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THE TRADE-OFF BETWEEN TRIPS AND DISTANCE TRAVELED IN ANALYZING THE EMISSIONS IMPACTS OF CENTER-BASED TELECOMMUTING

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Abstract—Several travel indicators were compared between telecommuting (TC) days and non-telecommuting days for a sample of 72 center-based telecommuters in California. Distance traveled decreased significantly on TC days, with average reductions of 51 person-miles (58%) and 35 vehicle-miles (53%). When weighted by telecommuting frequency, average reductions of 11.9% in PMT and 11.5% in VMT were found over a five-day work week. Person-trips and vehicle-trips increased slightly (but not significantly) on TC days. This was due to statistically significant increases in commute trips by telecommuters (who more often went home for lunch on their TC days), partly counteracted by decreases in non-commute travel. The drive-alone mode share increased on TC days, both for all trips, and for commute trips in particular. Walking and biking shares also increased modestly on TC days, whereas shares of transit and ridesharing declined. Despite the increase in trip rates, TC-day reductions were found for all pollutants analyzed: 15% for total organic gas emissions, 21% for carbon monoxide, 35% for oxides of nitrogen, and 51% for particulate matter. The reduction in VMT more than compensated for the marginal increase in number of trips (and consequently, cold starts) on telecommuting days. © 1998 Elsevier Science Ltd. All rights reserved

Keywords: telecommuting, telecommuting centers, emissions analysis, travel diary analysis

1. INTRODUCTION

In recent years, telecommuting has generated considerable interest in the research and planning community for its potential as an effective transportation demand management strategy (Mokhtarian, 1991). As the adoption of telecommuting becomes more widespread, opportunities arise to evaluate telecommuting for its ability to alleviate congestion (Kitamura *et al.*, 1990; Hamer *et al.*, 1991; Pendyala *et al.*, 1991; Mokhtarian *et al.*, 1995) and improve air quality (Henderson *et al.*, 1996; Koenig *et al.*, 1996). The travel and emissions impacts of center-based telecommuting are of particular interest and have been little-studied to date (Henderson and Mokhtarian, 1996 being one small-sample exception).

Center-based and home-based telecommuting could potentially differ considerably in terms of the resulting transportation and air quality impacts. An obvious difference concerns the commute trip: although telecommuting from a center should reduce the length of the regular commute, home-based telecommuting may eliminate it altogether. On the other hand, a home-based telecommuter may be more likely to generate new trips, either just to get out of the house, or as a consequence of not being able to chain non-work activities to the commute trip. Thus, we are likely to see some interesting trade-offs between distance, the number of trips, and the number of cold and hot starts, all of which are important factors in modeling travel and air quality impacts.

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This paper analyzes the travel and emissions impacts of center-based telecommuting using data collected for the Neighborhood Telecenters Project. An earlier paper (Balepur *et al.*, 1998) reported transportation findings based on an interim sample of 24 center-based telecommuters; the current paper briefly updates those results for a final sample three times as large. More importantly, the current paper is the only one to report emissions results for the NTP. The structure of this paper is as follows: Section 2 describes the empirical setting of the evaluation; Section 3 highlights the key transportation findings; Section 4 presents the emissions analysis; and the final section summarizes the results and suggests directions for future research.

2. EMPIRICAL SETTING

The Neighborhood Telecenters Project (more formally known as the Residential Area-Based Offices Project) was a multi-year research program designed to evaluate the effectiveness of telecommuting centers, or telecenters, as an alternative work arrangement and as a transportation demand management strategy. In this study, a telecommuting center is an office facility shared by remotely-supervised staff of multiple employers, generally on a part-time basis. The center is furnished conventionally (with computers, fax, photocopier, conference room, and so on), and is typically much closer to participants' homes than is their regular workplace. The NTP established a total of 15 telecenters, and evaluation data were collected from an additional 5 centers, all in California (for more information on the project centers, see Mokhtarian *et al.*, 1997; for more information on other California telecenters, see Buckinger *et al.*, 1997). Only about 15 of the 20 telecenters yielded usable data, however.

