Title

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Abstract

A spatial and temporal analysis of travel diary data collected during the State of California Telecommuting Pilot Project is performed to determine the impacts of telecommuting on household travel behavior. The analysis is based on geocoded trip data where missing trips and trip attributes have been augmented to the extent possible. The results confirm the earlier finding that the Pilot Project telecommuters substantially reduced travel; on telecommuting days, the telecommuters made virtually no commute trips, reduced peak-period trip making by 60%, vehicle miles traveled by 80%, and freeway use by 40%. The spatial analysis of the trip records has shown that the telecommuters chose non-work destinations that are closer to home; they exhibited contracted action spaces after the introduction of telecommuting. Importantly, this contraction took place on both telecommuting days and commuting days. The telecommuters distributed their trips over the day and avoided peak-period travel on telecommuting days. Non-work trips, however, show similar patterns of temporal distribution on telecommuting days and commuting days. Non-work trips continued to be made during the lunch period and late afternoon and evening hours. Telecommuter driving-age household members also exhibited contracted action spaces after the introduction of telecommuting. In addition, they did not show any significant increase in automobile use after telecommuting commenced.

Introduction

The lifestyle of a person plays a major role in determining his travel behavior. It is then possible that insights into changes in travel patterns can be obtained by examining the changes in lifestyles. However, opportunities to study changes in lifestyle and concomitant changes in travel behavior are rare. A unique opportunity to describe changes in household travel behavior that arise from a change in lifestyle is offered by telecommuting. The use of telecommunications to substitute for the commute to work has recently drawn extensive attention as a strategy for reducing travel demand. This came to be known as telecommuting, broadly defined as "the partial or total substitution of telecommunications, with or without the assistance of computers, for the twice-daily commute to/from work" [Nilles, 1988].

Telecommuting entails a certain amount of change in the lifestyle of a person. The telecommuter now works at home and can allocate his time to various tasks with increased flexibility. Telecommuting releases some of the work-related constraints such as the commute to and from work and the lunch hour which usually take place according to a fixed schedule. This added flexibility in a telecommuters' life, as a result of the relaxation of the time-space constraints under which he operates, may lead to changes in the travel behavior of not only the telecommuter, but also his household members [Garrison and Deakin, 1988]. An accurate assessment of these changes is necessary to determine whether telecommuting is an effective travel demand management technique.

The State of California Telecommuting Pilot Project was started in 1988 to evaluate the feasibility and effectiveness of telecommuting within the State Government agencies [JALA Associates, 1985]. As part of this project, a three-day travel diary was distributed in 1988 and 1989 in order to assess the changes in household travel patterns due to telecommuting. In the diary survey, the participants and driving-age members of their households were requested to report detailed information on the trips they made on three consecutive survey days. In the second round, the employees who were selected to telecommute had started doing so and this facilitated a "before-and-after" analysis.

Trips are generated by a persons' need to perform activities at different locations at various times of the day. Useful insights into individual and household travel demand can be obtained by studying individual activity engagement and trip making patterns. If the trip-generating activities are studied over a multi-day period, then it would be possible to see how an individual allocates his activities among the days. At the household level, it would be possible to see how household members allocate their tasks among themselves.

In the short run, it is conceivable that telecommuting will reduce the number of work trips, which will in turn reduce the peak period traffic and vehicle miles traveled. However, this reduction coupled with the added flexibility in scheduling could lead to the generation of new discretionary trips that the telecommuter did not make before.

Another possible outcome is that a telecommuter may be choosing different destinations and different times of the day to pursue his activities. For example, shopping and other activities that were previously done during the commute trips in the peak period may now be pursued independently from home, possibly at different locations and at different times of the day. Also, tasks that were previously performed by the household members may now be assigned to the telecommuters as they have gained additional discretionary time.

Under normal commuting situations, the time of day distribution of trips involves two peaks--one in the morning and one in the afternoon. It is necessary to see how telecommuters choose to distribute their activities over the day to assess the impacts of telecommuting on peak period trip generation. Will they spread out their activities and trips such that the peaks are flattened, or will they continue making trips during those periods by force of habit? Or will they take on other household tasks which need to be performed at peak periods such as dropping and picking up children at school, thus giving no benefits on peak period traffic conditions? Answers to these questions will also prove useful in addressing not only congestion but also air quality and energy impacts [Horowitz, 1982].

Changes in mode use are also probable. The irregular commuting schedules may make car-pooling difficult for telecommuters, who could switch to driving alone to work. The presence of an additional car at home on telecommuting days could induce household members to switch mode too. In the long term, this switch in mode use may induce changes in car ownership levels.

This report aims at assessing the impacts of telecommuting on household travel behavior. Its objectives are twofold. Firstly, the study attempts to confirm the trip reduction effects of telecommuting reported earlier [Kitamura, et al., 1990a, 1990b] through a detailed analysis of the quality of trip reporting in the three-day travel diary survey. Secondly, the study extends the previous analyses by examining changes in spatial and temporal characteristics of travel patterns that are due to telecommuting. All trip origins and destinations were geocoded to facilitate the spatial analysis of trip making. Given the one year time-frame of the survey, this report assesses the short term impacts of telecommuting.

First, trip-activity profiles showing the details of every trip and activity performed by an individual over the survey period were constructed and used to augment missing information. The profiles involved chronologically ordering all trips and activities pursued by an individual. Missing trips or activities which resulted in an interruption of the sequence were identified and augmented. Also, trip attributes such as origin, destination, and duration, were imputed wherever logically possible using information available in the reported trips. This effort was undertaken to account as much as possible for the potential effects of trip reporting errors, which are common in multi-day panel travel diary surveys of this type [Golob and Meurs, 1986; Meurs, et al., 1989; and Pas, 1986].

The preliminary spatial analysis was performed on the augmented geocoded data in an effort to capture the effect of telecommuting on destination choice and household task allocation. The spatial analysis provides useful insights into the trip distribution patterns that emerge as a result of telecommuting. The temporal analysis presented in this report examines the distribution of activities by time of day.

The next section describes the State of California Telecommuting Pilot Project briefly. This is followed by a description of the data files and the procedures followed for geocoding and the maximum retrieval of information. The analysis of travel characteristics and trip reporting quality is presented in the fourth section. The fifth section describes the results of the spatial and temporal analysis of trip making. Finally, the conclusions are presented in the last section.

The State of California Telecommuting Pilot Project

The State of California Telecommuting Pilot Project [JALA Associates, 1990] involved conducting a panel travel diary survey at two time points with the intent of evaluating the impacts of telecommuting on household travel [Kitamura, et al., 1990b]. The first wave of the survey was administered in 1988 and the second wave in 1989. The sample of the study in the first wave comprised 269 state employees who participated in the Pilot Project on a voluntary basis and 178 of their household members who were of driving age. Of the 269 project participants, 17 returned unusable diaries in the first wave of the survey, which yielded a first wave respondent employee sample of 252.

The sample consisted of 137 experimental telecommuter group employees, and 115 control group employees. All the participants were asked to record trip characteristics in three-day travel diaries both in 1988 and 1989. In the first wave of the survey, all employees commuted to work conventionally, while in the second wave, the telecommuter group had commenced telecommuting. Thus, travel characteristics were measured before and after the introduction of telecommuting. The presence of the control group allowed the isolation of the impacts of telecommuting on telecommuter household travel patterns.

Attrition is evident in this panel study. In the second wave, a total of 257 persons (159 households) responded. However, of the 430 persons who responded in the first wave, information of both waves was available for only 219 persons. These respondents shall be referred to as 'stayers' in this report. The stayer sample is made up of 73 telecommuter employees, 65 control group employees, 45 telecommuter household members and 36 control group household members. Those who did not respond in the second wave include those who did not return diaries or returned unusable diaries[1], and those who left the project due to retirement, promotion, etc. The additional respondents in the second wave (38 persons for whom first-wave information is not available) include new project participants and participants who did not return diaries or returned unusable diaries in the first wave. Figure 1 shows the transition of the sample from the first wave to the second wave and finally to the stayer sample.

Data Files

Two types of data files were created in each wave using the information contained in the travel diaries returned by the respondents. The first type contains personal and household information while the second type contains trip information. The person files provide socio-demographic information such as the respondents project participant status (telecommuter or control group), age, gender, employment status, vehicle ownership and frequently used transit companies. The file also contains the addresses of the respondent's home, work, school and other frequently visited locations, which proved useful for the spatial analysis.

