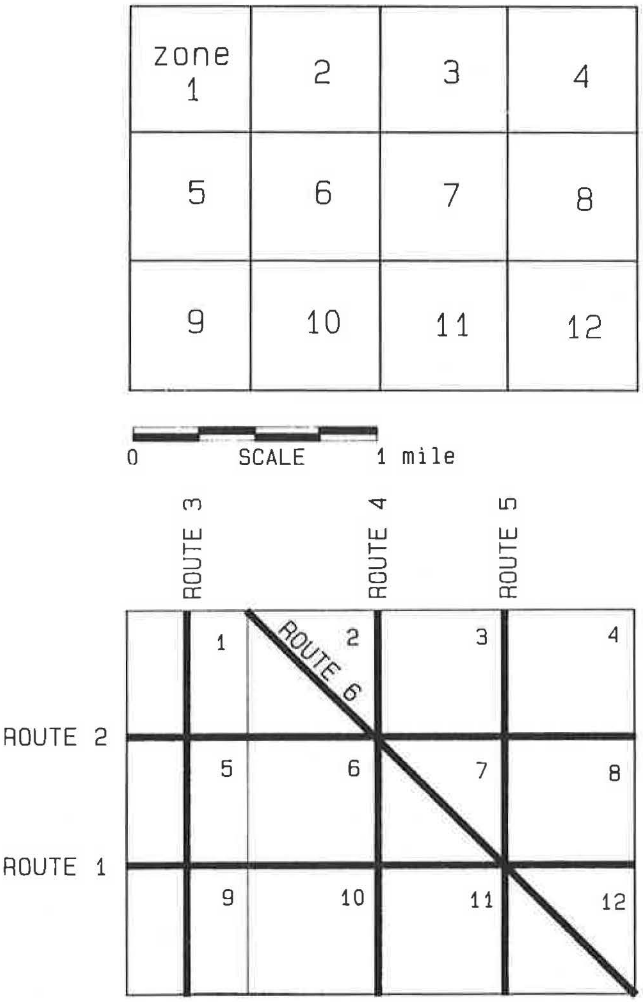

FIGURE 2 Hypothetical study area showing the TAZ boundary alignment (*above*) and the transit route alignment (*below*) consisting of six routes.

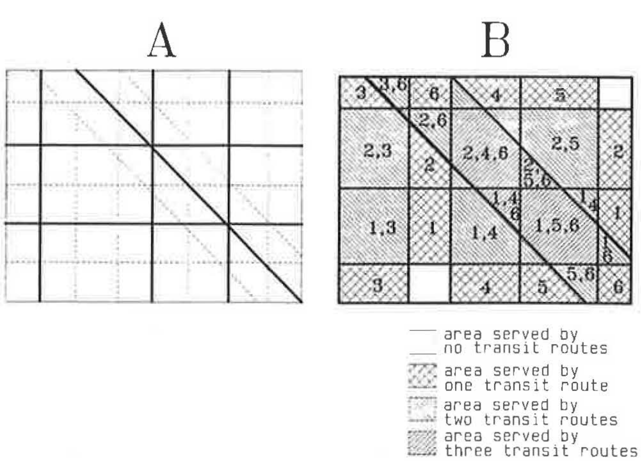

FIGURE 3 Construction of transit zones for network displayed in Figure 2.

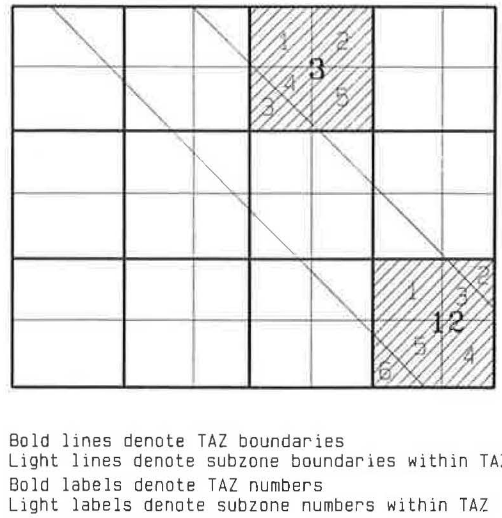

FIGURE 4 The transit zones created in Figure 3 are overlaid on the TAZ system to produce the current zone configuration, in which each TAZ is partitioned into a set of subzones.

interpolation methods is provided in several sources (*5,12–14*). This approach is documented in previous work for single-route ridership forecasting using the service corridor concept (*7,8,15*).

In the method presented here, total trip ends in a given TAZ are allocated to individual subzones on the basis of an areal split, in which the percentage of trip attractions and productions allocated to each subzone is based on the percentage of area occupied by each subzone in its corresponding TAZ.

The procedure is carried out in a two-step process. In the first step, trip productions and attractions are transferred from the original TAZs to the subzones. In the second step, trip productions and attractions are summed within each subzone to obtain the total trip ends.

Trip productions and attractions are transferred separately to account for differences in the spatial distributions of these two components. Trip attractions are generally concentrated at employment centers, shopping centers, schools, and other similar facilities (*8*), whereas trip productions may be more widely dispersed throughout residential areas. Therefore, two separate transfers capture the underlying variation in the distribution of the two components more effectively than a single transfer of the combined components.

The procedure described here is similar to the method described by Hunt et al. (*7,8*). After the subzones have been constructed in the TAZ system, the total area is measured separately for each TAZ and for all subzones in the system. Then the areal fraction (w_{st}) is obtained for each subzone s in its corresponding TAZ t using the following equation:

$$w_{st} = \frac{r_{st}}{R_t} \quad \text{if subzone } s \in \text{TAZ } t \qquad (1)$$

where

w_{st} = the areal fraction of subzone s in TAZ t,

r_{st} = the areal measurement of subzone s in TAZ t, and
R_t = the total areal measurement of TAZ t.

Trip productions and attractions are then allocated to each subzone using the areal fractions obtained in Equation 1. At this point, the number of trip productions and attractions allocated to each subzone is a function of the area occupied by subzone s in TAZ t. First, trip productions are allocated to each subzone using the following equation:

$$p_{st} = p_t\, w_{st} \qquad \text{if subzone } s \in \text{TAZ } t \qquad (2)$$

where p_{st} is the number of trip productions allocated to subzone s in TAZ t and p_t is the total number of trip productions in TAZ t.

The same procedure is carried out for trip attractions allocated to subzone s in TAZ t:

$$a_{st} = A_t\, w_{st} \qquad \text{if subzone } s \in \text{TAZ } t \qquad (3)$$

where a_{st} is the number of trip attractions allocated to subzone s in TAZ t and A_t is the total number of trip attractions in TAZ t.

Trip productions and attractions allocated to subzone s from Equations 2 and 3 are summed to obtain the total trip ends in subzone s. The sum is divided by the total number of productions and attractions in its corresponding TAZ t in order to obtain the weighted fraction of total trip ends (f_{st}) gaining access to the network through the subzone:

$$f_{st} = \frac{(p_{st} + a_{st})}{(p_t + A_t)} \qquad \text{if subzone } s \in \text{TAZ } t \qquad (4)$$

The fraction f_{st} is then used as a weight to allocate the proportion of trips loaded onto the accessible routes serving subzone s.

The method described is limited in its sensitivity to the internal distribution of productions and attractions in any given TAZ. Implicit in the procedure is an assumption that the data are distributed evenly throughout any given TAZ. This is rarely true, particularly for trip attractions. Thus, little information is available concerning the internal distribution of total trip ends within a TAZ, and the probability is high that total trip ends may be misallocated from the TAZ to its corresponding subzones (5).

To overcome this limitation, the procedure is refined by the construction of "vacant polygons" to modify the internal distribution of data in each TAZ. Vacant polygons are used to exclude undeveloped areas, where trip productions and attractions are not expected to occur, from interpolation, thereby reducing the magnitude of interpolation errors. Vacant polygons can be inserted to squeeze the distribution of trip attractions into areas along arterials or at highly localized generators (e.g., shopping centers, employment centers, etc.). As a result, a significant portion of the zone would be excluded from interpolation of trip attractions. For trip productions, vacent polygons are added to eliminate open spaces (e.g., floodplains, freeway corridors, cemeteries, parks, etc.). The use of vacant polygons is illustrated in Figure 5, in which the shaded areas represent areas where the data have been excluded for both productions and attractions.

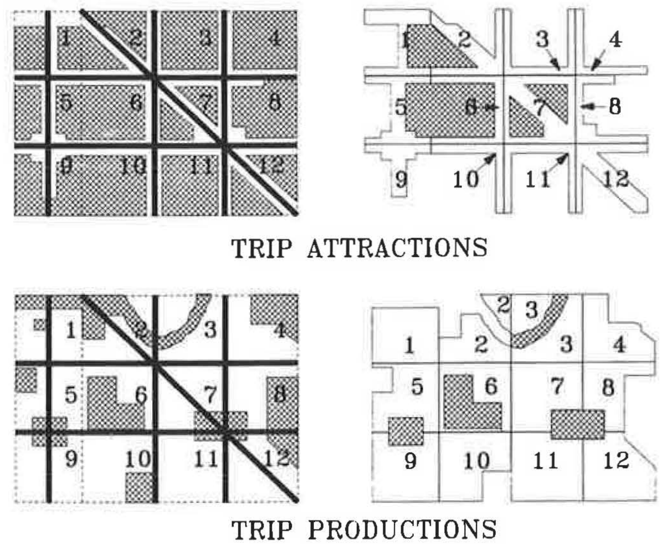

FIGURE 5 The application of vacant polygons to modify the distribution of trip attractions (*top*) and trip productions (*bottom*) within each TAZ.

At this point, an additional step is needed to convert the subzone system from an area-based format to a network-based format for execution of mode split and trip assignment. A single centroid is first placed in each TAZ, following standard modeling methods. Specialized links are then added to connect the centroid to specific routes serving individual subzones. Each specialized link, or subzone centroid connector, represents an individual subzone and links the TAZ centroid to each route serving that specific subzone. This procedure is illustrated in Figure 6. The weighted total trip end fraction calculated for each subzone is then assigned to its corresponding centroid connector to restrict the proportion of trips that may be loaded onto specific routes through the centroid connector.

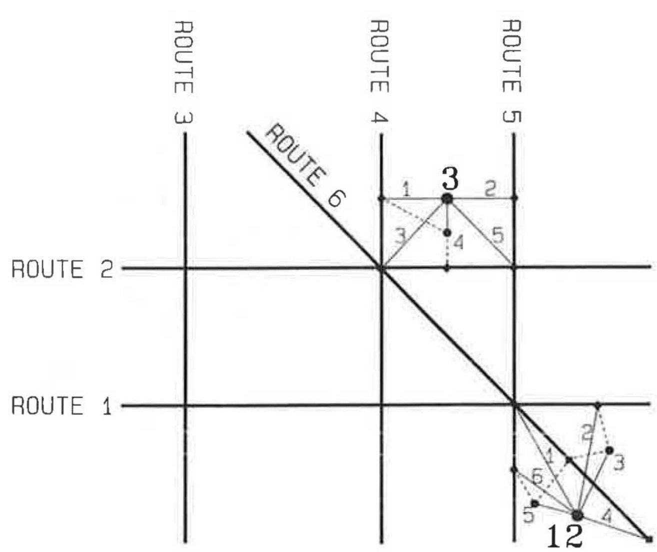

FIGURE 6 The addition of subzone centroid connectors to the transit network. The centroid connector labels correspond to the subzone labels shown in Figure 4.

Model Execution in the Modified TAZ System

One of the principal design objectives of the zone modification procedure is to minimize redundant execution of models in the four-step process yet account for access to transit. The procedure presented here allows execution of the four-step process to take place for all modes up to mode split, as seen in Figure 1. Within this framework, the same TAZ-based trip table produced in a single execution of trip distribution can be applied to all modes. The only changes in the four-step process lie in modifications of the mode split and trip assignment models. These changes must be made to account for increased sensitivity to transit access in the modified zone structure. The modifications described here have been implemented in QRS-II (*16*).

The current approach departs from more conventional applications of the four-step process for transit at the mode split stage. The primary difference is in how the travel disutility between zone pairs is calculated for comparison with other modes. A multinomial logit-based mode split model was adopted for this approach (*16*). This model uses a "weighted disutility," or weighted average of travel disutilities obtained between all subzones for each TAZ pair in the trip table. The modification replaces more conventional approaches, which use a single representative travel disutility from the centroid of each TAZ. Disutilities are weighted on the basis of the weighted total trip end fractions of trips calculated for each subzone using Equation 4. As a result, subzone pairs that support a higher proportion of trips between a given TAZ pair will contribute more to the overall travel disutility than other subzone pairs. In addition, areas in each TAZ that have no access to transit will not contribute at all to the transit disutility. This procedure is documented in detail elsewhere (*16*).

The transit trip table produced by the mode split model is entered into the transit trip assignment model in the final stage of the four-step process. Under this approach, transit trips are loaded onto the network on a subzone-to-subzone basis, rather than on a TAZ-to-TAZ basis. The TAZ-based trip table is expanded to account for subzone-based trips by using the weighted total trip end fractions obtained in Equation 4. Trips are loaded separately onto the network between all possible subzone pairs within their corresponding TAZ pairs, resulting in an expansion of trip loadings between all TAZ pairs in the system. Referring to Figure 6, the cell in the trip table originating in TAZ 3 and ending in TAZ 12 could be expanded up to 30 times as these trips are separately loaded onto the network between each possible subzone pair within the larger TAZ pair.

This procedure is described in the following equation, in which the weighted total trip end fractions (*f*) for each subzone are multiplied by the total number of trips between the TAZ pair to obtain the number of trips loaded onto the network between each subzone pair. For all possible subzone pairs in the trip table that begin at TAZ *b* and end at TAZ *e*, the number of trips loaded onto the network from the origin subzone *k* in TAZ *b* to the destination subzone *m* in TAZ *e* is obtained as follows:

$$t_{km} = T_{be} f_{bk} f_{em} \quad \text{if subzone } k \in \text{TAZ } b \text{ and subzone } m \in \text{TAZ } e \qquad (5)$$

where t_{km} is the number of trips assigned to the network between subzone *k* and subzone *m* and T_{be} is the number of trips distributed between TAZ *b* and TAZ *e* from the transit trip table.

The TAZ-based trip table is maintained because trips are still assigned between TAZ centroids. However, trips are loaded onto the transit network through centroid connectors *k* and *m* at both ends of the TAZ pair. The number of trips permitted to travel through each centroid connector is restricted by the weighted trip end fraction associated with its corresponding subzone.

The modifications of mode split and trip assignment models described above are found in QRS-II. In practice, QRS-II expands the trip table from a centroid-to-centroid basis by assigning trips to the network on a centroid connector–to–centroid connector basis. Further details concerning the implementation of these modifications are documented elsewhere (*16,17*).

An additional feature of the QRS-II is a stochastic multipath trip assignment algorithm for transit. The algorithm, termed Newdial, assigns riders among all reasonable routes serving the subzone pair, thereby accounting for route choice among trip makers. The Newdial model is a variation of Dial's original multinomial logit-based multipath trip assignment algorithm (*18*); it incorporates transfer penalties, access times, wait times, fares, and other measures of disutility in calculating travel times along each path between a given origin and destination. A complete description of the model is provided by Horowitz (*17*).

Route choice and its behavioral implications must be considered in a systemwide modeling approach that accounts for user access to specific routes. This is particularly true when service corridors overlap, and the subzones created from the overlap may be served by a set of routes that offer a variety of choices to potential riders (*4*). It follows that trips loaded onto the network should be assigned to any reasonable path between any given origin and destination. Under conventional all-or-nothing trip assignment methods, route choice is based entirely on the shortest path between any given TAZ pair, because it is assumed that potential riders will always select the shortest path between an origin and destination. However, riders may not always select the optimal route because of limited information concerning travel disutility (*19*). In other cases, riders having a choice between two routes will board the first bus to reach the stop regardless of the service characteristics of the route (*20*). In still other cases, travelers may perceive one route for reasons of safety, convenience, intervening opportunities, or other similar route characteristics.

Despite the behavioral advantages of multipath trip assignment, a major criticism of models incorporating Dial's method for multipath trip assignment is the Axiom of Irrelevant Alternatives. It has been shown that in many applications the model will assign an inordinate number of trips to relatively insignificant links lying within efficient paths and that the majority of trips will be assigned to denser parts of the network—particularly in cases where different paths may use the same links (*21,22*). As a result, the behavior displayed in the model may not represent the behavior of urban travelers.

For highway networks this shortcoming is serious. However, it has been effectively argued that this problem is not as critical in transit networks (*5,17*). Transit networks are rarely as dense or as interconnected as street networks, and the reluctance of passengers to transfer between routes will place limits on the number of available efficient path choices.

The refinements in zone definition enable access to individual routes to be the most important criterion in trip assignment. In addition, multipath trip assignment allows route choice to be considered in the loading of trips between zones having access to more than one route. With travel alternatives more clearly defined, behavior is accounted for in a more realistic manner than in conventional methods. Individual choice between routes may now be based on route service characteristics such as headways, travel times, and transfers, rather than on the simple assumption that riders will always choose the shortest path (*17*).

IMPLEMENTATION AND EXECUTION OF THE ZONE MODIFICATION METHOD

The zone modification method described in this paper was developed for execution with QRS-II, a microcomputer-based travel demand model that forecasts both highway traffic and systemwide mass transit ridership.

The zone modification method was originally executed using the Zone Program, a highly specialized experimental microcomputer package that calculates area-based weighted trip end fractions for TAZs. The program specifications and descriptions of algorithms in the program are detailed in a separate report (*5*). Input to the program consists of an encoded QRS-II transit network, the coordinates of the TAZ boundaries (registered to the coordinates of the transit network), and the corridor width specification for construction of transit zones. The Zone Program carries out the zone modification procedures, allocates trip productions and attractions to subzones within TAZs, and calculates the weighted trip end fractions, which are output to a report file. The weighted trip end fractions are input into the QRS-II transit network as "weighted area splits" (*16*).

Additional work has shown that the use of geographic information systems (GISs) may be a feasible alternative to the Zone Program for TAZ modification. A vector-based GIS can carry out TAZ modification with line buffer polygon generation and polygon overlay procedures. With some additional effort, trip productions and attractions can be allocated among subzones within partitioned TAZs, and in turn the weighted trip end fractions can be calculated and output to a report file to be used for encoding the weighted area splits in the QRS-II transit network.

Preliminary tests using these procedures on the Wausau Area Transit System, a small urban bus network in Wisconsin, indicated a significant decrease in transit ridership estimation errors compared with conventional methods that use intact TAZ systems and all-or-nothing trip assignment. With minimal modifications to model parameters, Lindquist (*5*) reported systemwide root-mean-square (RMS) error rates of 12 percent using the zone modification system compared with systemwide RMS error rates exceeding 43 percent using conventional methods over a wide range of parameter settings. Test results also indicated that multipath trip assignment is more effective in reducing ridership estimation errors than is all-or-nothing assignment in a modified zone system. However, multipath trip assignment errors increased drastically when the TAZ system was left intact. In contrast, zone modification did little to improve ridership estimates for all-or-nothing assignment (*5*).

CONCLUSIONS

The zone modification method presented in this paper can be described as a way to refine the TAZ system to both remove potential trip makers located outside of transit service areas and more clearly identify the portion of trip makers who truly have access to specific routes serving each TAZ. The preservation of the TAZ-based trip table to minimize redundant execution of the four-step process differentiates this approach from previous approaches.

The zone system's improved sensitivity to passenger access permits modifications of mode split and trip assignment models that were not possible before. Under this approach, mode split estimates are refined by removing potential passengers who do not have access to the transit network. Mode split estimates are further refined by incorporating a weighted disutility calculated for all intersubzone trips between a given TAZ pair.

Trip assignment is refined by restricting the proportion of trip makers in a TAZ that may be loaded onto specific routes serving that TAZ; trip makers outside individual route service corridors are prevented from being loaded onto those routes. Route choice in overlapping service corridors is addressed by using multipath trip assignment.

Three major problems were overcome in the development of this procedure: (*a*) modification of the TAZ system to account for passenger access to the network, (*b*) identification of the distribution of total trip ends in each TAZ and allocation of total trip ends to individual subzones in each TAZ, and (*c*) modification of the four-step modeling process in the modified zone system.

The problem of TAZ modification is addressed by refining the TAZ system without radically realigning the zonal boundaries. A TAZ-based trip table can be maintained throughout the four-step process without losing sensitivity to passenger access. As a result, redundant model execution among modes as seen in previous single-route approaches can be avoided. Modifications of the four-step process lie in modification of mode split and trip assignment models—not in the separate execution of the four-step process among modes.

The success of initial tests suggests that further study in the application of the zone modification procedure to systemwide mass transit ridership forecasting is warranted. First, tests of the method over a wide range of urban bus networks are needed to provide insight into the reliability of the method for a wide range of applications. This is particularly important in large urban systems with a high proportion of crosstown routes that would produce a complex web of overlapping service corridors.

Modes other than local bus service should also be investigated for adaptability to the service area concept. Such analyses would be more complex because the service area is not simply defined through walking distance. Access to modes such as express bus or rail can be gained through other modes of travel. Service areas would necessarily include the networks of these other modes. Such an approach introduces a number of problems not considered in previous studies using this method.

An alternative to areal interpolation should also be explored for allocation of total trip ends among subzones. Although areal interpolation has been an efficient technique in the allocation of total trip ends to individual subzones of each TAZ, previous studies have indicated that accuracy may be a major issue in its implementation. However, areal interpolation can be an acceptable technique to allocate total trip ends to subzones, particularly in sketch planning applications where efficiency is desired.

An alternative to this technique may be to incorporate GISs into transportation planning. As geographic data sources become more readily available for a wider variety of applications, raw trip generation data may be stored in a GIS at a relatively low level of aggregation; when necessary, the data can be conveniently assembled in subzones for calculation of total trip ends in the modified zone system.

Initial tests have shown that the TAZ modification procedure is an effective method for reducing errors in systemwide ridership forecasting on urban bus networks. The zone modification method presented in this paper thus provides an effective alternative to conventional methods in systemwide mass transit ridership forecasting. It provides a strong argument for discarding more-conventional approaches to transit ridership forecasting. The transit planner should not be required to settle for a suboptimal zone system when alternative methods are available that can quickly generate a zone system that considers passenger access.

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Television Media Campaigns To Encourage Changes in Urban Travel Behavior: A Case Study

DAVID T. HARTGEN AND MARK A. CASEY

The University of North Carolina at Charlotte and WSOC-TV Channel 9 developed and implemented a TV-based traffic mitigation campaign for the Charlotte metropolitan region. The development process, the methods used in the campaign to encourage shifts in transportation behavior, and preliminary results from the campaign are described. Although the short-term shifts in behavior resulting from such efforts are likely to be small, longer-term impacts may be more substantial. It is concluded that cooperative ventures between the media and government can be an important component of transportation mitigation strategies in metropolitan regions and should be considered as important elements of such plans.

As metropolitan regions of the United States continue to grow, they are often confronted with problems involving transportation. The problems concern urban congestion, improvements in transit service, airport access, highway and bridge repairs, specialized services for the elderly and handicapped, air pollution, energy consumption, spreading development patterns (particularly in suburbs), and access to downtown. The Charlotte, North Carolina, metropolitan region is no exception. It has experienced these and other transportation-related problems during the last decade, as the pace of growth in the Southeast generally and the Charlotte region in particular has continued to accelerate. Numerous polls indicate that transportation problems are important to Charlotte citizens, and the recent change in city administration is attributed partially to a campaign focusing on increased need for expenditures for improved transportation systems.

Central to these arguments is the belief that consumers respond favorably to new services, but that is often not the case. Transportation officials are often frustrated by the resistance of consumers to exhortations to use transit and carpooling. In the Charlotte metropolitan region, transit usage is about 1 percent of regional work travel and less than 8 percent of downtown work travel. Single-occupant automobile use is high, averaging around 87 percent, and carpooling and park-and-ride services are not heavily patronized. The problem is compounded by the difficulty of obtaining significant federal capital funds for transit systems because the region is below UMTA thresholds for rapid transit investment. In this environment, frustrations of public officials, the public at large, the private sector, and the media can and often do rise to shrill levels.

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The media have traditionally reported progress on or deterioration of transportation systems. The media often are content to report the facts, occasionally point fingers at government officials and others perceived to be slow or incompetent, or join in the campaign for more money from the state capital. Whereas all these activities can occasionally work, they generally do not improve congestion.

But the media can also participate cooperatively with government and the private sector in developing and implementing solutions for communities. The thought of the media going beyond suggesting solutions to providing solutions is revolutionary. The traditional role of the media includes informing through standard reporting, finger pointing through interpretive reporting, and suggestion through editorial page and on-air commentary. In the case study described, the media left that traditional role, identified an aspect of a problem that viewers may not have considered, then offered personalized answers through a traditional media adversary: government.

The attitude described above is changing with the change in the nature of television news that has become evident during the past 3 years. Fragmentation of audiences due to cable, VCR, and remote control pushes television news operations beyond traditional journalistic duties, and the media's role as government adversary softens with the addition of the role as public servant. In short, television news must now do much more than inform. It must offer solutions to the problems identified in news reports and offer those solutions on a personal basis. Audience fragmentation, which is documented in research conducted by the major media consulting agencies, network television, and the major ratings services, enhances the need for this change. There isn't less local news, but more competition in news time periods for audiences. The competition is as varied as the channels in a cable system, games available through Nintendo and Atari, and movies for rent for the VCR. If news broadcasts are to maintain audiences in this ultracompetitive environment, traditional "facts and nothing but the facts" presentations must be altered. Some in the media may perceive this as a co-opting process in which the media's agenda is diluted by government and its goals, but another viewpoint is that the media are also community citizens with a public responsibility to help citizens of the region in their daily lives.

In this spirit the University of North Carolina at Charlotte (UNCC), in cooperation with WSOC, Channel 9, embarked on an effort to change urban commuting and travel behavior patterns. The reasoning behind the approach stems from their joint view that existing transportation systems, though not completely adequate, can better serve commuting demands if those demands are bent to fit the system's capabilities. Commuters and citizens need to understand the cumulative effect of their individual behaviors on highway congestion generally, the importance of government investment and the balance between the capabilities of government and the capabilities of private citizens, and the cumulative effect of individual actions concerning transportation and land use on society. A "can-do" media campaign that focuses on helping individuals to cope with problems, reduce them, and understand their source is an approach that has had less attention, but that, it is believed, has potential.

A "media campaign" in the sense of advertising or public affairs is not what is meant. The WSOC-TV news operation, a for-profit entity, viewed the campaign as an opportunity to educate, provide a public service, and dominate traffic and highway reporting in the Charlotte market. A media campaign in the traditional sense would include advertising built around a central theme like "take the bus."

WSOC-TV and UNCC's purpose was to allow travelers to see that they are part of the problem and that solutions lie in each person's behavior. This is a concept not previously presented in this market. The series offered advice, the opportunity for direct government contact, and a way out of the traffic jam.

Technical literature on how the media can encourage changes in transportation behavior is sparse. Seat belt campaigns and anti–drunk-driving campaigns have appeared in news broadcasts, but only in recent years have they become interactive or featured partnerships with government agencies. Though the authors did find material on similar subjects (e.g., use of the media to improve community health, use of TV to monitor traffic, and use of TV to avoid travel), no references were found on the specific topics. The subject is essentially unresearched.

More information is available on the theory of altruistic efforts. For instance, Macauley and Berkowitz (*1*) describe a number of theories of altruism—helping behavior—on the basis that altruism is "behavior carried out to benefit another without anticipation of rewards from external sources." However, the many studies reported by Macauley and Berkowitz suggest the presence of strong personal, situational, and motivational components (such as alleviation of guilt or assumption of risk or adventure) in many altruistic behaviors. Schwartz's more cynical model (*2*) suggests an involvement process building on perceived gains to the players. In the case described here, the TV station, UNCC, and the government stand to gain by cooperation in the campaign, so pure altruism models do not apply. The campaign is better thought of as a mutually beneficial activity with a socially positive goal (reducing traffic congestion) rather than as an altruistic effort.

The process by which UNCC and WSOC-TV developed a campaign to change travel behavior is described. The focus is on the processes used in the campaign, the steps undertaken, and preliminary results.

OBJECTIVES

Discussions between WSOC and UNCC to establish reasonable objectives began in spring 1989. It was recognized that huge changes in travel behavior were not likely to be achieved. In addition, it was recognized that the budget and time frame would be limited. Therefore, the following goals were established:

1. Inform citizens about transportation problems in clear terms.
2. Help citizens cope with transportation issues by suggesting alternative behaviors.
3. Improve Charlotte's quality of life.
4. Preempt the traffic issue for Channel 9 and its affiliates; become *the* traffic station for Charlotte.

The team recognized that the easy stories—finger pointing, construction plans, and so forth—were already done; what was needed was a concerted effort to make things better. This meant understanding why people traveled, the choices available, and the costs to society when many people travel at the same time. The following fundamental ideas were to be developed:

- Mobility: Everyone wants to be able to travel at any time because mobility allows people to engage in activities that are associated with a high quality of life. But when everyone travels extensively, traffic congestion reduces the quality of life.
- Choices: Society provides many options for living patterns, modes of travel, and destinations. It was decided to let marketplace competition increase or reduce options.
- Balance: Travel time is balanced with activity time; travel must be worth less than the activity it permits.

In short, the value of mobility is high, but its negative effect on society can be significant.

Several major activities to be undertaken were identified:

- A public opinion survey on traffic issues intended to support ongoing stories;
- A week-long series of reports termed the "Bumper-to-Bumper Blues" series, each report to be 3½ min in length and to run in the hour-long evening news time slot;
- Cooperative assistance by local governments in solving personal transportation problems and encouraging ride-sharing and transit usage; and
- A follow-up plan focusing on issues that would continue into the spring and summer.

The team recognized that all the possible material could not be covered in a week-long series but that over time more material could be introduced. To compress the time frame and make the project manageable, the team focused on six elements:

1. Causes of traffic congestion,
2. Severity of traffic congestion,
3. Mobility—what it is and why people want it,
4. Choices for commuters,
5. Social costs and health effects, and
6. The future—new technology.

CAMPAIGN PLANNING

The idea for a sweep series on traffic congestion entered in-station discussions after a short study indicated that many summer road projects were scheduled for major thoroughfares. Traffic congestion, compounded by road construction, would stress commuters in just a few months. However, most of the sweeps series—groups of reports with high-interest subject matter designed to increase viewership when ratings are compiled—were already in production, and most newsroom personnel already were assigned to prepare sweeps or had other assignments.

Therefore, the traffic reporting segments had to operate with limited manpower and budget, yet generate a level of viewer interest that would increase ratings. Subject matter was to emphasize the innovative in explaining the traffic situation, and more important, offer solutions to the drivers.

The focus on solutions required reporters who regularly offer advice and options to viewers or who have more credibility than the average beat reporter. The news managers decided to assign five reporters to work the five separate segments of the story. Each was either a specialist or a high-profile reporter. Three specialists were chosen in the health, consumer, and technology areas. Two reporters who often anchor on weekends and in substitute roles took two of the reports.

Four reporters each took one of the six elements, and a fifth reporter took two for an overview segment. A producer with a specialization in technology took management control of the project. The production schedule was compressed, running just 9 days and finishing 1 week before air date.

News managers decided to place the series in the first week of the month-long sweeps period. That "week" actually began at midweek. However, five parts, running Monday through Friday, allowed advertising to be developed and put in place the weekend before the series began; it was hoped that the advertising would build momentum and viewership into the first 2 or 3 days of the sweeps period.

The advertising campaign was to emphasize the expertise of the reporters in offering solutions to the problems of the Charlotte area commuter—the health specialist reporting health information, the consumer specialist reporting consumer information, the high-profile reporter giving the viewer information about traffic congestion that the viewer probably did not know, and offering a way out of jams at the same time. High-profile, recognizable people were offering new information on an old subject. Advertising targeted print, radio, and television viewers in off-news time periods.

Some consideration was given to development of a pamphlet outlining potential traffic bottlenecks and offering alternative routes. Consumers would pick up the map free from a commercial sponsor, probably a supermarket chain, and use it as they commuted. The pamphlet would be both a marketing tool for the station and the project and a self-help mechanism to encourage behavioral change in drivers, because it offered advice on route and trip planning. But the compressed production time, the lack of a commercial sponsor, and difficulties in producing workable maps for the pamphlet killed that idea.

AIR-TIME STORIES

A preliminary list of suggested material was developed focusing on the goals described earlier and concentrating the subject matter into seven areas. Figure 1 shows the initial material

(1)	Benefits of mobility	
	Family's day	• follow a family around, add up the miles and activities (av. family 50+ mi.).
	I love my Chevy	• why do people love their cars; car as personality and freedom - provider.
(2)	What causes traffic congestion	
	Get out of my way!	• go along on the commuter trip; sit in traffic.
	Where is that store?	• show how land use spreading generates traffic
	Big car/Little street!	• old inadequate street designs
(3)	How bad is it?	
	Charlotte traffic woes	• Traffic Index for Charlotte, reported quarterly/monthly • Poll - readings on what people think
	How bad will it get?	• Future projections ("war-of-worlds")

FIGURE 1 Preliminary material for "Bumper-to-Bumper Blues" series. (***continued on next page***)

(4)	Costs of Traffic	
	• Dollar costs	• family car purchase • gasoline • insurance
	• Accidents • Stress	• costs of injury and repairs • imitation levels (medical)
	• "Social" - congestion - air pollution - energy - land use & "sprawl"	• show clogged streets, low-density subdivisions
(5)	Government Costs	
	• Road Construction	• I-85, Independence Blvd. • '88 Bond issue
	• Other Services	• as land use spreads, other services are needed
(6)	Choices for commuters	
	• Transit	• show bus riders, park-and-ride
	• Carpooling	• employee pools, neighborhood pools
	• Flextime	• Leave earlier or later
	• Route choices	• Show how to choose other routes
	• Walking and bicycling	• Charlotte bike trails and parks
(7)	The longer term prospects	
	• Transit	• Show light rail in other cities
	• Mixed land uses	• University Place/clusters
	• Telecommuting	• People using computers/ phones while working at homes
	• "Smart" cars "Smart" roads	• Project "Prometheus" and Calif. projects On-board and roadside vehicle navigation.

FIGURE 1 ***(continued)***

used as a guide for story development. Ultimately, not all of this material was covered.

At this stage, the effort focused on allocating the material to reporter assignments and making it fit the time constraints. Separate subjects were developed for the 5-day series. The series began at 6 p.m. Monday on "Eyewitness News."

Day 1: What Causes Congestion? How Bad Is It?

The first report provided an overview of traffic in the Charlotte area and examined the elements that had produced high growth in development and matching growth in congestion. It was introduced by using an "Eyewitness News" poll of viewer perceptions of Charlotte area traffic. The poll contained information that most viewers already knew—traffic was Charlotte's most serious problem and the majority of Charlotte commuters preferred to drive alone—but the report helped them understand what had happened. No effort was made to find a culprit. Charlotte was simply a victim of its own success.

An editorial decision put the reporter, a high-profile weekend and substitute anchor, "live" in a helicopter over a busy intersection on a highway that rates level-of-service F for congestion in peak periods. The report was timed to air just as the evening peak slowed. Live remote broadcasts are used to showcase and emphasize stories. Show producers and the editorial staff believed that a live broadcast would add appeal to the subject matter, especially for viewers who had just encountered the evening peak or who were waiting for breadwinners to arrive home.

In the story, the lead (anchor) reporter developed a multilevel picture of congestion at the national, local, and personal level. Content focused on establishing the causes of Charlotte's rapid recent congestion growth, comparing it with that of other cities, and getting on-the-street driver reactions. Local experts who were consulted indicated in on-camera interviews that Charlotte is probably in the top 15 to 20 or even in the top 10 cities nationally in traffic congestion. The increase in congestion was attributed to a squeeze: the cumulative effect of drivers and developers adding traffic to static street capacity. The prognosis for the next few years was viewed as not good, and the streets due to be repaired were highlighted. But 61 percent of those polled wanted to widen existing roads and build new ones.

The segment ended with a theme that would be reinforced in later reports: you and your attitudes should be part of the solution. Another reference to the "Eyewitness News" poll indicated that road construction was the commuters' preferred solution. UNCC traffic experts suggested that this was not likely to solve congestion under present circumstances.

Day 2: What Is Mobility? Why Do People Want It?

Part 2 picked up where Part 1 left off, delivering a new concept to viewers: people's habits, not an outmoded highway system, contribute substantially to traffic problems. The "Eyewitness News" poll focused on Charlotte's love for the automobile, noting the use of two, three, and even four cars per family.

A multiple-car household was sought to demonstrate how a family, in a sense, abused its mobility with overuse of cars. The reporter, again a high-profile weekend and substitute anchor, found a two-car family to fit the profile. A couple in their 30s with three pre-teen girls and two cars was asked and agreed to participate (they were friends of a friend of the reporter). Two news photography crews followed them throughout the day and recorded travel for later analysis. Their activities revealed what became a working title: "travel junkies," people whose lifestyles relied completely on the ease of access and mobility provided by the automobile, generating much travel and contributing to the city's congestion.

In telling the family's story, the reporter emphasized the family's similarities to many others in the Charlotte area. The report examined travel frequency, hoping to shock viewers who shared the lifestyle. The piece was produced in a form of time lapse, using the lower left-hand portion of the screen as a clock that allowed the viewer to equate time of day with driving chore.

Dedication of two news crews to any one project for a full day is a major manpower commitment for a newsroom the size of WSOC. On a given day, from 4:30 a.m. to midnight, WSOC averages eight crews on the street. Cutting that number by two full crews, working toward a story that will not air on the day of the shoot, indicates that the project is manpower intensive.

This family's travel activity was traditional in many ways. The family clearly divided its roles, with husband working and wife nurturing. The wife made a total of 18 trips, totaling 42 mi, primarily to and from school to deliver and pick up the children; she also rotated chauffeur duties with other families. She made extensive use of neighborhood streets and shortcuts, avoiding main-street congestion. During a 7-hr day, she spent 2 hr 6 min in the vehicle. The husband went to a breakfast meeting, then to work, and then to lunch and afternoon meetings. He made nine trips totaling 55 mi in 1.5 hr, all as a solo driver. For one activity—to view a daughter's school dance recital—husband and wife were together during the day. The family indicated that they did not even think about the amount of travel—almost 100 mi—because it was necessary to their lifestyle.

The family's travel pattern was shown to a traffic analyst. The analyst's view was that the wife had done a good job of carpooling, using side streets, and planning. Some of the roles—shopping and some chauffeuring, for example—could be shifted to the husband, and the husband could have carpooled. The story also had suggestions for drivers: (*a*) plan trips, (*b*) combine errands, (*c*) change the time of trips, (*d*) use side streets, and (*e*) share duties. The story was rounded out with more data on the poll, focusing on the percentage of families that regularly carpool.

Extreme situations always catch the eye of journalists. Driving 100 mi/day in a small area both highlights an extreme situation and offers information that can be promoted by the television station. The realities of audience fragmentation make excellent promotion essential for motivating viewers to stay with a report or a newscast.

Finally, the reporter offered advice to reduce the travel—trip planning. Planning, the advice offered, will lead to more effective use of trips and less hassle.

The reporter closed the segment from a news studio equipped as a phone bank. Workers from Charlotte's Rideshare and Information Program staffed the phone lines, and the reporter offered their services to establish carpools to save time for the harassed commuter. Again, the theme of cooperating with government and providing solutions came through.

Day 3: Commuting Options

The third segment focused on the automobile as the primary transportation tool for the working individual. People who choose suburban and exurban lifestyles choose reliance on the personal vehicle for transportation to and from work. Do they have other options?

The reporter, a specialist in consumer affairs, offered several options, starting with the vanpool. Vanpooling, the reporter suggested, is good advice for a consumer of *time*. A description of life in the vanpool was followed by a demonstration of time and money saved. The vanpool allowed the reporter to suggest other alternatives for both travel and driving style, including leaving for work at off-peak times, changing routes, involving the employer in mass transit, and using mass transit.

Data from the "Eyewitness News" poll indicated that changes in commuter behavior were coming. Poll data were used to show commuting modes and report on what people would do if congestion increased; 54 percent would start to work earlier, 24 percent would change routes, and 20 percent would do nothing.

The reporter closed his segment with radical advice: give up the car. And, working from the Rideshare and Information phone bank, he offered its services in setting up vanpools, park-and-ride, carpools, and mass transit service. The theme of cooperation and advice to "beat those bumper-to-bumper blues" closed the segment.

Day 4: Health Effects

The fourth segment used health dangers to persuade commuters to change their behavior. The station's "Healthbeat" reporter provided the expertise, focusing on stress and the commuter.

The piece used time lapse, deadlines, and the force of habit to show health traps for a subject commuter, a Charlotte businessman whose daily travel included a trip to pick up his children from day care. A doctor went along on the trip. The discussion of dangers included stress, risk taking, and poor air quality. The doctor and the reporter offered advice to make the ride tolerable, safe, and healthy. The story closed on an upbeat, noting that commutes may be great for people who prefer country living and like using drive time as personal time.

Day 5: The Future

This segment portrayed the commute as an "eternal" task and offered some hope through technology. The station's "Breakthrough" reporter, a science and technology specialist, described research projects and inventions that may provide relief. Smart cars, smart highways, home offices, automobile-based fax machines, and lap-top computers all may someday make drive time useful for completion of work and personal tasks.

The story focused on advanced-technology (electric, solar) cars, on-board maps and vehicle navigation, and centrally controlled traffic signal systems of the future. It was couched in simple terms, describing both "what's here now" and "what's coming." The story also covered futuristic trains, vehicle-reading toll systems, fuel-efficient cars, and car-as-office environments.

PUBLIC OPINION SURVEY

To put the series in perspective, a small public opinion survey on travel behavior and attitudes of local residents was conducted. A short telephone survey instrument was developed with questions concerning perceptions of traffic problems, travel patterns to work and shopping (distance, time, and mode), and planned behavior if congestion were to increase. The survey was administered to 280 residents of Mecklenburg County (Charlotte) and surrounding counties. Data were coded manually and simple charts were prepared for use with the TV series. An effort was made to simplify the statistics for the public.

In general, the poll confirmed staff perceptions of traffic problems and consumer behavior. Residents put traffic congestion at the top of the list of traffic problems by a wide margin and identified southeast Charlotte as the most congested area. It is significant that people outside Mecklenburg County, who probably do not often drive in southeast Charlotte, still regard it as a congested area. However, most people drove to work alone. If congestion increased, most would start earlier or later, change routes, or just cope; only 4 percent said they would carpool or take a bus. Citizens believed that the government should concentrate primarily on widening existing streets (32 percent) and building more streets (27 percent), not on light rail (3 percent) or carpooling (4 percent). Table 1 shows the results.