Telecenter users in this study were volunteers who participated with the approval and cooperation of their employers. Hence, their selection could not be considered random, but in that respect they are likely to be representative of current telecenter users, who are typically selected in the same way.

Various data collection instruments were employed in the project evaluation, including attitudinal surveys, travel diaries, attendance logs, and exit interviews. The evaluation of travel and air quality impacts relied primarily on travel diary data, supplemented as appropriate with information from the attitudinal surveys and attendance logs. Travel diaries were administered to center-based telecommuters and comparison groups of home-based telecommuters and non-telecommuters in similar occupations in the same organizations. Driving-age household members of all three groups were also asked to fill out travel diaries; however, these data are less complete and are not analyzed here. The travel diaries were to be completed for periods of three consecutive days, once before beginning to telecommute (for the telecenter users) and again 5–6 months later. However, a number of respondents came from 'non-NTP' sites which were evaluated by, but not established by, the program. For these previously-established non-NTP sites, many respondents were already telecommuting when their site entered the evaluation, and hence could not complete 'before' surveys. Telecommuters were asked to include at least one telecommuting day in their 'after' wave travel diary. The data analyzed here were collected between October 1993 and June 1996.

The ideal analysis would make comparisons along the three dimensions of wave (before and after), day type (telecommuting or non-telecommuting), and person type (center-based, home-based, or non-telecommuter). For this sample, however, including a wave dimension would result in the loss of a great deal of data, as only respondents common to both the before and after waves could be considered. Further, telecenter users who reported telecommuting days in the before wave should properly be discarded as not having a true 'before' measure. These two screens would have reduced the sample size of telecenter users from 72 to 32. Thus, for this analysis, the before and after waves of data were pooled, and the primary comparison is between telecommuting (TC) days and non-telecommuting (NTC) days. The disadvantage of this approach is that observed differences between TC days and NTC days may be confounded by spill-over effects from one day type into another (for example, in the form of deferred trips); these interactive effects could theoretically be controlled for in a before-and-after study. This limitation should be kept in mind when interpreting the results below.

For economy of presentation, we here focus on the telecenter users only. Specifically, we present data from 72 center-based telecommuters. This represents 35% of the 203 telecenter users registered in the project. Although agreement to complete all evaluation instruments was a condition of using the NTP telecenters, monitoring and enforcing compliance with that condition—across 15 centers, with staggered dates of entry into the program—proved to be difficult. Participation in the evaluation by users of non-NTP centers was purely voluntary and hence less complete. Further, an estimated 36 of the 203 registered users dropped out of the program before the after-wave travel diaries were distributed, meaning that no TC-day data were available for them. The current sample is 43% of the remaining 167. One important implication of the high attrition rate (see Varma *et al.*, 1998, for more details) is that the *per capita* transportation and air quality impacts reported here will not be attained in perpetuity for most telecommuters, but rather for a median telecommuting duration currently estimated at nine months. This has a critical impact on forecasts of the system-wide effects of telecommuting as adoption continues to spread (Mokhtarian, 1998).

The travel diary data for the 72 telecenter users analyzed here comprise 207 NTC person-days (and 904 person-trips on those days) and 116 TC person-days (538 person-trips). Mokhtarian *et al.* (1997) and Varma (1997) contain detailed comparisons of telecenter users to the other two groups. Some of these comparisons may be summarized as follows. Compared to non-telecommuters, home-based telecommuters on their NTC days made a similar numbers of trips on average and had similar average levels of vehicle-miles traveled (VMT), but traveled nearly 10 more person-miles (58.3 vs 48.7; however, the difference was not statistically significant). Center-based telecommuters on their NTC days made fewer person-trips than either of the other two groups, but traveled many more person-miles (87.8) and vehicle-miles (66, compared to 30 and 31). Longer-than-average commute distances for center-based telecommuters probably account for these results.

3. TRANSPORTATION FINDINGS

The key findings related to trips and distance traveled are presented in Table 1, where the numbers represent per person-day averages. In this study, vehicle-miles and personal-vehicle trips refer to *drive alone* trips. This is because only reductions in drive-alone travel will have an impact on congestion and emissions, and it is those potential impacts of telecommuting which are of most interest in this context.