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1 Diaries containing no information are unusable diaries.

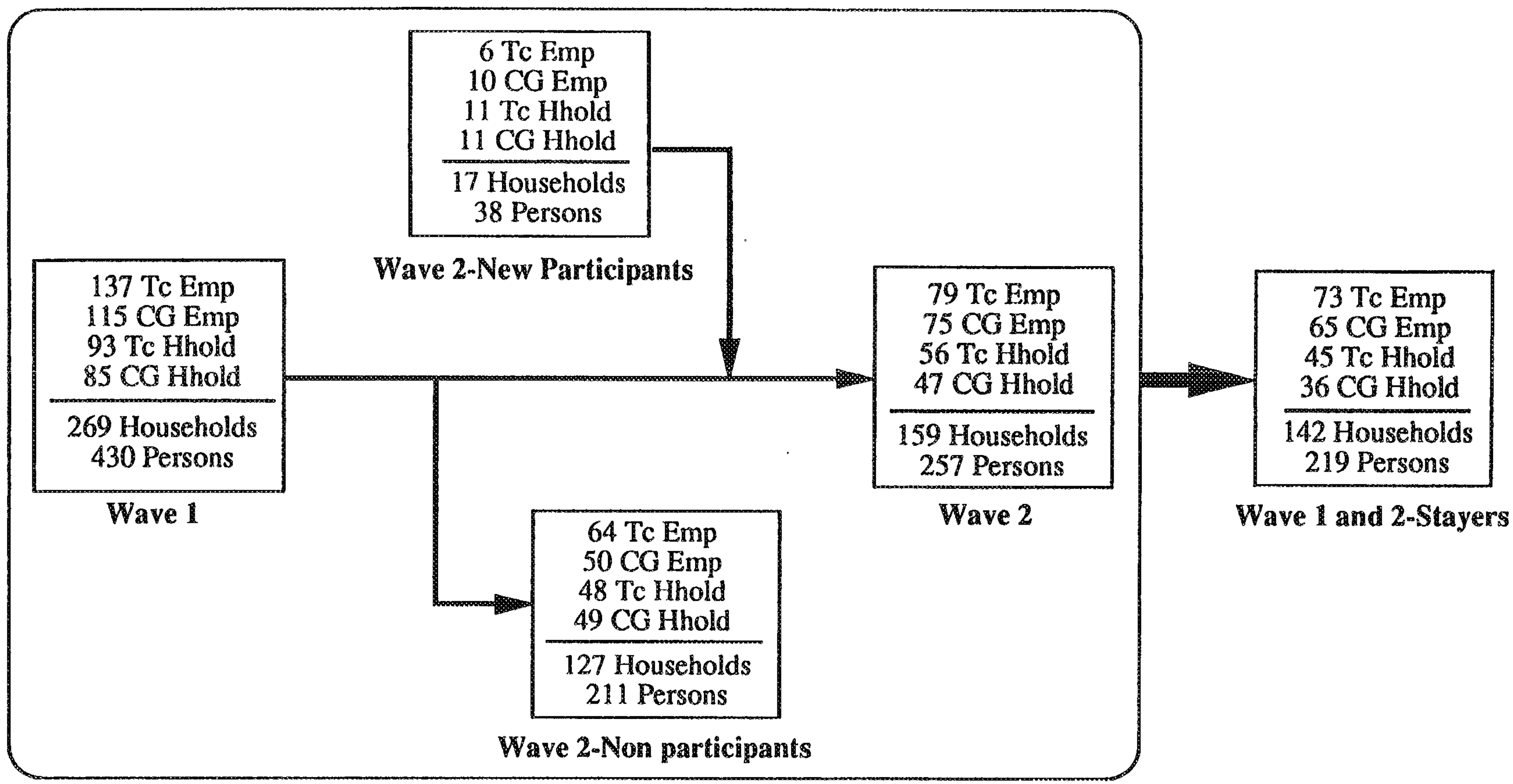

Figure 1: Evolution of the Study Sample

Tc Emp: Telecommuter Employees
CG Emp: Control Group Employees
Tc Hhold: Telecommuter Household Members
CG Hhold: Control Group Household Members

The trip files contain detailed characteristics of each trip reported by the respondent. The information includes the trip origin and destination, trip beginning and ending times, trip purpose, estimated trip length in miles, mode used, and, if a car was used, the beginning and ending odometer readings, the number of passengers, and the percentage of the trip spent on the freeway. The trip file from the first wave contains information on 4808 trips reported by 430 persons in 269 households while that from the second wave contains information on 2389 trips reported by 257 persons in 159 households.

Geocoding of Trip Ends

All trip origins and destinations along with home, work and school locations were geocoded using detailed maps obtained from the Maps Division of the California State Department of Transportation. The latitude of a location was used as its Y-coordinate and the longitude as its X-coordinate. The latitudes and longitudes were coded to the nearest second, thus providing an accuracy of ± 100 feet in terms of distance. The spatial analysis, whose results are reported in the next section, was performed using this data file and offers a concise picture of the spatial spread of trip ends before and after the introduction of telecommuting.

Trip-Activity Profiles and Data Augmentation

Trip-activity profiles are constructed for each individual by sequentially arranging his trips and activities over the three day survey period. A computer program originally written by van Wissen [1989] was modified and used in this effort. The profiles contain pertinent trip information (e.g., trip length, trip duration, trip purpose, and mode used) and information on the activities pursued (e.g., type, duration, and beginning and ending times).

This ordering of information contained in the trip diaries helps in identifying and imputing missing information. For example, if it is found that a particular trip ends at home and the next trip starts from a location other than home, then it can be deduced that a trip from home to the other location, is missing and may be augmented. Thus a trip not reported by the respondent is inferred with imputed origin and destination information. Trip durations were augmented by dividing the trip distance by an average assumed speed of 30 mph. The intent of this augmentation was to reduce much of the bias that may result from trip under-reporting.

An example of a trip-activity profile and how it can be used to augment information can be seen in Tables 1 and 2. Table 1 shows a trip-activity profile constructed from a travel diary returned by a respondent, while Table 2 shows the trip-activity profile after augmentation.

In Table 1, it can be seen that the respondent reported 3 trips on two days which constituted 2 trip chains[2], 4 activities and a total of 8 activity and trip nodes. The clock starts at midnight of day 1 and ends at midnight of day 3. The respondent reported a home-to-shopping trip on the first day departing from home at 4:50 pm (1010 min) and arriving at the shopping location at 5:10 pm (1030 min). The next trip reported is also a home-to-shopping trip and occurs on the third day departing at 11:00 am (3540 min) and arriving at 11:20 am (3560 min). The last trip made during the survey period is one of coming back home after completion of the shopping activity. The activity durations are computed by subtracting the arrival time of a trip from the departure time of the next trip.

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[2] A trip chain is a sequence of trips in which the origin of the first trip leg and the destination of the last trip leg are home. All intermediate origins/destinations are non-home locations.

Table 1: Trip-Activity Profile of a Sample Respondent Before Augmentation

Number of Trip Reporting Days: 2
Number of Reported Trip Chains: 2
Number of Reported Trips: 3
Total Number of Reported Activities and Trips: 8

	Act 0	Trp 1	Act 1	Trp 2	Act 2	Trp 3	Act 3	End
Activity Duration(min)	1010	--	2510	--	40	--	690	--
Trip Distance(mi)	--	9	--	9	--	9	--	--
Activity Type	Home	--	Shop	--	Shop	--	Home	--
Trip Mode	--	Car	--	Car	--	Car	--	--
Clock Time(Min)	0	1010	1030	3540	3560	3600	3630	4320

Notes: Act: Activity; Trp: Trip
Clock Time: Beginning time of activity or trip
--: Not Applicable
Distances are in miles and durations are in minutes

An examination of this profile clearly shows that at least one trip was not reported by the respondent, i.e., the return-home trip on the first day after the shopping activity. Since the first trip ended at shopping and the next trip started from home, it can be safely assumed that at least one trip must have been made with origin shopping and at least one trip must have been made with a destination home. This prompts us to augment a missing trip with origin shopping and destination home.

Table 2 shows the trip-activity profile obtained after augmentation. A trip with origin shopping and destination home has been imputed with missing trip distance. The duration of the home-stay immediately following the return-home trip is also missing. However, it can be seen that the imputation of the trip has eliminated the erroneous shopping activity time of 2510 minutes observed in the original profile. Thus the trip activity profiles have helped us not only in recovering non-reported trips, but also in eliminating erroneous information.