To simplify the presentation, only a few of the statistics were highlighted and used with reporter stories. Table 2 shows the simplified data and the reporter voice-overs.

TABLE 1 SUMMARY OF POLL RESULTS

Issues		
1.	Thinking about traffic problems here, what do you think is the **#1 problem**?	% Response
	1. too much traffic congestion on the routes I use	51
	2. have to wait for signals	9
	3. not enough parking	-
	4. roadway construction ties up traffic	12
	5. traffic accidents	-
	6. potholes and poor street conditions	5
	7. other________	12
	(8. Lack of roads	6)
	(9. Roads need widening	5)
2.	Where do you think these problems are most severe?	
	1. Uptown Charlotte	5
	2. UNCC Corridor (N. Tryon, US 49, I-85 East)	7
	3. Southeast (Independence Blvd., Rt. 51, Matthews)	56
	4. Southwest (Park, Tyvola, I-77, Southpark)	15
	5. West (Billy Graham, West St., Wilkinson Blvd.)	3
	6. Northwest (Freedom Drive, Brookshire Parkway)	1
	7. North (Beatties Ford Rd., I-77 North, Graham St.)	3
	(8. Other/All	10)
Work Travel		
3.	How far is it to your **school/work**? (If respondent doesn't work or is in school, go to Question 8).	
	______ miles	12 mi. av.
4.	How long does the trip normally take?	
	______ minutes	23 min. av

TABLE 1 (*continued on next page*)

TABLE 1 (*continued*)

5. How do you usually get to work?

1. drive alone (car or light truck)	87
2. passenger with family member	2
3. carpool with someone else	10
4. bus	-
5. walk or bicycle	1
6. other ________	-

6. Thinking about the traffic congestion you encounter on your usual route to work, how would you grade it (A-F)?

1. A - no congestion, lightly traveled street	11
2. B - light traffic, 55 mph	10
3. C - moderate traffic, 50-55 mph	26
4. D - heavy traffic, 45-50 mph	25
5. E - slow going, 30-45 mph	16
6. F - stop and go traffic, 0-30 mph	12

7. Suppose traffic congestion of this route were to increase substantially to Level F most of the time (read Level definition). Please tell me if you would be willing to do any of the following to deal with that? [Circle all that are mentioned. If level F already, start with "Please..." above.]

• Change the route you use	24
1. move 1 street over	
2. move 2 streets over	
3. further away	
• Start the work trip earlier or later	49
4. 15 min. earlier or later	
5. 30 min. earlier or later	
6. Carpool to work	3
7. Take a bus	1
8. Walk or bike to work	-
9. Combine shopping and work trips	1
10. Move closer to work	1
11. Change to a job closer to home	-
12. Move away (change both jobs and home)	1
13. Nothing - just cope!	20

[Go to Question 11.]

Shopping Travel (if don't work)

8. How far is it to your usual (most frequently visited) shopping stores?

__________ miles	3 mi. av.

9. How long does the trip normally take?

__________ minutes	11 min. av

10. How do you usually get to shopping?

1. drive alone (car or light truck)	69
2. passenger with family member	23
3. carpool with someone else	3
4. bus	2
5. walk or bicycle	3
6. other ____________	-

Government Actions

11. What is the **one thing** you think government should do to help reduce traffic congestion?

1. build more freeways and expressways	29
2. upgrade and widen existing streets	32
3. better traffic signal timing	3
4. reduce access to driveways and side streets	2
5. increase bus services	3
6. build light rail transit lines	3
7. encourage carpooling	4
8. encourage flexible work hours	-
9. encourage mixed land uses	-
10. other ________	9
(11. don't know	15)

TABLE 2 POLL MATERIAL USED IN TV STATISTICS

	Material Shown on TV		Voice-Over
(1)	What is our Number One Traffic Problem?		"An eyewitness news poll puts traffic congestion above everything else as the number one traffic problem"
	Congestion	51%	
	Road Construction	12%	
	Traffic Lights	9%	
(2)	Where do you think problems are most severe?		"Southeast Charlotte leads as the top trouble spot for driving around here"
	Southeast	56%	
	Southwest	15%	
	UNCC Area	7%	
(3)	Traffic solutions?		"Nobody wants to give up that freedom"
	Widen streets	32%	
	Build more freeways	29%	
	Suggest carpools	4%	
(4)	87% drive alone to work 69% drive alone to shop		"Most of us drive alone to work"
	46% have 2 cars 62% in Gaston have 2 cars 64% in Cabarrus have 2 cars		"A lot of us have 2 cars"
(5)	[how change behavior during rush hour]		
	24% change routes		
	start to work earlier? 45% in Mecklenburg Co. 74% in Gaston Co. 58% in York Co.		"45% are getting up earlier"
	20% just cope		"20% are just gritting their teeth"

GOVERNMENTAL COOPERATION

To provide carpooling assistance, WSOC-TV arranged with Rideshare, a local government agency, to provide carpool-match services for 3 hr (4:30 to 7:30 p.m.) on each of 3 days of the series. The Rideshare workers were shown on TV.

Governmental cooperation came at two levels. The primary level involved Charlotte's Rideshare and Information Office. Rideshare and Information works in the city's Department of Transportation to develop strategies for use of mass transit, park-and-ride, carpools, and vanpools. WSOC-TV offered Rideshare and Information the opportunity to work from an in-studio phone bank for a total of 6 hr during 2 days of the "Bumper-to-Bumper Blues" series. Three to four staff members would operate the telephones beginning at 4:30 p.m. and continuing through the afternoon news access, newscast, and the first ½ hr of prime time access programming, ending at 7:30 p.m. Rideshare and Information was featured during afternoon news headlines and throughout the 6 p.m. newscast, and a phone number was put on the screen to encourage viewers to call and use the service. The phone banks operated in conjunction with reports that identified Rideshare and Information services as options for commuters seeking relief from traffic congestion.

Despite the access offered, calls to the phone bank were disappointing. The director of Rideshare and Information said that approximately 29 people called the WSOC phone bank during the 2 days it was active (interview with M. Swinson, July 11, 1989). Most of the callers needed information on carpools and vanpools. Callers were asked to give information for computer matches (location of residence and workplace, etc.). The information was fed into a computer that identified potential matches. Information on matches was sent to the caller through the mail. Callers who were not matched were also notified by mail. After the series, Rideshare received 10 additional calls from people who "saw about it on TV." Rideshare does no television advertising, so it believes that the 10 callers saw the series. The director judged the series to be neither helpful nor a hindrance. She believed that it shows that people are not yet unhappy enough to carpool. She indicated a willingness to participate again.

This service fit into one of the primary aims of the series: to offer solutions to traffic problems identified by the reports. Rideshare and Information programs certainly fit the solutions offered in the report, and the agency was happy to participate.

The agency's air access came during key viewer time periods. Afternoon news access on WSOC-TV routinely carries audience shares ranging from 39 percent to 45 percent. These are some of the highest-rated television programs in the Charlotte market ("The Oprah Winfrey Show," "The Andy Griffith Show," and "The Cosby Show"), and Rideshare and Information services were featured twice per day in this period during the 2 days the phone bank operated. The 6 p.m. edition of "Eyewitness News" also commands up to 39 percent of the audience share for the time period, and the phone bank was featured up to three times per newscast.

The second area of government cooperation was in providing reporters with information for their segments. The Charlotte Department of Transportation, Charlotte Rideshare and Information, the North Carolina Department of Transportation, and the South Carolina Department of Transportation provided information to aid reporters. The level of cooperation was high, and it enabled the reporters to develop an accurate analysis of the area's history, problems, and future.

COSTS AND RESULTS

Major costs for the series were in advertising and staff preparation time. WSOC spent about $50,000 on pre-series advertising ($25,000 for value of on-air spots; $8,750 for advertising in *TV Guide*, *TV Week*, and similar publications; and $16,250 for selected radio advertising). In addition, reporter, producer, and camera crew time was estimated to cost about $20,000; the public opinion poll cost another $1,300.

Results were generally positive, but the picture was not clear. Table 3 shows the percentages viewing the series and a subsequent series for WSOC and its major competitor. Compared with year-before statistics, the series-week share declined according to one monitoring system and increased according to another.

After the "Bumper-to-Bumper Blues" series ended, in-house analysis concluded that the reports were successful on several levels.

- Production quality: the quality of production in the five segments was graded A or B by news managers. The reports were visually interesting, touched areas not previously seen by WSOC viewers, and presented the city's legendary traffic problems in a manner never before attempted by Charlotte area media.
- Audience interaction: Despite the low number of calls to the Rideshare and Information telephone bank, news managers considered the attempt at audience interaction somewhat successful. The reports identified problems, offered solutions, and even offered help in implementing the solutions for the interested viewer. Those moved enough by what they saw were offered the service instantly.
- Ratings: Arbitron (*Audience Estimates in the Arbitron Ratings Market of Charlotte, North Carolina*) and Nielsen (*Viewers in Profile, Charlotte, North Carolina*) ratings analysis for May 1989 indicated no significant jump or decline in ratings for the week the series aired. Ratings for that week were mixed compared with ratings for May 1988 and were down from February 1989. The decline from February is common in winter-spring trends.

One other form of follow-up remains in development: creation of a specialist position in traffic reporting in the newsroom. There are enough traffic-related stories in Charlotte to merit such attention, but the beat is nontraditional and would pull manpower from a daily use role. The concept remains under consideration.

CONCLUSIONS

The effort indicated that an interesting series can be done on traffic without resorting to the usual "who's at fault" focus. This series, concentrating instead on explaining problems and helping people find personal solutions, was interesting, well received, and constructive.

Television news should not be undersold in considering a governmental role in shaping a series similar to that outlined here. As audiences fragment and news becomes available at any time of the day or night, there is less and less traditional material offered through local television news that cannot be found elsewhere at a time convenient to the viewer.

Local television news must generate material significantly different from that generated by its network and cable rivals and package it in a manner attractive enough to guarantee tune-in at 6 p.m. Public service subjects are becoming more and more prominent in the newscast as stations try to reach that goal. In the past year, WSOC-TV has used the Internal Revenue Service to help viewers with income tax returns, the Better Business Bureau to help viewers with retail problems, the North Carolina Attorney General's office to help viewers who have problems with used cars, the Charlotte Employment and Training Office to help teenagers find summer jobs, the Mecklenburg County Medical Society to provide viewers with telephone help for medical problems, the Charlotte Social Security Office to answer questions relating to Social Security, and now the Charlotte Rideshare and Information Office to assist with commuting problems. Instant identification of problem areas comes from the agencies involved, but so do potential solutions. No discussion is given to the merits of the government-offered solutions, but their availability is put in the forefront. These reports say "Here is the problem, and here is *a* solution, not *the only* solution."

TABLE 3 VIEWER DATA FOR TRAFFIC SERIES FROM ARBITRON AND NIELSEN RATINGS REPORTS FOR FEBRUARY 1988, MAY 1988, FEBRUARY 1989, AND MAY 1989

		Arbitron Shares		Nielsen Shares		
Date	Item	WSOC	Competitor	WSOC	Competitor	
4-27-88	year before	39	35	31	41	
2-01-89	winter	39	36	35	38	
4-26-89	traffic series	32 (-7)	39 (+4)	36 (+5)	35 (-6)	
5-20-88	year before	38	35	38	42	*3*
2-15-88	winter	36	41	31	41	*weeks*
5-50-88	teen job series	47 (+9)	31 (-4)	36 (-2)	45 (+3)	*later*

In each of these cases, the government agency involved recognized a need of its constituency, recognized the value of free television time in a slot with high tune-in (to "purchase" a series like this would cost $80,000), worked with the television station to package its material in a way that did not compromise journalism principles, and helped the public. Recognition of these factors by the government agency is a key to making these programs work.

Ten years ago, if these items had been aired at all, they would have been found in the graveyard of early Sunday morning public affairs programming. But with local television news seeking a new role—one that makes it more than a news provider—it must locate material that helps improve people's lives.

This has always been a goal of journalism, but the methods have changed. Bettering society no longer means just pointing out its ills. It means taking an active role in finding solutions, even to the point of acting as a middleman between government agencies and a public that finds them increasingly difficult to understand and use. Whenever this method of reporting is successful, the public remembers the television station and the government agency in a positive light.

There are no firm plans at this point to follow up this paper. However, the data base remains intact, and if WSOC-TV and UNCC decide to follow up, it can be done in a direct manner. The names and telephone numbers of those contacted in the original survey were received for a possible follow-up. Areas for additional research include:

1. Did "Bumper to Bumper Blues" change your outlook on travel behavior in the Charlotte region?
2. Would you be interested in a personal travel plan (carpool, vanpool, park-and-ride) prepared by a government agency to make your travel a bit easier?
3. Do you recognize that travel habits combined with growing population and obsolete highway systems create the present traffic congestion problem?

In short, follow-up is possible. However, the media need a "hook"—an incident that can lead to a series of reports that might provide a ratings advantage in addition to the service.

If a government official wants to establish constructive dialog with the media, what actions should the government official take? Here are a few suggestions:

1. Decide what is to be accomplished.
2. Develop potential story lines—what items would the media be most interested in? How can these items be told and sold as stories? What makes them interesting?
3. Plan. Meet with the media informally, off the record, to discuss ideas.
4. Compromise. Get the interest level up. Decide how the media can help. Be prepared to discard items of less importance.
5. Implement. Work with the media to develop stories or issues. Work out an agreeable schedule.
6. Help the media put stories together. Answer questions, do interviews, provide sources. But don't write the story or push it in ways you want it to go.
7. Follow up. Continue to offer assistance over time. Establish a long-term rapport. Build mutual trust.

As with most situations, an open, honest approach, geared to cooperation rather than confrontation, will encourage a spirit of friendliness that will yield dividends for both parties.

This concept can be repeated anywhere. It is transferable if the government agency, university, and media outlet are able to seize an issue and, through a pool of resources, orchestrate attention and possible change. In recent months, WSOC-TV has embarked on similar ventures with the local medical society, agencies dealing with abused children, agencies and businesses seeking teenage employees, and agencies who agreed to provide free phone counseling for drug abusers.

The need for simplicity is emphasized. To pack many ideas into a short series means that many thoughts have to be shortened, some eliminated. Good journalism requires this. The traffic expert, for example, needs to recognize that complex problem descriptions and solutions will be greatly distilled for airing. But the benefits gained—reaching a wide audience, helping many citizens, and fostering understanding—outweigh the costs. The traffic analyst who is willing to compromise—and that is not always easy—may find that the media can be an ally in improving transportation for the community.

The media need not be viewed as an enemy. The media's role as helper is increasing as competition from other sectors encourages traditional TV news to expand its functions. The media are also community citizens and themselves depend on services such as transportation, so they too have a stake in transportation solutions. Series such as that described clarify the complexity of the problems and the difficulty of implementing solutions. This does not mean that the media have sold out. Carrying forward the public agenda is still a valid goal and will continue to be so.

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Developing a Household Travel Panel Survey for the Puget Sound Region

ELAINE MURAKAMI AND W. T. WATTERSON

The Puget Sound Transportation Panel (PSTP) is the first application of a general-purpose urban travel panel survey in the United States. Following the Dutch National Mobility Panel, it responds to needs for direct data on the effects of demographic characteristics and transportation conditions on household travel behavior in an urban area. The first-wave travel diaries for the 1,687-household sample in the PSTP were completed in 1989. The sample was stratified by travel mode and residence county. The panel was surveyed for attitudes and values in early 1990, and a second wave of travel diaries was scheduled for late 1990.

Transit agencies and metropolitan planning organizations have long relied on household travel surveys for urban travel data to use in long-range forecasting models, transportation policy analysis, and transit marketing research. These surveys, though in some cases quite large, tend to be infrequent, expensive, and invariably cross-sectional in design. The data are then applied to the analysis of change—for example, policy changes, mode shifts, and the dynamics of future travel. Changes are difficult to predict from data that are fundamentally static snapshots of travel conditions. Yet public policy is often based on inferences from these snapshots, without benefit of direct information on what factors influence personal travel behavior.

Panel (or longitudinal) studies have long been used in economic, demographic, epidemiological, and social policy research, but they are just beginning to emerge as valuable tools in analyzing and predicting travel behavior. The Dutch National Mobility Panel study, initiated in 1984 and continuing into its 10th wave (6-month intervals), is perhaps the longest ongoing transportation-related panel study (*1*,*2*). The Dutch panel was designed as a general-purpose longitudinal travel survey and was financed exclusively with public funds. The primary objective was to analyze public transportation policies, but a large volume of research in many aspects of travel behavior has been drawn from the panel data [see van Wissen and Meurs (*2*)].

Other travel behavior panel studies have been designed for specific research purposes. International examples are in Sydney (*3*) and Oxford (*4*). In the United States, panel designs have been applied to evaluations of before-and-after conditions of public transportation policies. Recent examples include studies of high-occupancy vehicle lanes in San Diego, staggered work hours in Honolulu, and telecommuting in Sacramento.

Initiated in 1989, the Puget Sound Transportation Panel (PSTP) is the first general-purpose travel panel survey in an urban area in the United States. It is similar in design and direction to the Dutch National Mobility Panel but is also descended from the long line of cross-sectional urban travel surveys in the United States and is more focused on transportation and transit policy issues in U.S. cities. Like the Dutch Panel, the PSTP is intended to continue indefinitely into the future, assuming continuation of funding.

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CURRENT PRACTICE IN URBAN TRAVEL SURVEYS

During the last 30 years, metropolitan planning organizations (MPOs) have conducted hundreds of urban area household travel surveys for preparing input to travel forecasting models. The objective has usually been to collect information on trip generation rates, zone-to-zone trip tables, and trip length frequencies. Traditionally, surveys have been made of households, using cross-sectional sampling, on the basis of household size, number of cars in the household, and household income.

In the past 4 or 5 years, many MPOs have conducted new regional household surveys to obtain current data for calibrating travel demand models. Examples described include Minneapolis-St. Paul (1982–1983), Denver (1985), Houston (1984), Dallas-Ft. Worth (1984), the Puget Sound region (1985–1988), and national surveys (1969, 1977, and 1983) (*5*). Other MPOs are planning surveys to coincide with the 1990 census.

In addition, the transit agencies in the Puget Sound region and elsewhere have been active in cross-sectional surveys for marketing and system planning. The Seattle Metro in particular has used surveys of rider and nonrider attitudes to analyze effects on mode choice and travel behavior of local residents.

The 1985–1988 cross-sectional travel surveys by the Puget Sound Council of Governments (PSCOG) originated from concerns by local policy makers about the lack of recent data on trip generation rates (the last previous survey had been in 1971). About $270,000 was spent on six separate surveys to collect new household data in the four-county PSCOG region. More than 4,500 households were surveyed (of about 1,000,000 households in the region), with travel diaries for all household members aged 5 and over.

Although the techniques of designing and conducting these surveys have changed, the general method and purpose have not. Some of the limitations of this approach when applied to forecasting and policy analysis are as follows:

- The surveys are costly and therefore are conducted infrequently. In the Puget Sound region there was an almost 15-year interval between data collection surveys on household travel. Increasing trip rates were suspected, and minimal increases had been introduced into the forecasting models. The models were coming up short in forecasting vehicle trips—forecasts for 1990 and 2000 were not even meeting current ground count figures.

- Changes in travel behavior are inferred to be directly related to changes in demographic characteristics. Repeated cross-sectional surveys can measure both travel behavior and demographic characteristics, and both have changed dramatically in the last 20 years. However, it is difficult to know how to predict travel in the future when it is not known how changes in labor force participation or the presence of preschool-age children, for example, have affected travel behavior historically.
- Effects of transportation policies on travel behavior have been built into models using results of cross-sectional studies. Transit fare and automobile operating cost elasticities from cross-sectional data are frequently included as key components of urban travel demand models. But, as with the problem of demographic characteristics, these relationships are used to predict the dynamic impacts of transportation policies, such as transit fare restructuring and gasoline costs, on travel behavior.

PANEL SURVEYS—A DIFFERENT APPROACH

A panel survey is one in which similar measurements are made on the same sample at different times. This may differ from longitudinal data, in which periodic measurements are made on the same variables, but different samples may be drawn. Cross-sectional surveys make no attempt to connect systematically to prior or subsequent surveys.

Duncan, Juster, and Morgan (*6*) have identified several advantages of a panel design for travel behavior analysis:

1. Direct measurement of individual changes;
2. Ability to analyze causality about changes in place of residence, place of work, and commute mode;
3. Smaller sample requirements for the same statistical reliability; and
4. Lower ongoing costs.

There are also disadvantages (*7*):

1. Higher initial costs at empanelment,
2. A possible higher nonparticipation rate,
3. Attrition and replacement of the panel, and
4. Locating in-migrants for recruitment (a regional problem).

Perhaps the greatest advantage is that change is measured directly on the respondents themselves, thus permitting inferences to be drawn about the effects of changes in one variable on travel behavior. This cannot be legitimately done with cross-sectional data.

In addition, a panel survey may be a more cost-effective way to collect data during a period of time. This advantage, of course, may depend on the local objectives and resources. Higher initial costs and problems of panel replacement or refreshment could offset the smaller sample and lower ongoing costs. However, analytic techniques have been developed that minimize the panel attrition problem for research and permit statistically valid analysis even when the attrition is serious (*8*).

Travel behavior and the dynamic character and demographics of urban areas make a strong case for the application of panel surveys for data collection. Change is the norm, not the exception, in our society and its mobility needs:

- Many urban areas are growing,
- Most urban areas are suburbanizing,
- About one in five U.S. households moves in any year,
- This many or more change job locations each year,
- People form and dissolve households and add household members, and
- Household incomes change.

Long-range forecasting of urban travel and the effects of transportation policies on travel behavior depend on the measurement of changes. When aggregates or cross sections are measured, many of the dynamics that affect important aspects of urban travel, such as automobile trip making or transit ridership, are missed.

Application of panel surveys to nontransportation subjects has led to dramatic challenges to prevailing wisdom on behavior and policy that had been derived from cross-sectional studies. Cross-sectional surveys provide snapshops of the population at one or more times. The apparent stability of the population inferred from the similarity of these snapshots is almost always incorrect. The Panel Study on Income Dynamics, for example, has indicated that the poverty population, rather than being mostly the same 10 to 15 percent of the population, turns over rapidly and completely (*9*). Similar results were found on the nature of welfare recipients (*10*). It is likely that similar insights can be drawn from transportation panel surveys in the United States once the data have been collected and analyzed.

Although several American researchers, notably Kitamura and Golob, have been active in analyzing the Dutch National Mobility Panel data on various facets of travel behavior, travel behavior and household characteristics in the Netherlands are quite different from current U.S. urban patterns [Dutch data, Kitamura (unpublished), 1989]. For example, in the 1985 (second-wave) data from the Dutch panel, the average number of automobiles per household was 0.90. In the Puget Sound region, the average in 1989 (PSTP telephone "acceptors") was 2.21 vehicles per household. Similarly, the Puget Sound sample showed an average of 1.47 workers per household versus 0.93 in the 1985 Dutch sample; the average Puget Sound household size was 2.77 versus 2.91 in the Dutch sample.

The Dutch data also indicate a much higher proportion of trips by transit, walking, and bicycles than found in U.S. cities. Table 1 compares modes for all trips of households.

The Dutch Mobility Panel data have been extensively analyzed for change or stability in travel behavior with respect to changes in household variables, and the results have even been applied to issues relevant to U.S. transportation policy. It is believed that the differences in transportation systems, travel behavior, and household characteristics between Dutch and U.S. cities are too great to justify such transfer. There is

TABLE 1 HOUSEHOLD TRIPS BY MODE

	Dutch 1984-85	Puget Sound 1986-88
Auto Drive	25.8 %	68.3 %
Auto Passenger	9.7	19.7
Walk	33.3	5.0
Public Transit (& School Bus)	12.2	6.3
Bicycle/Other	19.0	0.7
	-----	-----
	100.0 %	100.0 %

Source: Dutch data are sample of mobility panel, all trips ages 12 and over (*11*); Puget Sound data are from 1986-88 household surveys, all trips ages 5 and over.

need for similar longitudinal data from American urban areas to support such behavioral and policy analysis.

PSTP

The PSTP, begun in 1989, is being conducted by PSCOG in partnership with the transit agencies in the region. The funding is from a special transit data grant administered through the Washington State Department of Transportation, covering two waves, 1 year apart, with intervening supplementary surveying.

The panel is intended to serve three basic objectives:

- To be a metropolitan "current population survey" to track changes in employment, work characteristics, household composition, and vehicle availability;
- To monitor changes in travel behavior and responses to changes in the transportation environment; and
- To examine changes in attitudes and values as they affect mode choice and travel behavior.

Sample Stratification

The survey plan is for a regionwide sample of households with stratification based on usual mode of choice (transit, carpool, or drive alone) and geography. As such, the panel consists of three discrete household populations:

- Households without regular (four one-way trips per week) transit users or carpoolers,
- Households with regular transit users, and
- Households with regular (work trip) carpoolers.

Each of these samples is further stratified by county of residence. The transit user sample is stratified by transit operator (five in four counties). The objective of these stratifications was to ensure that in all but a couple of cells there would be a sufficient sample for valid analysis.

Kitamura (*12*) has demonstrated that stages in the household life cycle are important for the analysis of travel behavior and future changes in behavior. So, each household in the PSTP is also classified by life-cycle stage for analytic purposes, though the sample was not stratified as such when drawn. The following eight stages are used here:

1. One adult less than 35 years old without children;
2. One adult 35 to 64 years old without children;
3. Two or more adults less than 35 years old without children;
4. Any number of adults, any age, with pre-school-age children (under 6 years old);
5. Any number of adults, any age, with school-age children (6 to 17 years old);
6. Two or more adults 35 to 64 years old without children;
7. Two or more adults 65 years old or older without children; and
8. One adult 65 years old or older without children.

Survey Method

The empanelment plan called for the use of three different means of contacting potential panel members.

- Telephone random digit dialing (the primary source, effective for nontransit-noncarpool and carpool households,
- Recontact of respondents on Seattle Metro transit surveys who had indicated willingness to participate in further research, and
- Distribution of letters on randomly selected bus runs requesting volunteers.

Transit ridership in the Puget Sound region is proportionally too small to obtain a valid transit sample by using telephone random dialing without an extraordinary number of contacts—as many as 20 calls for every regular transit user.

The primary means of data collection on household trip behavior is a 2-day trip diary completed by each household member aged 15 and over. The diaries were mailed out after initial telephone contact and screening, filled out, and returned.

Trip diaries are the standard instrument for reporting of objective trip data. A 1-day diary is commonly used in cross-sectional studies but can be insufficient for analyzing changes in travel behavior from one time to another, in light of the known variability in travel across days of the week. The Dutch panel uses a 7-day diary, but Golob and Meurs (*13*) report on diary fatigue as trip recording falls off markedly and uniformly over the week. Kitamura (*14*) recommended a diary period of 2 to 3 days—sufficient for panel analysis but not onerous enough for significant fatigue—administered at intervals no less than 12 months apart.

Diary Incentives

The subject of incentives to respondents in diary surveys has been of interest to researchers for a long time. Prevailing opinion among survey researchers has favored use of incentives to complete travel diaries, though the approach and amounts appear to vary widely. After some lottery approaches were discarded for legal and political reasons, three alternatives to monetary incentives were considered for the PSTP: (*a*) no incentive at all, (*b*) $1 for each household member (attached to the diaries when mailed out), and (*c*) $10 for each household returning a completed diary. The staff and the survey consultant decided to test the alternatives in the first wave of the panel. Households agreeing to participate in the telephone contact were randomly assigned one of the three groups for the dairy mailout.

After tabulating diary returns from approximately 1,500 households assigned equally among the incentive groups, the survey consultant reported that the $10 per household postcompletion alternative was performing about 10 percent above the no incentive alternative and about 5 percent above the $1 per person precompletion alternative. At that point, all further mailouts were shifted to the $10 per household postcompletion incentive.

Later results indicated that the $1 per person precompletion alternative performed somewhat better than the $10 per household postcompletion alternative (see the following table, which contains data as of December 8, 1989).

Alternative	*Mailouts Returned (%)*
No incentive	49.3
$1 per person precompletion	63.9
$10 per household postcompletion	60.3

The conclusion from this experiment, therefore, is that monetary incentives positively affect diary return rates, but it is not clear which alternative provides better results.

FIRST-WAVE EXPERIENCE

The first-wave data collection took place from September to early December of 1989 (excluding the Thanksgiving holiday week). A total of 5,152 households were contacted by telephone (including transit recontacts and volunteers). Of these, 2,896 agreed to receive diaries, and 1,687 returned completed diaries (Figure 1).

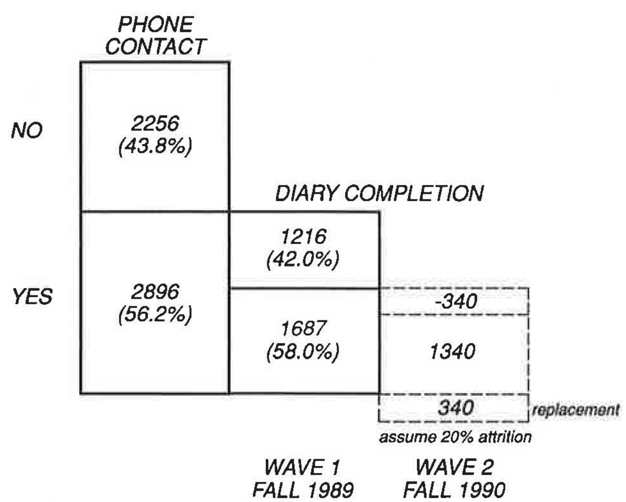


FIGURE 1 Acceptance and completion of Wave 1, 1989.

One unexpected problem in the first-wave data collection was a strike by 45,000 Boeing mechanics that started in early October. A number of households with striking workers were among the survey participants. The decision was made to hold the diaries for these households, because the strike obviously altered the travel patterns of household members. The strike lasted for 50 days and ended just soon enough to obtain travel diaries from the households right after the Thanksgiving week, before closing the survey.

All households who were contacted on the telephone were asked a brief series of questions before being asked to participate in the panel. There was a lower acceptance rate for this request than for travel diaries in previous cross-sectional surveys conducted by PSCOG, as indicated in the following table. But, interestingly, of those agreeing to participate in the panel survey, a slightly higher percentage completed and returned the diaries than in the earlier surveys.

	Survey Response Rates (%)	
	1985–1988 Surveys	*1989 Panel*
Acceptance at telephone contact	62	56
Diary completion after acceptance	55	58

There is usually some bias in the characteristics of households who choose to participate in a panel survey compared with those who refuse. Table 2 presents several comparisons between households who accepted panel participation and those who did not. Table 3 compares households who completed the diaries with those who accepted the diaries but did not return them.

There were limited differences between households who refused and those who accepted. Those who accepted

- Were slightly younger,
- Had more young children,
- Resided a shorter time in their county, and
- Rode buses more regularly.

There were more pronounced differences between the group of acceptors who completed the diaries and those who did

TABLE 2 TELEPHONE CONTACT ACCEPTORS VERSUS REFUSERS

Average Values for	Agree to Join	Refuse to Join	Statis. Signif.*
Household Size	2.781	2.786	No
No. Employed/Hshld.	1.472	1.453	No
No. Vehicles/Hshld.	2.203	2.252	No
Age of Phone Respondent	42.9	45.7	Yes
No. of Persons <age 6/Hshld.	0.260	0.225	Yes
No. Bus Riders/Hshld.	0.418	0.250	Yes
No. Carpoolers/Hshld.	0.246	0.202	Yes
Years in County	14.79	15.60	Yes

* statistically significant at +/- 5%.

TABLE 3 ACCEPTED AND COMPLETED VERSUS ACCEPTED AND NOT RETURNED DIARIES

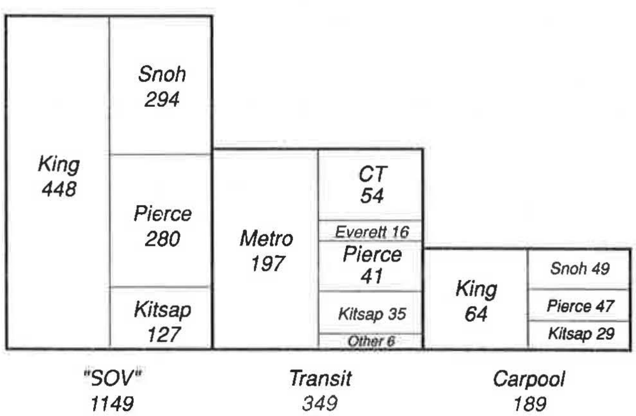
Average Values for	Completed Diaries	Did Not Complete	Statis. Signif.*
Household Size	2.595	3.041	Yes
No. Employed/Hshld.	1.362	1.626	Yes
No. Vehicles/Hshld.	2.120	2.319	Yes
Age of Phone Respondent	44.8	40.3	Yes
No. of Children <Age 6/Hshld.	0.235	0.296	Yes
No. of Bus Riders/Hshld.	0.266	0.484	Yes
No. Carpoolers/Hshld.	0.223	0.270	No
Years in County	15.18	14.24	Yes

* statistically significant at +/- 5%.

not. Those who completed the diaries

- Were slightly older,
- Had fewer young children,
- Resided a longer in their county, and
- Rode buses less regularly.

The composition of the panel as now constituted is shown in Figure 2. There are 1,687 households in the panel after the first wave, consisting of 1,149 nontransit-noncarpool households, 349 regular transit-using households, and 189 regular carpooling households. By county of residence, 709 are in King County, 413 in Snohomish County, 374 in Pierce County, and 191 in Kitsap County.



Transit - *at least one person in household makes at least 4 one-way trips by transit each week.*

Carpool - *at least one person in household makes at least 4 one-way trips in a carpool to work each week.*

FIGURE 2 Panel composition, Wave 1, 1989.

Preliminary analysis of total household trips for the entire sample indicates some trip reporting fatigue, even with the 2-day diaries. On the average, the results indicated 9.19 trips per household on Day 1 of the diaries and 8.81 trips per household on Day 2. Further analysis will compare Day 1 and Day 2 reporting with day of the week held constant. These average trip rates from the panel are lower than those from the 1985–1988 regional cross-sectional sample. However, the PSTP has a disproportionate number of transit-using households, which may contribute to the lower overall trip rate in this preliminary analysis.

NEXT STAGES AND PANEL ISSUES

The second-wave survey for the PSTP was scheduled for the fall of 1990. Duncan, Juster, and Morgan (*6*) have emphasized the critical importance of continuous "care and feeding" of panel participants, especially to minimize attrition between waves. Consequently, several follow-up efforts are under way to maintain contact (and update records) between the first and second waves. They include (*a*) a holiday card in late 1989 thanking panel members for their participation in the first wave; (*b*) a survey on panel attitudes and values administered in early 1990; and (*c*) a postcard seeking address changes in mid-1990.

Attitudes and Values Survey

Developing a longitudinal relationship between attitudes and values of transit and nontransit users and their travel behavior has been a keen interest of marketing staffs of the transit agencies in the region. The PSTP appeared to provide an important opportunity to analyze this relationship. It was decided to combine a survey of attitudes and values with a follow-up contact with the panel participants several months after the first-wave travel diaries.

Attitudes and values, as used here, is meant to cover the psychological aspects of mode choice, including attitudes, feelings, perceptions, and preferences. Examples of analyses of these phenomena are contained elsewhere (*15–17*). Market researchers for transit operators and carpool coordinating agencies are particularly interested in identifying factors outside the rational decision-making process that may influence or even control individual mode choice. The hypothesis is that travel behavior and changes in it are related to distinct and identifiable psychological factors. The problem is to measure the two together.

Local transit agencies have developed a good sense of their rider populations at particular times through on-board surveys, but they are becoming more aware that there are continuing fluctuations between rider and nonrider status. The same can be said for those who may be carpooling at any one time. The PSTP provides an opportunity for the transit agencies to obtain a baseline of data on attitudes and perceptions, along with measured travel behavior and demographics of households. Subsequent waves of travel diaries will permit analysis of changes in travel behavior (e.g., transit rider to drive alone and drive alone to carpool) and changes in demographics (e.g., residence and work location) with respect to the attitudes of changers and nonchangers.

The attitude survey instrument was designed by a group of transit agency staff and researchers from the University of Washington. The survey included questions on

- The importance of 17 attributes,
- The performance for three modes of 17 attributes,
- Attitudes toward three modes, and
- Constraints (e.g., need of a car for job, distance from home to nearest bus stop, and vehicle availability).

The survey was adminisitered on a mail out–mail back basis in February and March 1990 to 2,928 persons in the panel households on the basis of their ages and labor force participation. Results were to be available later in 1990.

Survey Unit to Follow

The issue is whether to follow the household unit over time or to follow individual members of households as a population. For the PSTP, the decision was made to use the household as the survey unit. The reasons are partly because of the travel data and forecasting work previously carried out at PSCOG and partly because the travel behavior of individuals is often influenced by characteristics of the household, such as vehicle availability and the presence of children.

Because there will be events (such as births, deaths, marriages, and separations) that change the household structure of panel members, the survey must make accommodations to the changes. The PSTP will follow and include persons from panel households as they leave and form new households if they remain in the region. Likewise, persons who join a panel household (e.g., through marriage) will be asked to join the panel. These changes may introduce some panel composition bias over time.

Panel Attrition and Refreshment

Attrition of panel participants between survey waves is a normal and expected problem of panel designs. The Dutch National Mobility Panel lost 40 percent of its households during the first year; the Panel Survey on Income Dynamics lost 15 percent. So, whatever the level, there is inevitable attrition in panel surveys. The attrition tends to be biased, occurring more in some demographic groups than others. The choices in panel survey administration are whether to replace lost households, and, if so, by what means. Duncan, Juster, and Morgan (*6*), from their extensive experience with the Panel Survey on Income Dynamics, still maintain that panel designs with refreshment are more cost-effective than repeated cross-sectional surveys.

Households drop out of panel surveys from one wave to the next for a variety of reasons. The most straightforward reasons for a regional panel will be death or moving out of the region; the latter has not been a significant problem in the national panels on Dutch mobility or the U.S. Panel Survey on Income Dynamics. In the Puget Sound region, as much as 5 percent of the population leaves the region each year, and recently almost twice that number has been entering. But there is attrition among those remaining in the region due to moving and becoming "lost" and to choosing not to participate further, for any number of reasons. The Dutch panel has found higher rates of attrition from lower-income households, singles, and retirees (*2*).

The biased attrition creates a potential problem for analysis of longitudinal data from panel surveys as well as for refreshment of the panel. Kitamura and Bovy (*8*) have demonstrated a technique for analyzing panel data, correcting for bias through a probabilistic model of household attrition applied as a weighting factor to remaining households. Refreshment of the panel should attempt to maintain overall representativeness of the population by adding new households that resemble the lost ones as closely as possible.

Replacement of households is a particular problem with a regional panel like the PSTP. Despite efforts to follow the panel members as closely as possible to minimize attrition, a significant level of attrition is expected. It will be necessary to find additional households within the region, including in-migrants, to maintain the profile of the panel. The problem of locating and contacting in-migrants is especially difficult. In-migrants can be identified through several data bases:

- Real estate transaction records,
- Driver's license changes,
- Motor vehicle registrations, and
- New residential telephone service.

But each of these has flaws—some records will not reflect intrastate moves, driver's license has a lag problem, real estate misses renters. A different approach is to contact new residents of dwelling units of panel out-movers, but this does not guarantee finding regional in-migrants.

The likely approach for the PSTP is to sample randomly for additional households and to find explicit in-migrants through one or more of these data bases. The approach will be finalized in mid-1990 and applied as contacts are made during the second wave in the fall of 1990.

CONCLUSION

Panel surveys have been in widespread use in many fields for years but are only recently entering research in transportation. There is solid evidence that panel data can significantly add to the understanding of urban travel and assist in its forecasting and the application of public policy to it. The experience of the Dutch National Mobility Panel demonstrates how a general-purpose panel can be accomplished and internalized as a regular governmental data collection and analysis activity.

The PSTP is the first such effort in the United States. It has now been launched and within 1 year will be producing data for analysis. Issues remain to be resolved, but that is normal for a new enterprise. This panel may provide insights into travel behavior in the Puget Sound area that can be reasonably applied to other U.S. regions.

Most important, the experience may enable other metropolitan regions (such as the San Francisco Bay Area, which is planning a 1990 start) to move toward panel surveys and their richer potential for forecasting and policy analysis.

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Practical Method for the Estimation of Trip Generation and Trip Chaining

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A model system of trip generation and trip chaining was developed by integrating concepts from activity-based analysis. The structure of the model system is recursive, depicting a sequential decision-making mechanism. The results were based on a data set from the Detroit metropolitan area. They were compared with those of a previous study that used a data set from the Netherlands. Differences were observed not only in the values of the regression parameters estimated but also in the decision mechanism inferred.

Trip generation is the first step of the conventional sequential forecasting procedure (*1*). The subsequent steps are based on estimates derived from trip generation analysis. Hence, the validity of the assumptions on which trip generation analysis is based and the accuracy of the trip generation models are major determinants of the overall quality of the forecast.

The conventional approach in trip generation is to estimate the number of home-based trips and non-home-based trips using separately formulated models. This approach, however, may not properly reflect behavioral relationships for several reasons. The implicit assumption that home-based and non-home-based trips are mutually independent is particularly dubious. The activities pursued at each trip destination may be related, resulting in dependence among the trips made. An approach that accounts for dependence among trips would be consistent with the notion of time budget (*2–4*). A more realistic depiction of the trip generation process is desired for improved predictive accuracy of trip generation models. Another issue related to travel behavior is the effect of unobserved constraints (e.g., unavailability of transit, restrictive store hours, etc.) on trip generation. A comparison of trip generation models obtained from areas of different characteristics would yield useful insights into constrained travel behavior.

In this study, concepts from activity-based analysis are combined with the concept of trip chaining to formulate a model system that links trip generation and trip chaining ("trip chaining" refers to the linking of trips, and "trip chain" is defined in this study as a series of linked trips that starts and ends at a home base). The model system accounts for interactions among various activities and provides trip generation rates by purpose as its outcome. The number of trip chains is expressed as a function of the trip frequencies by activity type. It is then shown that the model system can be applied to determine conventional home-based and non-home-based trip generation rates. Model systems are estimated using two data sets, one from the Netherlands and the other from the Detroit metropolitan area, to examine the nature of trip generation and trip chaining behavior in the two areas of substantially different land use and transportation network developments. The analytical method of this study draws on results obtained in a previous effort (*5*).