As expected, distance traveled is significantly lower on TC days than on NTC days. Fifty-one fewer person-miles are traveled (a 58% reduction), and 35 fewer vehicle-miles (53% lower). These reductions are almost entirely due to the savings in commute travel. The distance traveled for non-commute purposes also declines, but the differences are not significant. This result is counter to the hypothesis that telecommuting will generate non-work trips (e.g. Salomon, 1986), but consistent

Table 1. The impact of center-based telecommuting on trips and distance traveled

	Non-telecommuting days ($N=207$)	Telecommuting days ($N=116$)	Difference	Percentage change
Person-miles traveled/person-day				
Total	**87.8**	**36.9**	**−50.8**	**−57.9**
Commute	**62.6**	**17.7**	**−44.9**	**−71.7**
Non-commute	25.2	19.2	−6.0	−23.8
Vehicle-miles traveled/person-day				
Total	**66.4**	**31.2**	**−35.2**	**−53.1**
Commute	**49.7**	**16.2**	**−33.5**	**−67.4**
Non-commute	16.7	15.0	−1.7	−10.2
Person-trips/person-day				
Total	4.4	4.6	+0.3	+6.4
Commute	**1.7**	**2.3**	**+0.6**	**+35.3**
Non-commute	2.7	2.3	−0.4	−14.8
Personal-vehicle trips/person-day				
Total	3.0	3.3	+0.3	+10.4
Commute	**1.2**	**1.9**	**+0.7**	**+58.3**
Non-commute	**1.8**	**1.4**	**−0.4**	**−22.2**

The rows in bold indicate that means are significantly different (at the 0.05 level) between telecommuting and non-telecommuting days.

with previous empirical results for both home-based and center-based telecommuting (Hamer *et al.*, 1991; Koenig *et al.*, 1996; Henderson and Mokhtarian, 1996). However, other studies (Hamer *et al.*, 1992; Henderson *et al.*, 1996) have found no change or small (but insignificant) increases in non-commute travel. Hence, a reasonable inference from the evidence to date is that the data are exhibiting random fluctuations around an average of no change (Mokhtarian, 1998).

It should also be pointed out that even the reductions in commute travel may be somewhat context-specific. In a study of telecommuting from a center on Long Island, New York, Bain *et al.* (1995) reported that while the average commute distance decreased 63%, from 22 to 8 miles, VMT was not reduced at all! The reason was that the telecommuters would have taken public transit to get to their regular workplaces (in Manhattan, Brooklyn, or White Plains). The participants generally used a car to get to the telecenter, but that trip was apparently comparable to the auto trip they made to access public transit on their NTC days. Otherwise, VMT could have actually increased with telecommuting.

The picture for number of trips is different. Trip rates (both person- and personal-vehicle) not only did not decrease on TC days, they increased. Furthermore, the increase was not due to non-commute trips (which decreased, significantly so for personal-vehicle trips), but to commute trips! Commute person-trips increased 35%, an average of 0.6 trips per day, while commute personal-vehicle trips increased 58%, an average of 0.7 trips per day. Both changes are statistically significant, although, due to the counteracting decreases in non-commute travel, the net increase in total trips is insignificant in both cases.

Analysis of trip purposes and of attitudinal survey data made it clear that going home for lunch and returning to the telecenter in the afternoon (counted as a second commute trip) was primarily responsible for the observed findings. Although an increase in trips resulted, this could hardly be considered a negative outcome, in view of the facts that (a) VMT decreased so substantially, (b) the increased trip-making was primarily local and may not have taken place under congested conditions, and (c) an increased connection with family and community was a likely consequence.