The augmentation of data files was necessary not only to recover as much information as possible for accurate and detailed assessment of changes in travel behavior, but also for the spatial and temporal analysis of travel patterns presented in this report. A note is due here on the results obtained from the original (unaugmented) data files that have been disseminated earlier [e.g., Kitamura, et al., 1990a, 1990b]. As the results presented later indicate, the basic results in terms of the reduction in trip making and vehicle miles traveled do not change after the augmentation.

The resulting trip file contains information on 2706 first wave trips and 2235 second wave trips made by 219 persons in 142 households. The "before-and-after" comparison of travel characteristics and the spatial and temporal analyses are performed on this data file.

Table 2: Trip-Activity Profile of the same Sample Respondent After Augmentation

Number of Trip Reporting Days: 2
Number of Chains: 2
Number of Trips: 4
Total Number of Activities and Trips: 10

	Act 0	Trp 1	Act 1	Trp 2	Act 2	Trp 3	Act 3	Trp 4	Act 4	End
Activity Duration(min)	1010	--	-1	--	-1	--	40	--	690	--
Trip Distance(mi)	--	9	--	-1	--	9	--	9	--	--
Activity Type	Home	--	Shop	--	Home	--	Shop	--	Home	--
Trip Mode	--	Car	--	-1	--	Car	--	Car	--	--
Clock Time(Min)	0	1010	1030	-1	-1	3540	3560	3600	3630	4320

Notes: Act: Activity; Trp: Trip
Clock Time: Beginning time of activity or trip
-1: Missing information
--: Not Applicable
Distances are in miles and Durations are in minutes

A summary of the information retrieval achieved in both waves is shown in Table 3 for stayers by group membership. This summary can also be used to assess the reporting accuracy of the different groups. In general the telecommuter employees and control group employees along with the telecommuter household members showed very similar levels of augmentation. The employees were all participating in this project on a voluntary basis and the interest they had in the concept of telecommuting might have motivated their equally good reporting accuracy. The telecommuter household members who were directly affected by telecommuting may have been equally motivated as they experienced the benefits or disbenefits of telecommuting. The control group household members, on the other hand, showed a higher level of augmentation requirements, possibly because they had no motivating factor. In addition, we find that the levels of augmentation were higher in the first wave than in the second wave. This may be partially attributed to the updating of the panel survey instrument which provided an improved format in the second wave [Goulias, et al., 1990]. The augmentation resulted in a 8.3% and a 4.1% increase in the total number of trips analyzed in the first and second waves, respectively.

Analysis of Travel Characteristics

Table 4 shows a summary of the travel characteristics by group and wave. For the telecommuters, the second wave statistics are further divided by day type, i.e., telecommuting day and commuting day. Any travel characteristic in the second wave that is significantly different from that in the first wave (at a 5% level) is marked with an asterisk.

Table 3: Summary of Augmentation for Stayers

Trip Characteristics	Wave	Telecom Employees	Control Employees	Telecom Household	Control Household
# Reported Trips	Wave-1	822	808	532	336
	Wave-2	657	756	406	329
# Augmented Trips	Wave-1	62 (8)	74 (9)	26 (5)	47 (14)
	Wave-2	24 (4)	24 (3)	18 (4)	21 (6)
Home-start	Wave-1	10 (1)	11 (1)	5 (1)	1 (0)
	Wave-2	6 (1)	2 (0)	4 (1)	1 (0)
Home-end	Wave-1	34 (4)	41 (5)	13 (2)	36 (11)
	Wave-2	5 (1)	8 (1)	14 (3)	11 (3)
# Added Durations*	Wave-1	40 (5)	39 (5)	24 (5)	10 (3)
	Wave-2	25 (4)	22 (3)	6 (1)	14 (4)
# Added Departure Times•	Wave-1	8 (1)	9 (1)	6 (1)	3 (1)
	Wave-2	2 (0)	5 (1)	1 (0)	4 (1)
# Added Arrival Times†	Wave-1	5 (1)	0 (0)	2 (0)	0 (0)
	Wave-2	2 (0)	2 (0)	1 (0)	3 (1)

( ): Percentage of reported trips;
(0) implies less than 0.5%;
* Trip durations were imputed using the estimated trip length and an assumed speed of 30 mph.
• Trip departure times were imputed by subtracting the estimated trip duration from the trip arrival time.
† Trip arrival times were imputed by adding the estimated trip duration to the trip departure time.

Table 4: Comparison of Travel Characteristics

Travel Indicators	Wave	Telecom Employees (73)	Control Employees (65)	Telecom Household (45)	Control Household (36)
# Trips/day	Wave 1	3.99	4.30	3.98	3.53
	Wave 2-TC	1.94*	n/a	n/a	n/a
	Wave 2-NTC	4.00	3.95	3.08*	3.30
# Car Trips/day	Wave 1	3.25	3.17	3.53	2.72
	Wave 2-TC	1.77*	n/a	n/a	n/a
	Wave 2-NTC	3.25	2.88	2.83	2.69
# Work Trips/day	Wave 1	1.02	1.10	0.74	0.60
	Wave 2-TC	0.09*	n/a	n/a	n/a
	Wave 2-NTC	1.11	1.07	0.70	0.77
# Non-Work Trips/day	Wave 1	2.97	3.20	3.24	2.93
	Wave 2-TC	1.85*	n/a	n/a	n/a
	Wave 2-NTC	2.89	2.88	2.38*	2.53
# AM Peak-Period Trips/day	Wave 1	0.89	0.86	0.79	0.62
	Wave 2-TC	0.24*	n/a	n/a	n/a
	Wave 2-NTC	0.82	0.98	0.64*	0.50
# PM Peak-Period Trips/day	Wave 1	0.99	1.13	0.84	0.60
	Wave 2-TC	0.46*	n/a	n/a	n/a
	Wave 2-NTC	1.16	1.15	0.65	0.83
Avg Distance/day (miles)	Wave 1	53.7	50.0	36.4	25.7
	Wave 2-TC	13.2*	n/a	n/a	n/a
	Wave 2-NTC	56.1	45.1	33.1	23.8
Freeway Use/trip	Wave 1	53%	35%	31%	30%
	Wave 2-TC	10%*	n/a	n/a	n/a
	Wave 2-NTC	49%	40%	30%	25%
% Single Stop Chains	Wave 1	55%	53%	47%	57%
	Wave 2-TC	75%*	n/a	n/a	n/a
	Wave 2-NTC	50%	41%	59%	43%

Notes: Wave 1: Before Telecommuting
Wave 2-TC: Telecommuting Day
Wave 2-NTC: Non-Telecommuting Day
* significantly different from wave-1 at a 5% significance level

This tabulation of the augmented data file confirms the results reported earlier [Kitamura, et al., 1990a, 1990b]. Telecommuters reduced their trips by about two trips on telecommuting days; the two trips presumably being those corresponding to the commute trips to and from work. This reduction in total trip making per day is statistically significant at the 5% level. The telecommuters made practically no work trips on telecommuting days. The average number of non-work trips (including return-home trips) is 1.85, which is significantly less than the first-wave counterpart of 2.97.

The most encouraging results are seen in their car use and peak period travel. On telecommuting days, telecommuters made a significantly smaller number of total car trips and peak period trips. The notion that flexibility in task scheduling and the availability of free time increases car use does not seem to be supported by the data. Also, the drastic reduction in peak period travel suggests a possibly large impact that telecommuting could have on easing rush-hour traffic conditions. When given a choice, people choose not to travel during the peak period.

The vehicle miles traveled per day decreased by approximately 40 miles. This rather large decrease suggests that telecommuting could significantly reduce gasoline consumption, at least in the short term. Dividing the vehicle miles traveled by the number of trips shows that average trip lengths on telecommuting days are much shorter than on commuting days (6.8 miles vs. 14 miles). The percentage of single stop chains (home-based) increases from about 50% to 75%. These indications coupled with the 40% reduction in freeway use suggest that, on telecommuting days, telecommuters make short, home-based trips that involve surface street travel. While this could have salutary effects on freeway congestion, the effects of the increase in surface street travel on suburban congestion and air pollution are yet to be determined.

The changes found in the telecommuters' travel patterns can be attributed to telecommuting only if the control group employees did not show equivalent changes in their travel patterns. The control group employees, who commuted conventionally to work in both waves of the survey, did not show any statistically significant change in their travel characteristics, thus making it clear that telecommuting led to the changes observed in the telecommuters.