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BACKGROUND

A relatively new but well-established approach in travel behavior analysis is activity-based analysis [see Jones et al. (*6*) and Kitamura (*7*) for a review of past research]. The key concept behind the activity approach is that the travel patterns of households are a consequence of the more general structure of activities of the household members. It is explicitly recognized that trip making is a means of satisfying the need to pursue activities. The activity-based approach recognizes that decisions made by households to engage in different activities are correlated (*8*). Also considered in this approach is the presence of time and space constraints (*9,10*) under which a household makes travel decisions.

The linking of activities that leads to the linking of trips has motivated the trip chaining approach (*11–13*). The advantage of the trip chaining approach is that it offers a framework for rigorous investigation of possible interrelationships among travel characteristics. Thus the relationship among different types of activities pursued, time spent on these activities, and the characteristics of trips made for them can be coherently studied. Unfortunately, these concepts have not been widely applied (*12,14*). This study, which extends the results presented earlier (*5*), bridges the gap between theory and practice by adopting a simplified representation of the decision mechanism underlying trip generation and trip chaining.

FORMULATION OF THE MODEL SYSTEM

The trip generation models of the proposed model system are divided into two categories. The first includes trips made by a household to pursue mandatory activities, for example, work and school. The second includes trips made to engage in activities that can be considered discretionary. "Discretionary" is defined broadly: an activity is discretionary if decisions for engagement, location, timing, and duration involve flexibility. Trips made to pursue these activities are assumed to be more flexible. The focus of this paper is on the frequency of trips; direct analysis of the duration, location, and timing of activities is outside its scope.

Assuming that the number of discretionary trips is dependent on the number of mandatory trips, the formulation allows for one-way dependence among trip purposes. Given the mandatory trips made to work and school, households determine the number of trips for other purposes and eventually combine their trips (see Figure 1). This formulation is consistent with the hierarchical subdivision of activities (*7*) and the notion of time budget (*2–4*).

Given this conceptualization, the decision mechanism for household trip generation can be formulated by using a triangular or recursive structure that represents the hierarchical decision process outlined. The salient characteristic of this triangular system is that predetermined variables define the first set of endogenous variables, which, combined with exogenous variables, in turn define the second set of endogenous variables, and so on. The number of trips for mandatory activities can be expressed as a linear function of exogenous variables alone (e.g., income and structure of the household). The number of trips for discretionary activities may be represented by a linear function of the number of mandatory trips as well as exogenous variables. The statistical significance of each variable can be used to identify possible causal links between exogenous and endogenous variables. For example, a significant coefficient obtained by regressing the number of trips made for personal business on the number of trips made for work indicates that the household decision regarding the number of trips made for personal business is dependent on the number of trips made for work. Finally, the number of trip chains is formulated as a linear function of the number of trips by purpose.

The formulation of the model system is as follows. Let the general form of the model of the number of mandatory trips be

$$Y_i^m = \alpha_0^m + \alpha_1^m X_{i1} + \alpha_2^m X_{i2} + \ldots + \alpha_k^m X_{ik} + \varepsilon_i \qquad (1)$$

where

Y_i^m = number of trips made by household i for mandatory purpose m,

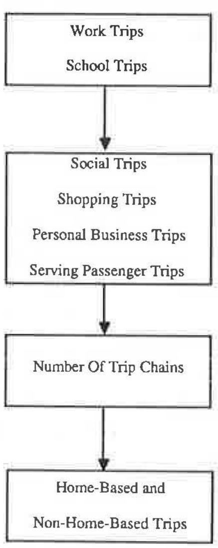

FIGURE 1 Model system.

X_{ij} = jth exogenous variable for household i,
α_j^m = the associated coefficient, and
ε_i = a random error term.

The form of the model for the number of discretionary trips is specified in a similar manner, using the number of mandatory trips as exogenous variables that are determined in the first tier of the model system. The model can be written as

$$Y_i^d = \beta_0^d + \beta_1^d X_{i1} + \ldots + \beta_j^d X_{ij} + \sum \theta_m^d Y_i^m + \xi_i \qquad (2)$$

where

Y_i^d = number of trips made by household i for discretionary purpose d,
$\beta_0^d, \ldots, \beta_j^d$ = coefficients,
θ_m^d = the coefficient associated with the endogenous variable Y_i^m,
ξ_i = a random error term,

and X_{ij} is as defined earlier.

The number of trip chains is modeled as

$$Z_i = \delta_1 Y_i^1 + \delta_2 Y_i^2 + \ldots + \delta_n Y_i^n + \nu_i \qquad (3)$$

where

Z_i = number of trip chains made by household i,
Y_i^n = number of trips for purpose n (both mandatory and discretionary) for household i, and
ν_i = a random error term.

The coefficients δ_j theoretically take on values between 0 and 1. They indicate the propensity of households to link trips. A higher value of a coefficient indicates a lower likelihood that trips for the particular purpose are linked in a multistop chain (a sequence of trips that includes more than one stop during the home-to-home tour) (*5*).

The estimated number of trip chains is

$$\hat{Z}_i = \hat{\delta}_1 \hat{Y}_i^1 + \hat{\delta}_2 \hat{Y}_i^2 + \ldots + \hat{\delta}_n \hat{Y}_i^n = \hat{\boldsymbol{\delta}}'\hat{\mathbf{Y}}_i \qquad (4)$$

where

$\hat{\boldsymbol{\delta}}'$ = vector of the estimated coefficients,
$\hat{Y}_i^j$ = estimate of the number of trips for purpose j, and
$\hat{\mathbf{Y}}_i$ = a vector of the $\hat{Y}_i^j$.

$\hat{Y}_i^j$ is expressed for mandatory trip purposes as

$$\hat{Y}_i^m = \hat{\alpha}_0^m + \hat{\alpha}_1^m X_{i1} + \hat{\alpha}_2^m X_{i2} + \ldots + \hat{\alpha}_k^m X_{ik} \qquad (5)$$

and for discretionary trip purposes as

$$\hat{Y}_i^d = \hat{\beta}_0^d + \hat{\beta}_1^d X_{i1} + \hat{\beta}_2^d X_{i2} + \ldots + \hat{\beta}_j^d X_{ij} + \sum \hat{\theta}^m \hat{Y}_i^m \qquad (6)$$

The conversion of the number of trip chains into home-based and non-home-based trip rates is based on simple identities. For household i, the expected number of home-based trips is

$$(\text{HB trips})_i = 2\,\hat{Z}_i \qquad (7)$$

and the expected number of non-home-based trips is

$$(\text{NHB trips})_i = \sum \hat{Y}_i^n - (\text{HB trips})_i \tag{8}$$

where n indicates a mandatory or discretionary trip.

Now, let the sample mean of $\hat{Z}_i$ be

$$\overline{Z} = \sum \hat{Z}_i/N \tag{9}$$

where N is the sample size, and let the estimated mean number of trips for purpose n be

$$\overline{Y}(n) = \sum \hat{Y}_i^n/N \tag{10}$$

The average number of home-based trips per household is given by

$$\text{HB trips} = 2\,\overline{Z} \tag{11}$$

and the average number of non-home-based trips per household is given by

$$\text{NHB trips} = [\overline{Y}(1) + \overline{Y}(2) + \ldots + \overline{Y}(n)] - \text{HB trips} \tag{12}$$

ESTIMATION OF THE MODEL SYSTEM

The estimation procedure followed the same methodology as the previous study (*5*). Trip generation models by purpose were estimated first. Alternative specifications were defined and tested for significance of the included regressors. Subsequently, a trip chaining model was obtained using the expected trip generation rates by purpose as explanatory variables. Home-based and non-home-based trip rates were then obtained through Equations 11 and 12 using the predictions from these models.

Sample

A sample from the 1980 Southeastern Michigan Transportation Authority survey was used in the estimation. The data file contains the demographic and socioeconomic attributes of 2,285 sample households. In addition, records of all trips made by household members age 5 or over by all modes of travel (motorized as well as nonmotorized) are included.

The household was chosen as the unit of analysis for several reasons. First, from the viewpoint that the household is a decision unit where resources are pooled, tasks assigned, and activities jointly pursued, it is a logical unit of analysis. Moreover, trip generation at the household level is much less variable than at the personal level, leading to smaller standard errors in parameter estimates. In addition, in the previous study (*5*) the unit of analysis was the household; to compare the results the household was used in this study also.

The explanatory variables used in the model system are shown in Table 1. The variables are grouped into six categories. The first group consists of variables that describe the household structure—household size, number of children by age group, number of adults, and number of adult males and females. The second group includes variables that describe the stage in the household life cycle. The third group consists of variables describing the characteristics of the head of the household, such as gender and age. The latter is represented by a set of dummy variables to account for possible nonlinearities. The economic status of the household is described by variables in the fourth category. The fifth category is made up of variables describing the intensity of land use and residential location. The notion that trip generation is invariant across different types of areas has been shown to be inappropriate (*15*). The sixth category is made up of variables that represent the availability of cars to household members. Unlike the Dutch data set used in the earlier study (*5*), no informtion on employment and education levels of the household members was included. The variable for employment in the original data file was excluded due to its poor quality, and no variable was available for education. It is expected that other variables will function as surrogates for them. For example, it is well known that income of a household is strongly correlated with the employment and education levels of its members (*16*).

Trip Purposes

The definition of trip purposes is based on the activity engaged in at the trip end. The trip purpose categories in the original data file were grouped in this paper into work, school, shopping, social, personal business, and serving passengers. Social trips include trips made for recreation, social visits, and other social activities. Personal business includes non-work-related personal business trips, medical trips, eat-meal trips, and other unclassified trips.

Estimation Results

All the regression models were estimated using a generalized least-squares procedure with weights as described in the previous study (*5*). The weights were defined as functions of the theoretical variance of the dependent variable to account for heteroskedasticity (variation of the variance of the error term across observational units). For regression models that involve the numbers of trips for other purposes as explanatory variables, the estimates obtained from the models in the earlier tiers were used as instruments to obtain consistent coefficient estimates. See Johnston (*17*) for a detailed discussion.

The estimated trip generation models are shown in Tables 2 to 8. The presence of possible multicollinearity was measured through the use of the tolerance value. This is defined as $1 - R_j^2$, where R_j^2 is the multiple coefficient of determination obtained when the jth variable is regressed against the other independent variables in the model. Hence, a high value of tolerance implies small multicollinearity, and vice versa. A description of each model follows.

Work Model

The daily household work trip generation model is shown in Table 2. It explains 31 percent of the total variation in the

TABLE 1 VARIABLES USED IN MODEL FORMULATION

VARIABLE	DEFINITION
Household Demographics	
HHLDSIZE	Number of persons in the household
NADULTS	Number of adults in the household
NCHLD:0-4*	Number of children 0-4 years old
NCHLD:5-15	Number of children 5-15 years old
NCHLD:16-18	Number of children 16-18 years old
NMALES	Number of adult males
NFEMALES	Number of adult females
Household Lifecycle Stage	
NOCHLD-YNG	1 if head of household less than 35 years of age and no children in the household less than 18 years of age
NOCHLD-MID	1 if head of household greater than 35 years of age but less than 65 years of age and no children in the household less than 18 years of age
NOCHLD-OLD	1 if head of household geater than 65 years of age, and no children in the household less than 18 years of age
PRESCHOOL	1 if the youngest child in the household is less than 6 years of age for head of household of any age
SCHOOLAGE*	1 if the youngest child in the household is 6 years of age or older for head of household of any age
Household Head Characteristics	
HDMALE	1 if head of household is male
HDFEMALE	1 if head of household is female
HDAGE:16*	1 if age of head of household is less than 16 years
HDAGE:16-30	1 if age of head of household is between 16 and 30 years
HDAGE:31-50	1 if age of head of household is between 31 and 50 years
HDAGE:51-64	1 if age of head of household is between 51 and 64 years
HDAGE:65	1 if age of head of household is greater than 65 years
Household Income	
LOW*	1 if annual household income is less than $10,000
MID-LOW	1 if annual household income is between $10,000 and $20,999
MID-HIGH	1 if annual household income is between $21,000 and $34,999
HIGH	1 if annual household income is $35,000 or more
Residence County and Area Type	
DETROIT	1 if residence zone is in Detroit
WAYNE	1 if residence zone is in Wayne County
OAKLAND	1 if residence zone is in Oakland County
MACOMB	1 if residence zone is in Macomb County
WASHTENAW	1 if residence zone is in Washtenaw County
MONROE	1 if residence zone is in Monroe County
STCLAIR	1 if residence zone is in St. Clair County
LIVINGSTON*	1 if residence zone is in Livingston County
COMMERCIAL	1 if 10 or more employees per acre of usable land
HIDENSITY	1 if less than 10 employees and more than 5 dwelling units per acre of usable land
MIDDENSITY	1 if less than 10 employees and from 0.5 to 5 dwelling units per acre of usable land
LOWDENSITY*	1 if less than 10 employees and less than 0.5 dwelling units per acre of usable land
Car Availability and Ownership	
NLICENSE	Number of licensed drivers in the household
NCARS	Number of cars owned by a household
ALWAYS	1 if the number of cars is greater than or equal to the number of licensed drivers in the household
SOMETIMES	1 if there is at least one car and one driver in the household and the number of cars is less than the number of drivers
NEVER*	1 if no car is available to the household

*omitted dummy variable

TABLE 2 WORK TRIP GENERATION MODEL (NUMBER OF WORK TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
NADULTS	0.2210	5.14	0.4583
NLICENSE	0.2009	4.50	0.3010
NCARS	0.1267	3.68	0.4296
NOCHLD-OLD	-0.4601	4.25	0.9400
HDAGE:31-50	0.2194	3.79	0.9042
MID-LOW	0.2909	3.90	0.6004
MID-HIGH	0.6809	7.96	0.4629
HIGH	1.1062	10.37	0.4929
OAKLAND	0.2238	3.25	0.9102
Constant	-0.3235		

R^2	0.3125
F	114.92
df	(9,2275)
N	2285

β = Estimated Model Coefficient
t = t-statistic

Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables

TABLE 3 SCHOOL TRIP GENERATION MODEL (NUMBER OF SCHOOL TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
NADULTS	0.2625	12.50	0.9702
NCHLD:16-18	1.0514	18.40	0.9205
NCHLD:5-15	0.8372	36.46	0.8122
PRESCHOOL	-0.1989	3.74	0.8324
HDAGE:16-30	0.2601	5.00	0.6701
HDAGE:31-50	0.1152	2.41	0.6693
WASHTENAW	0.5549	6.69	0.9731
Constant	-0.2415		

R^2	0.5453
F	341.149
df	(7,2277)
N	2285

β = Estimated Model Coefficient
t = t-statistic

Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables

TABLE 4 SHOPPING TRIP GENERATION MODEL (NUMBER OF SHOPPING TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
HHLDSIZE	0.1720	8.15	0.6073
NFEMALES	0.1334	2.84	0.7878
NOCHLD-YNG	0.1059	1.79*	0.7909
ALWAYS	0.1773	2.92	0.6399
SOMETIMES	0.1420	1.77*	0.6196
HIGH	0.1259	1.60*	0.9295
MACOMB	0.3154	3.64	0.9654
Constant	-0.0598		

R^2	0.0787
F	27.80
df	(7,2277)
N	2285

β = Estimated Model Coefficient
t = t-statistic

Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the multiple R-square obtained when the jth variable is regressed on the other independent variables
* not significant at $\alpha = 0.05$

TABLE 5 SOCIAL TRIP GENERATION MODEL (NUMBER OF SOCIAL TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
HHLDSIZE	0.0786	3.29	0.3922
NCHLD:5-15	0.1458	3.46	0.5495
NLICENSE	0.1486	5.77	0.5938
NOCHLD-MID	-0.1289	-2.94	0.9154
WAYNE	-0.1128	-2.32	0.9817
STCLAIR	0.2660	1.77*	0.9873
Constant	0.0847		

R^2	0.0869
F	36.15
df	(6,2278)
N	2285

β = Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the multiple R-square obtained when the jth variable is regressed on the other independent variables
* not significant at $\alpha = 0.05$

TABLE 6 PERSONAL BUSINESS TRIP GENERATION MODEL (NUMBER OF PERSONAL BUSINESS TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
HHLDSIZE	0.1537	5.86	0.5159
HDMALE	-0.1607	-2.84	0.9791
PRESCHOOL	-0.3612	-4.35	0.7388
WASHTENAW	0.3865	2.70	0.9914
HIDENSITY	-0.1535	-2.42	0.9331
Y(Work)	0.3845	8.49	0.6226
Constant	0.2423		

R^2	0.1142
F	48.94
df	(6,2278)
N	2285

β= Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables

TABLE 7 SERVE-PASSENGER TRIP GENERATION MODEL (NUMBER OF SERVE-PASSENGER TRIPS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
MPHH*ADULTS	-0.0014	-0.09*	0.3069
MPHH*NCHLD:16-18	0.1338	1.42*	0.9750
MPHH*NCHLD:5-15	0.1139	3.93	0.9451
MPHH*NLICENSE	0.0494	1.96	0.1992
MPHH*HDMALE	-0.0667	-2.23	0.6697
MPHH*Y(Work)	0.0940	2.64	0.2156
Constant	0.0324		

R^2	0.0500
F	15.00
df	(6,2278)
N	2285

β= Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables
MPHH = 1 if HHLDSIZE > 1.
* not significant at $\alpha = 0.05$

TABLE 8 TRIP CHAIN MODEL (NUMBER OF TRIP CHAINS PER HOUSEHOLD PER DAY)

Variable	β	t	Tolerance
Y(Work)	0.4130	3.99	0.0567
Y(School)	0.9684	13.89	0.1833
Y(Shop)	0.5146	2.54	0.0419
Y(Social)	1.1300	4.16	0.0374
Y(Personal Business)	0.5687	2.78	0.0243
R^2	0.7970		
F	1790.77		
df	(5,2280)		
N	2285		

β = Estimated Model Coefficient
t = t-statistic
Tolerance (a measure of multicollinearity) = $1-R_j^2$ where R_j^2 is the value of the coefficient of determination obtained when the jth variable is regressed on the other independent variables

number of work trips per day. The number of work trips was strongly associated with the income level. Income may function as a surrogate for the education and employment levels of the household members, which, as mentioned earlier, were not adequately represented by the variables available in the data base.

The number of work trips increased with increasing number of adults, cars, and licensed drivers in the household. It decreased when the head of the household was aged (more than 65) and had no children, presumably indicating the effect of retirement on work trip generation.

The presence of a variable indicating the county of residence (Oakland) indicates that other factors that influence work trip generation are captured in this dummy variable. This variable could be interpreted as representing the average unmeasured characteristics of households residing in that area relative to those of the counties represented by the omitted dummy variables.

School Model

The school trip generation model is shown in Table 3. As expected, the primary determinant of the number of school trips was the number of children in a household. Elder children (16 through 18) contributed more than their younger counterparts (5 through 15). The result agreed with the previous results from weekly trip generation models estimated on a Dutch data set (*5*). Children in both age groups are almost entirely students, and this was reflected in the magnitude of the coefficients (0.8372 for age group 5–15 and 1.0514 for age group 16–18), indicating that they were each making approximately one school trip per day.

However, the number of adults was another important determinant because of the presence of adult students in the household. The dummy variable associated with Washtenaw County presented a positive and significant effect, presumably because of the large universities present in that jurisdiction. The age group of the head of the household with a maximum contribution to school trip generation was 16–30, suggesting that the school trips were made by either the head of the household or the household head's young children. The dummy variable for this group (HDAGE: 16–30) and the one for the households with preschool children with the negative coefficient appear to separate households of adult students from families.

Shopping Model

Table 4 shows the shopping trip generation model. Household size contributed the most. Trips also increased with income and car availability. The coefficient of the number of adult females in a household implies that they make more shopping trips than adult males. As in the school trips, some difference by county of residence was indicated.

Social Model

Quite notable is the result that the number of licensed drivers in the household contributed most to social trip generation (Table 5). Household size and the number of children aged 5 to 15 were the other two important variables with positive influence. Fewer social trips were generated when there were no children in the household and the head was 35 to 65. Again, variations across county of residence were indicated by the model.

In the beginning of the study, it was anticipated that shopping and social trips would be discretionary and thus influenced by mandatory trip generation. However, estimation results indicated that shopping and social trips were not significantly influenced by work and school trips. This result contradicted the previous findings (*5*), in which a trade-off between mandatory and discretionary trip generation was evident. Apparently the indication obtained in this study does not support the notion of travel time budget, namely, that if household members spend more time on mandatory activities, they are left with less time to pursue discretionary activities and therefore make fewer discretionary trips. However, if time-space constraints are less restrictive (for example, if store hours extend well beyond work hours) trip generation for shopping and recreational activities may not be influenced by mandatory trips. The validity of this conjecture must be determined by further investigation of time expenditure patterns and spatial distribution of activity locations.

Personal Business Model

Two trip generation models in which the number of work trips was significant were those for personal business and serving passengers (Tables 6 and 7). Household size was one of the most significant variables and contributed positively to the number of personal business trips generated. The household's life cycle entered the model through the dummy variable for households with preschool children. The instrument variable for work trips was the most significant, contributed positively, and indicates that, other factors being equal, a household on the average generates one personal business trip for every three work trips.

Serve-Passenger Model

The peculiarity of this trip purpose was clearly reflected by the model structure (Table 7). During the model development process, in which a variety of model formulations were estimated, it was found that single-person households generate a negligibly small number of serve-passenger trips. Thus the model in Table 7 contains variables that are defined exclusively for households with two or more persons. The same approach was used in the previous model formulation (*5*). Serve-passenger trips were positively influenced by the number of children and the number of licensed drivers. All these indications are as expected. The work trip instrument variable positively influenced the number of serve-passenger trips and indicates that 1 serve-passenger trip is generated for every 10 work trips, on the average.

Trip Chain Model

The trip chain model is shown in Table 8. It consists of five instrument variables, Y(work), Y(school), Y(social), Y(shop), and Y(personal business). The number of trip chains is equivalent to the number of home trips (trips made with home as the destination). The largest theoretical value of these coefficients is 1 (one trip cannot generate more than one trip chain). All the coefficients in the model are consistent with this requirement except the one for social trips, although the coefficient is not significantly greater than unity.

If a coefficient is closer to 1, it indicates a lower propensity to link trips for that trip purpose with other trips. The estimated coefficients showed that work, shopping, and personal business were more likely to be linked in a multistop chain, whereas social and school activities tended to be pursued in a single-stop chain. In the short term the coefficients associated with each trip purpose can be used to estimate the relative effect of changes in trip generation on the formation of trip chains. For example, if a household makes one more shopping trip, the number of trip chains is likely to increase by slightly more than 0.5.

Estimation of Home-Based and Non-Home-Based Trip Generation

By using Equations 4 and 6 and the model presented in Table 8, the estimated number of trip chains for this sample was obtained as

$$\hat{Z} = 0.4130\,\hat{Y}(\text{work}) + 0.9684\,\hat{Y}(\text{school}) + 0.5146\,\hat{Y}(\text{shop}) + 1.1300\,\hat{Y}(\text{social}) + 0.5687\,\hat{Y}(\text{personal business})$$

whose sample average was 2.87. From Equation 11 the total number of home-based trips was

$$\text{HB trips} = 2\,(\text{number of chains}) = 2\,(2.87) = 5.74$$

Therefore the number of non-home-based trips was given by Equation 12 as

$$\text{NHB trips} = (\text{total number of trips}) - (\text{HB trips}) = 7.27 - 5.74 = 1.53$$

Thus 21 percent of all trips were non-home-based and all others were home-based. This agrees with the figures in Sosslau et al. (*1*, pp. 13–14) and Allaman et al. (*4*, p. 18), which indicate that approximately 20 percent of all trips are non-home-based.

COMPARISON

In this section a comparison between the results presented in this paper and those from the previous study (*5*) is presented. The comparison is divided into three parts: a description of the differences between the two data sets, a summary of differences in the estimation results, and a discussion of the differences in model structure between the two studies.

The data set used in the previous study consisted of 1,739 households from the Dutch National Mobility Data Set, referred to as the Dutch data set. Details of this data set can be found in Golob et al. (*18*). The data set used in this study (the Detroit data set) contained 2,285 households.

The trip rates observed in the Dutch data set represent weekly household trip generation by purpose, whereas daily household trip generation was studied in this paper. In the Detroit data set, the average number of cars owned by a household was 1.59, whereas in the Dutch data set it was considerably lower (0.87 cars per household). The average household size, number of children, and number of licensed drivers (Detroit data set versus Dutch data set) were 2.92 versus 2.82, 0.89 versus 1.05, and 1.73 versus 1.36, respectively. The average total number of trips made by a household was 10.22 trips per day in the Dutch data set and 7.27 trips per day in the Detroit data set.

The composition of the household was the most important predictor for trip generation in both studies. As expected, this was particularly pronounced for school trips. In the Dutch study the presence of children in the household in the 12–17 age group contributed approximately one school trip per day. The same was found in this study.

The role of income in the trip generation models was substantially different for the two studies. In the Dutch study, income appeared to be significant for school trips and shopping trips but not for work trips. In this study, income was significant for work trip generation but not for the other trip purposes. This was partially due to the lack of employment and education information in the Detroit data set; presumably income enters the Detroit models as a surrogate for the employment and educational level of the household members.

Car ownership was an important predictor in the serve-passenger trip model on the Dutch data set (a set of dummy variables representing car ownership indicated high *t*-statistics). On the other hand, in the serve-passenger model for the Detroit data set, car ownership levels did not appear as explanatory variables (a series of specifications for this model did not yield significant car ownership coefficients at the 5 percent level). Given the higher car ownership levels in the Detroit data set, the serve-passenger trip generation may have been more directly influenced by the number of licensed drivers in the household, which was a significant variable in the model. Even though the importance of land use for trip generation was recognized in both studies, its effect was not explicitly incorporated in the models because of the unavailability of adequate land use variables.

Overall, the Detroit data exhibited more multistop trip chains than the Dutch data, in particular those involving work trips and shopping trips. On the other hand, social and recreational trips were more likely to be made in single-stop trip chains (home-stop-home) in the Detroit data. School trips were less likely to be linked with other trips in the Detroit model, whereas they were more likely to be linked according to the Dutch model. Personal business trips were not included in the Dutch study due to the small number of personal business trips reported in the data file, whereas they indicated a high propensity to be linked in this study.

In the Dutch data set, 15 percent of the trips were non-home-based. The corresponding figure in the Detroit data set was 21 percent. Considering the high levels of car ownership and dispersed pattern of land use development in the Detroit area and the tightly developed and more transit-oriented urban areas in the Netherlands (one of the most densely populated countries in Europe), this result is not surprising. However, these may have been but some of the factors contributing to the difference in trip chaining between the two areas. Possible effects of other factors still need to be investigated.

The structure of the model system in this paper is different from the one developed for the Dutch data set (see Figure 2). Most important, the Detroit system represented no negative correlation between discretionary and mandatory trips. This contrasts sharply with the Dutch system, in which the discretionary trips were negatively correlated with the mandatory trips, indicating the possible binding effects of time-space constraints.

The average household in the Dutch data set, compared with its counterpart in the Detroit data set, has fewer adults and more children, owns fewer automobiles, and has fewer drivers. Combined with other environmental factors—for example, the restrictive store hours (8 a.m.–5 p.m.) in the Netherlands—these characteristics represent a higher degree of constraint within which a Dutch household arranges its trips. The apparent discrepancy between the results from the two studies suggests the importance of environmental constraints on household travel. This also suggests that there is no universally applicable trip generation model system; a model system must be developed to capture the salient contributing factors in the study area by appropriately selecting its structure, explanatory variables, and model coefficients. The study results contradict the notion of transferability in trip generation models across study areas.

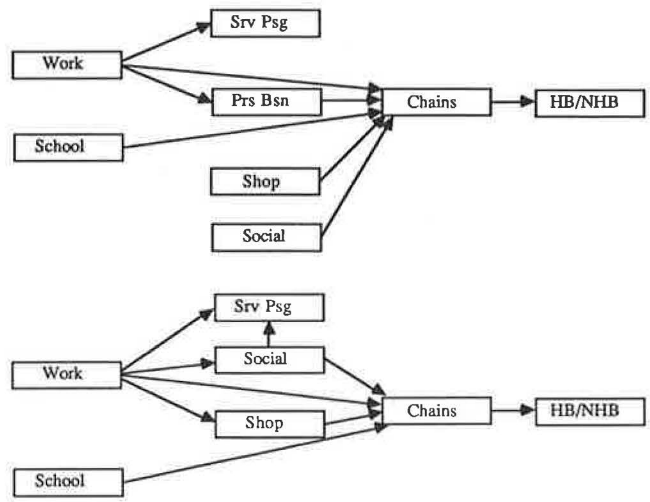

FIGURE 2 Detroit (*top*) and Dutch (*bottom*) model systems.

CONCLUSIONS

A model system was developed to depict trip generation in a more realistic manner through a recursive model structure representing trip generation by purpose. Concepts from the activity-based approach, trip chaining analysis, and conventional home-based and non-home-based trip generation were integrated in the proposed model system. One advantage of this method is that it reflects a possible multistage decision-making process that may be followed by households when making trips. Another important property of the model system is that it explicitly considers the interface among trips made for different purposes, thus integrating home-based and non-home-based trip generation in a coherent manner.

An important exercise of this study concerns the interpretation of the estimates of the coefficients in the trip chain model. The likelihood that a trip for a given purpose is combined with other trips into a trip chain was assessed from these estimates. Work trips, shopping trips, and personal business trips were linked into multistop chains more often than social trips and school trips.

A comparison of the results of this study (which was based on a Detroit data set) with those of a previous study [which was based on a Dutch data set (*5*)] offered useful insights into the differences in travel behavior under different environments. The salient element was the difference in the model structure. This was presumably due to differences in land use development, transit service levels, store opening hours and other institutional elements, and culture. The comparison suggests the need for further comparative analyses in trip generation, especially with regard to the transferability of model systems.

The model system needs further development to be a component of a comprehensive procedure of travel demand forecasting. For example, the model system developed in this paper cannot be used to predict the sequence in which trips for different purposes are linked. Consequently, it is unable to estimate home-based and non-home-based trip generation by purpose. If the proposed model system is to be used as part of the UMTA Transportation Planning System procedure, a model for trip sequencing must be introduced. This is the next step of this continuing effort.

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Characteristics of Urban Commuter Behavior: Switching Propensity and Use of Information

HANI S. MAHMASSANI, CHRISTOPHER G. CAPLICE, AND C. MICHAEL WALTON

The results of a survey of commuters in Austin, Texas, are presented. The focus is on commuting habits, particularly changes in route and departure time due to traffic conditions for both the home-to-work and work-to-home commutes. Models of commuters' propensity to switch each of these two choices are developed for both the a.m. and the p.m. commutes. The models relate switching propensity in each case to four types of factors: geographic and network condition variables, workplace characteristics, individual attributes, and use of information (radio traffic reports). The results provide insights into the relative importance of each type of factor to switching as well as differences between the mechanisms underlying a.m. and p.m. behavior.

Concern about urban and suburban mobility has motivated interest on the part of planners, policy makers, and urban residents in approaches to manage and reduce traffic congestion. In addition to the wide spectrum of demand-side and supply-side approaches that have been referred to in the past decade as transportation system management techniques, the potential for advanced telecommunications and microprocessor technologies to improve traffic conditions in urban networks is being pursued in several initiatives worldwide. A key determinant of the effectiveness of such strategies is the manner in which users might adjust their travel behavior in response to these strategies to alleviate peaking conditions through route-selection and trip-timing decisions. More needs to be learned about trip maker behavior, especially with regard to work trip commuting, the major contributor to morning and evening peak periods.

Little systematic knowledge is available regarding commuter behavior, which is surprising in light of its importance to urban congestion. Part of the reason is the inadequacy of the traditional 1-day diaries used in transportation planning studies to yield information on the dynamic aspects of the process or on the path selection decisions of commuters. The available knowledge consists mainly of scattered small-scale studies, including models of departure time choice (*1–4*) (made by commuters under steady-state conditions), and, to a lesser extent, route choice (*5*,*6*). Joint models of departure time and route choice have been formulated by Ben-Akiva et al. (*7*) and calibrated by Abu-Eisheh and Mannering (*8*) using the equilibrium choices of a small sample of commuters in a lightly congested two-route system. Insights have also been gained from activity-based approaches, which have gone a long way toward placing trip making and commuting in the context of individuals' and households' activity patterns (*9*).

The dynamic aspects of commuter behavior have received attention in the past few years, particularly departure time choice and, to a lesser extent, route choice. In particular, laboratory experiments have been conducted at the University of Texas that involved commuters interacting within a simulated traffic system (*10–13*). The experiments have yielded both methodological and substantive insights into the mechanisms governing day-to-day switching of departure time and route in a.m. home-to-work commuting in response to trip time variability as well as exogenous information. However, obvious limitations are associated with such experiments, particularly in terms of the effect of some factors that were controlled for, the representativeness of the participants, and possible systematic differences between laboratory simulations and actual commuting corridors. Mahmassani and Herman (*12*) have highlighted the role of such experiments in bridging the gap between speculative assumptions and full-scale field studies. It is desirable to build on and proceed beyond such experiments by conducting behavioral studies that will expand the boundaries of the theoretical constructs developed to date.

Limited field surveys of commuting behavior have recently been conducted (*14–17*). Chang and Williams (*14*) examined the departure time decisions of a small sample of a.m. home-to-work commuters in Salt Lake City and related the delays experienced to socioeconomic characteristics. Mannering (*15*) examined the frequency of route switching and departure time switching reported in a survey of a small sample of Seattle commuters. In another small-scale survey of Seattle workers, Mannering and Hamed (*16*) examined the decision to delay the usual work-to-home p.m. commute and related it to the severity of prevailing congestion during the peak as well as the socioeconomic characteristics of the commuter.

The goal of this study was to document the actual departure time- and route-switching decisions of commuters, quantify the day-to-day variability of these decisions, and identify the relative importance of factors such as the characteristics of the user, the rules at the workplace, the user's experience with the traffic system, and the use of information. The approach consisted of a two-stage survey. In the first stage, general characteristics of commuting behavior for a sample of trip makers in Austin, Texas, were obtained. In the second stage, detailed diaries were maintained of actual departure times

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and link-by-link itineraries (including intermediate stops in a multipurpose trip chain) from a smaller group of commuters during a 2-week period. In this paper an exploratory analysis of the results of the first-stage survey is presented. The focus is on two principal aspects of commuter behavior: (*a*) users' preferences and risk attitudes, captured through their preferred arrival time at work and the factors that affect it, particularly rules at the workplace; and (*b*) the extent and determinants of departure time and route switching in anticipation of or in response to traffic conditions. In addition, the analysis examines the role of two factors on these aspects of commuting behavior: the extent to which lateness is tolerated at the workplace and the use of information. Both a.m. and p.m. commuting are addressed, revealing asymmetries in behavior and possibly different underlying mechanisms. The analysis also presents an opportunity for comparison with the results obtained in Mannering's studies of Seattle commuters (*15,16*).

SURVEY DESCRIPTION AND GENERAL COMMUTER CHARACTERISTICS

Questionnaires were mailed to 3,000 households randomly selected in an area of five zip codes in the northwest section of Austin, Texas. All daily work commuters in the household were requested to complete separate questionnaires (each household was mailed two questionnaires for this purpose). The zip codes were chosen for their large residential areas and proximity to two major congested corridors, MOPAC and Route 183. The survey area is mostly suburban, with a generally higher income level than the overall urban area. It is also close to major technology-based manufacturing and research and development activities. Thus commuting is not exclusively oriented to the central business district (CBD) but includes a large inter- and intrasuburb component. A total of 482 households responded and 156 households completed two questionnaires, yielding 638 (in some cases partially) completed surveys.

The survey consisted of three main parts: screening questions, personal characteristics, and commuting habits. The screening questions identified suitable participants for the second stage of the study, such as those who drive their car for daily commutes to and from work locations in specific zones of interest. The commuter characteristics questions included job title, sex, age, type of work hours (regular, flexible, or other), tolerance of lateness at the workplace, and dwelling tenure (own or rent). The commuting habits portion requested the commuters' preferred arrival times at work, travel times to and from work, listening habits for radio traffic reports, other information sources, and route and departure time switching (specifically because of traffic conditions) for both a.m. and p.m. trips. A copy of the mail survey is shown in Figure 1.

Several items are important in the analysis and appear to be unique to this survey. For instance, tolerance of lateness addresses the penalty function for late arrival at the workplace, which is a central concept in departure time choice modeling (*7,18,19*). Trip makers were given a choice of three responses on this item: "I am expected to arrive on time," "I am allowed to arrive up to __ minutes late," and "It does not matter if I am late." The second item of particular interest is the preferred arrival time at work, subject to the official start time. Unlike the previous laboratory experiments (*10–13*), the wording of the question did not specify that the reported preferred arrival time should be independent of traffic congestion conditions. It was thought that commuters would have already adapted their behavior to the existing congestion patterns and might not be able to separate the congestion factor. Because of the interest in information use and its effect, respondents were asked if they listened to radio traffic reports. Finally, the questions on switching behavior were directed separately at departure time and route for each of the a.m. and p.m. commutes, unlike other studies, which addressed one or the other. It was specified that the changes of interest in either choice were those associated with traffic conditions. The particular survey area is affected by continuing highway construction. Respondents were not asked for the frequency of either type of change, as in Mannering's study (*15*), which asked for the number of monthly route changes and departure time changes. It was believed, and subsequently confirmed in pilot testing, that respondents may encounter definitional problems, especially with regard to what constituted a route change, in addition to the possible unreliability of recall of the exact number of changes. Some of these concerns could be better addressed in a telephone survey, which was used in the Mannering study (*15*), than in a mail survey such as the present one. Much of the motivation for the second-stage survey is to observe, in a longitudinal study, actual changes made by commuters, thereby obviating the need for reliability of recalled responses. Summary statistics for the survey results are presented in Table 1, and the various items asked are explained in greater detail hereafter.

The majority of respondents were male, between ages 30 and 44, and owned their own home. Virtually all (98.8 percent) used their own car to commute to and from work and only 2.4 percent belonged to a carpool. Less than 1 percent of the respondents indicated a steady use of public transportation for their daily work commute, accurately reflecting the sociodemographics of the study area and the difficulty of providing competitive transit service from this essentially suburban area to a diversity of work destinations. Just under one-third of the respondents worked in the CBD, which is dominated by financial and government offices. Another one-third worked in the northern section of the city, outside of the loop, which consists mainly of technology-oriented industries and research laboratories. The remaining third was scattered throughout the surrounding areas, with 12 percent commuting outside of Austin's city limits. The average reported home-to-work trip time was just under 21 min and the return commute averaged slightly more at 24.4 min. The distributions are shown in Figure 2; the differences in the distributions were found to be statistically significant using a chi-squared comparative test.

The majority of the commuters (77 percent) had regular work hours. Only 17 percent indicated flexible work hours, and the rest indicated either scheduled shift work (3.5 percent) or other (2.5 percent). Of those commuters with regular work hours, the majority had work start times between 7:30 and 8:00 and work end times between 4:00 and 5:30 (Figure 3).

TRANSPORTATION SURVEY

|__|__|__|__|__|

Thank you for participating in our survey. Before you begin, are there any other people in the household who also commute to work? If so, please have them complete the additional enclosed survey. Please answer all questions to the best of your knowledge. All answers, of course, will be kept strictly confidential. Thank you.

1. What is your work (parking) address?

________________ Street Address ________ City

2. Do you normally drive your own car (automobile, pick up, van etc) to work? __ Yes __ No

3. If not, how do you normally commute to and from work?
- __ Carpool
- __ Capital Metro (Bus)
- __ Park & Ride
- __ Other ________

4. How would you best describe your work hours?
- __ Regular Work Hours: (____ am to ____ pm)
- __ Scheduled Shift Work
- __ Flexible Hours: (____ hours a week)
- __ Other ________

5. How many minutes before your work actually starts do you prefer to arrive at your workplace? ____ Minutes

6. How important is it for you to not be late to work?
- __ I am expected to arrive on time.
- __ I am allowed to arrive up to ______ minutes late.
- __ It does not matter if I am late.

7. On a typical day, how long is your driving time:
- **from home to work?** ____ Minutes
- **from work to home?** ____ Minutes

8. During your usual drive to and from your workplace, do you listen to:
- **traffic reports on the radio?** __ Yes __ No
- **CB radio for traffic information?** __ Yes __ No

9. Do you normally adjust the <u>time</u> at which you leave specifically with traffic conditions in mind on your trip:
- **from home to work?** __ Yes __ No
- **from work to home?** __ Yes __ No

10. Do you normally modify the <u>route</u> you drive specifically with traffic conditions in mind on your trip:
- **from home to work?** __ Yes __ No
- **from work to home?** __ Yes __ No

The next four questions will only be used in determining our test sample demographics.

1. What is your job title? ________________
(Example: Store Manager, Professor, Secretary, Coach)

2. Do you rent or own your home? __ Rent __ Own

3. What is your gender? __ Male __ Female

4. What is your age? __ Under 18 __ 18-29 __ 30-44 __ 45-60 __ Over 60

Would you be willing to assist in providing more detailed information on your commuting habits? __ Yes __ No

PLEASE RETURN THIS SURVEY IN THE ENCLOSED ENVELOPE, *regardless of whether or not you choose to participate in any further studies. Thank you for your promptness and cooperation. Your assistance will help us better understand the problems of traffic congestion. If you have any questions, please feel free to enclose them or call us at 471-4379. Thank you again for your time and effort.*

FIGURE 1 Mail survey form.