The comparison of TC day and NTC day travel indicators is useful as far as it goes, but can easily be misinterpreted. To understand the overall impact of telecommuting on an individual's travel, it is necessary to weight each type of day (TC, NTC) by the frequency with which that type of day occurs. This was done for the present sample, using individual telecommuting frequencies calculated from the attendance log data (the average frequency was 24.8%, or about 1 1/4 days per five-day work-week). It was found that overall, there was a reduction of more than 11.9% in average work-week PMT and 11.5% in average work-week VMT when compared to the no-telecommuting alternative. Also, person- and personal-vehicle trips increased but only marginally (1 and 6%, respectively) over a work week, compared to the no-telecommuting alternative. This is to be expected based on the results presented above, where we saw an increase in person-trips and PV trips on TC days compared to NTC days.

Table 1 shows that vehicle-miles were not reduced as much as person-miles on TC days, and that vehicle-trips increased slightly more than person-trips. The implication is that there was a shift toward driving alone on TC days. This observation is confirmed in Table 2, which presents mode splits calculated in two ways: proportion of trips by each mode and proportion of distance traveled by each mode. The table shows that there was an increase in the proportion of drive-alone trips and distances on telecommuting days: the distance-based split shows an increase of almost 9 percentage points in drive-alone travel, from 75.6 to 84.4%, whereas the trip-based split shows a

Table 2. Mode split on telecommuting and non-telecommuting days for telecenter users

Mode	Trip-based mode split		Distance-based mode split (miles)	
	NTC days	TC days	NTC days	TC days
Drive alone	616 (68.3%)	382 (71.0%)	13,742.3 (75.6%)	3615.1 (84.4%)
Carpool/vanpool	195 (21.6%)	122 (22.7%)	3093.3 (17.0%)	643.0 (15.0%)
Bus	10 (1.1%)	0	210.0 (1.2%)	0
Rail	17 (1.9%)	2 (0.4%)	709.0 (3.9%)	1.6 (0.0%)
Walk/bicycle	55 (6.1%)	32 (5.9%)	33.4 (0.2%)	25.3 (0.6%)
Other	9 (1.0%)	0	376.3 (2.1%)	0
Total	902 (100.0%)	538 (100.0%)	18,164.3 (100.0%)	4285.0 (100.0%)

more minor shift. Also, there was a marginal decrease in the share of total distance that was traveled by rideshare/transit modes and a marginal increase in the share of total distance that was traveled by walk or bicycle on telecommuting days.

These changes are consistent with hypotheses expressed in the literature (e.g. Mokhtarian, 1991), suggesting that trips to the telecenter will be less conducive to being taken by rideshare or transit modes, but that increases in walking and biking may occur for either commute or non-commute trips. Similar results were found when analyzing commute mode choice only: the drive-alone share of distance traveled increased from 75.2% on NTC days to 88.7% on TC days, and the share of commute trips for which driving alone was the primary mode increased from 79.7 to 87.2%. The share of transit commute travel declined from 4.5% (primary mode basis) and 7% (distance basis) to zero on TC days, and small increases in walking/biking were observed (see Mokhtarian *et al.*, 1997 and Varma, 1997 for details).

4. EMISSION FINDINGS

In this and previous studies of the emissions impacts of telecommuting, four criteria pollutants are analyzed: total organic gases (TOG), carbon monoxide (CO), oxides of nitrogen (NO_x), and particulate matter (PM). The last two are closely related to distance traveled, whereas the first two are most strongly related to number of cold starts but also depend to some extent on distance traveled. The studies of home-based telecommuting cited in the Introduction have found beneficial air quality impacts, including significant reductions in all pollutants analyzed. However, it is not clear that center-based telecommuting will have similar benefits, especially since the commute trip is not entirely eliminated. An earlier study of center-based telecommuting (Henderson and Mokhtarian, 1996) showed that TOG and CO emissions were essentially unaffected (related to the finding that the number of trips did not change significantly), and that NO_x and PM emissions were significantly reduced (following from the observation that VMT was significantly reduced), comparing TC days to NTC days. However, the results were based on only 8 center-based telecommuters. So the present research offers a larger sample from which to draw conclusions.