Despite their statistical insignificance, however, the reductions shown by the control group employees cannot be ignored. If their trip rates, trip durations and trip distances in fact decreased, then the constancy shown by the telecommuter employees actually implies a relative increase. In an effort to determine whether the reductions in control group employees' trip characteristics are true or a manifestation of poor trip reporting in the second wave (panel fatigue), trip reporting characteristics are summarized by group in Tables 5 through 7. If we find that the control group employees show a poorer trip reporting accuracy than the telecommuter employees, then a reduction shown by the former may actually imply stability.

Table 5 summarizes the average number of reported trips by diary day to examine the presence of diary fatigue (second-wave statistics for telecommuters reflect the effects of telecommuting). A decline in reported trip rates as the survey period progresses would indicate the presence of diary fatigue and imply poor reporting. The table shows that, in the first wave, the telecommuter employees and control group employees showed decreases in trip rates towards the end of the diary period, providing evidence of diary fatigue. However, the decreases shown by the control group employees are not greater than those shown by the telecommuter employees. Quite notable is the increased number of trips reported by the telecommuters on the second day of the first wave followed by a significant decrease on the third day (the second-wave trip rate in part represents the fact that the third diary day tended to be a telecommuting day).

Table 5: Reported Number of Trips by Day

Group	Wave	Day 1	Day 2	Day 3
Telecom Emp	Wave-1	3.76[23]	4.02[13]	3.38[12]
	Wave-2*	3.05[3]	3.17[3]	2.62[12]
Control Emp	Wave-1	4.31[23]	4.09[13]	3.76[12]
	Wave-2	3.61[23]	4.00[13]	3.85[12]
Telecom Hhld	Wave-1	4.56[23]	3.38[13]	3.50[12]
	Wave-2	3.21[23]	2.98[13]	2.66[12]
Control Hhld	Wave-1	3.99[23]	2.93[13]	2.34[12]
	Wave-2	3.14[3]	3.02	2.98[1]

[i] significantly different from day i at a 5% level of significance
* Reflects trip reduction due to telecommuting

This is different from the control group employees' reporting pattern in which the trip rates decline consistently over the three days. The control group employees show smaller trip rates in the second wave than those in the first wave. However, the variation in trip rates across the three days by itself does not indicate that their reporting accuracy was inferior in the second wave.

Table 6 shows the distribution of respondents by the number of days for which they reported no trips. A typical pattern of under-reporting is one in which no trips are reported on some or all of the survey days. Here it may be inferred that the control group employees are not reporting as accurately in the second wave as they did in the first wave. In the first wave 92% of the telecommuter employees reported trips on all days and 94% of the control group employees did. In the second wave, telecommuting undoubtedly contributed to the increase in zero-trip reporting days for the telecommuters. The control group employees show an increase in the number of zero-trip reporting days for no apparent reason. When a contingency table analysis is performed under the assumption that all survey days represent independent observations, this increase is found to be significant at a 5% level.[3]

Tables 5 and 6 offer indications that the quality of trip reporting by the household members of both telecommuter and control group employees deteriorated in the second wave. The presence of diary fatigue is evident and the number of individuals with zero-trip reporting days also increased in the second wave. The reductions in the household members' trip rates and trip distances shown in Table 4 are thus likely to be artifacts of trip under-reporting in the second wave.

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[3] Under the assumption of independence, the total number of control group employee survey days (observations) is equal to 195 (65X3). In the first wave, there were 4 days (4X1) on which zero trips were reported, while in the second wave, there were 12 (4X1+4X2). A contingency table analysis of the number of zero and non-zero trip reporting days by wave yields a χ^2 statistic of 4.19 with 1 d.f., which is statistically significant at a 5% level. However, the assumption of independence may not be perfectly valid when each respondent report trips over three survey days. Therefore the results of this test must be carefully interpreted as they may over-state the significance of under-reporting.

Table 6: Distribution of Respondents by Zero-Trip Reporting Days

Group	Wave	Number of Zero-Trip Reporting Days			Total
		0	1	2	
Telecom Emp	Wave 1	67 (92)	3 (4)	3 (4)	73
	Wave 2*	63 (86)	7 (10)	3 (4)	73
Control Emp	Wave 1	61 (94)	4 (6)	0 (0)	65
	Wave 2	57 (88)	4 (6)	4 (6)	65
Telecom Hhld	Wave 1	34 (76)	8 (18)	3 (6)	45
	Wave 2	30 (67)	10 (22)	5 (11)	45
Control Hhld	Wave 1	30 (83)	4 (11)	2 (6)	36
	Wave 2	24 (67)	4 (11)	8 (22)	36

( ): Percent of row totals
* includes zero-trip telecommuting days

As another indicator of reporting quality, Table 7 gives the percentage of missing information for various trip characteristics. The control group employees reported trip characteristics as accurately as did the telecommuter employees. The only indicators where telecommuter employees show a smaller percentage of missing information are the trip mode and the odometer readings. However, the control group employees showed a better performance on the trip purpose, origin and destination.

In summary, the control group employees' 8% reduction in trip making may be attributed to trip under-reporting in the second wave, but sufficient statistical evidence has not been obtained to conclude this. If we assume the same level of trip under-reporting for telecommuters, their trip rates in the second wave would be 2.09 on a telecommuting day and 4.32 on a non-telecommuting day. Even under this assumption, it can be concluded that telecommuting substantially reduces trip generation.

It is very likely that the household members of both telecommuters and control group employees under-reported trips in the second wave. Their travel characteristics presented in Table 4 need to be carefully interpreted with this in mind.

Table 7: Summary of Missing Information

Trip Characteristic	Wave	Telecom Employees	Control Employees	Telecom Household	Control Household
Begin Trip Time	Wave 1	8 (1)	13 (2)	8 (2)	3 (1)
	Wave 2	4 (1)	10 (1)	2 (0)	12 (4)
Ending Trip Time	Wave 1	17 (2)	14 (2)	11 (2)	4 (1)
	Wave 2	20 (3)	13 (2)	3 (1)	15 (5)
Mode*	Wave 1	79 (10)	110 (14)	37 (7)	35 (10)
	Wave 2	2 (0)	1 (0)	1 (0)	8 (2)
Purpose	Wave 1	13 (2)	7 (1)	16 (3)	7 (2)
	Wave 2	5 (1)	7 (1)	3 (1)	14 (4)
Origin	Wave 1	25 (3)	6 (1)	14 (3)	12 (4)
	Wave 2	2 (0)	5 (1)	3 (1)	11 (3)
Destination	Wave 1	28 (3)	7 (1)	19 (4)	14 (4)
	Wave 2	12 (2)	2 (0)	3 (1)	12 (4)
Odometer Readings	Wave 1	67 (8)	69 (9)	48 (9)	19 (6)
	Wave 2	10 (2)	28 (4)	2 (0)	3 (1)
Freeway Percent	Wave 1	4 (0)	0 (0)	2 (0)	1 (0)
	Wave 2	6 (1)	10 (1)	1 (0)	42 (13)

( ): Percentage of reported trips;
(0) implies less than 0.5%;
* A much larger proportion of trips have missing mode information in the first wave because the survey instrument did not provide for non-motorized modes of transport (walk and bike) explicitly. As a result, all these trips were reported with missing mode information. In the updated second wave questionnaire [Goulias, et al., 1990], these mode choices were explicitly provided and the information was retained.

Spatial Analysis

A spatial analysis of the impacts of telecommuting on travel patterns is essential in assessing its impact on energy, air quality, and land use development. The spatial analysis presented in this section is a first step in which destination locations of non-work trips are examined. Figures 2 through 10 show the trip end distributions around home by group and by wave. The geocoded addresses of all non-work trip destinations are plotted such that their relative locations can be seen with respect to the home location, which is represented by the origin. Only non-work trip destinations are shown since work destinations are unlikely to be influenced by telecommuting. The X and Y axis give the coordinates in miles. The circle in the middle of each graph is a 25 mile radius circle and gives an idea of the proportion of trip destinations that were chosen more than 25 miles away from home.

Figures 2,3 and 4 show the trip destination distributions for telecommuters. The trip destination distribution for the first wave is shown in Figure 2, while that for the second wave is shown in Figures 3 and 4 for telecommuting days and commuting days, respectively. A comparison of these three figures clearly shows that the trip destinations chosen on telecommuting days are very much closer to home than those chosen in the first wave. In the first wave, there is a much larger number of trip destinations that fall outside the 25 mile radius circle than on telecommuting days in the second wave. Even the spread of trip destinations within the 25 mile circle seems to be greater in the first wave.