TABLE 1 SUMMARY STATISTICS FOR SURVEY RESULTS

Characteristic	Survey Result
Commuters using their own cars (%)	98.8
Commuters (%)	
With regular work hours	77
With flexible work hours	17
Average PAT (min)	14
Tolerance to Late Arrival at the Workplace (%)	
None	58.5
Unlimited	33.9
Given time (average 19 min)	7.6
Average daily travel time (min)	
From home to work	21.7
From work to home	24.4
Commuters who listen to radio traffic reports (%)	65.8
Commuters who modify their time of departure (%)	
From home to work	54.4
From work to home	31.1
Commuters who switch their route (%)	
From home to work	50.8
From work to home	53.4
Male (%)	62.9
Age (%)	
18–29	8.7
30–44	56.2
45–60	30.3
Over 60	4.7
Commuters renting their residences (%)	12.9

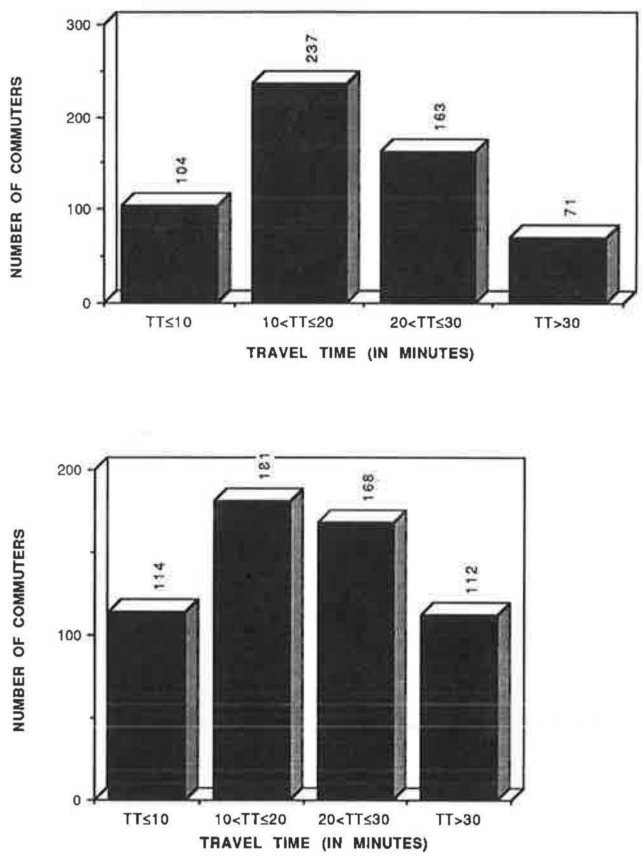

FIGURE 2 Travel time distribution (*top*) for the home-to-work commute and (*bottom*) for the work-to-home commute.

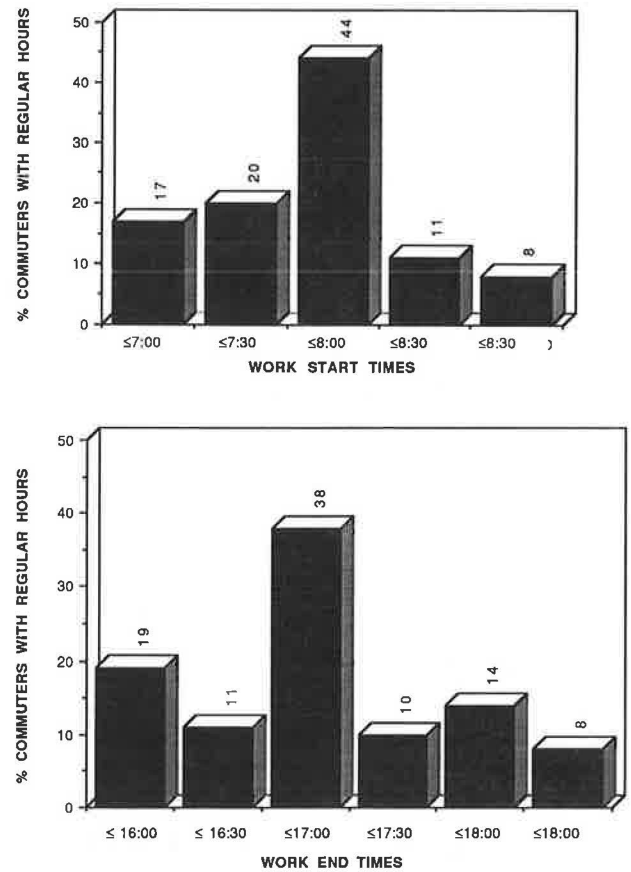

FIGURE 3 Distribution of (*top*) work start times and (*bottom*) work end times for regular commuters.

Those with flexible work hours were split about evenly as indicated in the following table:

Work Hours per Week	*Percentage*
Less than 30	21
30–40	25
41–50	25
51–60	23
More than 60	6

The relatively low fraction of commuters with flexible hours indicates a potential for reducing congestion through peak spreading. In recent simulations of a commuting corridor with real-time in-vehicle information availability, Mahmassani and Jayakrishnan (*20*) found greater potential to reduce congestion through peak spreading (where feasible) than through route control.

Whereas more than half of the respondents stated that there was no tolerance for lateness at their workplace, one-third stated that they had unlimited tolerance (as defined earlier in this section). The remaining 7.6 percent reported a time ranging from 5 to 60 min, with an average of 19 min and a mode of 15 min. Commuters working in the CBD, female commuters, and those with scheduled shift work were more likely to have no lateness tolerance at the workplace, as shown in Figure 4. The data in Figure 4c confirm that commuters with flexible work hours were the least likely to have no lateness tolerance at work. Commuters with work starting times in the congested

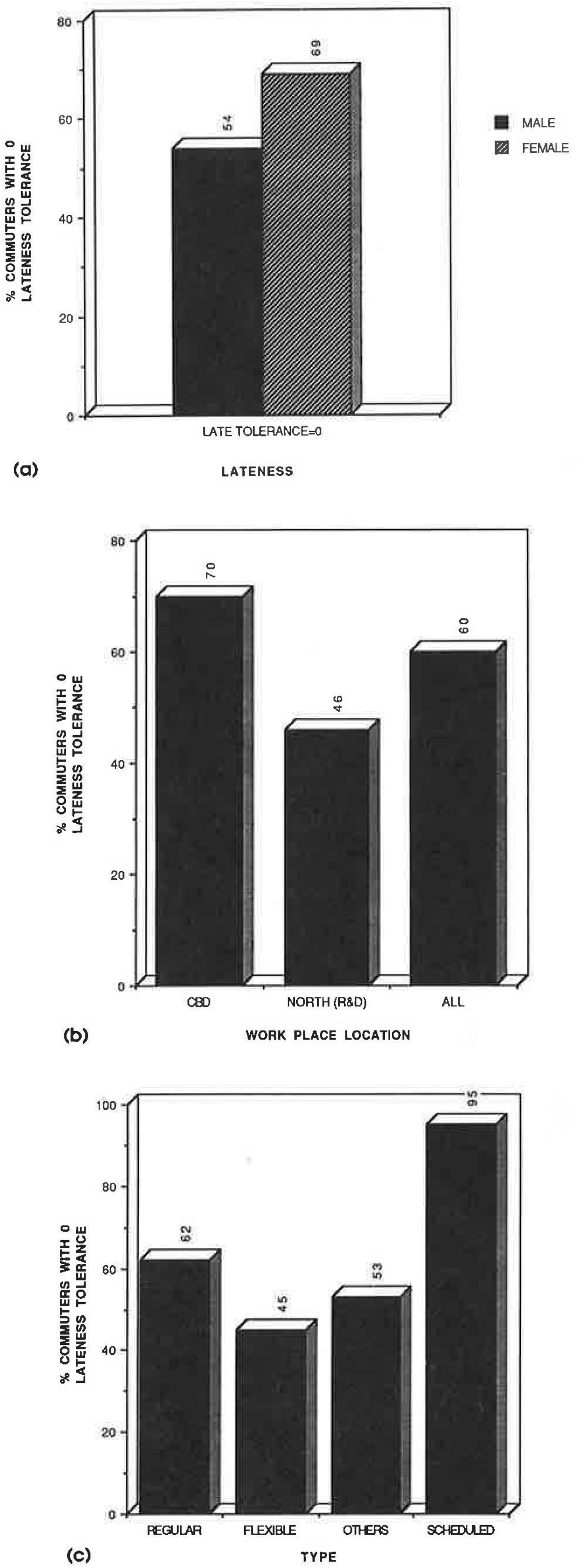

FIGURE 4 Percent of commuters with no lateness tolerance by (*a*) sex, (*b*) work location, and (*c*) type of work hours.

peak period of 7:31 to 8:30 appear to have greater tolerance for lateness at the workplace than commuters outside those peak times, as shown in Figure 5.

Two-thirds of the commuters reported listening to radio traffic reports during their commutes. Those with longer travel times were more likely to listen to traffic reports, because they had more opportunity to use the information and avoid potentially long delays due to traffic conditions. The in-vehicle information fad of the 1970s, CB radio, was reportedly used by only three respondents. No question was included in the first-stage survey on the availability of cellular telephones to obtain traffic information. This item was, however, included in the second-stage survey.

PREFERRED ARRIVAL TIMES

The survey asked for the commuter's preferred arrival time (PAT) at the workplace before work actually starts. PAT was found to be an important determinant of the dynamics of commuter behavior in the previous experiments conducted at the University of Texas (*10*,*12*). It serves as a goal for anchoring users' adjustment of departure time in response to experienced congestion (*21*). In addition, as an indicator of preferences and risk attitudes, it is a good predictor of a commuter's initial indifference band of tolerable schedule delay, which governs the acceptability of the consequences of departure time decisions (*10*,*22*). However, other than in those experiments, no previous attempt has been made to measure this quantity. The results of the present survey are unique in this regard and contribute to characterizing the distribution of this quantity across the commuting population and to identifying the factors that affect it.

The distribution of PAT, expressed as the number of minutes before the official start time, is shown in Figure 6. The average was 14 min and the standard deviation was 13.9 min; 16 percent reported a PAT of zero. Although PAT can be viewed as a reflection of a commuter's individual preferences, it is useful to examine its variation with respect to two factors:

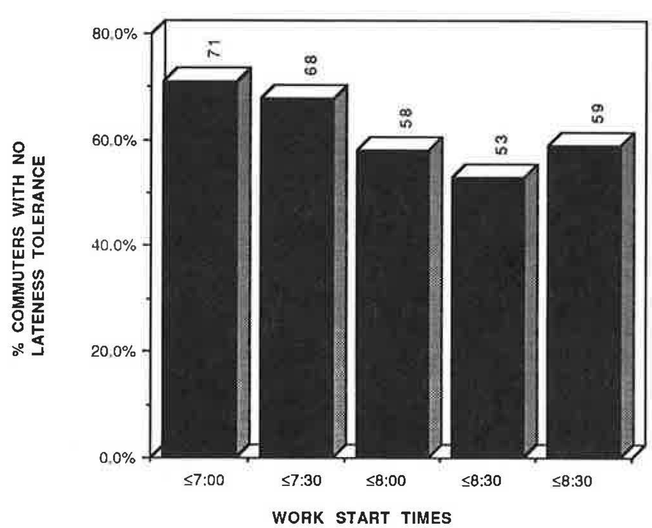

FIGURE 5 Percent of commuters with no lateness tolerance by work start time.

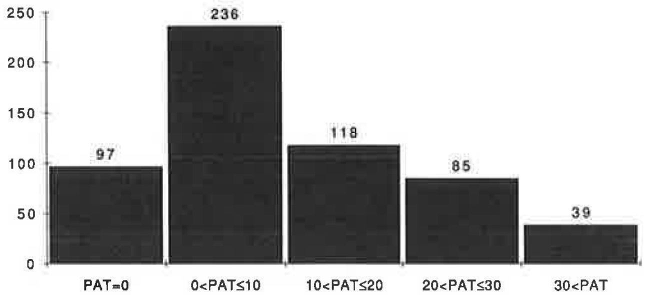

FIGURE 6 Distribution of PAT.

(*a*) the type of work schedules and rules of the workplace and (*b*) the traffic conditions and level of congestion prevailing during the commute. Figure 7a shows the PAT distribution for the four types of work hours described earlier, indicating that those with regular work hours had essentially the same distribution as those with flexible hours. This conclusion was confirmed by a chi-squared test of the corresponding hypothesis. The distributions shown in Figure 7a for those with scheduled shift work and "other" work hours were not meaningful because of the relatively small samples on which they were based.

A more dramatic difference in the PAT distribution was associated with lateness tolerance at the workplace. Figure 7b shows this distribution for commuters with a lateness tolerance of 5 min or less and those with a tolerance of more than 5 min. A chi-squared test indicates that the two distributions are significantly different at any reasonable confidence level. Commuters who work for companies with a lateness tolerance in excess of 5 min exhibited a significantly lower PAT (mean of 9.7 min and standard deviation of 11.9 min) than those with a low tolerance for late arrivals (mean of 16.9 min and standard deviation of 14.4 min). This conforms to intuition—commuters who are not allowed much slack for lateness would rather arrive early than incur a penalty by arriving late. The strong relationship between PAT and lateness tolerance was also reflected in the variation of the PAT distribution with workplace location, shown in Figure 8. Commuters working in the CBD had a higher-than-average PAT, in contrast to those working in the northern areas, due to the differences between work-rule policies in downtown businesses and government offices (no lateness tolerance) and those at the research-and-development and technology-based industries in the suburbs (greater lateness tolerance).

The effect of the second factor, traffic conditions, was examined by testing the variation of the PAT distribution by travel time and by work start times (as an indicator of peak-period congestion). No significant differences were detected with respect to either of these factors. The PAT distribution for different travel time categories, shown in Figure 9, appears to suggest an increasing trend of PAT with travel time. This is probably due to the higher likelihood of encountering congestion and thus experiencing greater trip time variability on longer trips, which the commuter might accommodate by a larger PAT.

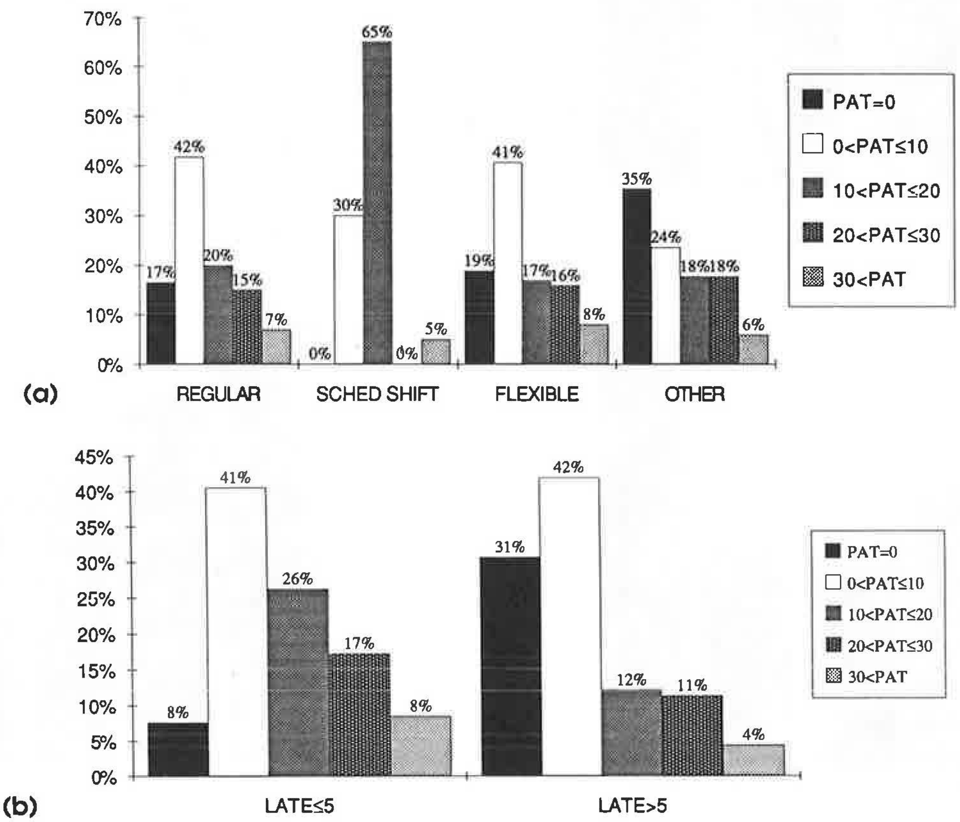

FIGURE 7 PAT distribution (*a*) for different types of work hours and (*b*) under different lateness tolerance policies.

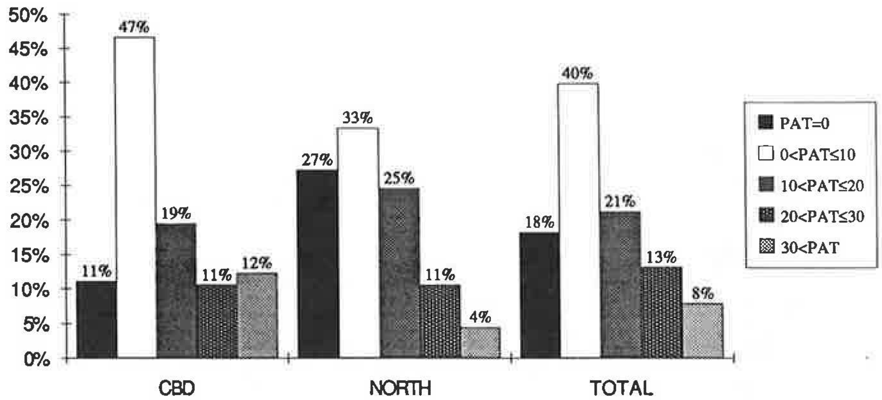

FIGURE 8 Distribution of PAT for different work locations.

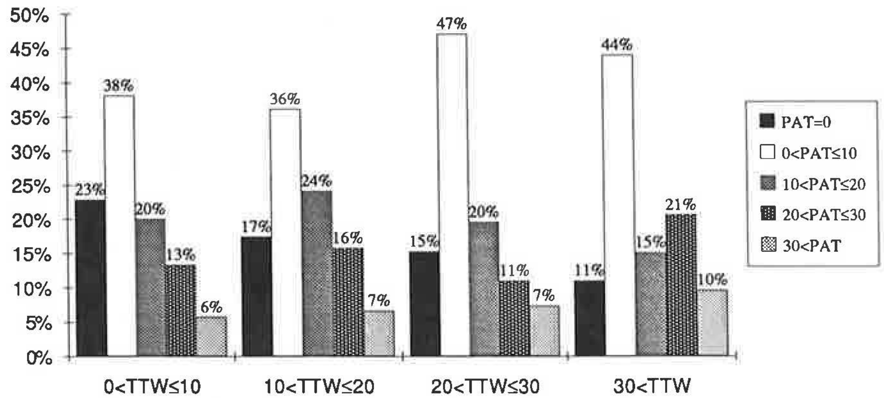

FIGURE 9 Distribution of PAT for different travel time categories.

In the next section, the effect of some of these factors on commuters' propensity to change routes and departure times is examined.

ROUTE AND DEPARTURE TIME SWITCHING

General Characteristics of Reported Switching Habits

The survey asked if the commuter normally adjusted the time of departure or modified the route "specifically with traffic conditions in mind" for both the home-to-work and work-to-home commutes. This wording was chosen to exclude route deviations due to multipurpose trip chains or side trips during the morning and evening commutes. The results are summarized in Table 1. The results indicate that considerably more commuters adjust their departure time for the home-to-work commute than for the return trip. A slightly higher fraction switches routes in the work-to-home commute than in the morning. Interestingly, a significantly larger fraction of commuters reported switching routes than time in the work-to-home commute. Relatively few commuters appear to be willing to delay their departure from work. However, a somewhat larger fraction may adjust departure time than switch routes in going from home to work. These results cannot be compared directly with those of the laboratory experiment reported by Mahmassani and Stephan (*13*). In the latter, the actual numbers of switches were monitored. In the present survey, only a reported indication of whether the commuter deviates from some usual time and route to accommodate traffic conditions is available, and no information is available on the frequency of such switching of either choice.

Additional insight into commuters' habits is obtained by further breaking these results into the following four categories: both route and departure time switching, route only, departure time only, and neither. Figure 10 shows the respective distributions of the home-to-work and return commutes of the four categories. It confirms that few work-to-home commuters change their departure time only, probably because they are not supposed to leave earlier than their work end time, and the vast majority do not appear to be willing to stay longer to avoid traffic. The largest fraction (41 percent) of home-bound commuters changes neither. A chi-squared test confirmed that these differences between the home-to-work and work-to-home distributions are statistically significant at better than the 1 percent level.

The results suggest that the considerations governing home-to-work commuter switching behavior may be different from those governing the work-to-home commute. Similarly, different considerations may affect route versus departure time switching.

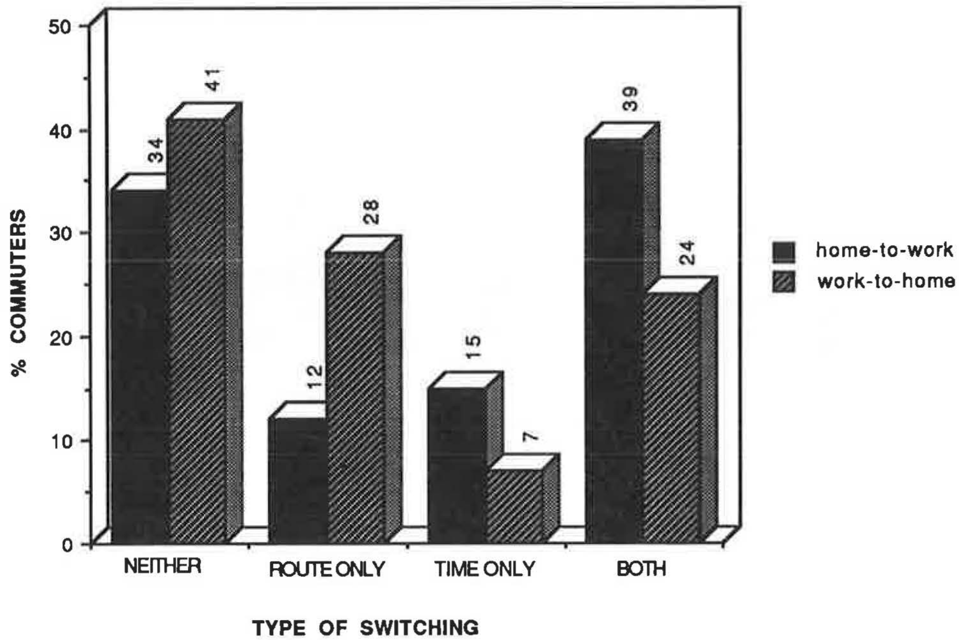

FIGURE 10 Route and time switching for home-to-work and work-to-home trips.

Switching Models: Background

To gain insight into the factors that influence departure time and route switching and the motivations that underlie the asymmetry between a.m. and p.m. commuting, models were calibrated that related the propensity for switching to four principal types of factors: (*a*) characteristics of the commute itself, such as travel time, congestion, and network features; (*b*) work rules, such as lateness tolerance and type of work hours; (*c*) individual characteristics, such as sex, age, and income; and (*d*) information use, captured here by whether or not the commuter listens to radio traffic reports.

A simple formulation was adopted to analyze switching habits. For each of the four decision situations considered (route and departure time switching for a.m. and p.m. separately), the decision to switch was modeled as the result of a latent variable crossing a threshold (*23*). Let Y_i denote the latent variable governing the response of user *i* to a particular decision situation (for example, a.m. route switching). Two states are possible for the response: $d_i = 1$ (i.e., switch) if and only if $Y_i \geq 0$, and $d_i = 0$ (no switching) otherwise. The variable Y_i can be interpreted as the propensity to switch for the particular choice under consideration. It consists of (*a*) a systematic component, which is a function $f(X_i)$ of a vector of attributes X_i of commuter *i*, capturing the four types of factors mentioned previously; and (*b*) a random disturbance term ε_i capturing unobservables that vary across commuters. Thus $Y_i = f(X_i) + \varepsilon_i$. Assuming that the random term ε_i follows the logistic distribution, the probability $\Pr(d_i = 1) = \Pr(Y_i \geq 0)$ is given by the usual binary logit model form (*24*).

In this analysis, different specifications of the function $f(X_i)$ were developed and calibrated separately for the commuters' responses to the a.m. route-, a.m. time-, p.m. route-, and p.m. time-switching questions. All specifications considered were linear in the parameters; thus $f(X_i) = \beta X_i$, where β is a vector of parameters that can be estimated by maximum likelihood. The analysis allows the identification and assessment of the relative importance of the factors influencing propensities for switching route and departure time as well as differences between the home-to-work and work-to-home trips. In interpreting the results, it is important to note that the dependent variable in each case is not an actual decision to switch for a given trip, but the response to the question of whether the commuter normally switches route or departure time. The results are discussed for each of the four cases.

Morning Route Switching

Because the type of work hours (regular versus flexible) was thought to affect commuting behavior in a manner that would not be properly captured by an additive term in the specification of $f(.)$, models were calibrated separately for those commuters with regular work hours and those with flexible or "other" hours. As seen later, this stratification was meaningful—it was not possible to obtain plausible and significant models for those without regular work hours because of the absence of systematic patterns underlying the high degree of variability in their behavior and the relatively small subsample (and sparse exogenous data) available to study it.

Table 2 describes the variables included in the specification of the a.m. route-switching response model along with the corresponding coefficient estimates and *t*-statistic values obtained for commuters with regular work hours. Of the four categories of variables discussed in the previous section (commute characteristics, individual attributes, workplace conditions, and information use), it was found that those describing the characteristics of the commute itself had a dominant effect relative to workplace rules or individual characteristics (captured somewhat weakly with the age variable here). The use of information in the form of radio traffic reports also exerted a strong effect, indicating that regular listeners to traffic reports

TABLE 2 ESTIMATION RESULTS FOR A.M. ROUTE-SWITCHING MODEL FOR COMMUTERS WITH REGULAR WORK HOURS

Variable Description	Estimated Coefficient	t-statistic
Constant	-1.215	-0.63
Travel time (tt), in minutes, if 10 ≤ tt ≤ 35 (0 if tt < 10, 35 if tt > 35)	0.055	3.48
Travel time in excess of 35 minutes (0 if tt ≤ 35)	-0.059	-0.99
Average travel speed, in mph, if 20 < tt ≤ 30 (0 otherwise)	-0.063	-1.00
Alternate route availability indicator (1 if available, 0 otherwise)	1.267	3.19
Age category index (1 if age < 18, 2 if 18≤ age ≤ 29, 3 if 30 ≤ age ≤ 44, 4 if 45 ≤ age ≤ 60, 5 if age > 60)	-0.221	-1.53
Radio traffic report listening indicator (1 if yes, 0 otherwise)	1.090	4.36
Number of observations	372	
Log-likelihood at zero	-257.85	
Log-likelihood at convergence	-227.75	

had a greater propensity to switch routes. This suggests that commuters may deviate from their regular routes in response to in-vehicle information.

With regard to the dominant type of factor affecting a.m. route-switching propensity, commute characteristics, four variables were included in the specification. The first two were reported trip time variables, which together captured some nonlinearities in the effect of trip time. The first nonlinearity was a threshold at about 10 min, below which no systematic pattern could be discerned, thereby providing the base or reference level against which the effect of higher trip times was measured. A further justification for this particular threshold is that the trip time used here was a reported "usual" value, and may thus exhibit some inaccuracy because of perceptual factors, especially for low values. Beyond this threshold, trip time had a significant positive effect on route switching, as expected, because longer trips imply more meaningful savings due to switching and greater exposure to variability due to incidents.

This effect held to about 35 min, when the second nonlinearity appeared. The marginal effect of increasing trip time became negative. The net effect of trip time on the latent propensity (Y_i) remained positive relative to the above-mentioned reference level, though, because of the combined effect of the two trip time variables [the first was set equal to 35 for $tt > 35$, whereas the second was set equal to ($tt - 35$), i.e., the trip time in excess of 35 min]. This nonlinearity reflected a tapering off of the previously mentioned opportunities for improvement; for long trips, there was a tendency for one particular facility to dominate all alternative routes. Although the statistical significance of this coefficient was not particularly convincing, in-depth analysis of the data indicated the necessity to include it in the specification. Statistical significance would undoubtedly improve with a larger sample. Though the particular value at which this nonlinearity appeared was specific to the Austin network (and consistent with the authors' experience), a similar phenomenon may be present in other areas' networks as well. On the other hand, the magnitude of the first threshold, which is rooted in behavioral considerations, is probably more directly transferable to other commuting populations. Both threshold values were first identified, as is usually the case, through exploratory analysis followed by the estimation and testing of alternative model specifications. The estimation model confirmed their significance.

Other than the trip time variables, a powerful explanatory variable is an indicator that captures the availability or abundance of meaningful major route alternatives to the commuter. This particular variable reflects the network under consideration and the relative locations of the origin and destination of the trip. This variable captures the abundance of alternative routes, not the presence of any alternative route. As noted, the sample of commutes was representative of metropolitan commuting patterns in that only part of it was CBD-oriented (the CBD is located to the southeast of the survey area). Nonnegligible proportions of the destinations were located in suburban locations that involved travel in all directions from the survey origin area. In this case, for instance, much of the CBD-oriented travel had access to several alternative facilities for the commute, whereas travel in the northwest or northeast directions had only one major facility to anchor path formation. As expected, the sign of the coefficient of this variable was positive, with high statistical significance, reflecting that an abundance of alternatives increases the propensity to switch routes in the a.m. commute. Although it would have been desirable to have more descriptive variables on the relative quality of the various alternatives, particularly trip time variability, such detailed information was not available for this analysis.

The fourth term included here is a measure of congestion in the form of an estimated average speed for the commute (obtained by dividing an estimated network distance by the reported trip time). Its contribution as a separate term was limited to medium-length trips, for which the data were sufficient to allow a separate estimate for this term. As expected, for a given trip time, the propensity to switch decreased with increasing perceived average speed (i.e., lower congestion). Congestion (captured by the average speed) and the reported trip time were generally positively correlated, precluding the identification of a separate congestion effect other than in the indicated range.

The only sociodemographic attribute included in this model was age. It had somewhat lower statistical significance than the dominant variables, though with the correct sign, confirming that older commuters have less inclination to switch routes. Those variables not included in the specification are equally noteworthy. In particular, sex and job type category had no significant effect on route switching, nor did lateness policies at the workplace, suggesting the preeminence of geographic factors and network conditions, in addition to the use of information, as determinants of route-switching propensity.

These results are generally consistent with and complementary to those of Mannering's Poisson regression model of reported switching frequency by a smaller sample of Seattle commuters (*15*). Though the exact variable definitions were different, the results confirm Mannering's findings on the relative importance of trip time and network condition measures. Similarly, age was significant for both Mannering's and the Austin commuting populations. The principal difference was that sex was definitely not significant in explaining route-switching propensity in the Austin data; it is possible that the effect of sex on the frequency of switching is significant or that the data may be capturing patterns in recall, perceptions, and reporting of frequency by the two sexes.

Morning Departure Time Switching

The specification and estimation results for the departure time-switching propensity of a.m. commuters with regular work hours is presented in Table 3. Compared with the a.m. route-switching model, workplace-related variables and individual attitudes exerted greater influence. Whereas travel time was still significant, geographic variables and other network condition indicators did not yield improved explanatory capability. The threshold effect associated with reported trip times below 10 min was present here as well. However, the nonlinearity beyond 35 min was not present here, as the propensity of departure time switching continued to increase with trip time. Longer commutes offer greater time-savings potential than shorter trips, and switching departure time is possible (and even more important) when there are no route alternatives for the trip.

The new group of variables in this model pertain to the commuter and the workplace. Lateness tolerance at the workplace was discussed in a previous section; a binary indicator variable was included in the specification to capture its effect. The estimated coefficient, which exhibited strong statistical performance, indicates that commuters working in an environment with a high tolerance for late arrivals had lower switching propensity than commuters whose environment is without such tolerance. In the absence of a penalty for late arrival, there appears to be less incentive to change departure times to beat traffic. Beyond its significance for commuting behavior, this finding may have broader implications from the standpoint of the effect of rules at the workplace on the employee's lifestyle, morale, and productivity.

Interestingly, commuters with lateness tolerance who still prefer to arrive at the workplace before the official start time had greater departure time-switching propensity than those, also with tolerance, who prefer to arrive "as work starts." This effect was captured by the PAT variable (for those with tolerance) included in the specification. Apparently, these commuters set a target for themselves and thus behave more like those who do not have such flexibility at work, probably a reflection of inherent preferences and attitudes (work ethic), including risk aversion. A similar effect was captured in the laboratory experiment results of Chang and Mahmassani (*21*). However, considering the effect of this variable together with

TABLE 3 ESTIMATION RESULTS FOR A.M. DEPARTURE TIME-SWITCHING MODEL FOR COMMUTERS WITH REGULAR WORK HOURS

Variable Description	Estimated Coefficient	t-statistic
Constant	-1.267	-3.95
Travel time (tt), in minutes, if tt ≥ 10 (0 if tt < 10)	0.042	3.83
Lateness Tolerance at workplace indicator (1 if yes, 0 otherwise)	-0.891	-3.33
Preferred arrival time, in minutes prior to official work start time, if lateness tolerated at workplace (0 otherwise)	0.025	1.72
Job type indicator for category 3 workers, i.e., with low power or strict schedules (if category 3, 0 otherwise)	0.290	1.15
Radio traffic report listening indicator (1 if yes, 0 otherwise)	0.965	4.19
Number of observations	412	
Log-likelihood at zero	-285.58	
Log-likelihood at convergence	-253.63	

that of the lateness tolerance indicator, it was found that even commuters with lateness tolerance and a large PAT still had lower switching propensity than commuters with no lateness tolerance. A similar PAT term, but for those without lateness tolerance, exhibited no significant explanatory capability.

An attribute that captured both individual attitudes and workplace considerations was the worker's job status and whether the work was constrained to a particular schedule. All job titles reported in the survey were divided into three categories: professionals and supervisors; blue collar and semitechnical; and support, clerical, and schedule-bound. Clearly, those in the third category had less control of their work schedules. Whereas some of this effect was captured by the lateness tolerance variable, an indicator variable for workers in the third category was included in the model, though it exhibited moderate statistical performance. Typical reported job titles included in this category were secretary, teacher, clerk, paralegal, and administrative assistant. Other attributes, such as age and sex, did not exhibit significant explanatory power.

As in the route-switching model, commuters who listen to radio traffic reports had greater propensity to switch their time of departure for work. The statistical performance of this variable was strong, as in the a.m. route-switching model. This effect is important from the standpoint of in-vehicle navigation systems. Whereas one would assume that real-time information might only influence path selection (because the commuter would have already left home), the results obtained here suggest that such information could significantly influence trip timing decisions as well, possibly through repeated exposure to the information over time. This would enhance the desirability of such information, given the previously mentioned relative effectiveness of peak spreading versus route control suggested by simulation results described elsewhere (*20*).

The conclusions pertaining to the effect of trip time are similar to those of Mannering (*15*) (trip time was included in both specifications, though with no threshold effect in the Seattle case). However, there appear to be conflicting indications regarding the effect of "flexibility" at the workplace. Part of the apparent contradiction may be definitional. Mannering included an indicator for "flexible work start time," which exhibited a positive coefficient (i.e., those with flexibility switch more), though with unconvincing statistical significance (*15*). The Austin model explicitly differentiated between commuters with regular and flexible work hours. The results pertain to the former group; the latter group eludes explanation given the sample information. The notion of flexibility included in the Austin model is tolerance for late arrivals relative to the regular work hours. Its effect has consistently emerged with the proper sign and convincing statistical significance. The age and marital status variables, included in Mannering's model, were not significant for the Austin sample.

Evening Route Switching

The specification and estimation results for the p.m. route-switching model are shown in Table 4. Essentially the same variables as the a.m. route-switching model were included in the specification. The principal differences were that the tapering off of route-switching propensity for trip times in excess of 35 min could not be picked up and that there was no need to restrict the effect of average travel speed to medium-length trips. In addition, the specification included the previously described lateness tolerance indicator. Commuters with tolerance appeared to be more inclined to switch routes in the p.m. commute. This may have been due to their ability to leave earlier to take advantage of opportunities on alternative routes or to the capture of other geographic characteristics that could not be otherwise identified. The effect of radio traffic reports on switching propensity remained strong in this case as well.

TABLE 4 ESTIMATION RESULTS FOR P.M. ROUTE-SWITCHING MODEL FOR COMMUTERS WITH REGULAR WORK HOURS

Variable Description	Estimated Coefficient	t-statistic
Constant	-1.227	-1.76
Travel time (tt), in minutes, if $10 \le tt \le 35$ (0 if tt < 10, 35 if tt > 35)	0.046	3.83
Average travel speed, in mph (0 otherwise)	-0.018	-1.01
Alternate route availability indicator (1 if available, 0 otherwise)	0.744	1.96
Lateness tolerance at workplace indicator (1 if yes, 0 otherwise)	0.343	1.44
Age category index (1 if age < 18, 2 if $18 \le$ age ≤ 29, 3 if $30 \le$ age ≤ 44, 4 if $45 \le$ age ≤ 60, 5 if age > 60)	-0.185	-1.09
Radio traffic report listening indicator (1 if yes, 0 otherwise)	1.311	5.129
Number of observations	365	
Log-likelihood at zero	-253.00	
Log-likelihood at convergence	-223.01	

Evening Departure Time Switching

The last model relates the propensity to switch departure time in the p.m. commute to the four types of factors discussed earlier. As noted previously, relatively fewer commuters reported changing the time at which they leave work for home than in the other three decision situations analyzed. Table 5 summarizes the model specification and corresponding parameter estimates. Several differences from the other three cases can be noted. First, the radio traffic report indicator did not significantly influence commuters to change their work leaving time, even though it may have induced them to switch routes. Second, female commuters had a greater propensity to adjust their work leaving time than males, possibly because of more stringent constraints associated with picking up children from school. This finding is consistent with Mannering and Hamed's results in their study of commuters' decisions to delay their work-to-home trips (*16*).

Compared with the a.m. departure time-switching model, this model included additional terms to capture network conditions. Two indicators for work end time captured commuters' greater propensity to adjust their work leaving time when the official work end time falls during the evening peak period. A differential effect appears to be present within the peak. Commuters with later work end times (but still within the congested peak) tended to switch more, possibly because they could avoid the worst by slightly delaying their departure. The alternative route availability indicator was also included in this specification. The positive sign suggests that the same trips for which several alternative routes were available experienced generally higher congestion than the rest of the network. Another difference from the a.m. departure time-switching model was the significance of the PAT for those with no lateness tolerance at the workplace. Commuters with greater PAT and no lateness tolerance were less likely to change their p.m. departure time. This variable appears to capture individual risk preferences. Commuters with high PAT were likely to be more risk averse and thus less likely to want to change the time at which they leave work.

In general, congestion appears to be the major determinant of commuters' propensity to change the time at which they leave work. The majority of commuters do not appear willing to stay later at work to beat the traffic, and most cannot leave earlier. Listening to traffic reports does not appear to exert additional influence on this behavior.

CONCLUDING COMMENTS

The analysis presented in this paper has provided useful insights into the trip making behavior of commuters, particularly with respect to departure time- and route-switching behavior for both the home-to-work and work-to-home commute. The relative effects of geographic considerations, network conditions, rules at the workplace, individual characteristics, and use of information on this behavior were analyzed. Generally, a.m. route switching appears to be primarily motivated by geographic considerations and network considerations rather than by sociodemographic characteristics (other than age) or rules at the workplace. On the other hand, a.m. departure time switching is clearly more influenced by factors such as lateness tolerance at the workplace, job position, and other individual characteristics. For the p.m. commute, congestion is the main motivator for both route and departure time switching. The main asymmetries between a.m. and p.m. were observed for departure time switching.

The use of information, captured through the radio traffic reports indicator, exerted a significant positive effect on the propensity for switching in all cases with the exception of p.m. departure time switching. The indirect implication for in-vehicle information systems is that users who receive such information tend to respond through path selection and may even

TABLE 5 ESTIMATION RESULTS FOR P.M. DEPARTURE TIME-SWITCHING MODEL FOR COMMUTERS WITH REGULAR WORK HOURS

Variable Description	Estimated Coefficient	t-statistic
Constant	-1.396	-3.92
Travel time (tt), in minutes, if tt ≥ 10 (0 if tt < 10)	0.025	2.60
Early PM peak indicator (1 if work end time between 4:45 and 5:45, 0 otherwise)	0.282	1.06
Late PM peak indicator (1 if work end time between 5:46 and 6:15, 0 otherwise)	0.854	2.41
Alternate route availability indicator (1 if available, 0 otherwise)	0.666	1.87
Preferred arrival time, in minutes prior to official work start time, if no lateness tolerance at workplace (0 otherwise)	-0.017	-1.89
Gender (1 if male, 0 female)	-0.557	-2.29
Number of observations	393	
Log-likelihood at zero	-272.4	
Log-likelihood at convergence	-221.7	

adjust their departure time in the morning. However, the scope for spreading the evening peak period (by having commuters with regular work schedules alter their work leaving time) appears to be more limited.

As noted earlier, this analysis is primarily exploratory in nature. The limitations in the data are recognized, and the self-reported nature of the variables used in the analysis introduces unavoidable inaccuracies. Nevertheless, the insights obtained appear plausible and complementary to other findings in the limited body of knowledge available on commuting behavior. It is hoped that this analysis will provide insight into the interaction between the choices. Some of the data concerns have motivated the second stage of the survey, described earlier, which will provide detailed diaries of commuters' actual trip time and path selection decisions, though for a smaller sample. With increasing concern for urban and suburban congestion in cities worldwide and interest in the potential of advanced technologies, it appears that further attention should be directed at commuting and trip making behavior.

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Combined Trip Distribution and Assignment Model Incorporating Captive Travel Behavior

YOU-LIAN CHU

Most of the previous literature on combined trip distribution and assignment problems has focused on the logit and entropy distribution models. Though these models are satisfactory for many applications, they are incapable of handling situations in which the observed trip patterns are represented by both compulsory (captive) and discretionary (free) travel behavior. Consequently, the use of a dogit distribution formula in the construction of a combined trip distribution and assignment model is suggested. The new version of the combined model can itself be reformulated as an equivalent mathematical programming problem so that the equilibrium conditions on the network and the dogit destination demand functions can be derived as the Kuhn-Tucker conditions of the proposed programming problem. Moreover, this equivalent mathematical program turns out to be a convex programming problem with linear constraints, a great advantage from the computational aspect. Numerical experiment indicates that this behaviorally sound combined model can be used in a realistic application at a reasonable cost and within a reasonable time period.

The transportation planning process as currently carried out consists of four major stages: trip generation, trip distribution, modal split, and trip assignment. Planners customarily treat the four stages sequentially as a set of independent problems. The potential drawbacks of this approach are twofold. First, actual interactions among stages are not explicitly accounted for, and biased demand predictions usually result. Second, as far as traffic equilibrium is concerned, the estimates of traffic flows are not always consistent, and, in general, do not converge to a stable solution. These deficiencies suggest that some or all of the stages in the transportation planning process be handled simultaneously or combined.

With this in mind, a combined trip distribution and assignment model is considered in which the solutions of interzonal trips and link flows are solved jointly. Because trip generation and modal split are not treated here, the proposed model should be applied exclusively on the automobile network, and the model requires the total number of automobile trips originating at each zone as input. Generalization of the model to include trip generation and modal split will be the subject of future research.

To some extent, the proposed model may be considered a variation of the combined trip distribution and assignment models that were studied by others (*1–3*). The major difference between the previously developed models and the proposed model is that the latter uses the dogit model (instead of logit- and entropy-type models) to find how observed trips are distributed among the various destinations. The principal reason to employ the dogit model in distribution analysis is because at any time an observed trip pattern is typically composed of at least two types of trips: (*a*) compulsory trips (e.g., work, business, school, etc.) and (*b*) discretionary trips (e.g., shopping, recreation, etc.). Compulsory trips are those that will be made even in the worst conditions. Thus, frequency, destination, and mode are nearly, if not absolutely, fixed. On the other hand, discretionary trips are less regular both in time and space (mainly because they are less economically motivated and are more sociologically and psychologically motivated). For example, these trips may be suppressed by inclement weather, crowded highways, or substitutes that are offered for them.

Because both compulsory and discretionary trips will exist in many travel situations, some people in an urban area are captive to one or more specific aspects of travel, and some are free to make one or more choices. Despite this fact, most existing demand models have failed to explicitly distinguish between captive and free travel behavior. For example, the well-known logit model is structured so that each individual is assumed to exercise a choice for each travel decision to which the model is applied. A clear disadvantage of this assumption is that when the captive travel behavior is observed, the logit estimation will yield errors in parameter estimates and demand predictions. One way to alleviate the estimation problem is to carry out the model calibration with data only for people who have free choice rather than with mixed data. This approach, however, requires a careful preparation of the calibration data, and, most significant, leads to inability to detect the effects of certain transportation policies and actions that may remove captivity for some people or make others captive.

Thus, to take into account captive and free travel behavior, a combined trip distribution and assignment model will be developed in which trip distribution is given by a behaviorally more realistic dogit model. To fulfill this objective, a dogit distribution model will be formulated on the basis of its original individual probabilistic form. After the dogit-type stochastic trip distribution is combined with a deterministic user network equilibrium, an equivalent minimization problem is proposed for which the Kuhn-Tucker conditions include the usual user-equilibrium equations for the basic network and the dogit demand functions for the interzonal trips. Because this equivalent minimization problem turns out to be a convex programming problem with linear constraints, it can be solved

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efficiently by available algorithmic approaches. Finally, a numerical example is presented to demonstrate that the proposed combined model and methodology can be used in a realistic application at a reasonable cost and within a reasonable time period.

MODEL DEVELOPMENT

In this section a new version of the combined trip distribution and assignment model is presented in which the trip distribution is given by a dogit model. To explain the theories and assumptions underlying the proposed combined model, trip distribution and trip assignment models are first described separately and then combined into a single formulation.

The dogit model, as derived independently (*4,5*), is a special case of mixed probability discrete choice (or random utility) models. The functional form of the dogit model is

$$P_{jt} = \frac{\sigma_j}{1 + \sum_k \sigma_k} + \frac{1}{1 + \sum_k \sigma_k} \frac{e^{V_{jt}}}{\sum_k e^{V_{kt}}} \qquad (1)$$

where

P_{jt} = the probability that an individual t randomly drawn from the population will choose the jth of K alternatives,
σ_j = a nonnegative parameter associated with the jth alternative, and
V_{jt} = the systematic utility of the jth alternative.

The dogit model has two distinct features. First, when σ_k, $k \in K$, is not equal to zero for all alternatives in the model, the ratio of the probabilities of choosing any two alternatives will depend on the attributes of all alternatives and hence be unconstrained by the Independence from Irrelevant Alternatives (IIA) property. Furthermore, if $\sigma_k = 0$ holds for some alternatives, the dogit model also allows some pairs of alternatives to exhibit the IIA property, while allowing the remaining pairs to be free from the IIA restriction.

Second, because the parameters σ_k in the model can represent the likelihood of an individual randomly drawn from the population being captive to particular alternatives, the dogit model can distinguish between compulsory (captive) and discretionary (free) travel behavior. To see this, assume that the population under study can be partitioned into $K + 1$ groups (see Figure 1), where K is the number of available alternatives. The jth of K groups represents a group of individuals captive to the jth alternative, whereas the last [i.e., $(K + 1)$th] group represents a group of individuals not captive to any alternative. The first term on the right-hand side of Equation 1 can be interpreted as the probability that a randomly drawn

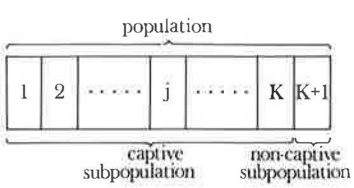

FIGURE 1 Partitioned population.

individual comes from the jth group, in which case the individual is captive to the jth alternative, and thus the probability of the jth alternative being chosen is clearly 1. The second term on the right-hand side of Equation 1 has two parts. The part involving the σ vector can be interpreted as the probability that a randomly drawn individual comes from the last group, and the other is the logit probability model of choosing the jth alternative given that the individual has free choice. The probabilities that a randomly drawn individual may also come from the other groups in K are ignored because in these cases the probabilities of the jth alternative being chosen are zero.

On the basis of Equation 1, the trip distribution model in this paper is specified as

$$T_{ij} = O_i[E(P_{j|i})]$$
$$= O_i \left[\frac{\sigma_{ij}}{1 + \sum_k \sigma_{ik}} + \frac{1}{1 + \sum_k \sigma_{ik}} \frac{e^{V_{ij}}}{\sum_k e^{V_{ik}}} \right] \qquad (2)$$

where

T_{ij} = the number of trips from Origin Zone i to Destination Zone j,
O_i = the fixed and known number of trips leaving from Origin Zone i,
σ_{ij} = a nonnegative parameter representing the odds that population in Origin i is captive to the jth destination,
V_{ij} = the systematic utility function associated with the i-j pair,
$P_{j|i}$ = the probability that a randomly selected individual who originates at Zone i will choose the jth destination, and
$E(P_{j|i})$ = the expected value of P, which will be interpreted as the share of the population originating at i that is attracted to the jth destination.

The trip distribution model formulated in Equation 2 needs some explanation. In discrete choice modeling, the utility function relates the choice probability $P_{j|i}$ to a vector of variables that may include individual characteristics and transportation attributes. Thus, the aggregation process is usually required because the intent is to expand the individual choice estimates to an entire population or subpopulation to obtain a forecast of aggregate shares of alternatives. However, the aggregation process can be ignored if the utility function in the dogit model do not include variables that vary across individuals. This helps explain the reason why the trip distribution model in Equation 2 has a form similar to that in Equation 1, and the expected value of $P_{j|i}$ can be interpreted as the share of the population originating at i that is attracted to Destination j.

To interpret the model in Equation 2, T_{ij} can be viewed as the expected number of trips from Zone i to Zone j in the daily peak-load period, and during that period, the number of compulsory work trips from i to j is given by

$$\frac{O_i \sigma_{ij}}{1 + \sum_k \sigma_{ik}} \qquad (3)$$

The number of discretionary nonwork trips from i to j is given by

$$\frac{O_i}{1 + \sum_k \sigma_{ik}} \frac{e^{V_{ij}}}{\sum_k e^{V_{ik}}} \quad (4)$$

In addition, because the captivity parameters σ_{ij} can be expressed as

$$\frac{\sigma_{ij}}{1} = \frac{O_i \dfrac{\sigma_{ij}}{1 + \sum_k \sigma_{ik}}}{O_i \dfrac{1}{1 + \sum_k \sigma_{ik}}}$$

they are simply the ratios of the number of compulsory trips from i to j and the number of discretionary trips leaving i.

The dogit distribution model constructed in Equation 2 is theoretically more general than the logit distribution model used by Expression 3. This is because by setting all captivity parameters equal to zero (i.e., $\sigma_{ik} = 0 \ \forall \ k \in K$), the logit distribution model can be obtained as a special case of the dogit distribution model. Similarly, the dogit distribution model is more general than the standard entropy distribution model used elsewhere (*2,6,7*), because the latter model is a limiting case of the logit distribution model [see the proof by Safwat and Magnanti (*8*)].

For convenience, the utility functions in Equation 2 will be specified as

$$V_{ij} = M_j - \theta u_{ij} \quad (5)$$

where

M_j = a measure of attractiveness (a constant) associated with the jth destination,
u_{ij} = the travel cost over the shortest path connecting the i-j pair, and
θ = the parameter associated with u_{ij}.

Trip Assignment Model

Given a network of links and nodes and a trip table listing trips between all pairs of zones, the trip assignment problem is concerned with the allocation of the trips to the network links. In this paper, the driver's behavior on a road network is assumed to follow Wardrop's first principle. The principle states that, at equilibrium, the average travel cost on all used paths connecting any given i-j pair will be equal, and the average travel cost will be less than or equal to the average travel cost on any unused path (*9*). In the transportation literature, the flows that satisfy this principle are said to be a user-equilibrium or user-optimal flow pattern. The mathematical expression equivalent to user equilibrium can be stated as follows:

$$(c_p^{ij} - u_{ij})h_p^{ij} = 0 \quad \forall \ i, j, p \quad (6)$$

$$(c_p^{ij} - u_{ij}) \geq 0 \quad \forall \ i, j, p \quad (7)$$

where

c_p^{ij} = the average travel cost of Path p between Origin i and Destination j,
u_{ij} = the minimum (or equilibrium) travel cost between i and j, and
h_p^{ij} = the flow on Path p connecting the i-j pair.

Equations 6 and 7 imply that users' behavior is deterministic. Route choice might be treated more realistically as stochastic, as was trip distribution choice. Nevertheless, the deterministic assumption is reasonable for congested network systems (*10*). The major reason is that as congestion increases, the differences between alternative routes are more accurately perceived by users, and, hence, the route choice approaches the deterministic equilibrium solution.

Now, if Equations 6 and 7 are combined with the conservation of flow conditions

$$\sum_p h_p^{ij} = T_{ij} \quad \forall \ i, j \quad (8)$$

and the corresponding nonnegativity constraints

$$h_p^{ij} \geq 0 \quad \forall \ i, j, p \quad (9)$$

they constitute a quantitative statement of user-equilibrium conditions.

It is well known (*11*) that these equilibrium conditions can be interpreted as the Kuhn-Tucker conditions for an equivalent minimization problem, which is

$$\min Z(f) = \sum_a \int_0^{f_a} c_a(w)dw \quad (10)$$

subject to Constraints 8 and 9, and a definitional constraint,

$$f_a = \sum_i \sum_j \sum_p \delta_{ap}^{ij} h_p^{ij} \quad \forall \ a \quad (11)$$

where

f_a = the flow on Link a,
$c_a(f_a)$ = the average travel cost per trip on Link a for Flow f, and
δ_{ap}^{ij} = 1 if Link a belongs to Path p from i to j, and 0 otherwise.

Combined Trip Distribution and Assignment Model

The equilibrium trip assignment model described above is used for a fixed distribution of trips. In this case, because demand is constant, travelers will not alter their destination even when faced with the additional costs that travel to a specific destination entails. This counterintuitive travel behavior leads to consideration of a combined trip distribution and assignment model in which the trip flows of origin-destination (O-D) pairs will respond to changing network flow conditions. The proposed equilibrium distribution assignment model combines a dogit-type stochastic trip distribution with deterministic network equilibrium and is specified as follows:

$$T_{ij} = O_i\left(\frac{\sigma_{ij}}{1 + \sum_k \sigma_{ik}} + \frac{1}{1 + \sum_k \sigma_{ik}} \frac{e^{M_j - \theta u_{ij}}}{\sum_k e^{M_k - \theta u_{ik}}}\right) \quad \forall i, j \tag{12}$$

$$(c_p^{ij} - u_{ij})h_p^{ij} = 0 \quad \forall i, j, p \tag{13}$$

$$c_p^{ij} - u_{ij} \geq 0 \quad \forall i, j, p \tag{14}$$

This equilibrium model will be called the combined dogit trip distribution and assignment (CDDA) model in the following discussion. Equations 12, 13, and 14, when combined with the flow conservation conditions

$$\sum_p h_p^{ij} = T_{ij} \quad \forall i, j \tag{15}$$

the two corresponding nonnegativity constraints

$$h_p^{ij} \geq 0 \quad \forall i, j, p \tag{16}$$

$$T_{ij} \geq \sigma_{ij} O_i/(1 + \sum_k \sigma_{ik}) \quad \forall i, j \tag{17}$$

and one definitional constraint (Equation 11), constitute a quantitative statement of user equilibrium conditions for the CDDA model. The equilibrium conditions (Equations 11–17) state that at equilibrium, a set of O-D trip flows and path flows must satisfy the following requirements:

1. The O-D trip flows satisfy a distribution model of the dogit form (Equation 12).
2. The path flows are such that the user-equilibrium criterion is satisfied (Equations 13 and 14).
3. The O-D trip flow between i and j equals the total trip flows generated from i (resulting from summation over j on both sides of Equation 12).
4. The flows on all paths connecting each i-j pair equal the O-D trip flow between i and j (Equation 15).
5. Each path flow is nonnegative (Equation 16).
6. Each O-D trip flow is equal to or larger than its corresponding O-D compulsory trip flow (Equation 17).
7. The definitional relationship between path and link flows is satisfied (Equation 11).

All used paths between each O-D pair must have equal path costs. These costs represent the minimum path costs, and the O-D trip flows are in equilibrium determined by the minimum path costs.

EQUIVALENT MINIMIZATION PROBLEM

To solve the equilibrium of the CDDA model, the approach is to show that an equivalent minimization problem (EMP) exists whose solutions satisfy the equilibrium conditions (Equations 11–17). Consider the following minimization problem:

$$\min Z(T, f) = G(T) + F(f) \tag{18}$$

such that

$$\sum_j T_{ij} = O_i \quad \forall i \tag{19}$$

$$\sum_p h_p^{ij} = T_{ij} \quad \forall i, j \tag{20}$$

$$h_p^{ij} \geq 0 \quad \forall p, i, j \tag{21}$$

$$T_{ij} \geq \sigma_{ij}\, O_i/(1 + \sum_k \sigma_{ik}) \quad \forall i, j \tag{22}$$

where

$$G(T) = \frac{1}{\theta} \sum_i \sum_j \left[\left(T_{ij} - \frac{\sigma_{ij} O_i}{1 + \sum_k \sigma_{ik}}\right) \times \ln\left(T_{ij} - \frac{\sigma_{ij} O_i}{1 + \sum_k \sigma_{ik}}\right) + \left(T_{ij} - \frac{\sigma_{ij} O_i}{1 + \sum_k \sigma_{ik}}\right) \times \ln\left(\frac{1 + \sum_k \sigma_{ik}}{O_i}\right) - T_{ij} M_j - T_{ij}\right] \tag{23}$$

$$F(f) = \sum_a \int_0^{f_a} c_a(w)dw \tag{24}$$

$$f_a = \sum_i \sum_j \sum_p h_p^{ij} \delta_{ap}^{ij} \quad \forall a \tag{25}$$

In this formulation, the objective function (Equation 18) comprises two sets of terms. The first set, $G(T)$, has as many terms as the number of O-D pairs in the network. Each term, $G_{ij}(T)$, is a function of the number of trips T_{ij} distributed from a given origin i to a given destination j. The second set, $F(f)$, has as many terms as the number of links in the network. Each term, $F_a(f)$, is a function of the flows over all paths that share a given link a [as implied by the link-path incidence relationships (Equation 11)].

Equations 19 and 20 are flow conservation constraints, which state, respectively, that the number of trips distributed from i to all j's must equal the number of trips generated from i and that the number of trips on all paths connecting each i-j pair must equal the number of trips distributed from i to j. Equation 21 represents the flow nonnegativity constraints required to ensure that the solution of the program is physically meaningful. Constraint 22 is required to ensure that the objective function is well defined. (Because $O_i \geq 0$ and $\sigma_{ik} \geq 0$ for all k, Contraint 22 implies that T_{ij} is greater than or equal to a nonnegative constant.) Finally, the link-path incidence relationships (Equation 25) express the link flows in terms of the path flows [i.e., $f = f(h)$].

The importance of the EMP (Equations 18–25) is that even with mild assumptions imposed on the problem data, it is a convex program, which has a unique solution that is equivalent to equilibrium on the proposed CDDA model. The formal proof of this result is given elsewhere (*12*), but it is worth mentioning that the equivalence between the EMP and the CDDA model can be established by examining the optimality conditions of the EMP.

PARAMETER CALIBRATION AND SOLUTION ALGORITHM

Dogit Model Estimation

The dogit distribution model specified in Equations 2 and 5 contains several free parameters that must be estimated, that is, σ, M, and θ. The dogit model parameters will be estimated using the maximum likelihood (ML) method. By assuming that all the values of variables in the utility function are the same for each traveler in a particular zone and that the sample is composed of zonal values, the likelihood function of the observed sample is given by

$$L = \frac{T!}{\prod_i \prod_j T_{ij}!} \prod_i \prod_j \bar{P}_{j|i}(\sigma, M, \theta)^{T_{ij}} \qquad (26)$$

where T is the total number of travelers (equal to $\Sigma_i \Sigma_j T_{ij}$) and $\bar{P}_{j|i} = T_{ij}/O_i$. The ML estimates of the parameters are obtained by taking the derivatives of the logarithm of L with respect to σ, M, and θ, equating the derivatives to zero, and solving for σ, M, and θ.

Three observations are made concerning dogit model calibration. First, an identification problem will result when calibrating the dogit distribution model. In general, if N zones are encompassed in the model, there are only $N^2 - N$ parameters that can be identified in the estimation.

Second, the number of parameters that must be estimated increases rapidly as the number of zones increases. This can be a serious problem in typical network analysis, where the observed number of O-D pairs is usually large. The usual way to reduce computational costs is to impose some reasonable constraints on the captivity parameters (*12*).

Third, because the log likelihood function of Equation 26 lacks concavity (*13,14*), the estimation must proceed with great care because multiple maxima or saddle points or both may be encountered. In this case, the appropriate way to check the global maximum may be to carry out several searches, using a different initial point each time. The main purpose of this process is to search for alternative maxima and establish a convincing case for the global maximum.

Evans Algorithm

Once the parameter values are obtained, the EMP can be readily solved by appropriate algorithmic procedures to yield the desired equilibrium on the CDDA model. Because the EMP is virtually a convex programming problem, the well-known Frank-Wolfe (*15*) and Evans (*2*) algorithms can be used to solve the equilibrium problem.

In this study, the Evans algorithm is selected for three reasons. First, in contrast to the Frank-Wolfe algorithm, in which only one destination is loaded at each iteration, the Evans algorithm ensures that every destination will be loaded with trips from each origin at every iteration. Thus, the Evans algorithm is more efficient than the Frank-Wolfe algorithm for the usual combined trip distribution and assignment problems.

Second, the objective function of the subproblem in the Frank-Wolfe algorithm is derived from the linearized objective function of the EMP (Equation 18). The objective function in the Evans subproblem, on the other hand, involves a partial linear approximation in the sense that the link cost functions in Equation 18 are linearized but the remaining functions are not. As Florian (*16*) has remarked, the feasible direction derived from partial linear approximation is better than linear approximation because the subproblem in the Evans algorithm used for finding the direction of descent is closer to the original EMP. The solution of the Evans algorithm would, therefore, require fewer iterations than the Frank-Wolfe algorithm.

Third, each iteration of the Evans algorithm computes an exact solution for equilibrium conditions of the CDDA model, whereas in the Frank-Wolfe algorithm, none of the equilibrium conditions is met until final convergence. This has an important implication in large-scale network applications because it is often unlikely that either the Evans or the Frank-Wolfe algorithm will be run to exact convergence because of the high computational costs involved.

NUMERICAL EXAMPLE

In this section the CDDA model and its associated methodology will be applied to a hypothetical transportation system. Two computer programs were written; one was used to estimate the parameters of the dogit trip distribution model, and the other was for the solution algorithm used to obtain simultaneous prediction of equilibrium in the CDDA model.

The hypothetical highway network, which consists of 6 nodes and 20 links, is shown in Figure 2. Two of the nodes are assumed to be intermediate, and the rest are origins or destinations (or both) defining 16 O-D pairs, as shown in Table 1. Table 1 also gives the travel demand associated with each O-D pair. Table 2 gives the following information for each link: name of the "from" node, name of the "to" node, link capacity, and free-flow (uncongested) travel time. [The travel time (t_a) is used as a proxy for the cost variable (c_a).]

To implement the CDDA model, the utility function (V_{ij}) in the trip distribution model must be specified as well as the link performance function [$c_a(f_a)$] in the trip assignment model. For the Evans algorithm to work, the link performance function must be monotonic increasing. To this end, a standard function developed by the U.S. Bureau of Public Roads (*17*) is used. The performance function has the following form:

$$t_a = t_a^0 \left[1 + \alpha\left(\frac{f_a}{p_a}\right)\right]^{\beta} \quad \forall\, a \qquad (27)$$

where

t_a = congested travel time on Link a,
t_a^0 = uncongested (free-flow) travel time on Link a,

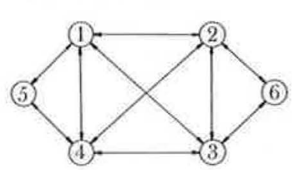

FIGURE 2 Hypothetical network example.

TABLE 1 LIST OF O-D PAIRS

O-D No.	Origin	Destination	Observed O-D Trip Flows
1	1	1	40.0
2	1	2	100.0
3	1	3	30.0
4	1	4	150.0
5	2	1	100.0
6	2	2	50.0
7	2	3	170.0
8	2	4	30.0
9	3	1	130.0
10	3	2	280.0
11	3	3	50.0
12	3	4	210.0
13	4	1	170.0
14	4	2	200.0
15	4	3	350.0
16	4	4	60.0

TABLE 2 HYPOTHETICAL LINK DATA

Link No.	From	To	Link Capacity	Free-Flow Travel Time
1	1	2	100.0	22.0
2	1	3	100.0	43.0
3	1	4	150.0	24.0
4	1	5	200.0	12.0
5	2	1	100.0	13.0
6	2	3	110.0	23.0
7	2	4	50.0	34.0
8	2	6	200.0	12.0
9	3	1	190.0	25.0
10	3	2	150.0	29.0
11	3	4	300.0	24.0
12	3	6	200.0	15.0
13	4	1	150.0	16.0
14	4	2	300.0	23.0
15	4	3	400.0	19.0
16	4	5	100.0	12.0
17	5	1	100.0	12.0
18	5	4	50.0	12.0
19	6	2	300.0	15.0
20	6	3	200.0	12.0

f_a = the flow (volume) on Link a,
p_a = the "practical" capacity of Link a, and
α, β = parameters whose usual values are 0.15 for α and 4 for β.

For convenience, the utility function in the trip distribution model is assumed to be linear in the parameters and has the form

$$V_{ij} = -\theta_1 u_{ij} + \theta_2 M_j \tag{28}$$

where

u_{ij} = travel cost over the shortest path connecting the i-j pair,
M_j = attractiveness of Zone j, and
θ_1, θ_2 = parameters to be estimated.

The M_js originally specified in Equation 5 were a set of alternative-specific constants. But for the sake of reducing the number of parameters to estimate, the M_js are treated as the explanatory variable in Equation 28 and associated with a single parameter θ_2. The above treatment is purely for simplicity in this study, but in practical applications the omission of constant terms in the utility function should be avoided whenever possible. This is because the inclusion of constant terms not only can compensate for sampling and measurement errors, but also can capture the mean effects of unobserved or unmeasured variables that describe the unique characteristics of the choice alternatives.

For convenience, the attractiveness of Zone j in Equation 28 is measured by the employment density (employees per acre) in Zone j. If other measures, such as population and area, are used for the representation of zonal attractiveness, the variable M_j must be replaced with a linear function of those measures with unknown parameters inside a log operation (*18*).

Given the data of O-D trip flow (Table 1), travel cost over the shortest path connecting each O-D pair (Table 3), and zonal employment density (Table 3), the calibration results for the dogit distribution model are shown in Table 4, and the estimated O-D compulsory and discretionary trip flows are shown in Table 5.

Given the estimated coefficient values and the data provided in Tables 1 and 2, equilibrium on the hypothetical transportation system can be predicted. The prediction procedure was required to stop when the changes in O-D trip flows and link flows between successive iterations were negligible or when the number of iterations reached 20. The final equilibrium results in Table 6 are those of the 12th iteration.

As indicated in Table 6, the equilibrium results of the example appear reasonable in that (*a*) the predicted number of trips between each i-j pair is larger than the corresponding estimated number of compulsory trips, implying that existing O-D compulsory trip flows will remain unchanged regardless of congestion potentially occurring on the network; (*b*) there are no positive flows on paths with higher than the minimum perceived costs, indicating that the user optimization principle is well satisfied; and (*c*) predicted O-D trip flows and minimum O-D path costs have values similar to those observed.

The value of the objective function in the Evans algorithm consistently decreased from one iteration to the next in all the runs. In particular, the improvement in the value of the

TABLE 3 HYPOTHETICAL DATA FOR MODEL CALIBRATION

Origin	Destination	Observed O-D Minimum Path Travel Time	Observed Employment Density
1	1	30.0	25.0
1	2	25.0	35.0
1	3	45.0	40.0
1	4	25.0	25.0
2	1	15.0	25.0
2	2	30.0	35.0
2	3	25.0	40.0
2	4	35.0	25.0
3	1	25.0	25.0
3	2	30.0	35.0
3	3	50.0	40.0
3	4	25.0	25.0
4	1	20.0	25.0
4	2	25.0	35.0
4	3	20.0	40.0
4	4	50.0	25.0

TABLE 4 DOGIT ESTIMATION RESULTS

Model Parameters	Estimated Coefficient Values
θ_1	-0.12
θ_2	0.08
σ_{11}	NI*
σ_{12}	0.27
σ_{13}	NI*
σ_{14}	0.96
σ_{21}	0.33
σ_{22}	NI*
σ_{23}	0.84
σ_{24}	NI*
σ_{31}	0.30
σ_{32}	0.96
σ_{33}	NI*
σ_{34}	0.69
σ_{41}	0.45
σ_{42}	0.51
σ_{43}	0.69
σ_{44}	NI*
log-likelihood at zero	-2938.943
log-likelihood at convergence	-2600.262

Note: NI* = not identifiable.

TABLE 5 COMPARISON BETWEEN OBSERVED AND ESTIMATED O-D TRIP FLOWS

O-D Pairs	Observed O-D Total Trip Flows	Estimated O-D Total Trip Flows	Estimated O-D Compulsory Trip Flows	Estimated O-D Discretionary Trip Flows
1-1	40.0	40.72	24.34	16.38
1-2	100.0	99.29	32.85	66.44
1-3	30.0	33.33	24.33	9.00
1-4	150.0	146.66	116.81	29.85
2-1	100.0	100.33	44.94	55.39
2-2	50.0	47.61	27.24	20.38
2-3	170.0	169.79	114.40	55.39
2-4	30.0	32.26	27.25	5.01
3-1	130.0	126.61	63.81	62.80
3-2	280.0	280.90	204.19	76.71
3-3	50.0	52.92	42.54	10.38
3-4	210.0	209.57	146.76	62.81
4-1	170.0	172.30	123.16	49.14
4-2	200.0	199.61	139.58	60.03
4-3	350.0	352.01	188.84	163.17
4-4	60.0	56.08	54.74	1.34

objective function during the first five iterations was substantial and tended to be insignificant during the following iterations. This result may suggest that a reasonably accurate solution can be obtained in no more than 10 iterations. Finally, because the hypothetical example had a much smaller number of links and nodes than real-life networks, it is somewhat difficult to extrapolate the CPU time necessary to run the CDDA model in actual applications. Nevertheless, because the CDDA model adds few simple arithmetic operations in the Evans algorithm, the computational time should be comparable with the time required to solve any of the existing combined models.

TABLE 6 DOGIT EQUILIBRIUM RESULTS

Trip Distribution

Origin	Destination	Predicted O-D Trip Flow	Predicted Minimum O-D Path Cost
1	1	40.33	F*
1	2	98.43	25.09
1	3	34.31	44.06
1	4	146.92	24.89
2	1	98.44	14.83
2	2	46.16	F*
2	3	172.77	24.19
2	4	32.63	33.90
3	1	129.22	24.77
3	2	276.54	30.99
3	3	52.93	F*
3	4	211.31	24.89
4	1	172.56	20.20
4	2	209.51	23.82
4	3	341.86	20.60
4	4	56.08	F*

Trip Assignment

Link No.	From	To	Predicted Link Flow	Predicted Link Cost
1	1	2	98.43	25.09
2	1	3	30.51	44.06
3	1	4	106.01	24.89
4	1	5	44.72	12.00
5	2	1	98.44	14.83
6	2	3	84.22	24.19
7	2	4	32.63	33.90
8	2	6	88.55	12.07
9	3	1	129.22	24.77
10	3	2	123.49	30.99
11	3	4	211.31	24.89
12	3	6	153.06	15.77
13	4	1	172.56	20.20
14	4	2	209.51	23.82
15	4	3	345.66	20.60
16	4	5	0.00	12.00
17	5	1	0.00	12.00
18	5	4	44.72	13.15
19	6	2	153.06	15.15
20	6	3	88.55	12.07

Note: F* = fixed intrazonal path cost.

CONCLUSIONS

The most important feature of the proposed combined trip distribution and assignment model is that the equilibrium O-D trip flows satisfy a dogit model that is able to describe users' compulsory and discretionary travel behavior in response to performance on a transportation network. Thus, the proposed model should be more sound behaviorally than any of the other combined trip distribution and assignment models reported in the literature. Moreover, because the model can itself be reformulated and solved by an EMP and because this problem is a convex programming problem with linear constraints, it can be solved efficiently by several algorithmic approaches that are available for such problems. In particular, when applying the Evans algorithm to the equilibrium problem, the proposed combined model should be usable in a realistic application at a reasonable cost and within a reasonable time period. To verify this expectation, future research should focus on the application of the model to a real large-scale network.

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Stated Preference Analysis of Values of Travel Time in the Netherlands

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A major program undertaken by Hague Consulting Group on behalf of the Dutch Ministry of Transport and Public Works is summarized. The topic investigated was travelers' valuations of savings or losses in travel time, often referred to as "value of time." Theory and previous research are outlined. The design of the study, including stated preference and revealed preference analyses, are summarized, and empirical results are presented. A number of conclusions are provided. The emphasis is on the stated preference data collection and analysis. The study provided monetary values of time changes that vary simultaneously along several household, personal, and situational dimensions, including the level of traffic congestion and the amount of free time and income available. The results contain the appropriate variables that, together with forecasts from the Netherlands National Traffic Model, can be applied to provide economic policy evaluations at a detailed level.

A major program of applied research undertaken by Hague Consulting Group on behalf of the Dutch Ministry of Transport and Public Works is described. The topic investigated was travelers' valuations of savings or losses in travel time. The context of the research was one in which substantial professional and public interest had been focused on rising congestion on the major road network in the Netherlands and in which a series of national forecasts anticipated large increases in both car traffic and congestion, even with a substantial program of road building. Two major factors causing the growth are (*a*) expectations that ownership of cars by the elderly (the middle-aged of the 1980s) will be far higher than at present and (*b*) expectations that the availability of cars to women and their possession of drivers' licenses will increase along with their participation in the work force (*1*).

Because of the prospect of large increases in travel time, several major initiatives were under way to investigate measures (including road pricing) to accommodate increasing mobility and reduce time losses in traffic congestion. The costs and benefits of the measures will eventually be appraised for periods up to 25 years in the future.

Assuming that wealth and leisure increase for all, the shifts in the composition of the Dutch traveling population (by age, sex, occupation, income, and so on) can be expected to affect the overall average valuation of gains or losses in travel time, but in an initially unknown manner.

The purpose of the research reported here was to provide empirical evidence for the different valuations of subgroups of travelers in today's circumstances in a form that would allow future valuations to be generated for different scenarios. This information was required to establish guidelines for evaluating projects concerned with investment in, or control of, transportation systems in the Netherlands. The principal aim was to contribute to formal evaluations, including (but not restricted to) formal cost-benefit appraisals in which the costs of a project are compared with the potential benefits, including changes in travel time, accident rates, and operating costs, all converted to monetary values.

The theoretical background for the study will be discussed briefly. The data sets assembled for the study will be described, with the focus on the "stated preference" (SP) information. The analysis results will be discussed and final conclusions and recommendations will be given.

The emphasis is on the SP research and results. A more detailed treatment of the theoretical background for the study and of the application of the research findings can be found in the final project report (*2*) and will be the topic of future publications.

THEORETICAL BACKGROUND

The theory of valuing future travel-time savings rests on a number of hypotheses about how individuals prefer to divide their time between different activities and how these preferences relate to decisions. The hypotheses generate broad rules for predicting which factors influence behavior and what general effect they have. The results can only be made specific through observing actual (or intended) behavior, which can be analyzed to reveal which actual factors are involved and how much each factor contributes to the decision.

The relevant economic theory focuses on the different mixes of activities available to the individual and the financial consequences of each distinct mix. The individual (it is supposed) allocates time between these activities to maximize personal satisfaction, or utility. Different schedules can allocate more time to one activity by saving time from others. Of course, time is never "saved" in the sense of "stored" (unlike money); it can only be transferred from one activity to another.

It is also assumed that such transfers have a money equivalent—an individual with a particular preferred schedule can derive the same overall satisfaction from a less attractive schedule if compensated by the necessary amount of money. Conversely, if circumstances place constraints on the best schedule available to the individual, it is assumed that the individual is willing to pay some amount of money to relax those constraints. (The assumptions are, of course, to be tested against actual behavior, and could be rejected in circumstances where it was found that this sort of trading did not occur.)

This is the basic notion behind a value of travel-time savings. It is seen that people often would rather pursue other

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activities than travel, and they would accordingly pay to shorten journey times. This effect can be seen in many travel markets, where speed can be purchased at a price (e.g., air versus land transportation); however, in the case of highway systems or where options are limited, the extent of the traveler's willingness to pay is unclear.

Authorities who wish to take investment or management decisions involving the expenditure of public money to achieve time savings (or avoid losses) and who wish to be guided by knowledge of travelers' willingness to pay for time savings, must resort to indirect means to establish appropriate values. This is the basic motivation behind this study (and its many predecessors).

The theoretical basis for this study is presented and worked out in some detail in the final project report (*2*), which applies ideas from conventional economic theory to decisions about activity patterns, including travel. The basic assumptions are as follows:

1. In dividing their time between different activities, including travel, people act consistently to maximize their satisfaction, as perceived by themselves. This is done within the limits set by available budgets of time and money. Options are evaluated and the most satisfying will be chosen.
2. In making decisions concerning travel options, such as choosing between train and car for a given journey or between different routes to the same destination, the utility of an option (for a given individual) can be approximately represented by a linear function of the time costs and the money costs associated with that option plus an "intrinsic" utility for that option regardless of journey duration or cost. It follows from this assumption that, subject to some constraints, time and money can be traded at a certain rate of exchange that will leave the individual no more or less satisfied.
3. The relative importance (utility coefficients) of travel time and cost should vary systematically between different groups of individuals and different types of travel options. In particular, the disutility of travel time should be related to the individual's external time pressures as well as to the comfort of travel by the option under consideration, and the disutility of travel cost should be closely related to available income. The intrinsic utilities of specific travel options are likely to be distributed more widely across the population.
4. A number of other ideas follow from the theoretical treatment. In particular, ideas have been developed about background variables that should be examined because they reflect systematic differences in time-cost trade-off ratios, especially for the scenarios being forecast for the Netherlands for the coming 10 to 25 years. Amounts of free time and levels of congestion and reliability emerge as important factors to consider in the study, in addition to more standard factors such as age, sex, income, occupation, household type, purpose of journey, and mode of travel.

DATA SETS ASSEMBLED

Introduction

During the more than 30 years the topic has been investigated, the classical source for estimates of travelers' rates of trading off travel time and cost has been actual behavior, so-called revealed preferences (RPs).

Such investigations have been carried out on the basis of observations of travel behavior as interpreted through formal mathematical models based on accepted microeconomic theory. In practice, both the theory and the derived models have been highly simplified, asserting that the relative attractiveness of two travel options (be they modes, destinations, or routes) is a simple function of their travel-time differences and their cost difference. On the basis of this theory, the major problem for the typical "value-of-time" study of the 1960s and 1970s was to find a suitable observational basis, a travel-based context clearly dominated by a choice between speed and economy.

By the mid-1980s, when the Dutch value of time study was designed, research workers in the area of travel demand had already received considerable exposure to SP techniques on the basis of travelers' statements about their behavior under hypothetical choice scenarios (*3,4*). With respect to using SP methods to provide values of time, the results from a national study in the United Kingdom (*5,6*) were extremely encouraging. The assertion that these techniques could yield valid information about travelers' preferences appeared to be verified.

Given the choice of study approaches—RP or SP—the initial stages of the project involved two separate activities. On the one hand, existing RP data sets were reviewed for their potential usefulness and subjected to preliminary analyses. On the other hand, after a theoretical appraisal of the subject, purpose-designed SP experiments were developed and corresponding survey instruments were piloted. The RP stream of work will be described briefly, then the SP surveys will be described in more detail.

It was decided to use existing RP data sources, including two large household travel-demand surveys that had formed the estimation base for the Zuidvleugel study of 1977 (8,000 travelers) and the Overdraagbaarheid study of 1982 (6,000 travelers). The model systems estimated by Hague Consulting Group (then Cambridge Systematics Europe) during those studies form the basis for the Netherlands National Traffic Model (Het Landelijk Model).

Both the data design and the modeling philosophy of these studies were consistent with the requirements of value-of-time estimation. They addressed the spectrum of travel decisions faced by the traveling public and supported synthetic models that credibly reproduced individual decision making in a manner consistent with the classical microeconomic theories that had traditionally supported value-of-time research.

SP Surveys

In contrast to the RP data sets, the SP data sets were purpose-designed and drew on the experience of previous studies in a number of ways. First, the theoretical basis established for the study drew attention to the need to distinguish between different types of time-money trading behavior: (*a*) for different journey purposes, (*b*) for different income groups, (*c*) for travelers on different modes, (*d*) for different occupation groups, (*e*) for different personal circumstances, (*f*) for those with different amounts of leisure time, and (*g*) for different travel conditions.

The last two differentiations are somewhat novel for research of this type. Although it had previously been recognized that available free time and travel conditions were both liable to affect willingness to pay to save travel time, at the time of the project design no work had been published that was based on direct observations of these factors. Both factors, it has been argued, are relevant not only to explain present day behavior but also to inform judgments on likely trends in the future.

For the Netherlands' SP study, the questionnaire was extended to ask about the respondent's regular weekday activities, broken down into paid work, unpaid (including household) work, and travel. From the responses, estimates were formed of total average amounts of free time.

The major aspects of travel conditions recognized in the international literature are traffic congestion (for cars) and reliability (for public transportation). The Dutch study organized its car-driver data collection over a number of different sites, including several on the national highway network. Those sites were chosen to ensure a variability in average driving conditions. They were also selected on the basis of the proximity of electronic detector equipment capable of providing mean stream speeds at all times during the recruitment interviews, which were later used as the basis for the SP time-cost trading questions. In addition, direct questions were asked in the SP survey about congestion and delays during that journey.

For public transportation, no good observable proxy for reliability was found, but respondents were asked directly about their reactions to factors such as delays and departures from schedules.

In terms of journey purposes, the SP survey applied directly to travelers; for business travelers, there is considerable uncertainty about the extent to which they can provide valuations that reflect an employer's valuation of their time. Instead, business travelers were asked to evaluate time losses or gains for their own satisfaction. The results thus provide only a partial evaluation of savings or losses of business travel time, as will be discussed later.

The method of recruitment was to approach potential respondents at gas stations, parking facilities, and public transportation interchanges. The sites were selected to cover areas inside and outside the Randstad metropolitan area, which includes Amsterdam, Rotterdam, and The Hague, and thus cover both congested and less-congested areas of the country.

Travelers were asked to answer questions regarding the journey they were making at that time and whether they would be willing to participate in a postal survey. There were few refusals at this point. Those travelers willing to participate further were sent a second questionnaire by mail. The follow-up SP questionnaire was retrospective, based as much as possible on the respondents' journeys and activities when they were intercepted. The questionnaire contained four sections:

1. Questions about the journey they were making when intercepted, such as their frequency of making that type of journey; whether or not they had a fixed arrival time; whether or not they encountered delays; ticket type and fare class; possible reimbursement of travel costs; number of people traveling with the respondent; other modes used during the journey; other modes available as alternatives; and what alternative use any travel-time savings (or loss) would have been put toward (or taken from). These questions provided background information for analysis and served to refresh the respondents' memories of their journey.
2. Pairwise choice questions offering different combinations of time and cost savings and losses against each other. The changes in travel time and cost were described and specified to be appropriate for the respondent's mode (car, train, bus, or streetcar) and journey distance (SP time savings or losses were limited to realistic ranges—up to 5, 10, 20, or 30 min—depending on actual journey duration). Each respondent provided 12 statements of preference regarding variations in travel times and costs for their journey. (One of the 12, a "check" in which one option was both faster and cheaper than the other, was used to test respondents' understanding of the SP choice task.)
3. Questions to gain insight into the amount of the respondent's free time and its flexibility, including the amount and rigidity of paid work hours, number of hours spent doing unpaid work (e.g., housekeeping), number of hours spent traveling, and the most probable alternative uses of those hours.
4. General questions about the respondents and their households, such as the income of the household and the number of workers, adults, children, and cars.

More than 2,000 usable questionnaires were returned, a response rate of more than 60 percent. (A further 15 percent were returned, but rejected because of missing or illogical data.) No attempt was made to ensure the representativeness of the sample in terms of age, travel purpose, mode, income, and so on; this was not necessary because the objective of the study was to establish trading behavior within these sorts of groups, with the possibility of subsequent reweighting to apply to different contexts.

Thus, for example, given estimates of values of time within subgroups, typical national values can be established by weighting by the distance each subgroup travels. Alternatively, typical peak-hour highway values can be established by reference to existing survey data that give the distribution of highway users in terms of these subgroups.

RESULTS OF THE SP ANALYSIS

Analysis Approach

In this section are reported models estimated for three main travel purpose groups: Commuting, Business, and Other. The choice of this purpose split was made specifically with regard to the definitions adopted for the Netherlands National Traffic Model (Het Landelijk Model), although variables were included to detect any evidence of subtler purpose-specific effects. For Business, the experimental questionnaires asked for preferences based on the traveler's own disutilities of travel.

The data were screened to include only those who appeared to have a good understanding of the SP task and who had answered all of the most important segmentation questions such as income. Samples of 485 respondents for Commuting, 469 for Business, and 1,106 for Other purposes (mainly social, recreation, shopping, and education) were then obtained.