On commuting days, the spatial spread of trips is certainly greater than that on telecommuting days with a larger proportion of destinations falling outside the 25 mile circle. However, it is important to note that the spatial spread is not as great as that in the first wave. The telecommuters are now choosing destinations closer to home even on commuting days. This is not an artifact of trip reporting errors because the control group employees do not show this difference between the waves. See Figures 5 and 6.

Trip Destination Distribution Around Home for Telecommuter Employees: Wave-1 Non-Work Trips

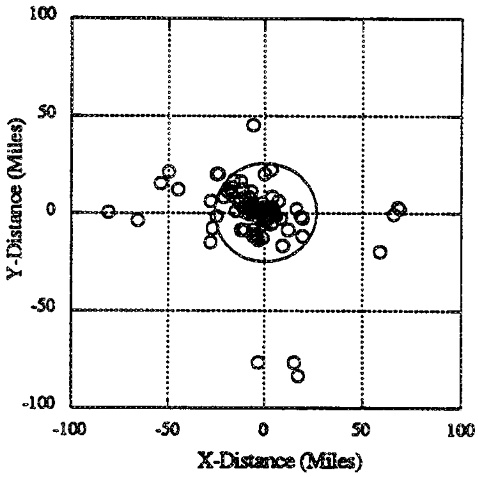

Figure 2

Trip Destination Distribution Around Home for Telecommuter Employees on Telecommuting Days: Wave-2 Non-Work Trips

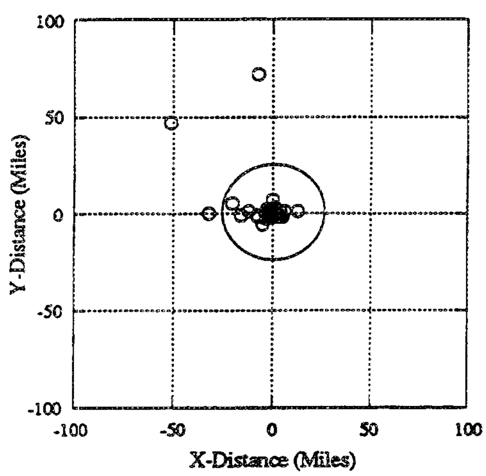

Figure 3

Trip Destination Distribution Around Home for Telecommuter Employees on Commuting Days: Wave-2 Non-Work Trips

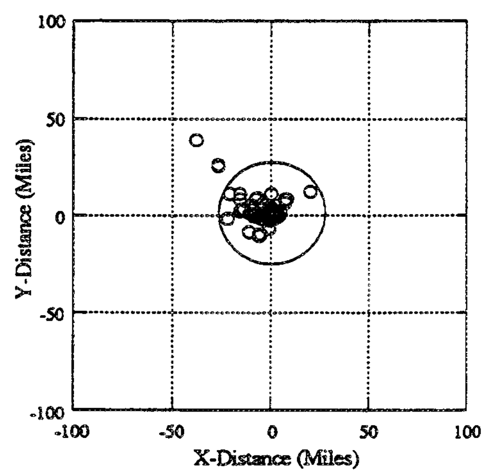

Figure 4

Trip Destination Distribution Around Home for Control Group Employees: Wave-1 Non-Work Trips

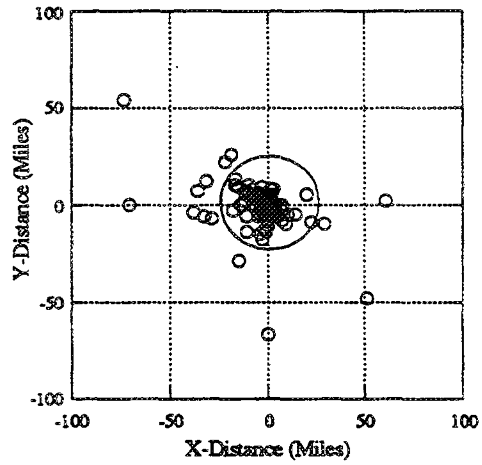

Figure 5

Trip Destination Distribution Around Home for Control Group Employees: Wave-2 Non-Work Trips

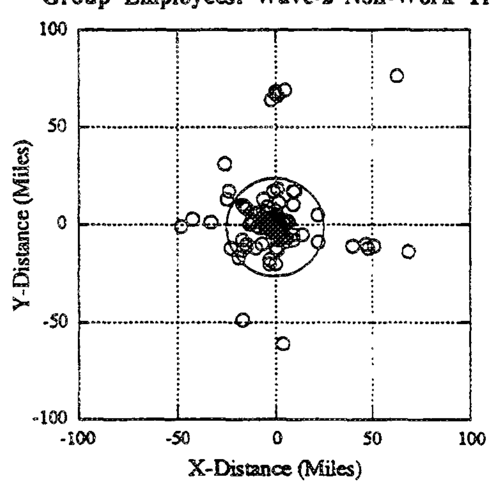

Figure 6

Probing into this dramatic change in the telecommuters' action space is critically important for a better understanding of travel behavior as well as for an accurate assessment of the impact of telecommuting. It is possible that, as telecommuters get accustomed to traveling to closer destinations on telecommuting days, they and their household members go through a learning process during which they realize the benefits of choosing these destinations such as savings in time and fuel. If this is so, then the telecommuter household would continue to use the same destinations on non-telecommuting days also and substitute farther destinations with closer ones. Another possible explanation is the household reallocation of tasks. As the telecommuters take over the household activities close to home on telecommuting days, they might continue performing these activities on commuting days also. Then, the household members would be taking over the household activities far away from home.

An examination of Figures 7 and 8 indicates no expansion in telecommuter household members spatial spread of trip ends. In fact, there seems to be a slight contraction in the spatial spread of destinations chosen for non-work activities. This observation seems to corroborate the first of the two hypotheses stated above. There is no evidence of a household task reallocation in which telecommuters take over close-to-home activities and their household members take over the far-from-home activities. If this were true, we would have observed an expansion, rather than a contraction, in the spatial spread of trip ends chosen by the telecommuter household members. A confirmatory analysis is necessary before the above conclusion can be drawn with certainty. A comparison of destination choices for different activities between the two waves for commuting and telecommuting days, would provide further insights into the validity of the hypothesis.

The control group household members, similar to the control group employees, show no changes in the spatial spread of their destinations chosen across the two waves. See Figures 9 and 10. On account of this, the differences in telecommuters' destination choice across the two waves can indeed be attributed to the introduction of telecommuting.

Trip Destination Distribution Around Home for Telecommuter Household Members: Wave-1 Non-Work Trips

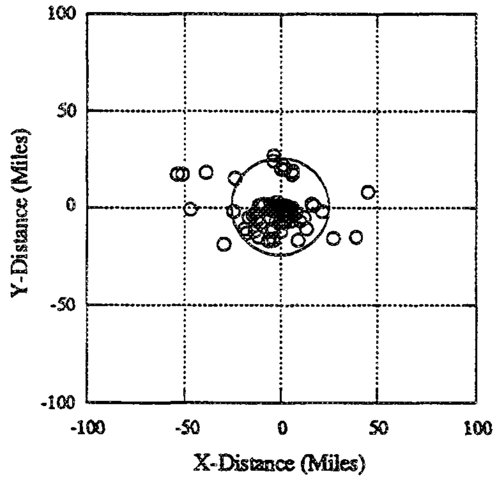

Figure 7

Trip Destination Distribution Around Home for Telecommuter Household Members: Wave-2 Non-Work Trips

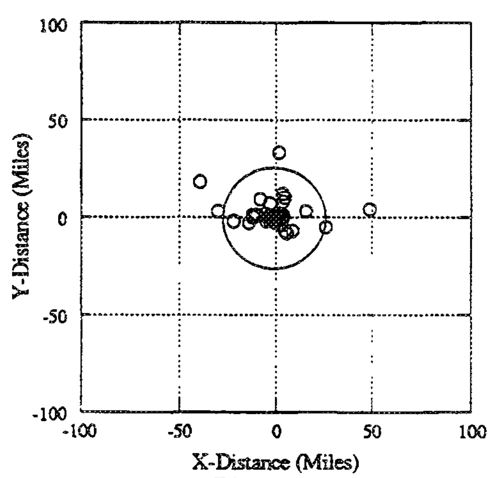

Figure 8

Trip Destination Distribution Around Home for Control Group Household Members: Wave-1 Non-Work Trips