The estimation data contained 11 SP choice observations per respondent.

The main estimation procedure was binary logit analysis using the orthogonal segmentation approach adopted in the U.K. study. In this approach, the choices are explained as a function of the utility difference between the two alternatives, using both "main" effect coefficients and a number of additional effects which only apply to certain segments of the sample. For respondent i, choice pair j, the model is specified as

$$p_{1ij} = 1/(1 + e^{U_{ij}})$$

$$p_{2ij} = 1 - p_{1ij}$$

and

$$U_{ij} = (c_{2j} - c_{1j})\cdot(\alpha_0 + \sum_k \alpha_k\cdot\delta_{ik}) + (t_{2j} - t_{1j})\cdot(\beta_0 + \sum_l \beta_l\cdot\delta_{il}) + \mu_{ij}$$

where

p_{1ij}, p_{2ij} = the probability of choosing Alternatives 1 and 2;
c_{1j}, c_{2j} = the travel costs for Alternatives 1 and 2;
t_{1j}, t_{2j} = the travel times for Alternatives 1 and 2;
α_0, β_0 = the main cost and time coefficients, respectively;
α_k, β_l = additional cost and time coefficients, respectively;
δ_{ik}, δ_{il} = 0/1 variables indicating membership in segments; and
μ_{ij} = the random error term.

Membership in the k segments for additional cost effects and in the l segments for additional time effects can be specified with regard to the respondent (e.g., age group), the household (e.g., income group), and the journey (e.g., mode of travel), and all additional effects are estimated simultaneously. Thus, each respondent may belong to a number of different segments. It is necessary, however, that for each type of segmentation one group be defined as the "base," for which no additional coefficient is estimated (avoiding perfect correlation with the main coefficient).

With the coefficients that result from this model specification, a value of time can be calculated for respondent i as

$$\text{VOT}_i = (\beta_0 + \sum_l \beta_l\cdot\delta_{il})/(\alpha_0 + \sum_k \alpha_k\cdot\delta_{ik})$$

A wide variety of segmentations were tested during analysis. Although some provided interesting results, they were not directly useful. The models discussed in most detail here were those for which all variables can be used in application. In addition, as discussed in previous sections, it was required that these variables be supported by economic theory. After describing the main results, additional findings not included in the final models will be discussed.

The main models for the three purpose categories are presented in Table 1. This table can be interpreted as follows: first, the base monetary value of in-vehicle time changes by income group is given. Then, the percentage adjustments from the base values for a number of additional segmentations are given. Because income was the segmentation used on the cost variable, the base values of time for each income group k can be presented directly as $\beta_0/(\alpha_0 + \alpha_k)$. For the additional segmentation effects on the time variable, the results are presented as percentage changes from the base value, on the basis of the fraction β_l/β_0 for Segment l.

To use the results in combination, the percentage adjustments must be added across all relevant segments for a given type of individual, and then applied to the base value for the relevant purpose and income group. For example, a commuter with a household gross income of F5,000 per month, in a one-person–one-worker household, employed full time, age 40, male, with 40 hr/week free time, and traveling by train, would have a value of in-vehicle time of F10.3/hr * (100 percent + 21.7 percent + 0 percent − 14.6 percent + 0 percent + 21.6 percent + 6.1 percent) = F10.3/hr * 134.8 percent = F13.9/hr.

Thus, when all of the segmentation variables are applied, the average VOT across an entire population may be quite different from the base values.

The main cost and time coefficients, α_0 and β_0, were estimated precisely for all purposes, with t-statistics exceeding 10.0. All other coefficients, estimated as differences from the main coefficients, were significant except where indicated in the table. Overall, the model fit and the number of different significant effects that could be estimated indicate that the data collection approach was successful at identifying systematic effects.

From the theory, it is expected that four main types of variables systematically influence the value of a given amount of travel time:

1. Money budget constraints,
2. Time budget constraints,
3. The characteristics of the journey itself, and
4. The circumstances (personal and organizational) under which the time savings or loss occurs (i.e., the alternative uses of that time).

Each of these types of factors will be discussed in turn.

Influence of Money Budget Constraints

For this dimension, household income is expected to be the main influence, with travelers willing to pay more (or save less) for a given change in travel time as income increases.

For all three purposes, using total household monthly gross income as the segmentation variable, the results indicate that value of time increases with income, as expected. The base values for Commuting and Other are similar. The wider distribution of incomes across the segments in the Other sample allows better estimation for low incomes. The values vary less than proportionally with income for all purpose groups.

For Business, the effects are more extreme for very low and high incomes. This may be related to the respondent's profession, which in turn will be related to the type of cost constraints imposed by the employer. Although business travelers were asked to respond as if they were spending their own money, the fact that such trips are often paid for by the

TABLE 1 VALUES OF IN-VEHICLE TIME FROM SP ANALYSIS RESULTS

PURPOSE GROUP:	COMMUTING	BUSINESS	OTHER
Sample/Observations:	485 / 5535	469 / 5159	1106 /12166
Base Values by Income (1988 ƒ/hour)			
0 - 1500 ƒ/month	7.0 *	9.1	6.3
1501 - 2500 ƒ/month	7.0 *	9.1	7.4
2501 - 4000 ƒ/month (*base*)	7.7	12.2	7.9
4001 - 6000 ƒ/month	10.3	12.7 *	8.9
6001 - 8000 ƒ/month	10.4	14.5	10.4
8001 ƒ/month or more	12.2	31.4	12.3
Additional Segment Effects:			
Household Composition			
1 person/1 worker	+21.7%	+42.5%	+9.0%
2 persons/2 workers	+14.8%	+8.3% *	+7.1%
1 or more children	+20.3%	+4.6% *	+2.0%*
All other types (*base*)	---	---	---
Personal Occupation			
House"wife"	NA	NA	-15.2%
Pensioner	NA	NA	-16.5%
Employed part-time	+29.1%	-17.6%	-4.5%*
All others (*base*)	---	---	---
Age Group			
20 or younger	+43.0%	+45.8%	-12.0%
21 - 35 (*base*)	---	---	---
36 - 50	-14.6%	-6.3% *	-3.1%*
51 or older	-17.3%	-3.4% *	-21.8%
Sex			
Male (*base*)	---	---	---
Female	-20.0%	-0.8% *	+3.5%*
Personal "Free Time"			
64 or more hours/week (*base*)	---	---	---
50 - 63 hours/week	---	---	+5.5%
36 - 49 hours/week	+21.6%	+16.7%	+17.2%
35 or fewer hours/week	+28.0%	+33.1%	+17.2%
Journey (Sub)Purpose			
"Other work"	NA	-19.0%	NA
Education	NA	NA	+19.0%
Shopping/personal business	NA	NA	-9.5%
All others applicable (*base*)	---	---	---
Journey Mode and Conditions			
Car- urban traffic (*base*)	---	---	---
Car- motorway, speed > 110 kph	+9.6% *	+5.0% *	+23.8%
Car- motorway, speed 100-110 kph	+35.4%	+14.5%	-11.6%
Car- motorway, speed 90- 99 kph	+53.0%	+33.4%	-6.8%*
Car, motorway, speed < 90 kph	+67.8%	+33.4%	-6.8%*
Train	+6.1% *	-18.5%	-1.6%*
Bus/tram	-9.1% *	-22.1%	-25.1%
Average Value across the Sample	12.7 ƒ/hour	19.8 ƒ/hour	8.1 ƒ/hour

Notes: --- = no parameter estimated;
* = estimate not significantly different from base group (T < 1.8)

employer will inevitably influence the responses. For the very high incomes, it may be that the high values are associated with business ownership or senior management (i.e., the employee is also the employer).

One might expect other variables besides income to influence cost sensitivity. Such variables include the number of people and vehicles to be maintained out of household income and the respondent's role in the household. Although such variables were tested, no significant effects were found. This may be in part because household-type and person-type variables are also important in determining time budgets, and these time budget effects may overshadow any cost budget effects.

Another issue that may be important is the possible reimbursement of travel costs by employers or others. For the most part, this effect is expected to be reflected in the journey purpose. Although all respondents were asked to answer as if they were paying all travel costs themselves, additional analysis indicated a residual effect in the Commuting and Other purpose groups, where those whose costs were reimbursed were willing to pay more for a given time savings. Though it is not clear how this result could be applied to exogenous data, given the imprecise concept of cost reimbursement, it may be an interesting area for further analysis.

Influence of Time Budget Constraints

Time budget effects are expected to be present at both the household and person levels. Three types of households in the sample were identified in which the members were expected to be under time pressures: (*a*) working adults living alone; (*b*) working adults living with one or more additional workers, but with no nonworking adults or children (the so-called DINKs); and (*c*) households with one or more children under working age.

Table 1 indicates that the effects of household type are much larger for Commuting than for Other private travel. This makes sense, as one would expect values for commuting journeys to reflect regular daily activity patterns, in which the type of household has a large influence.

There is not such an obvious explanation for the high value of time related to Business travel in one-person households. This effect may be related to the type of profession, as was the high income effect. In fact, people living alone have the highest values for all purpose groups. Though not tested here, this trend may also be related to lower money budget constraints, as these people do not have to share as much of their household income with others.

Occupation will often determine a person's role in the household and, thus, influence time constraints. For Business and Commuting, the only distinction to be made is between full- and part-time workers. Lower values for Business travel among part-time workers than among full-time workers may be related to professions with fewer time constraints or tighter cost constraints. Part-time workers have higher Commuting values, however. It is believable that part-time workers have tighter everyday constraints. In fact, it is likely that these time constraints prevent many such people from working full time.

For Other purposes—reflecting less regular travel—there is no significant difference between full- and part-time workers. House "wives" and pensioners appear to be less time constrained (have lower values of time), as one would expect. The effects for these two groups, however, are not as large as were found, for example, in the U.K. study. This may be because in the United Kingdom their time budget constraints are also reflected in the age, sex, and free time variables described below.

A person's age and sex will also influence activities and time constraints inside and outside the home. Both Commuting and Business values decrease with age, although the only large differences are for workers under age 21, who represent small proportions of the sample. This age group, consisting mostly of students, has a slightly lower value for Other purposes than the base age group (21 to 35). For the older groups, the values for Other purposes decrease with age, perhaps reflecting a less busy life-style. These values apply specifically to in-vehicle time, so the lower values could also indicate that older people find sitting in vehicles less disagreeable or boring than do younger people.

After the aforementioned factors have been accounted for, males and females do not have significantly different values for Business and Other purposes. Females have somewhat lower values than males for Commuting. This does not mean, however, that female commuters have lower values overall. In fact, this effect may counteract somewhat the higher values found for single workers, DINK households, and part-time workers—all of which include a higher-than-average number of female workers.

There may be other factors determining people's time constraints that are not fully captured by the standard segmentations considered thus far. As a more direct way of getting at such factors, people were asked directly how many hours per week they spent on paid work, unpaid work (including work in the household), and weekday travel. These hours were subtracted from the number of hours in a full week (168), and another 8 hr/day was subtracted for sleeping. What remained was labeled free time. So a person with 35 hr/week paid work, 14 hr/week unpaid work, and 3 hr/weekday travel time would have about $[7*(24 - 8)] - 35 - 14 - (5*3) = 48$ hr/week free time.

Such an estimate not only gives an additional indicator of present time constraints but also, by making assumptions about future trends in hours spent on paid and unpaid work, this variable (together with the income variable) can be used to adjust values of time to correspond to future economic scenarios.

Table 1 indicates that the free time segmentation gives significant results, even after the other household- and person-type variables have been accounted for. For Commuting and Business, respondents appear to value travel-time changes more highly as the amount of free time decreases. The cutoff points used here are 49 hr/week and 35 hr/week. The magnitude of the effects are similar for both purposes. For Other private purposes, usually reflecting less frequent travel, free time has less influence, although the effect is still significant below 49 hr/week.

Influence of Characteristics of the Journey

In addition to differences between respondents, there may also be differences due to the specific journeys they were making. The purpose of the journey is an important aspect. The Business and Other models were estimated by using subsamples that contain more than one journey purpose category. To determine whether the subpurposes yield different values of time, additional segmentation coefficients were included.

In particular, for Business a variable was introduced to test whether or not the traditional businessman had higher or lower willingness to pay than those merely traveling to a nonfixed workplace. The latter category, labeled "other work," includes trips usually made by people with nonfixed workplaces (sales representatives, construction workers, etc.) or by people running errands for their work. Although this distinction is difficult to make accurately in all cases, some systematic difference has been captured in a significantly lower value for "other work" journeys than for "employer's business."

Similarly, variables were included to detect any variation in willingness to pay for travel-time savings within the Other purposes; the subpurposes "education" and "shopping–personal business" were separately identified. The analysis indicated significantly higher values related to education journeys and somewhat lower values for shopping–personal business. These results conform to expectations—regular education journeys are often time constrained in the same way as commuting journeys, and such constraints are less common for shopping trips. No significant differences were found among the remaining purposes, which include social visits, recreation, and a small number of other miscellaneous journeys. It is worth noting that these three purpose groups—education, shopping–personal business, and social-recreation-other—are also separated in the Landelijk Model forecasting system, in combination with which these results will eventually be applied.

Other characteristics of the journey relate specifically to in-vehicle time. These are the mode used and the travel conditions for that mode. A large proportion of the sample consisted of highway car drivers. They were intercepted at times and places for which the average speed during the date and hours of recruitment was known. Travel time is expected to become more unpleasant as traffic flows increase and average speeds decrease. For Commuting and Business journeys, this is clearly the case. The effect is greatest for Commuting, where congestion is most likely to be perceived as a persistent problem.

The speeds used to determine the variables in Table 1 are 1-hr average traffic speeds, so that although these speeds do not reflect what one might consider "real" congestion levels, they do indicate traffic conditions in which delays could occur.

For Other purposes, it appears that journeys using the highway during off-peak hours (highest speeds) have higher values of time than those who use the highway during more congested periods. This is contrary to the results for Commuting and Business. One explanation may be that many non-work-related journeys can just as easily be made outside peak hours, so that those people who nevertheless travel in congested conditions may be less sensitive to travel-time losses than those who travel off-peak.

The base segment for all purposes is made up of motorists who were intercepted in city centers and may not have used the highway at all. Although this distinction is not accurate in all cases, the results indicate a generally higher value of time savings for interurban traffic than for urban traffic. This effect may arise because travel times for urban journeys tend to be shorter or because significant time savings for city trips may be seen as unrealistic.

The final results in Table 1 reflect values for in-vehicle time in trains and in buses and streetcars in contrast to car in-vehicle time. The differences between train and car for Commuting and Other are not statistically significant. For Business, train in-vehicle time changes are valued less than for car. This may be because useful work can be done on the train or may be related to the profession of the traveler.

Bus and streetcar in-vehicle time values are lower than those for car in all three models. For Commuting, the difference is not significant, and for Business the effect is similar to train and applies to a very small sample. The most important result is for Other purposes, for which the majority of bus and streetcar journeys in the Netherlands are made.

Lower values of time for public transportation users were also found in the U.K. national study. One explanation is that driving a car requires more concentration and is thus more disagreeable, and that people will be willing to pay more to avoid it. This explanation is compatible with the car congestion effects described above. Another possible explanation is that the effect is due to "self-selection"—urban travelers who are pressed for time (and have a choice) go by car, whereas those who are less time conscious go by bus or streetcar. This phenomenon is most likely to occur in the off-peak hours, when travel times between modes differ the most. The perceived unreliability of obtaining consistent travel-time savings in buses and streetcars may also play a role.

Influence of Alternative Uses of Time Saved or Lost

The theory suggests that this feature should show itself mainly in a difference in willingness to pay between travel purposes, which ordinarily differ in both the time of day of the trip and the rigidity of the traveler's timetable. Person- and household-type differences were also expected to be related to time budgets and the attractiveness of alternative uses of time. Although the effects mentioned above were expected to be the most important and useful, the survey was designed to provide additional insight into the circumstances surrounding particular trips.

Respondents were asked what the alternative use of any time saved or lost during their journey would have been and whether such changes would have been useful or inconvenient. Not surprisingly, those who considered time changes useful (disruptful) were most willing to pay to obtain (avoid) them—even after all of the effects in Table 1 were taken into account. Similarly, those who considered paid work to be the alternative use of travel time were most willing to pay for time savings, whereas those who indicated free time as the alternative were least willing to pay. The same result occurred for avoiding time losses for all purpose groups. It is possible that such results reflect journey-specific time pressures that are not fully captured by the free time variable. It is not evident, however, how variables based on such self-reported conjectures could be applied in practice.

Respondents were also asked about any in-vehicle delays during their journey and how frequently they expected such delays to occur. Those who were late due to delays valued time changes most highly (again, after the estimated effects were controlled for), as did those who expected delays most frequently for a journey such as they were making. Those who had to transfer to another mode during their journey also appeared relatively time sensitive, reflecting greater inconvenience due to delays. Finally, those traveling during the weekend and off-peak periods indicated somewhat less residual time-sensitivity than peak travelers, possibly reflecting the lower frequency of delays or less urgent alternative uses of time.

Another interesting result attributable to the value of alternative uses of time was that the value of a given time loss was considerably higher than the value of the same amount of time saved, and that a longer time saving or loss was valued more highly per minute than a shorter one. These effects were particularly evident for commuters, who valued time losses about three times as high per minute as savings. That the direction and magnitude of time changes influence the value placed on them came as little surprise; this effect has been found in other studies using similar techniques. It is likely, however, that such effects reflect short-term behavior—

rigidities of schedules (work hours, family activities, meetings outside the home, etc.) can mean that substantial increases in travel time cause disruption in the short term (i.e., until the schedules are rearranged). Further, the same sort of rigidities can mean that small time savings from travel cannot be used effectively in the short run.

In the longer term, such effects are less relevant—a person might be no better off after a gradual travel-time increase of 10 min than after a sudden increase of 15 min and a subsequent 5-min decrease. The results indicate, however, that the inconvenience during the transition period may vary according to the phasing of travel-time savings or losses, and suggest that investments or policies that avoid unexpected travel-time losses should be evaluated with higher values of time than those that improve "steady state" travel times.

For models applied to long-term policy evaluation, it was decided to use average values, incorporating time losses and savings in a single coefficient. The experimental design that was used was balanced between time savings and losses, and the general pattern of time valuations (e.g., variation with income and purpose) was similar for losses and savings.

Applying the Results

To apply these models, one must start with the base value for the travel purpose of interest and add all segmentation effects applicable to the person type, household type, and travel conditions of interest, as explained previously. This approach means that the models are best applied on a disaggregate level. When the models are applied separately to each respondent in the estimation samples, the sample mean values of time given at the bottom of Table 1 result: F12.7/hr for Commuting, F19.8/hr for Business, and F8.1/hr for Other purposes. Highway drivers and public transportation users, however, were purposely oversampled, so a "true" mean (e.g., an average value over a nationally representative trip survey) may lie closer to values for urban car drivers.

When the models are applied to a sample of individuals, averages can be taken within certain subsamples to examine the variation along variables of specific interest. Figure 1, for example, shows average values for the three purpose groups for different income bands. Just as for the base values by income in Table 1, the average values increase with income, but less than proportionally.

The distribution of values of time across the estimation sample after applying the models is shown in Figure 2. The general pattern for the three purpose groups is the same, but the Business model has an extended distribution at the high end, mainly due to the large high-income effect in the Business model. In application, of course, the distribution of values, as well as the means, will depend on the specific mode, route, time period, and population of travelers under study. One may also wish to adjust the models after comparing the average values with those given by RP evidence (see the following section).

Comparison of RP and SP Analysis Results

Approximate comparisons of the SP results quoted earlier with the analysis results obtained from the RP data are presented here. A more detailed report on the RP data analysis is given in the final project report (*2*). The figures given here are indicative only. The results highlight the great internal variability in individual-level values of time savings: a full comparison of average figures over different data sets thus requires an explicit reweighting of different traveler groups and contexts.

Similarly, other reported studies (e.g., the U.K. value of time study) can best be compared through a complete reweighting. This function of reweighting is addressed in the following section and is necessary to deriving forecast values for different traveler groups in different future year scenarios (in which, for example, income distributions, leisure time availability, and traffic conditions may vary from those of the base year). For the purposes of this section, some approximate "average" results have been estimated to illustrate broad comparability.

The approximate overall results are shown in Table 2 and Figure 3. Table 2 indicates the following:

1. For Commuting by car, the RP results were similar to the SP results for congested highway conditions; this may be appropriate because the RP sample consisted mostly of longer-distance urban commuters. For Commuting by train, the RP and SP results are comparable, given the measurement errors.

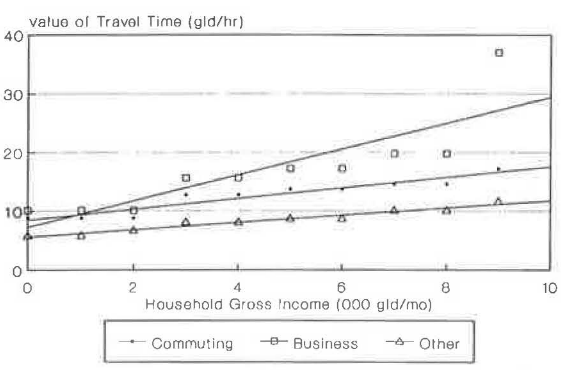

FIGURE 1 Trends in values of time with income (sample averages after applying models).

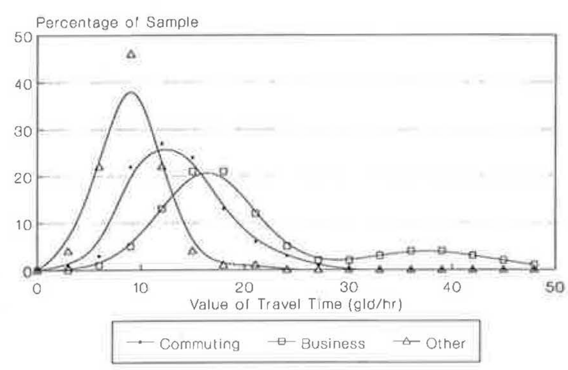

FIGURE 2 Distribution of sample values of time (sample values after applying models).

TABLE 2 COMPARISON OF RP AND SP RESULTS

	Commuting		Business		Other	
	RP	SP	RP	SP	RP	SP
Car ("uncongested")	21	13	37	21	7	11
Car ("congested")		19		22		9
Train	14	11	23	14	7	8
Bus/Tram	NA	9	NA	11	NA	6

Note: All values are in 1988 guilders per hour.

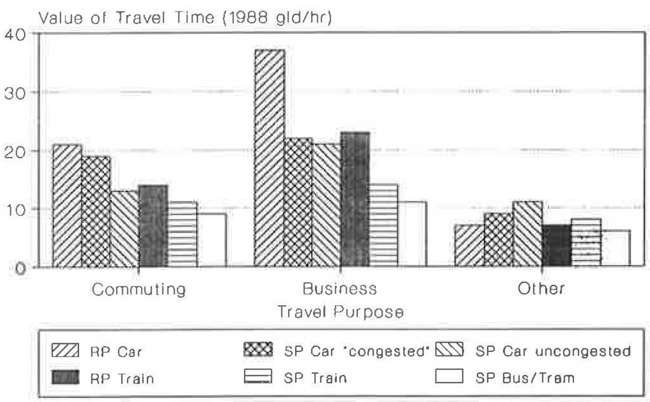

FIGURE 3 Comparison of RP and SP results (approximate average values).

2. For Business travel, the RP values are about 65 percent higher than the SP values for both car and train (though the RP estimates may contain large errors). Some discrepancy was expected because the RP values incorporate the willingness to pay of both employer and employee whereas the SP values are based on the employee's preferences only. The SP values thus require adjustment to include the employer's value, as discussed in the next section.

3. For Other private travel, all results fall within a fairly small band around F7/hr or F8/hr.

4. For all purposes, the RP mode-choice sample includes only travelers with a car available. The RP samples will thus tend to overrepresent higher incomes, which could contribute to the higher values found.

It has been concluded that the SP results are comparable overall with the independent evidence of the RP models. However, the evidence of the latter is much weaker in terms of statistical significance than had been hoped at the outset of the study, given the quantity of data available.

Finally, the similarity to the published U.K. results are noted: for the middle income band and using an approximate inflation factor to 1988 to 1.2 and a conversion rate of pounds to guilders of 3.6, Table 8.2 of *The Value of Travel Time Savings* (*6*), gives overall values for all nonbusiness purposes of F11/hr for car travelers, F14/hr for rail passengers, and F7/hr for bus passengers—all similar to the results presented here.

CONCLUSIONS AND RECOMMENDATIONS

Main Conclusions

This paper has summarized the planning, design, and execution of a program of research in the Netherlands into travelers' willingness to pay for travel-time savings. The purpose was to assemble a body of evidence to inform a later decision on the appropriate values to use in appraising potential transportation investments.

The study was not intended to be comprehensive; in particular, many issues associated with a full evaluation of business travel-time savings and losses were excluded.

The principal intentions of the study were (*a*) to reappraise the practice of valuing travel-time savings in the Netherlands and to provide current estimates of these values and (*b*) to examine existing methods of forecasting future values and to improve them where possible.

To fulfill these intentions, a number of secondary objectives had to be met. First, a theoretical economic framework was required to develop ideas about factors affecting values of time and the ways in which they would affect levels in future years. By building on ideas in the literature, a theoretical representation appropriate for both workers and nonworkers has been created.

Second, it was necessary to develop and apply research survey tools, SP experiments, to provide the quantity and quality of data needed to measure the effects that theoretical considerations suggested should influence willingness to pay.

Third, the methods had to be validated, which involved statistical comparisons of the results with overall indications of average willingness to pay drawn from observations of actual behavior. This in turn required the analysis of existing travel surveys (RP data) to find well-defined trading contexts containing such indications.

The principal conclusions were as follows:

1. Existing practice in the use of simple average values of time may lead to biased estimates of the traveling population's total willingness to pay. Many systematic effects, consistent with theory and a priori reasoning, have been found in the data. Trends that involve not only income but also many other characteristics of the traveler and the context and conditions of travel have been found in subgroups of travelers.

2. Neither theory nor data support the conventional assumptions that values of time are proportional to income levels or that they will develop proportionately to income in future years. A forecasting procedure involving a reweighting of subgroup values has been suggested, and a source of suitable information has been identified in the Netherlands National Traffic Model.

In addition, two areas for further research have been identified: (*a*) for travelers' own valuations of time savings and (*b*) for employers' valuations of business travel-time savings. These are discussed below.

Travelers' Valuations of Travel-Time Savings

The results indicate that there is no single value of travel-time savings that is appropriate for all occasions and contexts, nor are there simple rules (e.g., 30 percent of the wage rate) that accurately reflect travelers' willingness to pay and how this will vary over time. Simple logic, elaborated within the framework of economic theory, suggests many probable dimensions of variability, and experiment confirms that this is consistent with travelers' judgments of the value of time savings.

Two consequences follow from this finding. First, better estimates of overall willingness to pay may require the introduction of more detail into standard evaluation procedures; the same total time saving may have a different worth depending on the context and types of traveler to whom it is made available. Second, much more effort will be required to generate future values of time savings. The existing convention—merely to adjust (scale) for real income growth—is believed not reasonable. This problem should be approached by estimating how the distribution of the population by income categories has changed and then calculating a new weighted average value from the new distribution.

However, the implication is not merely that the treatment of income growth should be more detailed, but that many other effects are important in determining future values of time, and these also need detailed treatment.

In particular, it appears that the different time pressures associated with amounts of free time, occupational status, household composition, and age group of the traveler have a systematic effect on willingness to pay for time savings. During the 25-year horizon typically considered for major investments, the division of the traveling population between these categories will shift, in some cases substantially [see Gunn et al. (*1*) for a review of the demographic developments expected for the year 2010 and the impact these are expected to have on travel patterns]. Further, the conditions under which travel takes place (in particular, congestion on the roads) are important.

The question of the appropriate level of detail at which to conduct forecasting and evaluation exercises has many dimensions. For evaluation, it has been argued that applying simple average values of time regardless of context and traveler mix may lead to biased estimates of willingness to pay. The extent of this bias will depend on the scheme-to-scheme, policy-to-policy variation in traveler types (income, trip purpose, and so on) and travel contexts (degree of congestion, etc). To avoid this bias, overall willingness to pay must be calculated separately for each application, taking into account all of the dimensions of variability.

For many applications, the effort involved in applying these models to an appropriate exogenous sample of individuals will not be justifiable; the uncertainties in other factors (financial costs, passenger demand, or political considerations separate from time savings and money costs) may outweigh any bias in using average time-savings valuations. In such cases, some simple overall averages (e.g., by mode and by journey purpose) should be available to provide guidelines for minor investment decisions, and the detailed results generated in this project should be processed to provide these averages.

The processing will involve a reweighting of the values of time of the separate subgroups of travelers involved. For past years, this can be done with the aid of the Dutch National Travel Survey data; for the future, information similar to the survey must be synthesized to perform a corresponding reweighting. Such synthetic information already exists in the Netherlands National Traffic Model and offers a suitable basis for reexpansion.

Thus, for sketch planning, conventional average values will be produced. For evaluations at a national and regional level, however, the new disaggregated information about willingness to pay among the traveling population comes at a time when the applied forecasting methods themselves are based on detailed simulations of travelers, the choices they face, and how the choices are made.

In principle, the simulations can retain the information necessary to characterize the traveler in terms of the factors that determine willingness to pay for time savings. Both the Netherlands National Traffic Model and the associated disaggregate regional models that have been developed have these features. Thus, in addition to forecasts of numbers of trips and kilometers, the model systems could produce disaggregated forecasts of the time spent on travel and its monetary value.

Employers' Valuations of Business Travel Time

This study has focused on the business traveler's personal utility or disutility from travel, omitting the net costs or benefits to the employer. Estimating these net costs or benefits is a notoriously difficult task. At least two approaches have been advanced: first, direct contact with employers can be made and their best judgments about a series of hypothetical travel arrangements (different mixes of time and money) analyzed to infer the rate at which they value the time of the traveling employee (*7*). A second approach involves adjusting the marginal productivity of the traveling worker for any use that can be made of travel time (*8*). This approach requires direct evidence from travelers about their use of the time spent traveling (available from the SP surveys mounted in this study) and some estimates or assumptions about marginal productivity (usually taken as the wage rate plus additional costs of employing an individual). Initial estimates of the value of the time savings to the employer using this approach correspond closely to the discrepancy between the RP and SP business values presented earlier.

Further investigation into these areas is under way.

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Effects of Teleshopping on the Use of Time and Space

M. TACKEN

Developments in teleshopping offer many possible uses. As a supplement and alternative to transportation, teleshopping may have effects on traffic and physical planning. The use of time (both by point in time and by time budget) and the use of space (location and infrastructure) will change. These ideas have been elaborated in an investigation into a teleshopping service that examined the effects of teleshopping on the use of time and space. A sample of teleshoppers noted shopping trips during a number of days. With the aid of these diaries and the answers to a number of background questions, insight was obtained into the group, their motives, their shopping behavior, and the changes that occurred in the use of time and space. Teleshopping saved time, but most people did not mention any new activity. There was a change in shopping times. Some shopping trips could be scheduled to avoid the rush hour. Teleshopping also had effects on the use of space. A change in travel behavior occurred. Telecommunication was substituted for some consumer trips, and the modal split of some trips changed.

Teleshopping most directly affects an area's physical planning and traffic systems. These consequences, however, may become evident only in the long term. In 1988 Keyzers and Wagenaar (*1*) investigated the effects of teleshopping on the use of time and space by teleshoppers. They chose the following definition of teleshopping:

> Teleshopping is a personal exchange of information between a supplier and a consumer via electronic communication in which a transaction of shopping goods comes about.

In the teleshopping research project described here, attention was directed toward the consumer. Consumer shopping can be divided into (*a*) functional shopping (errands to provide oneself and the household with necessary articles) and (*b*) recreational shopping (visiting stores as a recreational activity, a means of social interaction and acquiring general product information without necessarily purchasing).

It is clear that teleshopping above all offers facilities for the functional form of shopping and the gathering of specific information about products.

The type of product is important to the decisions involved in the shopping process. Degree of freshness and uniqueness of the article are relevant characteristics.

In addition to the nature of the product, the following factors will be particularly important in the decision to teleshop: the accessibility of the shopping facilities, the available time, and how and when the ordered articles can be received. Here the elements of time and space come to the fore.

Sometimes different target groups are mentioned. On the basis of the characteristics of teleshopping, people who have too little time or are less mobile may be counted among the group of potential teleshoppers.

There will be a direct effect on traffic because of the disappearance of shopping trips and their replacement by fewer retailer delivery trips.

To obtain more insight into these assumptions, a pilot study was undertaken with an existing teleshopping business and its clientele. This project was directed toward the qualitative aspects of motivation and the kinds of changes people make when teleshopping rather than on the quantity of changes.

RESEARCH APPROACH

The central question of the survey project was as follows (*1*):

> What changes in expenditure of time and in the use of space of stores and infrastructure occur among consumers by the use of teleshopping?

To answer this question a postal survey of the clientele of James Telesuper was taken. This teleshopping service has been operating since 1983 and has the same range of articles as supermarkets. It has a clientele of approximately 10,000 households in a part of Holland (out of an approximate total of 170,000 households). Customers can choose items from a catalog or a screen and can state their order and the desired delivery time by telephone or microcomputer. Only a small group uses a microcomputer.

For this research project insight into the use of space was an important objective. The choice therefore fell on a town in which the relation to the existing shopping system could best be examined. Amstelveen, the town chosen, has a large central shopping area and a small shopping center in every district for the daily necessities.

A questionnaire and a request to note all shopping trips was sent in 1988 to all 429 customers of James Telesuper in the selected area. During 1 week, 34 percent of them noted all shopping trips on a prestructured list and answered the questions on background and pattern of activities. A nonresponse rate of 66 percent is high, but there was no indication that this sample was not representative. The main purpose of the questionnaire was to discover the characteristics of the users, their motivation in teleshopping, and the behavioral effects brought about by teleshopping.

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TELESHOPPERS AND THEIR MOTIVES

Eighty-five percent of the women completed the questionnaires. That fits the traditional pattern in which the woman attends to shopping. Patterns of background characteristics gathered through the survey indicate several recognizable categories of users:

1. Older persons living on their own who largely do not work any longer and
2. Young couples (married or living together) up to the age of 40, both of whom work and many of whom have young children.

The following categories were present to a lesser extent:

3. Young working single persons and
4. Traditional households (usually with children and with husband working and wife not working).

The educational level was fairly high, as was the job category. This confirmed the image of the teleshopper, which differs somewhat from that of the mail-order buyer, who is generally less well educated. Despite the profile of the teleshopper, one-third of the customers did not have a car, especially the elderly and the working singles.

On the basis of the characteristics of teleshoppers mentioned earlier, it can be assumed that young working people often have to contend with a lack of time for shopping, a problem compounded by the limited hours during which stores are open. Among the elderly the absence of a car and poor health play a part. Teleshoppers do not all hate shopping (though 40 percent do). The social aspects of shopping—"having a chat"—are only attractive for 17 percent. What was found most attractive was the ability to avoid dragging shopping home (75 percent). The saving of time (47 percent), one's physical condition (29 percent), and convenient transportation (29 percent) also played a role. There were clear differences in motives between the categories of users:

- Young working people chose to teleshop for the saving in time (82 percent of two-earner couples and 71 percent of single persons).
- Elderly people had their physical condition as the principal motive (74 percent).
- Transportation was a factor among young singles (57 percent) and in traditional households (50 percent).

A disadvantage of teleshopping mentioned was the inability to see the goods for oneself before delivery (24 percent). This was considered particularly important for fresh products.

SHOPPING BEHAVIOR IN TIME AND SPACE

This research project was performed after the teleshopping service had been functioning for some time. That meant that the users had to look back at their earlier shopping behavior, something which was done too carelessly for a precise comparison of behavior before and after the use of teleshopping. The actual situation and the perception of the past by those surveyed will therefore have to be compared.

Expenditure of Time

Frequency, the point in time, and duration are all relevant to a picture of expenditure of time. Only a small majority (51 percent) ordered from the teleshopping service with a frequency of once a week or once in 2 weeks. Others (49 percent) did so once a month or less. In addition the customers still visited stores. Most visits were made in the morning (35 percent) (not during the rush hour) and at lunchtime (19 percent). Orders with the teleshopping service were also placed at these times (35 percent) and also in the evening (33 percent).

In nearly half the cases shopping was delivered in the evening (6 to 9 p.m.) and then mostly among young people. The other half of the orders were delivered during the day, more so among the elderly.

The differences in duration were determined by comparing the time that was formerly spent on shopping with the time that was still spent on shopping (ordering via teleshopping and receiving the orders). Ordering from James Telesuper took less than 10 min for most (64 percent) and about half an hour for another 30 percent. However, in addition to the time for ordering, shopping errands were also done. The time required for the errands varied considerably: 38 percent spent less than 1 hr on them, including the trip to the store, and 43 percent devoted more than 1 hr/week. Because it is extremely difficult to state the exact time devoted to certain visits to stores after the event, the respondents were asked to make the comparison with the past themselves and on the strength of this to indicate whether more or less time was spent on shopping. More than 20 percent indicated that this takes as much time as before the introduction of teleshopping. However, 70 percent indicated that they had more time at their disposal than before teleshopping. The gain in time was divided as follows:

Respondents (%)	*Time Gained (hr/week)*
18	less than ½
24	½ to 1
26	1 to 2
15	more than 2

In the eyes of the users, therefore, teleshopping offered some gain in time. But there was no clear picture of what happened to that time: 80 percent gave no answer to the question about the use of the time that became available. Possibly privacy played a part, but the extra time may not have been devoted to new activities but to more time for existing activities, including sleeping in.

Use of Space

Two aspects of the use of space call for attention: the choice of places where the teleshopper still goes shopping and the nature and frequency of shopping trips.

Not all shopping errands were done at James Telesuper. More than half did not buy fruit or vegetables (49 percent), meat (58 percent), or bread (69 percent) via teleshopping.

These fresh articles in particular were bought in neighborhood stores, which acted as complements to teleshopping.

Change in Store Visits

The respondents were asked where the articles in question were formerly purchased. To a large extent most articles (e.g., 67 percent of the vegetables and 80 percent of the groceries) were formerly bought in a supermarket. Teleshoppers visited more specialized businesses for fresh articles. This means that part of the turnover of supermarkets, in particular, would be lost. In the longer term that may have unfortunate consequences for the survival of this kind of enterprise and thus its accessibility.

No clear indications were found that people have turned to teleshopping because of the poor accessibility of shopping facilities. The distances in the research area were not extreme enough to warrant that.

Frequency of Shopping Trips

Another spatial consequence of teleshopping concerns the nature and frequency of shopping trips. In the week examined the respondents who visited food stores visited 3.7 stores on the average, for which 2.6 trips were made. Thus a number of store visits were chained together. This total number of trips means that during the research period the respondents, on the average, made 0.4 shopping trips each weekday for food products. A summary of the figures of a national sample (*2*) mentions 1.0 as the mean number of shopping trips on each weekday for all kinds of stores. The difference of 0.6 shopping trips is probably not fully explained by shopping trips for nonfood products. This means that the respondents made fewer shopping trips than other people.

The most additional shopping trips were made by traditional households (3.2) and young two-earner couples (2.5), compared with 1.7 trips made by young working singles and the elderly. The number of trips and visits appears to be dependent on the number of household members.

Changed Modal Split for Shopping Trips

A direct comparison with the past on the basis of figures was impossible. Respondents were unable to describe their former behavior exactly. They were, however, asked to compare themselves with regard to the use of means of transportation and with regard to distance.

It is striking that 28 percent said that they travel less by car, 23 percent walk more often, and 14 percent travel more often by bicycle. The shift cannot be ascribed to a decrease in car availability. The explanation of the shift from car to a slower form of transportation may be found in teleshopping. Because the larger quantities of shopping were ordered and delivered through teleshopping, the transportation of heavy or bulky orders was not necessary. A result was that transportation on foot or by bicycle was more attractive and feasible.

In general the distance from the stores visited was not great. Most respondents appeared to travel from their homes to stores near home. Even workers first went home after work before doing their errands (*3*).

SUMMARY AND CONCLUSIONS

An investigation of the users of teleshopping indicates that there were effects on the use of time and space. Specific user categories were observed. Teleshopping can save time, which is the principal reason why young two-earner families participate. Teleshopping can also increase the accessibility of facilities; physical transportation is not necessary for the consumer. That is the most important reason for participation by the elderly who no longer work and who are less mobile because of their age or the absence of a car.

Effects on the use of time and space were identified. Effects on the use of space were demonstrated by the changed travel behavior. There is an indication of a certain substitution of consumer trips and a change in modal split. More teleshoppers did their remaining shopping errands by bicycle or on foot. At the same time, new trips for delivery were evoked. Through better logistics and a different supply system, the total effect could be a reduction of trips.

Effects on the use of time were more difficult to substantiate. The expenditure of the time that teleshopping saved was difficult to specify. Most people did not mention any new activity that required travel. Clearly, however, there was a change in shopping times. Teleshopping is not dependent on hours that stores are open, and ordering and delivery take place partly during evening hours. As a result, trips can be moved from the rush hour.

In summary there is sufficient reason to believe that a number of developments will follow expectations.

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Exploring Telework as a Long-Range Planning Strategy for Canada's National Capital Region

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The concept of telework, or working at a location other than the usual office, is receiving increasing attention. Telework is steadily becoming of more benefit as computers and telecommunications services continue rapid innovation and gain popularity. There are a number of important reasons to explore telework in Canada's capital region. The practice of telework is advancing despite the absence of guiding policy for federal employees and departments. Requirements for more flexible work environments and arrangements are increasing. Costs of office space in downtown Ottawa and Hull continue to increase. Computers and communications equipment are more affordable. Traffic congestion is growing, which slows travel and results in additional costs to the user and to the regional economy. The manner in which the National Capital Commission is dealing with telework as a planning issue is reported. A 1988 survey of the attitudes of senior federal managers toward telework in Canada's capital region is described. The public policy environments for telework are examined, several transportation and planning issues interacting with telework are identified, and opportunities for improved understanding and application of telework toward the future of Canada's capital are suggested.

Telework is becoming a more desirable work arrangement as the number of information employees increases and as communications technologies continue rapid innovations. With computers, modems, and reliable telecommunications, the workplace is no longer constrained to its traditional boundaries. This has important implications for urban transportation, management of travel demand, land use distribution, and the quality of life in Canada's national capital region (NCR). In its capacity as planner for all federal lands in the capital contributing to the shape and development of the capital region, the National Capital Commission (NCC) continues to explore these implications with regard for the distinct nature, character, and function of the capital.

NCC has, to date, sponsored a qualitative study of telework in the NCR and collaborated on a survey of the attitudes of senior federal decision makers in the NCR toward telework. The results of these studies and other pertinent research are helping planners understand the long-range influences of telecommunications on the future evolution of the NCR, including the interactions between telecommunications and transportation, effects on travel demand, and impacts on spatial pattern of urban and regional land use.

The focus of planning research at NCC is to identify and examine the organizational, social, and legislative issues associated with telework; to evaluate the feasibility of telework as an alternative work arrangement for federal employees; and to examine the effects of telework on land use and transportation.

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CAPITAL SETTING

The NCR is the fourth-largest metropolitan area in Canada, having an estimated population of 828,000. Metropolitan Toronto is the largest, with a population of about 3.52 million, and Montreal is the second-largest, with about 2.96 million.

The NCR spans the Ottawa River and covers an area of approximately 4660 km^2 (1,800 mi^2), with 2720 km^2 (1,050 mi^2) located in Ontario and 1940 km^2 (750 mi^2) in Québec.

Twenty-seven local municipalities and two regional governments constitute the region. Each has land use planning authorities and responsibilities delegated by provincial legislation. The responsibilities include the preparation of official plans and zoning bylaws and the provision of transportation, water supply, and community services.

The regional governments of Ottawa-Carleton and the Outaouais have produced plans that contain objectives and policies for the physical development of their jurisdictions with regard for social, economic, and environmental matters. The regional plans are complemented by plans and zoning bylaws adopted by each area municipality that direct development in accordance with regional and local objectives. The more detailed local plans are required to conform to the regional plans.

The plans and policies of the federal government influence the evolution of the NCR considerably. The federal government is a major landowner and the largest single employer in the capital.

NCC is the federal agency responsible for planning the federal interests in the capital. The federal government is not required to conform to regional or municipal plans and bylaws but maintains close contact with the regional governments as partners to ensure coordinated planning and development.

Parliament established NCC in 1958 as the federal planning agency for the capital. NCC's role includes preparing plans and assisting in development, conservation, and improvement of the NCR in accordance with its significance as the seat of federal government. NCC has a broad range of land use powers to realize this mandate, including planning for the capital, coordinating and approving the development of all federal lands in the capital, and acquiring lands for new federal buildings and facilities.

RESEARCH ABOUT TELEWORK

A number of methods are being used by NCC to obtain data about the nature and extent of telework, the way telework is applied, and the success of this application. The methods include literature search of Canadian and U.S. journals and publications associated with telework; contacts with a number of organizations in Canada, the United States, and Europe believed to be applying telework or remote work arrangements; and studies of the feasibility of telework and management attitudes toward remote work arrangements.

Canada Mortgage and Housing Corporation has recently embarked on research associated with the impact of information and communications technologies on aspects of urban functioning (Environmental Directorate, Group on Urban Affairs, unpublished material, 1989). This work is part of Canada's principal contribution to a project sponsored by the Organization for Economic Cooperation and Development (OECD) about the urban impacts of technological and sociodemographic change. The purpose of the OECD project is to identify applications of communications and information technologies that improve urban functioning; to assess their effectiveness in terms of quality, equity, and efficiency; and to develop policies that help spread these applications in both the public and private sectors.

Canada's contribution is identifying ways in which local authorities are applying these technologies for improved planning, management, and services. The functional areas dealt with in this project range from economic development, education, culture, environment, integrated planning, and information services to transportation. The OECD plans to establish dialogue with the European Economic Community, United Nations organizations, and other international groups about the issues arising from this project.

The federal Department of Communications in Ottawa is conducting a telework demonstration project whereby an employee works at home 2 to 3 days per week with the remainder of the week spent at the department offices downtown. The project is examining the effectiveness of information and communication support services and hardware. The department has not revealed any plans to evaluate the interactions among communications, transportation, and social aspects.

Examination of contemporary literature suggests that social, organizational, and policy rather than technological issues are constraining the acceptance and implementation of remote work. More empirical work is required to investigate management and employee perceptions about these substantive issues. The study by Stevenson Kellogg Ernst and Whinney (*1*) for NCC on telework and recent surveys of public-sector managers' attitudes toward telework in the capital region offer preliminary insight.

The Stevenson Kellogg Ernst and Whinney study examined the theory and application of telework. The study investigated possible changes in the nature and location of work in the NCR promoted by communications technology. It also examined potential impacts on the capital. The study essentially examined the probable extent to which telework would contribute to a delocalization of employment from the downtown area. It examined the distribution of federal employment among the principal occupational categories (Table 1), assessed the likely effect of telework on these occupational categories (Table 2), and suggested a likely number of potential federal teleworkers (Table 3).

TABLE 1 DISTRIBUTION OF FEDERAL EMPLOYEES IN THE NCR

	1971		1983	
Executive, Scientific, Professional	6,759	(13%)	13,659	(16%)
Administrative, Foreign Service	11,346	(22%)	23,882	(28%)
Technical	4,650	(9%)	7,678	(9%)
Administrative Support	22,246	(43%)	30.410	(36%)
Operational	6,807	(13%	8,514	(10%)

TABLE 2 POTENTIAL FOR TELEWORK

Category	Group	None (%)	Some (%)
Management	Sr. Management	75	25
Scientific	Actuarial	75	25
	Agriculture	90	10
	Arch. & Planning	90	10
	Auditing	60	40
	Economics, Stats	60	40
	Law	90	10
	Social Work	70	30
	Veterinary	70	30
Admin. and Foreign Serv.	Admin Services	50	50
	Computer Systems	75	25
	Financial Admin	75	25
	Program Admin	90	10
	Translation	10	90
Technical	Science & Engineering	90	10
	Social Science	50	50
Admin Support	Clerk and Regulatory	90	10
	Data Processing	90	10
	Steno & Typing	60	40

TABLE 3 NUMBER OF EMPLOYEES IN THE NCR LIKELY TO PRACTICE TELEWORK, BY OCCUPATION

Managerial, Scientific, Professional	1,700
Administrative, Foreign Service	2,400
Technical	500
Administrative Support	11,500
Operational	1,700
TOTAL	17,800

Total increases to more than 19,000 employees when applied to the estimated 112,000 federal employees in the Capital Region.

To evaluate the candidacy of federal employment categories for telework, the study authors defined the type of jobs having higher probability for telework as those performed independently and permitting flexible schedules, having measurable deliverables, and requiring information and communication support services that are easily provided at remote work locations. The study authors examined the occupational aggregations and estimated 19,000 of a total 112,000 as the most likely number of federal employees to be affected by telework in the capital (*1*). This total would probably be influenced by policies and locations of departments.

Telework is increasingly driven by motivational factors such as evolving work force demographics and values, affordable technology, and improved employee morale and performance. Forces of restraint include management's view of the traditional place of work and form of supervision.

In 1988 NCC collaborated with Carleton University, the University of Western Ontario, and York University to study the attitudes of senior federal managers toward telework. The study surveyed 208 senior managers with decision-making responsibility for organizational and personnel costs and benefits of remote work, compared the findings with attitudes toward conventional work arrangements, and raised management issues requiring resolution. The survey was designed to collect the following information:

- The extent to which telework, flexible time, and compressed work week are being implemented;
- The extent to which technologies required for remote work are being applied in the federal departments;
- The extent to which management anticipates application of technologies and work arrangements in 1990;
- Management's perceptions of the costs and benefits of remote work arrangements to employees and the organization;
- Whether, in management's opinion, the different work arrangements will lead to valued or undesirable results for the employee and the organization; and
- Demographic data on the managers, their departments, and their organizations.

Multivariate scaling methods and factor analysis were used to identify the predominant attitudes of the survey respondents. Other techniques, such as linear modeling, were also used to identify issues that influence support for flexible-time and telework arrangements.

The findings suggest that senior managers in the federal public service in the NCR are reasonably receptive to the introduction of alternative work arrangements. The data indicate a cautious approach—most managers would most likely adopt innovative arrangements like telework that have been successful elsewhere (L. E. Duxbury, unpublished material, 1989).

Senior managers support in principle the idea of remote work but do not regard telework as providing any benefits to federal departments and agencies. Absence of employees from a central office during regular work hours makes remote work unattractive to managers. Telework will require new management skills.

Senior managers also appear to disregard benefits of remote work for teleworkers (flexible work schedule, reduced costs associated with work, improved housing choice, higher level of management trust, fewer distractions, less work and commuting stress, higher morale, and better quality of work life and job satisfaction) (*2*).

The survey results also reflect a bias by federal public service managers against the implementation of telework. Successful telework programs indicate a number of economic benefits for the organization (gain in productivity, decrease in absenteeism, reduced air pollution, higher employee morale, reduced overhead costs, improved employee recruitment, and improved employee performance). Senior federal managers in the NCR report neutral attitudes toward employee loyalty, productivity, and staff turnover and recruitment issues. Neutral attitudes suggest that senior federal managers do not recognize the positive influence of telework. Senior federal managers in the NCR are aware of negative organizational impacts of telework but prefer not to recognize the benefits.

More substantive research associated with organizational, social, and policy issues; specific demonstration projects; and continued dialogue and public awareness of the benefits of telework will effectively eliminate bias and lead to a more forward-looking strategy.

POTENTIAL IMPACTS ON THE NCR

Telework could influence the nature of urban development in the NCR, particularly in the suburban communities. Some of the existing land use and travel patterns in the outlying urban areas will probably change. Telework will also probably have important social, economic, and employment impacts associated with increased access to the job market, reduced transportation costs, more housing choice, less commuting stress, and reduced organizational overhead.

Despite the demonstrated benefits of telework, a number of issues that require attention and action continue to restrain the rate of growth of telework in the NCR.

Perceptions by the Regional Governments

Neither the Regional Municipality of Ottawa-Carleton (RMOC) nor the Communauté Régionale de l'Outaouais (CRO) have developed corporate policies toward teleworking for their own employees. Regional planners, however, recognize the potential benefits of telework in helping to accomplish planning objectives. RMOC considers the key benefit of telework to be support of altered work schedules, which helps diminish travel demands during peak periods.

Deconcentration of employment and services from downtown Hull is an objective of CRO. Locating the property tax assessment function in outlying communities and developing Gatineau as the growth center in the eastern sector of the Outaouais are features of the planning policy (*3*). There are no explicit telework policies to help achieve regional development directives, but CRO planning officials appreciate that it can help achieve planning objectives, and they recommend a demonstration project involving the federal government.

Federal Telework Policy

The federal government is not developing corporate policies toward telework in the NCR. The Treasury Board Secretariat has no policies specifically directed at telework or telecommuting. There are, however, policies that deal with alternative work arrangements associated with quality of work life, flexible work hours, variable work week, and part-time employment.

The decision to implement telework and other work arrangements remains at the discretion of individual departments. Guidelines allow managers to refuse such arrangements subject to departmental requirements and also depending on their attitudes and understanding of the costs and benefits. More systematic research and progressive education is required to understand and influence managerial attitudes and decision mechanisms toward telework.

NCC Planning Policy

The Federal Land Use Plan developed by NCC and approved by the federal cabinet in 1988 is directed toward guiding decisions and actions concerning the use of federal lands in the NCR. The plan advocates careful consideration of the influences of telecommunications on transportation, employment, the political role of the capital, the quality of the work environment, and land use. The prominence of an information-based economy and the large federal public service in the capital are factors that can support successful telework activities in the NCR. The plan recommends (*a*) relocating administrative support and information sectors of federal employment (routine information activities are independent of downtown location and can be dispersed while retaining desired contacts) and (*b*) taking advantage of opportunities for application of telecommunications and information technology to delocalize employment (*4*).

The plan envisions a model capital for Canada's contemporary information society that demonstrates the benefits of Canada's technological accomplishments, enhances the role and identity of the capital, and projects the capital as a communications center.

Regional Planning Policy

The RMOC and CRO plans make no direct reference to telework or telecommunications. Several issues and policy directives, however, appear to favor telework application:

- Development of large suburban communities,
- Accessibility and associated financial considerations,
- Interaction between major employment locations and the planned regional transportation system,
- Convenience of goods and services through development of small community focal areas, and
- Energy conservation through reduced numbers and lengths of trips and increased transit service.

Telework is clearly a positive factor in locating employment close to residential areas and in helping reduce the length and requirement of peak-period commuting.

RMOC is endeavoring to achieve an integrated transportation system with emphasis on public transit and measures to alter travel demand during peak periods. Importance is also given by the regional governments to transportation systems that respect the environment (*5*).

The Ottawa-Carleton and Outaouais sectors of the NCR are presently formulating long-range visions. The Outaouais Transit Commission will conduct a strategic study of long-range transportation requirements taking into account the evolution of demographic, social, economic, infrastructure, and development conditions. The study will deal with future travel requirements for the 2020 planning horizon with emphasis on public transit. The influence of communications technologies on land use patterns and travel habits are not being incorporated in these plans.

The identification and assessment of key issues, opportunities, and priorities in any long-range planning process must take into account the interactions between transportation, land use, and telecommunications. It is essential that planners, in their long-range studies, not necessarily assume today's answers for tomorrow's challenges.

REGIONAL TRANSPORTATION ISSUES

Transportation demand in the Ottawa-Hull metropolitan area has grown substantially during the past 15 to 20 years. Although population growth in the Ottawa-Hull area has been steady (14 percent) between 1976 and 1986, employment has grown more (25.5 percent). In addition, the number of daily trips per person has increased by 21 percent between 1976 and 1986, or 2.3 percent annually. Accompanying this increase has been an increase in average trip length. Simulation of travel demand in the Ottawa-Carleton region suggests that average trip length for the 24-hr period will grow from 8.7 km (5.4 mi) in 1981 to 9.8 km (6.1 mi) in 2001.

More than 5.4 billion vehicle-km of travel occur annually in the Ottawa-Carleton sector of the capital. Total fuel consumption for all vehicles probably exceeded 8 billion L in 1989. An estimated reduction of 10 percent in travel attributed to telework arrangements could result in annual automobile energy savings of $31 million (Canadian) in Ottawa-Carleton.

The estimated growth trends indicate that the transportation system and facilities in the NCR will be required to continue to deal with higher and costly demands. Added to this is an estimated 27.3 percent increase in population by the year 2011 and a projected 135 percent increase by the year 2050 (*6*).

The NCR is expected to grow by 8,900 people annually. Steady growth in automobile and goods movement and associated increases in costs due to traffic congestion are also expected. A recent study of goods movement in Toronto, Ontario, estimated the annual cost of congestion attributable to goods movement to be $15 billion (Canadian) (*7*).

NCC continues to direct considerable effort and investment toward and to use federal lands in Outaouais and Ottawa-Carleton for improving regional roadway and transit systems, examining the probability and impacts of future interprovincial bridges, ensuring continued compatibility in interprovincial transit services, and developing and maintaining parkways.

Freeway and regional roadway rights-of-way up to 50 m (165 ft) wide along more than 755 ha (1,865 acres) of a total 3285 ha (8,117 acres) of the public urban corridor lands owned and managed by NCC are being considered by the regional governments for future transportation purposes. Whereas much remains undeveloped, about 1500 ha (3,706 acres), or almost half of the inventory, supports a variety of parkway, recreational, and public open-space uses implemented by NCC. These lands were acquired by NCC as components of a national trust on behalf of all Canadians. The use of federal lands to satisfy regional and community requirements is inconsistent with federal objectives and the NCC mandate.

The level of telework in North America is driven largely by issues associated with escalating costs of downtown office space, excessive traffic congestion, and deterioration in the quality of the air (*8*). Research into telework in Canada's capital region is also driven by other issues: improvements in organizational and individual productivity and morale in an area with high public service employment; growing techno-literacy; affordability; increased participation of women with children in the labor force; and a desire for sustainable development, healthy cities, and a society that practices conservation.

Environmental issues have assumed a profound urgency in the minds of most Canadians. Environmental preservation and conservation are today recognized as global concerns affecting the future quality and survival of life-sustaining ecosystems. The NCR has historically projected a strong, environmentally healthy image, the result of foresight by NCC and its predecessors. The image is manifested by a diversity of green space, ranging from extensive natural areas like Gatineau Park to agricultural and forestry areas in the Greenbelt and along river shorelines to highly structured public spaces like the Rideau Canal and urban parks.

Remote work in the form of working at home or from a neighborhood center offers an opportunity to reduce the length and amount of commuting during peak periods. Telework is also a way to avoid or level peak travel demands. Traffic congestion and transportation energy use could be reduced by telework.

NCC and other federal lands in the capital must be recognized for their functions associated with the environment. They represent the expression of Canadian attitudes and values about the environment. Telework offers significant help in accomplishing this objective by reducing dependence on traditional transportation solutions to urban development problems.

MORE RESEARCH REQUIRED

The implementation of telework is progressing in the NCR despite the lack of formal policies to manage these programs or to protect participating employees. Presently 1.8 percent (about 2,000 employees) of the federal public service work force in the NCR practices remote work arrangements full time.

There is significant yet cautious interest in telework in the region, but it remains a concept rather than a reality. Contemporary literature and experimentation in telework both indicate that working at home full time is at present not realistic, but formal part-time work-at-home arrangements are increasingly acceptable to management and unions.

More formal telework in the NCR appears to be probable. The survey of federal senior managers suggests that they are receptive to the concept. One-third of the working population in the NCR is employed by the federal government, a unique condition that favors the application of telework.

Additional work is required to investigate the merits of telework as an effective planning strategy in the future growth of the NCR. Study is required to examine interactions between telecommunications and travel behavior by trip mode and purpose. Telework could affect the cost of commuting to work, reduce traffic congestion, and contribute to transportation energy savings and improved air quality.

NCC will participate in a survey of public-sector employees to examine the relationship between work-family conflict and stress and evaluate pertinent individual and organizational results. Alternative work arrangements will be an important consideration in this proposed survey. The findings of the research should improve the understanding of how changing work environments affect families and organizations. The research is an important step toward the creation of more supportive work environments by organizations, improved management of the family-work interface, and wider acceptance of innovative work arrangements like telework. The survey will be conducted by Carleton University, the University of Western Ontario, and the University of Ottawa beginning in early 1990.

Assessment of the influence of telework on land use and development, economic development, and urban and regional growth is also required. Information is also needed on the choice of residential location associated with telework and the influence of telework on family life and quality of work.

Telework is a politically contentious issue given the wide range of interest groups. There has been active opposition to work-at-home arrangements by organized labor in the United States, and labor groups in Canada have been less than enthusiastic about the issue. More information is required about taxation, labor, liability, contracts, and compensation associated with telework.

NCC has a number of options to consider for future action. These include passive monitoring of other telework research and trends, promoting dialogue about benefits of telework, conducting additional studies, and designing a demonstration telework project in the capital area jointly with pertinent departments and agencies.

Should NCC decide to pursue telework more actively, it would be in a pioneering role in the capital.

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Telecommuting as a Transportation Planning Measure: Initial Results of California Pilot Project

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The travel impact of home telecommuting—the performance of work at home possibly using telecommunications technology—is evaluated using travel diary survey results from California's State Employee Telecommute Pilot Project. The data obtained from 185 state workers and their household members indicate that telecommuting reduces work trips as expected, and no indication is present that telecommuting induces new nonwork trips. In addition, the results suggest that family members of telecommuters may also reduce nonwork trips. The analysis offers strong empirical support for telecommuting as a means to mitigate traffic congestion and improve air quality.

Ever-worsening traffic congestion and air pollution have been major concerns of many growing urban areas. In particular, failure to meet the federal air quality mandates in most of the major metropolitan areas of California has forced planning agencies and air quality management districts to step up efforts to institute coordinated, effective, and enforceable programs for travel reduction. Among the options being considered by these agencies is telecommuting. Telecommuting refers to the performance of work outside the traditional central office, either at home or at a neighborhood center close to home.

Telecommuting is emerging as a feasible option because of two fundamental changes. First, the labor force has evolved from one whose workers were primarily involved in agricultural, industrial, and manufacturing processes to one in which information workers—those involved in the creation, collection, or handling of information—are a considerable portion. For these workers the conventional mode of work (i.e., being at the workplace to perform work functions) is less mandatory. Concurrently, advances in telecommunication technologies and greatly increased capabilities per unit cost have made location-independent work feasible and cost-effective.

In California, where information workers are almost 60 percent of the labor force, telecommuting first received attention as an energy conservation measure. A study done for the California Energy Commission (*1*) indicated that telecommuting had significant potential for mitigating both travel demand (particularly peak demand) and fuel consumption in the state—annual reductions could range up to 30 billion passenger-mi of travel and 700 million gal of fuel by 2000. However, the estimates contained in this study were based on scenarios of varying penetration rates for telecommuting (4 to 55 percent of the labor force) that assumed historical household travel behavior. Only direct substitution for the commute trip (by mode) was used in calculating travel and fuel reductions. Total household travel impacts were not addressed because no data were available. Without such data, the effectiveness of telecommuting as a travel demand management tool could not be adequately evaluated.

Another aspect of telecommuting, its feasibility as a business strategy (*2,3*), is equally important in assessing its role in demand management. If telecommuting is not feasible for a public agency or a private company, it makes no sense to promote it for transportation, energy, or air quality reasons. Earlier experience with telecommuting in the private sector appeared to increase worker productivity, but formal evaluations were proprietary and not available for analysis. Apparently, companies with telecommuting programs considered them part of their market competitiveness strategy.

An opportunity to assess both household travel impacts and business feasibility came with the establishment of California's State Employee Telecommute Pilot Project. Now nearing completion of its home telecommuting phase, this is the first large-scale telecommuting project in the United States from which nonproprietary data and analysis are available. The major goal of the project is to develop operating policies and procedures to permit expansion of telecommuting to all state agencies.

The project has involved more than 400 state employees from various departments. About 60 percent of them have been telecommuting, typically 1 or 2 days a week. The remaining employees have been participating in the project as control group members, providing data that aid in isolating the impacts of telecommuting on business-related performance and travel demand from the impacts of other factors that vary over time (e.g., organizational changes and gasoline prices).

To evaluate household travel impacts, project participants and their household members of driving age were surveyed before and after they began telecommuting. Three-day travel diaries were used in both surveys, which were conducted approximately 1 year apart in January through June 1988 and

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April through June 1989. The resulting panel data set constitutes a unique and valuable information source from which the effect of telecommuting on mitigating traffic congestion, reducing energy consumption, and improving air quality can be empirically evaluated.

This paper summarizes the initial results from the two waves of the panel survey. The objective is to assess the impact of telecommuting on household travel behavior on the basis of observations obtained from this large-scale pilot project. Of particular interest is the effect of telecommuting on nonwork travel. It is conceivable that telecommuting leads to reduced needs to commute and added flexibility in trip making, which, together with the corresponding increase in discretionary time, may induce new nonwork trips.

The impacts and issues related to the business aspects of telecommuting are beyond the scope of this paper. However, telecommuting appears to be feasible from a business perspective given the results of the first year of the California project (*4*).

The paper is organized as follows. First, trip making at an abstract level is discussed and a conceptual framework for assessing the impact of telecommuting on travel demand is given. The objectives and history of the California pilot project and the process for selecting project participants are then described. Travel characteristics of the project participants before they commenced telecommuting are summarized and differences between telecommuters and control group members are discussed. The impact of telecommuting on household travel is discussed next by comparing mobility measures obtained before and after telecommuting began. Finally, conclusions are given.

BACKGROUND

The evaluation of the impact of telecommunications on travel demand is a complex task. Several hypotheses have been advanced. Of particular interest is whether telecommunications technologies act as substitutes for travel or whether a complementary relationship exists between telecommunications and travel (*3,5,6*). Little empirical evidence on the interaction between the two appears to exist (*7*).

Determining the impact of telecommuting on household travel demand presents difficulties because its impact on the telecommuter's nonwork trips and the travel patterns of household members is not known [see Jovanis (*8*) and Garrison and Deakin (*9*) for related discussions]. The panel travel survey data available from the California pilot project offer a data base to examine this secondary effect of telecommuting.

An immediate consequence of telecommuting is a reduced number of work trips, which contributes to reduced peak traffic and vehicle miles traveled. The reduction, however, may produce repercussions that partially offset the savings. The reduced need to commute and the added flexibility in work schedule that telecommuting brings about may induce discretionary activities and trips that the telecommuter did not make before. The impact of this on travel behavior can be complex. For example, shopping and other errands that were done during commuting trips with practically no additional distance traveled may be pursued independently from home, possibly at different locations and at different times of the day. Or the errands that were performed by other household members may now be assigned to telecommuters, who have gained flexibility in scheduling activities.

Telecommuting may also lead to changes in travel mode use by the telecommuters and household members. For example, irregular commuting schedules resulting from telecommuting may make carpooling impractical and lead to a work trip mode switch from carpooling to driving alone. The availability of a family car left at home by the telecommuter may not only induce new trips but also trigger mode changes by other household members.

Conceivable as a result of telecommuting are changes in car ownership and, in the long term, residential location (the latter may in turn lead to a new form of urban sprawl). With its 1-year evaluation period, the travel panel survey of the California Telecommute Pilot Project will not be of much help in assessing the longer-term land use implications of telecommuting. However, the data being collected are valuable in getting at least a first-cut assessment of most of the other household travel changes of concern.

CALIFORNIA TELECOMMUTE PILOT PROJECT

Objectives and History

The central objective of the California Telecommute Pilot Project is to "test the utility of telecommuting in State government" (*10*) by having selected employees telecommute during the 2-year project period. A number of factors motivated the experiment, including

- The cost of acquiring office space,
- Characteristics of the state work force (information functions and computer literacy),
- Workload increases without concomitant work force expansion, and
- Worsening traffic congestion and the need to reduce air pollution and energy consumption.

Currently 13 state agencies, including the energy commission, public utility commission, and department of transportation (Caltrans), are active in the pilot project.

The concept of telecommuting was presented to the California Department of General Services in early 1984 as a means to decrease demand for office facilities in major metropolitan areas. The proposal was endorsed and a 6-month planning phase was initiated in January 1985 by the department in cooperation with other state agencies. This led to a project plan (*10*), which formed the basis of the pilot project that commenced in July 1987.

Implementation began in January 1988 with training sessions for home telecommuters and their supervisors. The training sessions were held during a 6-month period. During the sessions the participants were requested to fill out detailed questionnaires, including 3-day travel diaries on prespecified survey dates. The questionnaires helped establish the baseline data against which the second-wave survey data would be compared. The second-wave survey was conducted using similar questionnaires and diaries approximately 1 year after the first survey. The development of the instruments for this panel survey was directed by a special team including staff from Caltrans, the energy commission, and the air resources board (*11*).

Selection of Project Participants

Participants in the pilot project are all volunteers who expressed interest in telecommuting in response to the solicitation by the project coordinators. The initial set of volunteers comprised 1,039 potential telecommuters and their 413 supervisors, who were both requested to fill out an extensive questionnaire prepared by JALA Associates.

Two sets of questionnaires were prepared, one for prospective telecommuters and the other for their supervisors. The objective was to evaluate the likelihood of successful telecommuting for each employee-supervisor pair. The criteria used in the selection process can be grouped into three categories: the nature of tasks performed, sociopsychological characteristics, and managerial style and role. For example, in the first category, employees performing tasks that require high concentration are particularly suited for telecommuting, whereas those who need to maintain high levels of face-to-face interaction or who require access to special resources or sensitive information that requires physical security can best perform their tasks in the traditional office environment (*10*).

Each recommendation prepared by JALA Associates included the form and duration of telecommuting that was estimated to be initially suitable for each supervisor-telecommuter combination. The possible forms of telecommuting were (*a*) home-based, (*b*) satellite, and (*c*) none. The possible durations were (*a*) at least 3 days per week, (*b*) 1 to 3 days per week, (*c*) 1 day or less per week, and (*d*) none.

On the basis of these recommendations, the supervisors selected who would telecommute. Volunteers with similar job characteristics were requested to participate in the project as a control group. Initially, 230 telecommuters and 192 control group members from 16 agencies were selected. Their demographic, occupational, and employment characteristics are summarized elsewhere (*4*).

The selection process appears to have successfully identified employees suitable for telecommuting. Although a discernible number of the initial participants left the project, most did so because of promotions, job changes, reorganizations, new supervisors, retirement, or similar reasons. In only a few cases did participants leave because telecommuting was not workable. Furthermore, in most of the cases the participants attempted to telecommute against the recommendations offered by the project coordinator.

An analysis of the survey questionnaire by JALA Associates indicated that the telecommuters and control group members have similar job, socioeconomic, and personality characteristics. Control group members are not necessarily unsuitable for telecommuting. The similarities arise in part because both telecommuters and control group members are volunteers who share an interest in the pilot project. It is believed that the similarities aid in isolating the effect of telecommuting on travel patterns because the two groups are likely to respond to changes in the travel environment in similar manners.

A note is due here on the self-selected nature of the survey sample. Comprising volunteer participants, most of whom are mid-level professionals, the survey sample is not likely to be representative of the population of California. Likewise, their responses to telecommuting may not represent what would be exhibited by the population of information workers. The study may contain biased results because of the self-selected sample, and their immediate generalization is not warranted.

PRETELECOMMUTING TRAVEL CHARACTERISTICS

Three-day travel logs were available from 212 project participants and 135 driving-age members of their households before telecommuting began. Of the 212 state employees, 113 (53 percent) are home telecommuters and 99 (47 percent) are control group members. Summary statistics of the respondents to the pretelecommuting survey are given in Table 1 by status (home telecommuter and control group member) and person category (project participant, spouse, other household members).

Pretelecommuting travel characteristics of the project participants and their household members are shown in Table 2. The trip rates, trip lengths (in miles), and trip times (in minutes) shown in the table are all considerably greater than the corresponding statewide averages (3.00, 5.7, and 18.6, respectively) for each of the three person categories. This is partly because the sample of this study consists of individuals of driving age from households with (mostly professional) state workers. It is also plausible that those who volunteered to telecommute tend to have long commute distances for which telecommuting is particularly appealing.

There are certain differences between the telecommuters and control group members in travel characteristics. For example, control group members are more transit oriented than telecommuters, with much more frequent use of public transit for commuting (Table 3). This is the case for not only

TABLE 1 PRETELECOMMUTING TRAVEL SURVEY PARTICIPANTS BY STATUS AND PERSON CATEGORY (EXCLUDES INDIVIDUALS WITH UNKNOWN PERSON CATEGORIES)

	Self	Spouse	Others	Total
Telecommuters	113	66	12	191
Control Group Members	99	51	6	156
Total	212	117	18	347

TABLE 2 PRETELECOMMUTING TRIP CHARACTERISTICS OF PILOT PROJECT PARTICIPANTS

	Pilot Project Participants			
	Employee	Spouse	Other	Average
Person Trip Rate[1]	3.74	3.40	3.69	3.62
Average Trip Length (miles)	13.0	9.5	8.9	11.7
Average Trip Time (min.)	32.7	29.8	23.8	31.3
Number of Participants	212	117	18	
Number of Trips[2]	2380	1194	199	

[1]Trip rates are per person per day.
[2]The number of trips is a total for the three survey days.

TABLE 3 DISTRIBUTION OF PRETELECOMMUTING WORK TRIP MODES: TELECOMMUTERS VERSUS CONTROL GROUP MEMBERS

	Telecommuters			Control Group		
	Transit	Other	%Transit	Transit	Other	%Transit
Employee	58	544	9.6%	75	427	14.9%
Spouse	5	215	2.3%	7	163	4.1%
Others	0	23	.0%	1	5	16.7%
Total	63	782	7.5%	83	595	12.2%

the state employees themselves but also their spouses and other driving-age household members. The same result appears in the slight but meaningful difference in car ownership between the two groups (Table 4). The percentage of households without a car available is 8.4 percent (7 out of 83) for the control group, whereas the corresponding number is less than 1 percent (1 out of 109) for the telecommuter group (*12*).

MEASURED IMPACT

The results of the panel surveys conducted before and after telecommuting using 3-day travel diaries were the basis of the empirical analysis of this section. Matched before-and-after diaries were available from 194 persons categorized as follows:

Category	*Number*
Telecommuters	
State employees	66
Household members	39
Control group	
State employees	57
Household members	32
Total	194

The results indicate that negative effects were minor and that telecommuting contributed to an overall reduction of trips. The reduction in work trips was as expected (Table 5). During the 3-day diary periods, the telecommuters' home-to-work trip rate decreased by more than 40 percent, from an average of 1.11 trips per day before telecommuting to 0.62 trips after telecommuting (the reduction is significant at a confidence level of 1 percent, or $p = 0.01$). The control group members maintained similar trip rates of 1.14 and 1.02 in the before and after surveys, respectively.

This result was expected because most telecommuters in the pilot project telecommute 1 to 2 days per week. The average number of telecommuting days in this sample was 1.25 days per 3-day diary period, or approximately 2 days per week (the telecommuting respondents were requested to select three consecutive weekdays for the second survey such that the period contained at least one telecommuting day). Assuming this rate of telecommuting, weekly trip rates were estimated as shown in the second half of Table 5, where the reduction in work trips approximately equals the number of telecommuting days. [Statistics available from JALA Asso-

TABLE 4 DISTRIBUTION OF PRETELECOMMUTING HOUSEHOLD CAR OWNERSHIP: TELECOMMUTERS VERSUS CONTROL GROUP MEMBERS

	Telecommuters		Control Group	
No. of Cars	Frequency	Percent	Frequency	Percent
None	1	.9%	7	8.4%
One	48	44.0%	34	41.0%
Two	47	43.1%	30	36.1%
Three or More	13	11.9%	12	14.5%
Total	109	100.0%	83	100.0%

TABLE 5 CHANGES IN HOME-TO-WORK TRIP RATE BEFORE AND AFTER TELECOMMUTING (STATE EMPLOYEES ONLY)

Trip Rates During Three-Day Diary Periods

	N	Before	After	Δ
Telecommuters	66	1.11	.62	-0.49*
Control Group Members	57	1.14	1.02	-0.12

*Difference significant at p = 0.01.

Estimated Weekly Trip Rates

		Before	After	Δ
Telecommuters	2 Days/Week[1]	5.55	3.45	-2.10
	1 Day/Week	5.55	4.55	-1.00

[1]Estimated using trip rates by day type (telecommuting vs. commuting) and assuming the number of telecommuting days as shown.

ciates indicate that the average number of entire days in a week that the pilot members telecommute from home is 1.64. Most participants telecommute either 1 day (50.7 percent) or 2 days (23.9 percent) per week. In addition, they telecommute some part of the day on the average on 0.43 day per week.]

The reduction in work trips implies a reduction in trips made in peak periods (Table 6). Telecommuting employees reduced their morning peak period trips by 0.40 trip per day (a 34 percent reduction, significant at $p = 0.02$), whereas control group members reduced theirs by less than 4 percent.

The survey results offer no indication that either telecommuters or their household members increased nonwork trips after the telecommuting experiment commenced (Table 7). The extended flexibility and increased discretionary time brought about by telecommuting does not appear to induce additional nonwork trips. In particular, the family members of telecommuters had a much larger reduction in nonwork trips than their control group counterparts (significant at a confidence level of 5 percent). Possibly this was in part due to underreporting of trips caused by "panel fatigue," in which participants become less accurate when responding to questionnaires in later waves of repeated surveys. It is plausible, however, that additional flexibility in trip scheduling due to telecommuting leads to streamlined travel patterns by all household members, which in turn lead to a much-reduced nonwork trip rate by the household. Comments given in brief interviews with telecommuters indicated that they believed that the household members can be better organized and their trips can be better planned.

Table 8 shows the trip rates by telecommuters on the days they telecommuted and on the days they commuted to their offices, together with the trip rate among control group members. The average trip rate (including all trips) was only 1.92 trips per telecommuting day, which is approximately 2 trips

TABLE 6 CHANGE IN MORNING PEAK PERIOD TRIP RATE[1] BEFORE AND AFTER TELECOMMUTING (STATE EMPLOYEES ONLY)

Trip Rates During Three-Day Diary Periods

	N	Before	After	Δ
Telecommuters	66	1.18	.78	-0.40*
Control Group Members	57	1.20	1.16	-0.04

[1]Morning peak trips are defined as those that either begin or end between 7 am and 9 am.
*Difference significant at p = 0.02.

Estimated Weekly Trip Rates

		Before	After	Δ
Telecommuters	2 Days/Week[2]	5.90	3.97	-1.93
	1 Day/Week	5.90	4.86	-1.04

[2]Estimated using trip rates by day type (telecommuting vs. commuting) and assuming the number of telecommuting days as shown.

TABLE 7 CHANGE IN NONWORK TRIP RATE BEFORE AND AFTER TELECOMMUTING (STATE EMPLOYEES AND HOUSEHOLD MEMBERS)

Trip Rates During Three-Day Diary Periods

	N	Before	After	Δ
Telecommuters				
Employees	66	1.57	1.51	-0.06
Household Members	39	2.25	1.31	-0.94*
Weighted Average	105	1.82	1.44	-0.38
Control Group				
Employees	57	1.91	1.81	-0.10
Household Members	32	1.65	1.56	-0.09
Weighted Average	89	1.82	1.72	-0.10

*Difference significant at $p = 0.05$.

Estimated Weekly Trip Rates

		Before	After	Δ
Telecommuter	2 Days/Week[1]	7.85	7.47	-0.38
Employees	1 Day/Week	7.85	8.01	0.16

[1]Estimated using trip rates by day type (telecommuting vs. commuting) and assuming the number of telecommuting days as shown.

TABLE 8 TOTAL PERSON TRIP RATE PER DAY ON TELECOMMUTING DAYS VERSUS COMMUTING DAYS (STATE EMPLOYEES ONLY)

	Day of the Week					
Telecommuters	Mon	Tue	Wed	Thur	Fri	Total
Telecommuting Day						
Trip Rate	1.50	1.56	1.96	2.04	1.95	1.92
N	4	9	26	27	21	87
Commuting Day						
Trip Rate						4.08
N						99
Control Group Members						
Trip Rate						3.96
N						168

The sample size (N) is shown in person-days.

less than the average of 4.08 trips for commuting days. The latter average is close to the average of 3.96 trips for control group members. The results confirm the findings above and are another indication that the trip rate was reduced significantly (by two trips) on days that employees telecommuted, whereas there was no appreciable increase in trip making on days that they commuted to work.

The reductions in nonwork trips, however, must be subjected to further scrutiny before a conclusion can be drawn. The reductions by the control group members and the household members of telecommuters (Table 7) may be due to sampling variations if the large numbers of nonwork trips they reported in the first survey represent extreme trip making. Also, the reductions may in part be a result of underreporting of trips. This can be attributed to panel fatigue. An example of panel fatigue was reported for a large-scale Dutch panel study using weekly travel diaries (*13*). Analysis is currently underway to determine whether the apparent reductions reflect a genuine change in nonwork trip making.

CONCLUSIONS

The preliminary results obtained from the panel travel diary survey are encouraging. Telecommuting reduces work trips as expected, and no indication that it induces new nonwork trips has been observed. In addition, the results suggest that family members of telecommuters may also reduce nonwork trips. Together with the finding of feasibility for business (*4*), the analysis offers strong empirical support for telecommuting as a means to mitigate traffic congestion and improve air quality. Effort is currently under way to extend the scope of analysis to include changes in vehicle miles traveled, mode use (transit use and carpool participation), destination choice, trip linkage and timing, and other pertinent elements of household travel behavior.

The next phase of the California Telecommute Pilot Project being considered for funding involves telecommuting at multiagency neighborhood centers. This phase will allow researchers to analyze changes in travel behavior beyond home-based telecommuting. The Washington State Energy Office is pursuing a large public-private telecommuting demonstration program for the greater Seattle metropolitan area. The evaluation of this effort will add to the data base and help clarify telecommuting's role as a travel demand management tool. With time, evidence should become available as to the influence of telecommuting on land use and development.

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Comparison of Travel Behavior and Attitudes of Ridesharers, Solo Drivers, and the General Commuter Population

ROBERTA VALDEZ AND CARLOS ARCE

Research related to factors influencing an individual's propensity to carpool or vanpool is briefly reviewed to provide background for the findings of a survey of the general commuting population of suburban Orange County, California. The findings are presented as they relate to three groups of commuters: ridesharers, solo drivers, and the general commuting population. Comparisons between the survey's findings and previous research are made. Among the key findings was that travel time was the most important mode selection factor for all three groups. Whereas the availability of a car at work was the second most important factor for commuters in general and solo drivers, ridesharers rated commuting costs as the second most important factor. Ridesharers were more likely than solo drivers to believe that high-occupancy vehicle (HOV) lanes encourage ridesharing, and there was more support among ridesharers than solo drivers for a sales tax increase to build HOV lanes. The general commuter survey results support the previous findings with regard to the role of travel time and distance in commute mode choice: ridesharers commute for longer times and distances than either solo drivers or the general commuting public. Support was also provided for the role of parking cost and availability. Comparisons were also made between the data base of matchlist applicants of the regional commute management agency and the general commuting population. The commute distances of commuters completing applications for ridesharing matchlists were more like those of current ridesharers than the general commuting public or solo drivers. Also, the proportion of matchlist applicants currently ridesharing was larger than that of the general commuting public.

Recent findings will be presented as they relate to three groups of commuters: ridesharers, solo drivers, and the overall commuting population. Comparisons will be made with previous findings where applicable. First, the most important factors influencing ridesharing behavior will be reviewed.

FACTORS INFLUENCING RIDESHARING BEHAVIOR

In attempting to determine the factors that influence an individual's propensity to carpool or vanpool, researches have examined sociodemographic and attitudinal differences between solo commuters and ridesharers. Though research findings vary with regard to generalizations that can be made about those who are most likely to rideshare, there is a consensus regarding those who are effectively barred from such travel arrangements (*1*). The following groups are unlikely prospects:

- Individuals working at small, isolated sites;
- Individuals with irregular hours or fluctuating schedules; and
- Individuals who use their cars during the day (e.g., salespeople).

Additionally, child care issues are a strong deterrent to ridesharing. Parents who need to leave children at child care facilities, or are concerned about their ability to react to emergency situations involving their children, are reluctant to rideshare (*2–5*).

There are factors, however, that have been associated with a greater propensity to rideshare. Of all the factors, travel time and distance have been the best predictors of ridesharing behavior.

Many studies indicate that a higher proportion of commuters rideshare as distance and travel time increase (*1,6,7*). Brunso et al. (*6*) found that the groups with the best potential for ridesharing were the "far-fast" group (i.e., those with commutes of more than 10 mi that took 40 min or less) and the "far-slow" group (i.e., those with commutes of more than 10 mi that took 40 min or more). Transportation Demand Management (TDM) Market Research Studies conducted by the Orange County Transit District (*3–5,8*) have also consistently shown that ridesharers have longer travel times and commute distances.