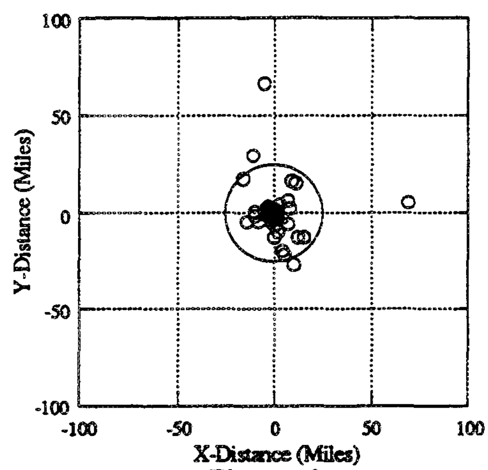

Figure 9

Trip Destination Distribution Around Home for Control Group Household Members: Wave-2 Non-Work Trips

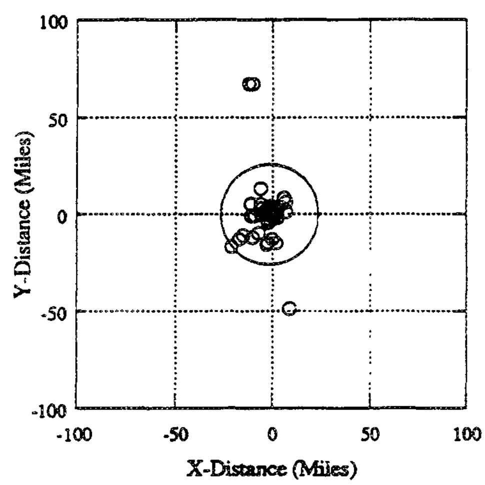

Figure 10

Table 8 shows a summary of the plots in terms of the frequency distribution of trip destinations by distance from home. Similar to the plots, the figures in the table represent percentages of trips made to non-work destinations. The first category corresponding to a zero distance from home represents the percentage of return-home trips. It is interesting to note that telecommuters are making the same percentage of return-home trips on both telecommuting days and commuting days. On average, about half of all non-work trips are home trips. In other words, every trip whose destination is neither work nor home generates one return-home trip. This pattern persists whether or not the telecommuter is telecommuting. When the telecommuter telecommutes, he makes an average of two trips (see Table 4), one of which is a return-home trip. This removes the opportunity to link trips because a multi-link chain would require making more than two trips. Therefore, the higher percentage of single-stop chains observed on telecommuting days (in Table 4) does not suggest that telecommuters reduce their trip-linking efficiency; it is simply a result of their reduced trip making and the reduced opportunities to link more than one out-of-home trip.

The table also shows the contraction in spatial spread of destination choice on commuting days. In the second wave, 42% of trips are made within 12.5 miles, while the corresponding percentage in the first wave is only 35%. There is a noticeable reduction in percentage of destinations chosen more than 12.5 miles from home; 15% in the first wave versus 7% in the second wave. Similarly, the household members of telecommuters showed a contraction in their trip distribution patterns along with an increased percentage of return-home trips. There is quite a large reduction in their destination choice more than 12.5 miles from home; 13% in the first wave versus 5% in the second wave. All of these findings indicate a substantial reduction in the telecommuter households action space.

Table 8: Distribution of Trip Destinations Relative to Home (excluding work trips)

Distance from Home (X miles)	Wave	Telecom Employees (73)	Control Employees (65)	Telecom Household (45)	Control Household (36)
X=0 (home trips)	Wave 1	50%	49%	40%	51%
	Wave 2-TC	50%	n/a	n/a	n/a
	Wave 2-C	51%	43%	55%	56%
0<X≤12.5	Wave 1	35%	38%	47%	40%
	Wave 2-TC	46%	n/a	n/a	n/a
	Wave 2-C	42%	41%	40%	36%
12.5<X≤25	Wave 1	8%	7%	10%	6%
	Wave 2-TC	2%	n/a	n/a	n/a
	Wave 2-C	5%	8%	2%	6%
25<X≤50	Wave 1	2%	2%	3%	2%
	Wave 2-TC	0%	n/a	n/a	n/a
	Wave 2-C	1%	3%	3%	1%
X>50	Wave 1	5%	4%	0%	1%
	Wave 2-TC	2%	n/a	n/a	n/a
	Wave 2-C	1%	5%	0%	1%

Notes: Wave 1: Before Telecommuting
Wave 2-TC: Telecommuting Day
Wave 2-C: Commuting Day

Contingency table analyses were performed on Table 8 for each group to test the statistical significance of difference in trip destination choice across the waves. The results are summarized in Table 9. The results in Table 9 support the discussions presented earlier. The telecommuter employees and household members show significant differences in their trip destination distributions across the two waves, while the control group households do not.

It is noteworthy that telecommuter employees did not show a significant difference in their trip destination distributions between the telecommuting and commuting days in the second wave. Non-work trip destinations chosen by telecommuters on commuting days are very similar to those chosen on telecommuting days. The hypothesis that telecommuter households go through an adjustment process in which they substitute farther destinations with closer ones is substantiated by the statistical analysis.

Temporal Analysis

A temporal analysis of trip making involves the investigation of how and when various activities are allocated and performed during the day or over a longer period such as a week. This section provides distributions over a day of trip starting times to see how telecommuting impacted out-of-home activity engagement.

Table 9: Results of Contingency Table Analyses on Trip Destination Distributions

Wave Comparison	Telecom Employees		Control Employees		Telecom Household		Control Household	
	Chi-sq	df	Chi-sq	df	Chi-sq	df	Chi-sq	df
Wave 1 vs. Wave 2-TC	13.4*	2	n/a		n/a		n/a	
Wave 1 vs. Wave 2-C	14.3*	2	5.0	2	20.9*	2	0.79	2
Wave 2-TC vs. Wave 2-C	0.89	2	n/a		n/a		n/a	

* significant at a 5% level
Wave 2-TC: Telecommuting Day
Wave 2-C: Commuting Day
Note: The last three distance categories in Table 8 have been aggregated to avoid small expected cell frequencies.

Figures 11 through 16 show the distribution of trips by time of day. The percentage of trips by purpose is computed for each two hour time slot to obtain these figures. In Figure 11, the distribution of home trips is shown for the telecommuter employees. Home trips are found to be very evenly spread out on telecommuting days when compared with other days, which could provide substantial relief to peak period traffic. On commuting days, the afternoon peak remains predominant both in the first and second waves. This probably corresponds to the return commute trip. However, it is interesting to see that the peak is more concentrated on second-wave commuting days than on first-wave (by default) commuting days.

Figure 12 shows the distribution of trips made to work by time of day. As expected the morning peak is predominant both in the first and second waves when the respondent is not telecommuting. The patterns are quite similar. The sample size of work trips is not large enough on telecommuting days to draw any meaningful conclusions. However, even among the few trips that were made to work, they were made in a more dispersed manner. This again shows the relief in peak period congestion that telecommuting can provide.

The distribution of trips made to non-work destinations (other than home) is shown in Figure 13. These trips include shopping, personal business, recreation, eat meal, dental and medical, and any other trips. It is noteworthy that all the graphs follow the same general pattern. In general these trips appear to be made at the same times of the day both on telecommuting and commuting days. There is a peak during the lunch hour, while they tend to be pursued in the afternoon with no clear peaks. This pattern persists both in the first and second waves, whether or not the employee is telecommuting. This is indicative of a certain amount of habit persistence where the telecommuters tend to use the same hour of the day to make these trips. It is possible that these are eat-meal trips (lunch hour peak) and transport child trips which are not easily adjustable.

Temporal Distribution of Home Trips:
Telecommuter Employees

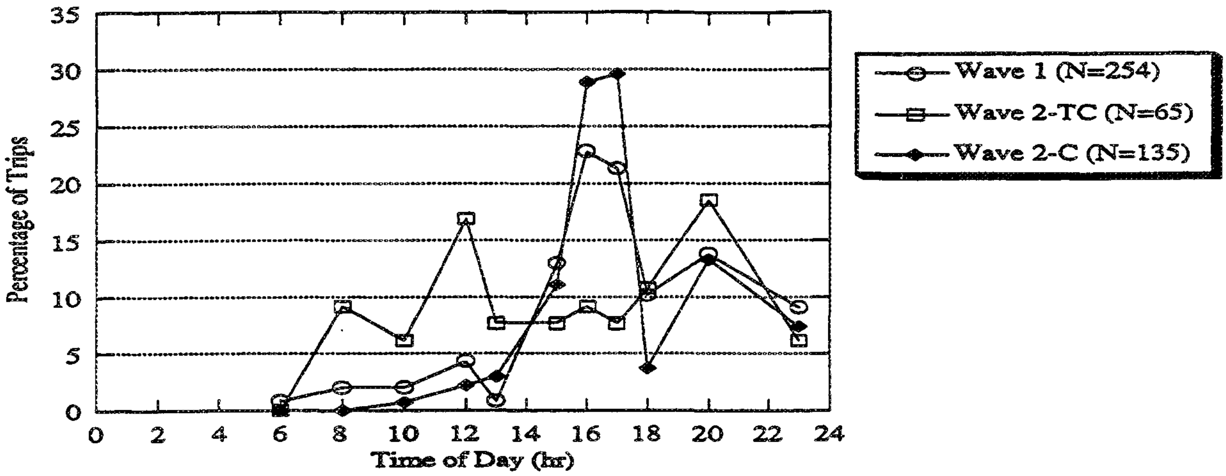

Figure 11

Temporal Distribution of Work Trips:
Telecommuter Employees

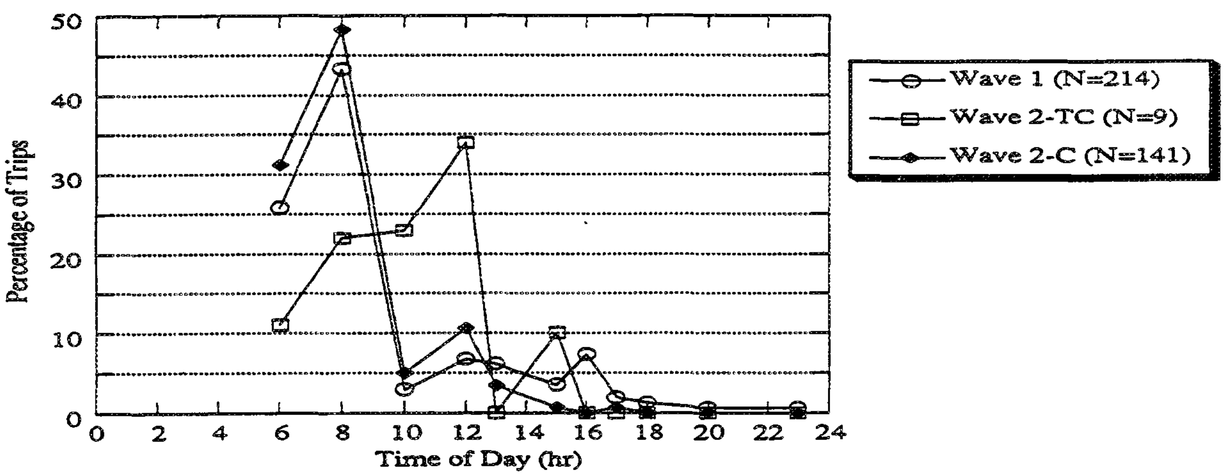

Figure 12

Temporal Distribution of Non-Work Trips:
Telecommuter Employees

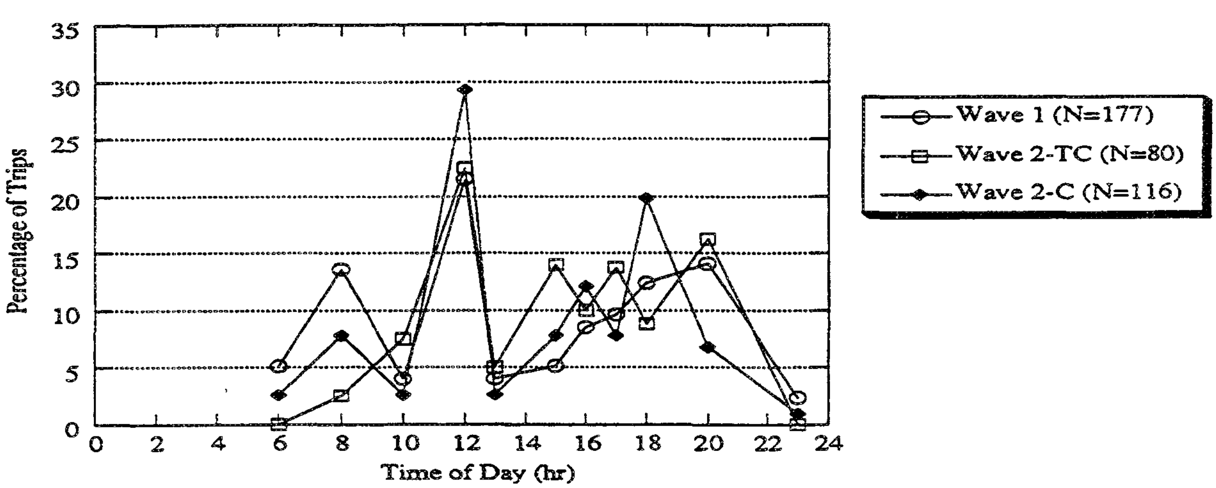

Figure 13

While the temporal patterns show this stability, the spatial analysis showed a significant difference in destination choice across the waves. In other words, it appears as though the non-work trips have been shifted in space, but not in time. In the first wave, they occurred close to work and involved substantial freeway use, while, in the second wave, they occurred close to home reachable via surface streets.

The control group employees show similar patterns of trip distributions over the day between the first and second waves. Figures 14 through 16 show the home, work and other trip distributions for control group employees in both waves. While the patterns are similar, there is a consistently higher peak in the second wave for all trip purposes. The home trips show a higher peak at about 5:00 pm, the work trips show a higher peak at about 7:00 am and the other trips show a higher peak at noon.

In order to assess the effects of telecommuting on peak period traffic, contingency table analyses were performed on the distribution of trip frequencies by time of day for each employee group. In the analysis, the day was divided into two categories--peak and off-peak periods; the former is defined as 7:00 am to 9:00 am and 4:00 pm to 6:00 pm while the latter represents the remaining hours of the day. Table 10 summarizes the results of the analyses.

The distribution of home trips between peak and off-peak periods is significantly different between the waves and is dependent upon whether or not the telecommuter is telecommuting. The difference between the first wave and the commuting days of the second wave is less pronounced, but still significant. The distributions of work and non-work trips show no significant differences between the waves. Also, the control group members showed very similar patterns across the waves. From this analysis, it seems that the relief in peak period congestion on telecommuting days comes only from the elimination of the two commute trips to and from work. The non-work trips show temporal stability and therefore do not contribute to any change in peak period trip making.