Automobile availability is another important factor influencing propensity to rideshare. On the basis of results from a nationwide survey, 40 percent of all carpoolers are from households with fewer vehicles than workers (*7*).

Peat, Marwick, Mitchell & Company (*9*) found that the parking situation at the workplace is also an important consideration. The characteristics (e.g., free parking for all employees) and availability of parking facilities at the workplace have a direct impact on mode choice (*10*).

Whereas commuters in general tend to underestimate commuting costs (*2*), individuals are three times more likely to rideshare when cost-to-income is greater than 5 percent (*7*).

Crain and Associates (*2*) found that opposition to carpooling was high in Santa Clara County, principally because of dependency on others or schedule imcompatibility. Whereas about 42 percent of the study's respondents believed that depending on others was not worth the money carpooling would save, higher proportions (55 to 58 percent) believed

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that achieving time savings in commuter lanes or fulfilling the requirement for pooling to obtain a guaranteed parking space at work would be worth depending on others or leaving work at a fixed time each day.

METHOD

The major source of data was a survey of commuters in Orange County, California, conducted in November 1988. The purpose of the survey was to gather information about travel behavior, attitudes toward alternative commute modes, and awareness of the commute management agency from the general commuting population.

A representative sample of all commuters in the region was obtained. Ridesharers were oversampled in order to obtain sufficient numbers for analysis. The data were subsequently weighted to achieve the appropriate influence on the aggregate findings. A total of 518 interviews were conducted between October 25 and November 17, 1988.

A second source was the data base of matchlist applicants of a regional commute management agency. Surveys are distributed to all employees of client companies in the region to generate computerized matchlists and to promote carpool and vanpool formation. The information obtained included name, address, phone number, work hours, present travel mode, and type of ridesharing arrangement desired. To provide comparability with the general commuter survey, the analysis used in this paper is based on the 92,513 applicants in the data base as of November 1988.

RESULTS

Travel Characteristics

As indicated in Table 1, applicants for ridesharing matchlists were more likely to use alternative commute modes than the general commuting population. These results are consistent with those obtained by Commuter Transportation Services in a similar comparison of the two groups in the Los Angeles area (*11*).

Both the average travel time and distance for ridesharers were longer than for solo drivers or the general commuting population (see Table 2). The table also indicates that the commuting distance for current ridesharers on the basis of the General Population Survey was almost identical to that of matchlist applicants.

When nonridesharers were asked the likelihood of joining a carpool or vanpool, 68 percent indicated that they were "not likely at all." Most would not be willing to try commuting by carpool (72 percent) or vanpool (78 percent) even for 1 day during the next 4 work weeks.

"Flexible work schedules" was the most commonly mentioned change commuters would make to achieve a more satisfying commute (17 percent). Ridesharing, moving closer to work, finding work closer to home, and getting a new car were each mentioned by about 5 percent of the commuters.

Of those commuters who had carpooled, vanpooled, or used transit within the past 3 years, the majority (51 percent) had done so for less than 1 year and about one-third (31 percent) had used a high-occupancy mode for 1 to 2 years. Most of those who quit did so because the company relocated (26 percent), whereas equal proportions (23 percent) either got a car or their carpool partner dropped out of the arrangement or changed jobs.

Attitudes

Travel time was the most important factor in deciding how to travel to work for the general commuting population (39 percent), as well as for ridesharers (39 percent) and solo drivers (30 percent). However, as indicated in Table 3, ridesharers

TABLE 1 TRAVEL MODE

	General Population (n= 520)	Matchlist Applicants (n=92528)
Drive Alone	89.6	82.6
Carpool	6.1	12.3
Vanpool	.1	1.0
Public Transit	1.3	1.7
Private bus	.1	--
Motorcycle	.7	.8
Bicycle/walk	1.6	--
Other	.5	1.5
	------	------
	100	100

TABLE 2 COMPARISON OF TRAVEL PATTERNS FOR GENERAL COMMUTER POPULATION AND APPLICANTS FOR RIDESHARING MATCHLISTS

	General Population			Matchlist
	All	Carpool/Vanpool	Drive Alone	Applicants
Travel distance	11.5	13.8	11.2	13.7
Travel time				
-Home to Work	23.0	27.0	21.6	--
-Work to Home	27.2	31.4	25.8	--
Arrive at Work	6-7:30AM (33%) 7:30-8:30AM (29%)	A little earlier 6:00-7:30 (39%)	A little later After 7:30 (56%)	--
Alternate Route When Traffic Backs Up	Very likely	Somewhat likely	Much more likely	--

differed from commuters in general and solo drivers in the second most frequently mentioned factor. For ridesharers, the second factor was commuting costs, whereas having a car available during work was the second factor for both general commuters (20 percent) and solo drivers (16 percent).

Other factors mentioned by commuters in general were not being dependent on others (11 percent), the amount and flow of traffic (9 percent), comfort and relaxation (7 percent), and safety concerns (6 percent). Less frequently mentioned were weather, road conditions, not having to take a freeway, commuting costs, and convenience.

As indicated in Table 3, there was more support for a proposal to increase the sales tax for high-occupancy vehicle (HOV) lanes among ridesharers (69 percent) than among solo drivers (53 percent). Ridesharers were also more likely to indicate that HOV lanes encourage ridesharing than those who drive alone.

Demographic Profile

As indicated in Table 4, ridesharers were more likely to be Hispanic, blue collar, and slightly less affluent than solo drivers. Ridesharers had also been at their present residence for a shorter period than solo drivers.

TABLE 3 COMPARISON OF TRAVEL BEHAVIOR ATTITUDES FOR RIDESHARERS, SOLO DRIVERS, AND THE GENERAL COMMUTING POPULATION

	General Population		
	All	Ridesharers	Solo Drivers
Commute Satisfaction*			
-Home-to-Work	5.8	5.7	5.7
-Work-to-Home	5.2	5.2	5.1
Mode Selection Factors	Travel time Car available at work	Travel time Commuting costs	Travel time Car available at work
HOV Lanes			
o Encourage ride-sharing	Yes-slightly	Yes-Overwhelmingly	No-slightly
o Support 1/2 cent sales tax for HOV lanes	55% support	64% support	50%/50%
Freeway			
o Gax tax for freeway improvement	56% against	50%/50%	More against than for

* On a scale of 1-9, with "1" being least satisfactory and "9" being most satisfactory.

TABLE 4 DEMOGRAPHIC PROFILE OF RIDESHARERS AND SOLO DRIVERS

	General Commuter Population	
	Ridesharers	Solo drivers
Gender	Male 52% Female 48%	Male 54% Female 46%
Age	No age differences	No age differences
Income	$50,000 or less	$65,000 or less
Ethnicity	Hispanic (25%)	Predominately white
Jobs	More likely blue collar	More likely white collar
Length of residence	Less than 5 yrs.	Nearly evenly split < & > 5 yrs.
Vehicles / household	More likely to own/lease 2 or less	More likely to own/lease 2 or more

CONCLUSIONS

The findings presented in this paper are consistent with past research with respect to travel time and distance. Ridesharers commute for longer distances and times than solo drivers. They are also likely to have fewer vehicles per household than solo drivers.

Previous research has indicated a correlation between automobile availability and ridesharing. The results from the general commuter survey were consistent with these findings. However, the number of vehicles per household is confounded with income (i.e., the number of vehicles per household is correlated with income).

The previous findings concerning the effects of parking costs and availability on mode choice are also supported by these results. The low ridesharing rate (7.5 percent, including transit, carpool, and vanpool) is consistent with the abundance of free parking found in the survey (e.g., only 6 percent of commuters surveyed indicated that they paid for parking).

Previous studies of carpool duration have suggested that those who are currently carpooling remain in that arrangement 2½ years (31 months) on the average, and those who had previously carpooled did so for 2¼ years (*11–13*). However, the findings of the survey reported in this paper indicate that such arrangements may be less stable (i.e., more than 80 percent of those surveyed indicated that the arrangement had lasted 2 years or less).

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Vanpool Operator Survey for the Washington, D.C., Region

JON WILLIAMS, PAUL MARCHIONE, AND ABDURAHMAN MOHAMMED

A survey of vanpool drivers in the Washington metropolitan region during the spring of 1989 was analyzed. The survey indicated that the number of vanpools increased from 670 in 1982 to 1,060 in 1989, a growth of almost 60 percent. The growth occurred despite the liability insurance crisis of 1985–1986 that forced a number of vanpools out of service. It was found that almost 12,200 people rode to work in vanpools on an average day, although there were more than 14,000 vanpool members. More than 2 percent of the commuters traveling to the D.C.-Arlington downtown employment center were in vanpools. Other study areas included trip length, travel time, membership, occupancy, collection and distribution, insurance, and equipment. Origin and destination analysis indicated a significant vanpool market share from Prince William County (approximately 30 mi southwest of Washington). Of the 17,300 commuters traveling daily from Prince William County to the downtown employment center, 3,140 (18 percent) were in vanpools. Prince William County had the largest number of originating vanpools of any county—more than 300. Among the strongest incentives for vanpool formation were high-occupancy vehicle lanes linked to employment areas with a significant parking cost.

Vanpooling is a high-occupancy commuter mode that was formally recognized during the oil embargo of 1973–1974. In the short time since then, vanpooling has become established in most U.S. metropolitan areas, including Washington, and has gained a reputation as a low-cost, efficient mode that requires little public subsidy. Vanpooling has been most successful in the long-distance commuting market, although some think that it can serve other commuter market segments.

A vanpool is defined here as a group of eight or more people who use a van for their daily transportation to and from work. The high occupancies of these vehicles have presented a special problem for the travel monitoring–cordon counting program of the Council of Governments/Transportation Planning Board (COG/TPB) because this program monitors vehicle volumes and occupancies. Monitoring vanpools in traffic is complicated by the "privacy windows" that many vanpool vehicles have for their passenger compartment. The windows use silvered or smoked glass, which makes it impossible to see into the van.

To address this problem, in 1982 the COG/TPB conducted a mail-back survey of Washington area vanpool operators. On the basis of the results of that survey, a monitoring technique was developed for the COG cordon counts, including average occupancies to be used for factoring occupancies. By 1989, it had become apparent that a revised technique was needed to reflect changes in van types and vanpool operating procedures. Consequently, a mail-back survey of vanpool operators was conducted in May and June 1989. This report presents the results of the 1989 survey. In addition to providing the basis for new vanpool monitoring procedures for COG/TPB's cordon counts, the survey provides an opportunity to study current vanpooling practices in the region and analyze changes since 1982.

Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, 777 North Capitol Street, Washington, D.C. 20002.

SURVEY METHODOLOGY

The survey was conducted by using a mail-back questionnaire. The surveyed population consisted of operators (drivers) of vanpools traveling to work destinations in the Washington region. Survey design was predicated on the following assumptions:

1. Given the experience of the 1982 vanpool survey, a high response rate could be expected for a mail-back survey.
2. Vanpool equipment has become standardized to the 15-passenger stretch van. This elongated van is easily recognized because of a 3-ft overhang between the rear-wheel well and the bumper and is seldom used for commuting purposes other than vanpooling.
3. Most of the vanpool population could be identified by assembling data bases available from the following sources: (*a*) state motor vehicle administrations, (*b*) ridesharing programs, (*c*) employers with vanpool programs, (*d*) third-party vanpool leasing firms, and (*e*) vanpool associations.
4. Most vanpools cross the Beltway in the line-haul portion of their journey to work, and thus the Beltway cordon count could be used to factor the survey response to a total population.

Following is a description of the conduct of the survey.

Assemble Population for Survey

As noted, a number of parties now keep data bases that contain names and addresses of vanpool operators. The parties each agreed to provide the operator information, which was entered into a single data base at COG/TPB. When the final data base was assembled, duplicate records were removed. The remaining 1,400 records were then converted to mailing labels.

Many identified operators actually operated more than one van. To ensure reaching all drivers, multiple copies of the survey were mailed to the multivan operators. Though duplicates were removed from the data base (no two labels had the same address, etc.), there was still a chance that a survey was mailed directly to an individual driver and another one sent through the multivan operator who oversaw that driver's van.

Design and Print Survey Questionnaire

The questionnaire was designed on the basis of experience with the 1982 survey. Where appropriate, questions were worded consistently with the previous survey. The questionnaire was designed as a postage-paid mailback, and each was printed with a unique identifying number, so that responses could be matched with the data base for record-keeping purposes.

Conduct Mail-Back Survey

The survey questionnaires were mailed in early May 1989. The mailing period was approximately coincident with the 1989 Beltway cordon count data collection. As completed survey questionnaires were received at COG/TPB, they were logged against the original data base. The log information was used to keep track of survey respondents, to verify that no sector of the data base was subject to undue nonresponse, and to guard against duplicate responses.

In early June a second phase of the survey was conducted. This consisted of phone calls and letters to nonrespondents urging immediate response. The intent was to ensure an adequate response before the beginning of summer vacation.

June 30 was designated as the survey cutoff date. Forms received before that date were keypunched into a machine-readable data base, edited, and coded for certain responses.

Conduct 1989 Beltway Cordon Count

The 1989 Beltway cordon count was conducted in May and June. It counted all inbound traffic on 39 major highways crossing the Beltway. The counts were taken just inside the Beltway from 6 a.m. to 7 p.m. and were classified by time period, vehicle type, and vehicle occupancy. Traffic checkers were equipped with equipment having a button for vanpools. They identified a vanpool by the following characteristics: a stretch van with privacy windows and an overhang of at least 3 ft from the rear-wheel well to the rear bumper, or a van without privacy windows having eight or more occupants.

Traffic checkers were also given a picture of a stretch van. All other vehicles were to be classified by occupancy, so a van with five, six, or seven visible occupants would be counted with other vehicles having that occupancy.

Factoring the Vanpool Survey

Because of the different definitions of a vanpool and the fact that 7 percent of the responding vanpools did not cross the Beltway, a four-step process for factoring the survey was established. The basis for the factoring was four categories of vanpools:

1. A cordon vanpool, as described above, that had eight or more regular passengers;
2. A vanpool with eight or more regular passengers that crossed the Beltway but was not carrying eight on the day of the count;
3. A vanpool with eight or more regular passengers that did not cross the Beltway; and
4. A van that did not have more than eight regular passengers.

To factor, the sample (respondents) and the population (vanpools) must both include Type 1, 2, and 3 vanpools, and not include Type 4 vans. The factoring process was as follows:

1. As determined by the Beltway cordon count, 927 cordon vanpools crossed the Beltway on a given day. From the sample, 541 responses were found to be cordon vanpools. From these two numbers, a regional cordon factor was determined, 1.71 (population = 927 and sample = 541).
2. There were additional vanpools that had eight or more regular passengers but would not be counted in the cordon definition. This number, 42, was factored to the population using the regional factor (1.71), and the population was expanded accordingly (population = 999 and sample = 583).
3. The vanpools that did not cross the Beltway were then added to the population. For some employer-sponsored vanpools, the total number of vans was known and was added for the population total. For the other vans not crossing the Beltway, the regional factor was applied to determine the number of vans not crossing the Beltway (population = 1,073 and sample = 631).
4. The final step was to remove from the sample and population any van that did not have eight or more regular passengers. This reduced both the sample and population and created the final data base used for survey analysis (population = 1,054 and sample = 625).

With the population and sample both containing the same types of vanpools, factors were established for each sector.

Response and Error of Estimates

As did the 1982 survey, the 1989 survey experienced a high response rate (59 percent). This value is at the far upper end of the range of response rates that may be expected from mail-back surveys. Because 41 percent of those surveyed did not respond, there is a possibility of some nonrespondent bias.

As in any survey, parameter values are estimates of true values for the population, and some error is associated with the estimation procedure. For parameters expressed as proportions for the entire region, values will have an error of ± 0.025, assuming binomial values of .5 and .5. In most cases the error will be less.

FINDINGS

Number of Vanpools

The 1982 study estimated the number of vanpools operating in the Washington region to be 667. The 1989 survey indicated that there were 1,058 vanpools, an increase of 391 vans, or 59 percent. Table 1 shows the numbers by state of origin.

The definition of vanpool used in 1982 was a van having seven or more occupants on the day of the survey; in 1989 the definition was a commuter van with eight or more regular members. Only minor differences resulted from the change of definition.

Passengers and Occupancies

The survey asked that van drivers report the actual occupancy of their van on an average day (the last Tuesday, Wednesday, or Thursday that the van traveled). Table 2 indicates that 12,152 passengers (including drivers) traveled in 1,058 vanpools on an average day. This yields an average regional occupancy of 11.48 passengers, slightly lower than the 1982 occupancy of 11.7. The occupancy factors that were used in the Beltway, metropolitan core, and D.C. core cordon counts were slightly different because of differences in the populations studied.

Total vanpool membership was also explored. Table 2 indicates that 14,084 commuters were regular vanpool members. Thus, on an average day, 86 percent of total members actually traveled in the van. Figures 1 and 2 depict the frequency distribution of average daily passengers and regular pool members. It can be seen that the most common occupancy level was 12 average daily passengers. A pool membership of 15 was by far the most common level, reflecting the prevalence of the 15-seat van.

Origins and Destinations

Table 1 indicates that 420 vanpools (40 percent) originated in Maryland, 633 (60 percent) in Virginia, 3 in West Virginia,

TABLE 1 NUMBER OF VANS BY STATE OF ORIGIN

ORIGIN STATE	1982 VANS	1989 VANS	PERCENT CHANGE
D.C.	0	2	--%
Maryland	238	420	+76%
Virginia	429	633	+48%
W Virginia	0	3	--%
TOTAL	667	1,058	+59%

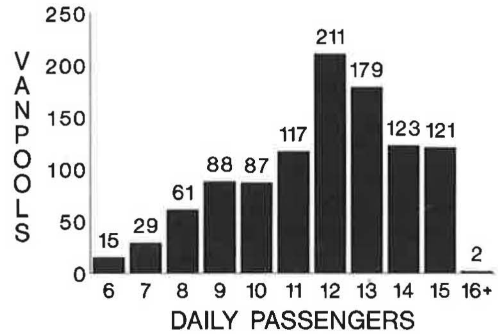

FIGURE 1 Average daily passengers.

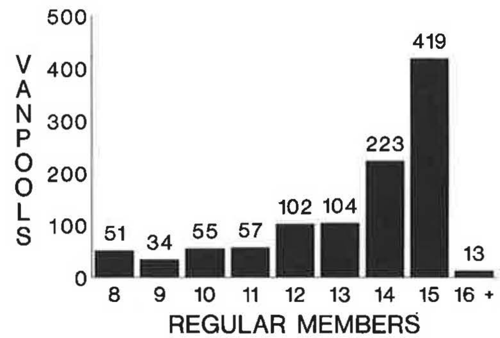

FIGURE 2 Regular vanpool membership.

and 2 in the District of Columbia. Figure 3 is a map showing vanpool origins by county. The map represents the extent of the Washington commuter shed and indicates the long distances traveled by many vanpools. Most vanpool travel was radial and followed seven principal travel corridors: Shirley Highway, I-66, and Route 7 in Virginia; and I-270, I-95, US-50, and Route 5 in Maryland. Prince William County had by far the most vanpools originating, with more than 300.

Vanpool destinations, as in 1982, were largely in the metropolitan core employment area (downtown D.C. and the Rosslyn, Crystal City, and Pentagon portions of Arlington). Table 3 indicates that 887 (84 percent) of vans were destined to the metropolitan core, which compares with 82 percent in the 1982 survey.

Figure 4 shows vanpool passengers traveling to the core and some peripheral areas, by employment area. Federal Triangle had the most passengers, followed by Southwest, Farragut Square, and Crystal City. Figure 5 shows passengers destined to noncore sites.

TABLE 2 PASSENGERS AND OCCUPANCIES (AVERAGE DAY)

ORIGIN STATE	1989 VANS	PASSENGERS	AVG. OCC.	MEMBERSHIP
D.C.	2	22	11.00	22
Maryland	420	4,818	11.47	5,621
Virginia	633	7,274	11.49	8,402
W Virginia	3	38	12.67	39
TOTAL	1,058	12,152	11.48	14,084

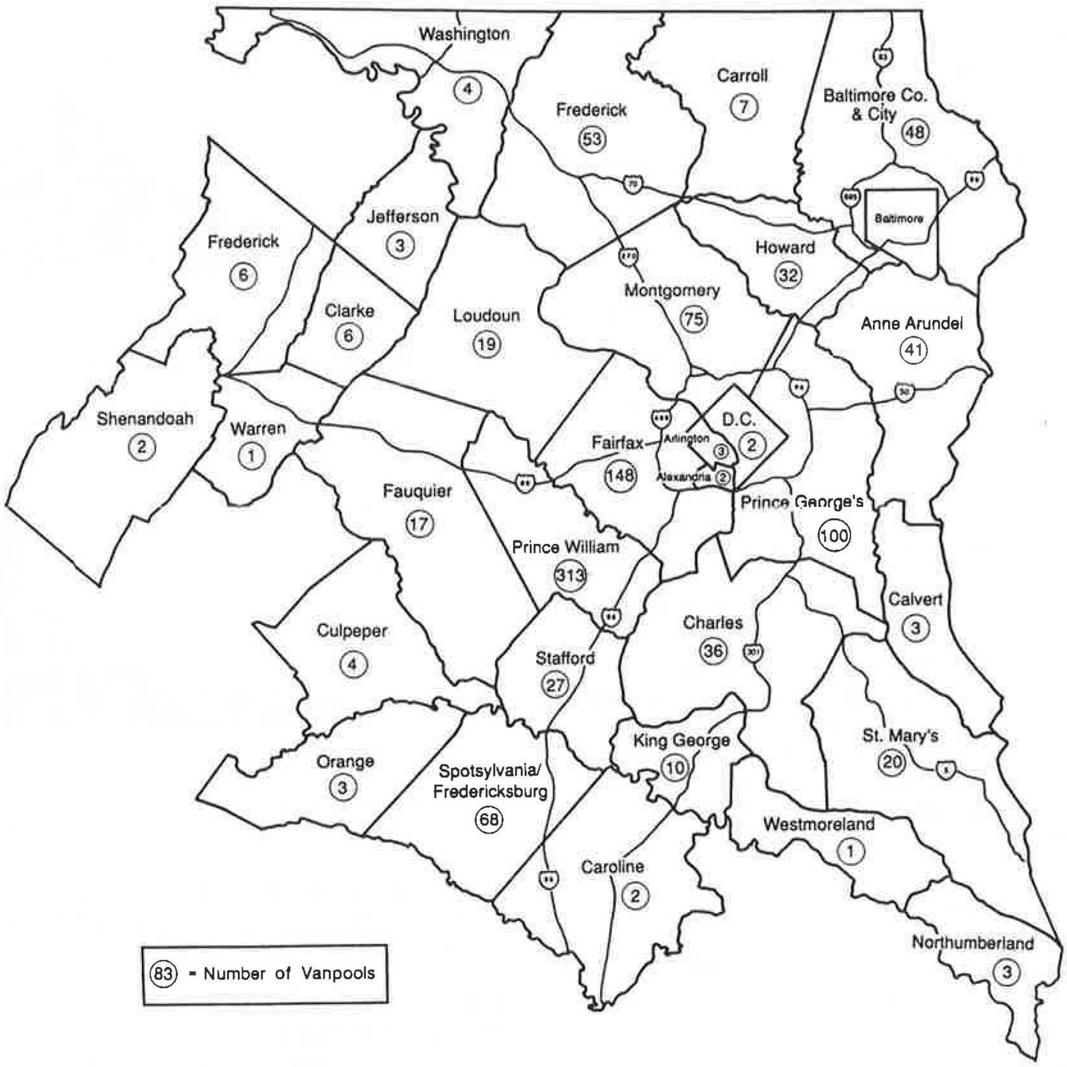

FIGURE 3 Vanpools by county of origin.

TABLE 3 NUMBER OF VANS BY FINAL DESTINATION

DESTINATION	1989 VANS	PERCENT
D.C. Core	643	61%
Arlington Core	244	23%
Subtotal Metro Core	887	84%
Inside the Beltway (not in core)	111	10%
Outside the Beltway	60	6%
TOTAL	1,058	100%

Trip Lengths and Travel Times

Vanpool drivers were asked to estimate their door-to-door commuting distances and travel times. As Figure 6 indicates, vanpools in 1989 continued to serve primarily the long-distance travel market. Only 1.2 percent of vanpools had less than a 10-mi one-way trip.

The average one-way trip length was 37.2 mi. Trip lengths were analyzed by state of Beltway crossing. The analysis had the effect of sorting vanpools according to whether they used high-occupancy vehicle (HOV) lanes; most Virginia vans did, and most Maryland vans did not. The average trip length for vanpools crossing the Beltway in Maryland was 38.5 mi; for Virginia vans, 36.5 mi.

Respondents were also asked to provide their door-to-door morning commuting time, which presumably includes some time for assembly. The average of the times was 62.4 min for all vanpools. The average travel time was 62.2 min for vanpools with a Maryland origin and 62.5 min for vanpools with a Virginia origin.

Values for vanpool trip distance and travel time have changed little from 1982, when the average distance was 36.3 mi and the average time was 58.8 min.

Collection and Distribution

At one time, it was thought that the model for carpool and vanpool operations was that the driver traveled to the homes

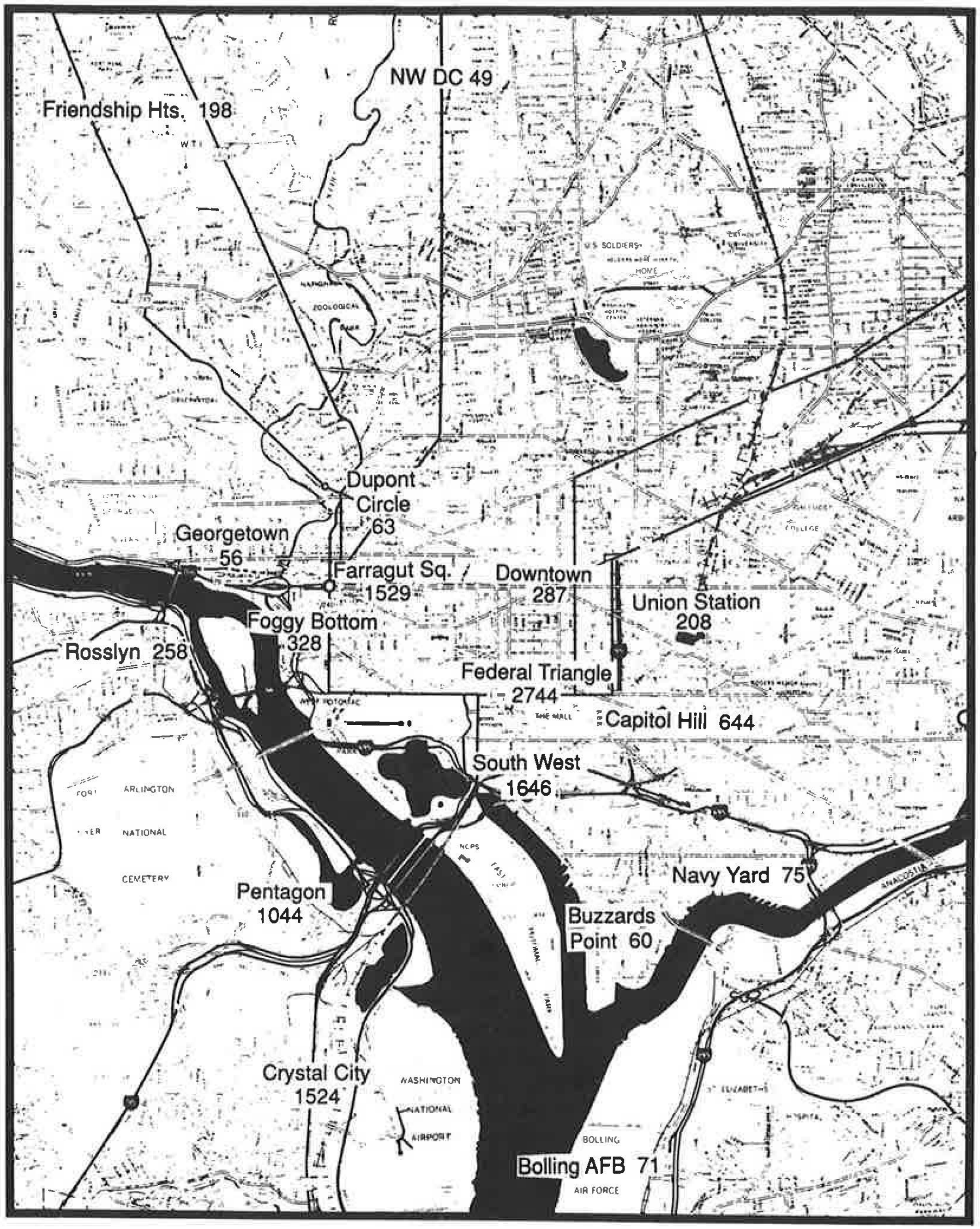

FIGURE 4 Passengers by destination (D.C. and core).

of all passengers for morning pickup, made the trip line-haul, and delivered all passengers to a single work destination. The results of this survey indicate that a different operating plan has evolved for most vanpools.

As can be seen from Table 4, less than 2 percent of vanpools picked up all passengers at home. The predominant means of assembly (66.3 percent) was for the van to stop at several meeting places, although 32.0 percent met at only one place. The typical morning assembly method, therefore, was for the van to drive to one or several meeting places and pick up passengers who had driven there. The availability of adequate park-and-ride lots was clearly a key element for vanpool operations.

Passenger distribution at the workplace was studied as well. Survey respondents were asked to specify the employment areas where their van dropped off passengers. These were coded during the survey processing to include only areas that were geographically distinct from each other. Table 5 indicates that, in 1989, more than one-third (35 percent) of vans visited more than one employment area to drop off passengers. This is an increase from 30 percent in 1982. Some vans visited three or even four areas. Because many of these drop-

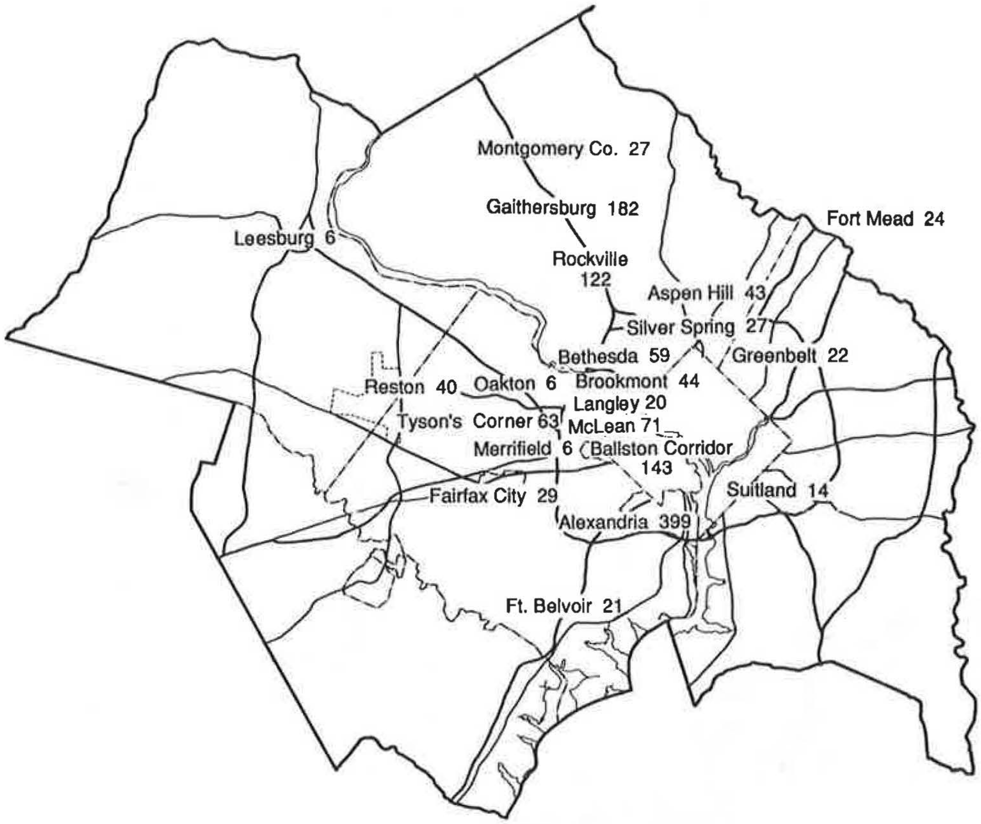

FIGURE 5 Passengers by destination (noncore).

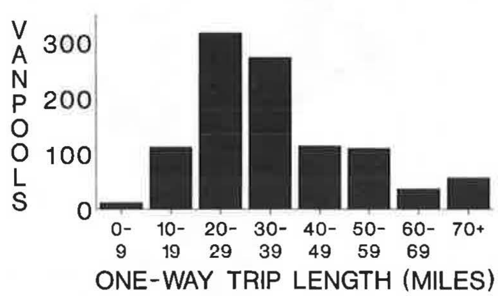

FIGURE 6 One-way trip length.

TABLE 4 VANPOOL MORNING ASSEMBLY METHOD

	1989		1982	
METHOD	VANS	PERCENT	VANS	PERCENT
Pick up at home only	18	2 %	45	7 %
Pick up at one meeting place	337	32 %	193	29 %
Pick up at several meeting places	699	66 %	425	64 %
TOTAL	1,054	100 %	663	100 %

TABLE 5 VANPOOL WORKPLACE DISTRIBUTION METHOD

	1989		1982	
METHOD	VANS	PERCENT	VANS	PERCENT
Drop off in one employment area	694	65 %	389	71 %
Drop off in two employment areas	284	27 %	136	25 %
Drop off in three employment areas	70	7 %	20	4 %
Drop off in four employment areas	10	1 %	3	1 %
TOTAL	1,058	100 %	548	100 %

offs (and pickups in the evening) were at curbside, there was a possibility of conflicts with peak-period traffic. There may, therefore, be a need for designated drop-off–pickup areas at major employment sites.

Van Insurance

Insurance is a matter of considerable concern to vanpool operators, and the survey asked for total annual insurance paid. More than half of those responding did not answer this question, many because they did not own the van they operated and therefore did not know the insurance cost. For the 469 operators who did respond, the average insurance paid was $1,307 annually. The range of annual insurance rates was from $358 to $11,000. The median was $1,200.

Equipment

The survey queried operators about the type of van that they used for their pool. Figure 7 indicates that the 15-seat van was by far the most common, constituting 83 percent of vans. In fact, the reported 14-seat vans are probably also capable of holding 15 occupants.

Figure 8 indicates that 72 percent of vans were of Dodge manufacture, followed by Ford, Chevrolet, and other makes. When van make was cross-tabulated with ownership of van, 60 percent of nonleased vans were Dodges and 34 percent were Fords. For leased vans 87 percent were Dodges. This difference was because the principal leasing firm, Vanpool Services, Inc., leased primarily Dodge equipment.

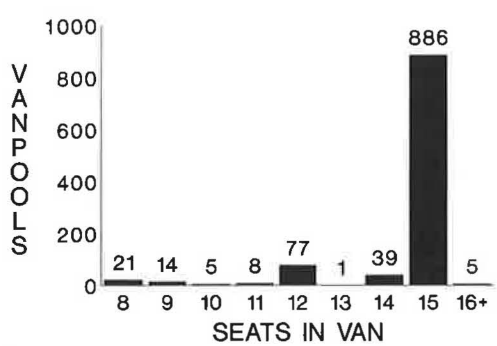

FIGURE 7 Van size.

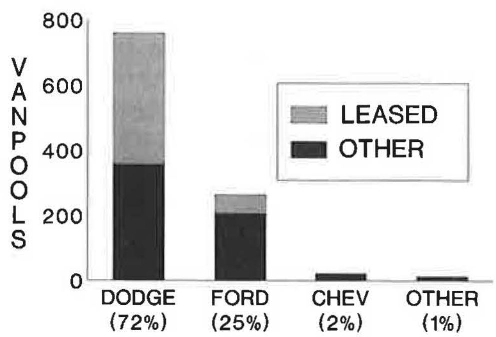

FIGURE 8 Make of vans by owner.

Figure 9 indicates that more than 80 percent of the vans had privacy windows, silvered or dark glass for passenger privacy. This was significant because it necessitated the development of special traffic-monitoring techniques to determine occupancies.

Van Ownership

Respondents were asked who owned the van they operated. Table 6 indicates that leasing companies had ownership of more vans than any other group, with a 44 percent share. This represents a change from 1982, when leasing companies had a 23 percent share. In 1982, 64 percent of vans were owned solely or in part by "self or family member," declining to 37 percent in 1989. The decline in individual ownership is probably attributable in part to the difficulty of acquiring insurance.

Issues of Concern

The survey asked vanpool operators to rank their concerns for the issues listed in Table 7 on a scale of 1 to 5. "More

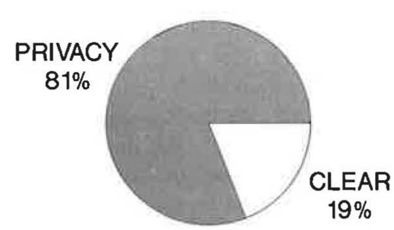

FIGURE 9 Type of van windows.

TABLE 6 VAN OWNERSHIP

	1989		1982	
OWNERSHIP TYPE	VANS	PERCENT	VANS	PERCENT
Self, Family, or with Partner	388	37 %	425	64 %
Leasing Company	460	44 %	156	23 %
Employer	109	10 %	51	8 %
Individual Outside Family	78	7 %	26	4 %
Other	21	2 %	6	1 %
TOTAL	1,058	100 %	664	100 %

TABLE 7 CONCERNS OF VANPOOL OPERATORS

1989 ISSUE AND RANK	1989 AVERAGE SCORE	NUMBER OF 5 SCORES	LEASED VANS RANK	OWNED VANS RANK	1982 RANK
1. More HOV Lanes	4.00	598	1	1	(1)
2. Parking At Work	3.41	416	2	4	(3)
3. Insurance	3.13	325	7	2	(2)
4. Operating Costs	3.30	294	4	3	-
5. Finding New Riders	3.27	288	3	5	(5)
6. Access To Parking Garage	2.90	272	5	7	(8)
7. Van Servicing	2.93	223	6	6	(4)
8. AM Meeting Place	2.06	84	8	8	-
9. PM Pickup Place	1.70	56	9	9	-
10. Competition	1.64	36	10	10	-

HOV lanes" and "parking at work" were the highest-scoring concerns, with ranks of 4.00 and 3.41, respectively. "P.M. pickup place" and "competition" were the lowest-scoring concerns. Only 56 and 36 operators, respectively, scored them at 5, and their average scores were 1.70 and 1.64, respectively.

The priority of concerns has remained fairly consistent, as can be seen by comparing the current rank order with that from the 1982 survey shown in the far right column. "HOV lanes" topped the list in both 1982 and 1989.

When the 1989 respondents were categorized by type of van ownership, some differences emerged. Specifically, insurance, which is covered by the lessor for most leased vans, was in second place for operators who own their vans and dropped to seventh position for leased-van operators.

DISCUSSION OF FINDINGS

Vanpooling is a fast-growing mode primarily serving long-distance commuter travel. It increased 59 percent from 1982 (667 vans) to 1989 (1,058 vans), and occupancies have remained at about 11.5 passengers since 1982. About 12,200 people vanpool to work daily. Regionally, about 1,570,000 people are estimated to commute to work each day in the region, and vanpools carry about 0.8 percent of these.

If specific segments of the commuting market are considered, vanpooling has an even larger impact. It is estimated that daily commuters to the downtown metropolitan core totaled 450,000 in 1989; vanpoolers to the core in 1989 totaled 10,300, or 2.3 percent of core commuters. By comparison, in 1989, commuter bus and commuter rail each carried about 5,000 passengers daily to the core, or half the number of vanpool passengers.

To segment the commuting market even more finely, travel from Prince William County to the core can be considered. This represents long-distance travel via two corridors with HOV lanes to a work destination with a high parking cost—an optimal situation for vanpooling. It is estimated that, in 1989, 17,300 commuters traveled from Prince William to the core on an average day. The vanpool survey found that about 3,140 vanpoolers in 270 vans commuted from Prince William to the core. Therefore, 18 percent of the Prince William-to-core commuter travel was by vanpool, a sizeable share of that market.

Vanpooling is an extremely efficient mode for long-distance commuters: the survey indicated that an average of 11.5 passengers traveled in one vehicle, and each vehicle occupied little more space in traffic than a full-sized automobile. In addition, the mode has started and grown in the Washington area with virtually no financial assistance from the public. It is of considerable interest whether vanpooling can capture commuters in the short-haul market—those who travel 10 mi or less to work each day. The survey indicates that this has not yet begun to occur: in 1989, the average one-way vanpool trip length was 37 mi, and about 1 percent of vanpoolers traveled 10 mi or less.

State and local governments have been interested in how best to encourage further growth in vanpooling. Incentive programs are being offered in Maryland by Montgomery and Prince George's counties and in Virginia by the Northern Virginia Transportation Commission, the Virginia Department of Transportation, and Prince William County. These programs offer various financial incentives for vanpool start-up. The strongest incentive that the public could offer appears to be continuation and expansion of HOV-lane policies; this has been the chief issue for vanpool operators in both the 1982 and 1989 vanpool surveys. It is notable that the Northern Virginia 2010 Transportation Plan includes a significant HOV-lane element, and that an HOV-lane alternative is being considered by the Maryland Department of Transportation for the Route 29 corridor in Montgomery County.

A final issue of public concern is insurance. Elsewhere in the nation, vanpooling is often organized by employers, or by a third party such as a ridesharing program or van-leasing company. In Washington, a different model has evolved: the owner-operated van. In 1982, 64 percent of Washington region vans were owner operated. This decreased to 37 percent in the 1989 survey. In 1985, owner-operated vans were deeply affected by a major liability insurance crisis. The basic insurance needed for operation became, for many, either unavailable or very expensive. As a result, many vanpools went out of service, and it is reasonable to assume that vanpooling would have grown more in the 1982–1989 period if the insurance crisis had not occurred. Other operators decided to switch to leased vans because lessors were able to provide insurance. Leasing grew from 23 percent in 1982 to 44 percent in 1989.

Leasing has become an attractive alternative to outright ownership, and there are many positive features of leasing besides availability of insurance. One concern is that currently only one major firm provides vanpool-leasing services, with a consequent constraint on alternatives and market competition. If vanpool operators could own their vans without fear that insurance will become unavailable or exorbitantly priced, a much more "level playing field" would result, and the attractiveness of this mode should be increased. Availability of fairly priced insurance is therefore an issue of continuing importance for vanpooling.

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