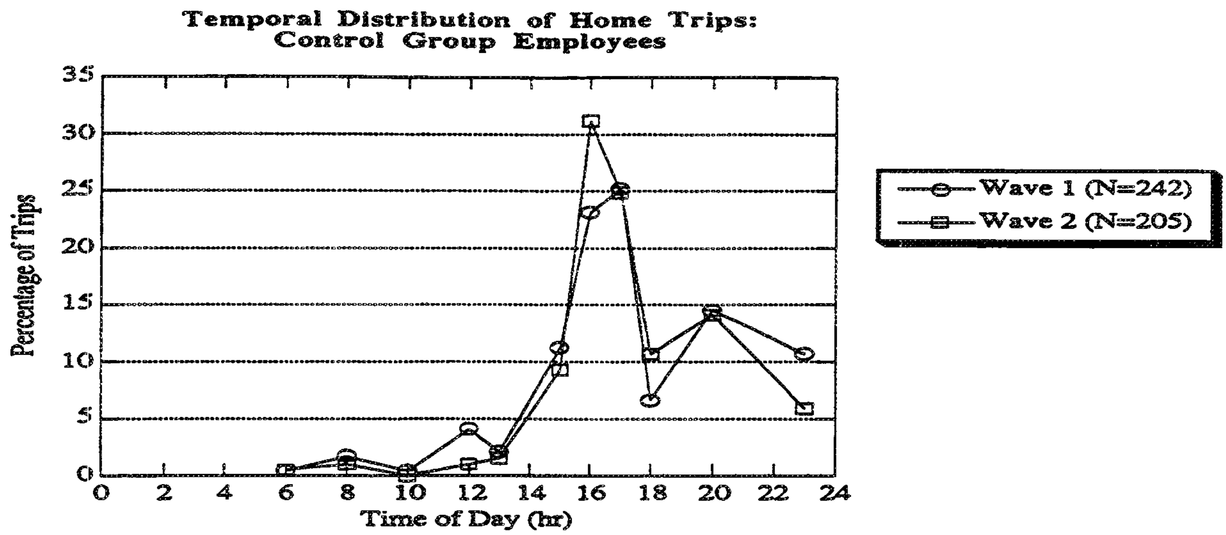

Figure 14

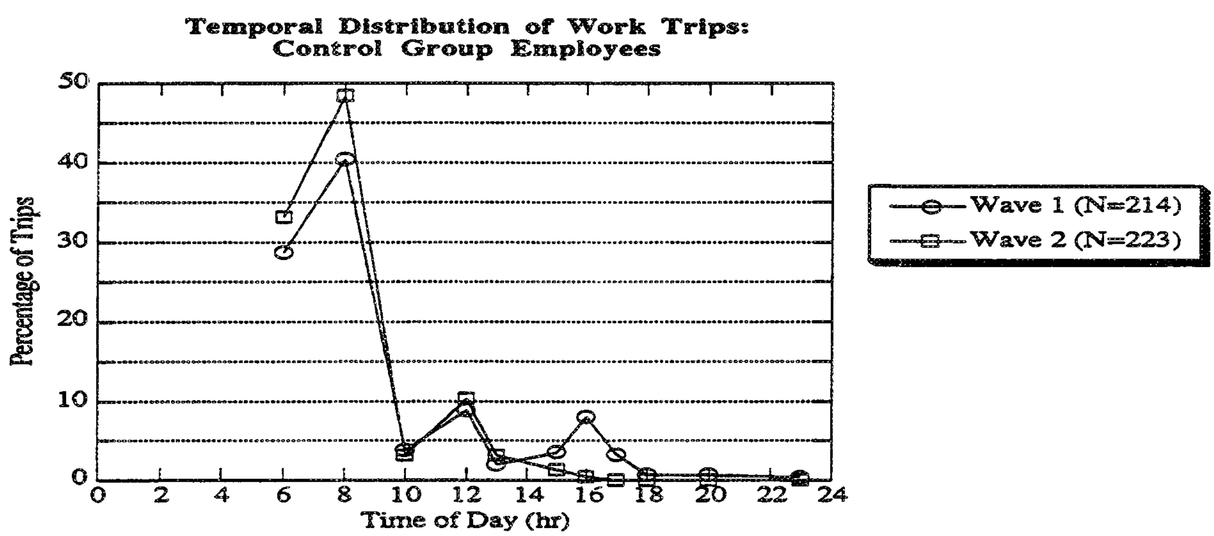

Figure 15

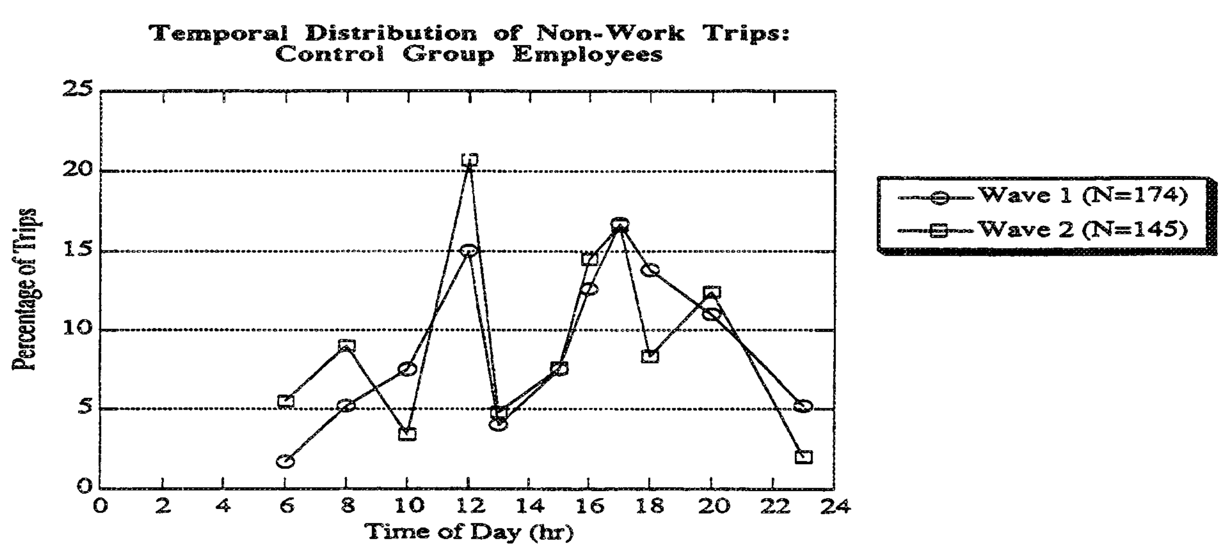

Figure 16

Table 10: Results of Contingency Table Analyses on Peak vs. Off-Peak Distribution of Trips

Trip Purpose	Wave Comparison	Telecom Employees		Control Employees	
		Chi-sq	df	Chi-sq	df
Home	Wave 1 vs. Wave 2-TC	26.80*	1	n/a	
	Wave 1 vs. Wave 2-C	6.77*	1	2.64	1
	Wave 2-TC vs. Wave 2-C	24.10*	1	n/a	
Work	Wave 1 vs. Wave 2-C	0.77	1	1.06	1
Non-Work	Wave 1 vs. Wave 2-TC	1.06	1	n/a	
	Wave 1 vs. Wave 2-C	0.10	1	1.04	1
	Wave 2-TC vs. Wave 2-C	1.51	1	n/a	

* significant at a 5% level
Wave 2-TC: Telecommuting Day
Wave 2-C: Commuting Day

Conclusions

The spatial and temporal patterns of trip making before and after the introduction of telecommuting have been examined in this study in an effort to evaluate the impacts of telecommuting on the destination choice and activity engagement of telecommuter household members. Data obtained from a two-wave three-day panel travel diary survey conducted as part of the State of California Telecommuting Pilot Project in 1988 and 1989 provided the unique opportunity to perform this empirical analysis.

Trip-activity engagement profiles showing all details of trips and activities performed by an individual were developed in order to recover the maximum possible information from the travel diaries and impute any missing information that could be logically deduced. The geocoding of trip ends using the latitude and longitude of locations proved useful in performing a spatial analysis of destination choice.

A detailed analysis of the quality of trip reporting was done in an effort to capture the effects of panel fatigue and diary fatigue on the reported trip characteristics. It was found that the control group employees and the household members of both telecommuters and control group employees showed increases in the number of zero-trip reporting days in the second wave. This finding suggested that the reductions in trip rates shown by these groups may be partially attributed to trip under-reporting.

It was found that telecommuters significantly reduced their trip making and vehicle miles traveled. A particularly encouraging result was the large reduction in peak-period trips and car trips. Trips made on telecommuting days were found to be shorter and involved less freeway use.

The spatial and temporal analysis presented in this report is a first attempt at addressing long-run effects of telecommuting on fuel consumption, air pollutant emission, and suburban congestion. Telecommuters were found to have much reduced action spaces, i.e., spatial extention of activity locations. This pattern seemed to persist on both telecommuting and commuting days. The trip distribution patterns can be studied to assess the impact of telecommuting on suburban traffic conditions and land use development to gain an understanding of the long-term impacts of telecommuting on the urban environment. The results are also useful for identifying questions that need to be addressed in future research efforts, such as those dealing with the timing and duration of activities and trips.

The distribution of activities by time of day showed that telecommuter employees rescheduled and possibly reallocated their activities. Telecommuters spread out their home trips more evenly over the telecommuting day. They also showed higher and narrower home-trip peaks on commuting days. They showed no significant differences in the peak vs. off-peak distribution of work and non-work trips between the waves. The prevalence of non-work trips during the afternoon on telecommuting days suggests that activities performed in the afternoon are more binding (picking up children after school, etc.) or that the telecommuters had to get out of their home-office by force of habit. The relief in peak period congestion can therefore be expected only from the elimination of the two commute trips to and from work.

The determination of the impacts of changes in destination choice and timing of trips on suburban congestion, air pollution and long-term land use development remains a challenging task. It calls for exploring and modeling the causal relationships existing among various factors influencing trip making, activity engagement and destination choice.

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