The travel analysis presented in the previous section indicated that center-based telecommuting in fact resulted in a marginal increase of 0.3 (10%) vehicle-trips/person-day, although VMT decreased by almost 53%. The significant reduction in VMT will have a positive impact on vehicle emissions. However, the increase in the number of vehicle-trips may have a negative impact. Using VMT and trips alone to gauge the probable emissions impacts has its limitations, as these measures only partially explain vehicle emissions. The vehicle emission process is complex and depends on the interaction of numerous other factors including the vehicle types (light duty auto, light duty truck, and so on) and pollution control technologies (catalytic convertor or not) in the fleet; how the vehicles are operated (speeds, acceleration/deceleration patterns); environmental conditions (including season and ambient temperature); and engine state (cold vs hot start). It is important to model the effects of these factors as faithfully as possible in evaluating the emissions impacts of transportation strategies such as telecommuting.

This analysis used the EMFAC7F and BURDEN7F models developed by the California Air Resources Board (1993) to calculate aggregate emissions inventories generated from vehicle activity for air basins in California. The models were run for the summer season, where the ozone precursors TOG and NO_x are of greatest concern. The models were customized to the extent possible, to reflect the fleet mix, time-of-day distribution, and proportion of cold starts for trips on TC days and NTC days in our sample. Details regarding the models and their customization are found in Mokhtarian *et al.* (1997) and in the earlier papers using a similar methodology. Improving the models and developing entirely new ones is the subject of considerable research at the present, but in the meantime these models represent the current best practice. Though the numerical values for emissions presented here may not be as accurate as desired, the shortcomings of the models should apply approximately equally to both TC days and NTC days. Hence the relative comparison of emissions between the two day types is expected to be meaningful.

Table 3 summarizes the emission findings, where only drive-alone trips made by personal vehicles were included in the analysis. All numbers are averages per person-day. The denominator of the grams per person-day calculation includes days on which participants did not make personal-vehicle trips. These days are included to represent emissions across the population as a whole, not

Table 3. Emissions impacts of center-based telecommuting (per person-day averages)

	Non-telecommuting days ($N=207$)	Telecommuting days ($N=116$)	Difference	Percentage change
Vehicle-miles traveled	66.39	31.16	−35.23	−53.1
Personal-vehicle trips	2.98	3.29	+0.31	+10.4
Cold starts	2.18	2.26	+0.08	+3.7
Hot starts	0.80	1.03	+0.23	+28.8
Average speed, weighted by VMT (mph)	46.49	46.38	−0.11	−0.2
Total organic gases (gm)	19.13	16.27	−2.86	−15.0
Carbon monoxide (gm)	105.64	82.94	−22.70	−21.5
Nitrogen oxides (gm)	24.41	15.88	−8.53	−34.9
Particulate matter (gm)	13.37	6.49	−6.88	−51.5

just the population of those who drive alone. Further, one of the key impacts that is being measured is the reduction in personal-vehicle travel due to center-based telecommuting. Personal-vehicle trips were made on 190 (92%) of the 207 NTC person-days, and on 103 (89%) of the 116 TC person-days.

Comparing the grams/day emissions of telecommuters on TC days and NTC days shows that vehicle emissions are greatly reduced as a result of telecommuting. (Statistical tests of the differences between day types cannot be performed since the model produces only aggregate rather than disaggregate emissions estimates, and hence, standard deviations cannot be estimated.) There is a 15% reduction for total organic gas emissions, 21% for carbon monoxide, 35% for oxides of nitrogen, and 51% for particulate matter. Another interesting observation is that the average speeds (weighted by VMT) on TC and NTC days are almost identical. This is not necessarily surprising since effects in either direction are plausible: telecommuting could shift trips to off-peak periods of the day when speeds are higher; however, it could also shift trips from freeways to surface streets where speeds are lower.

The 53% reduction in VMT on TC days is the primary reason for the decrease in the emissions of all pollutants. VMT is the primary contributor to PM and NO_x and therefore we see the largest reductions for these emissions. The decrease in PM emissions is almost exactly proportional to the reduction in VMT.

The reductions in TOG (15%) and CO (21%) emissions (which are less directly related to VMT) occurred despite marginal increases in the numbers of trips, cold starts and hot starts. Further analysis was done to find out the causes for the reductions. Figure 1 shows the disaggregation of TOG, CO, NO_x and PM emissions into the different emission-producing processes. From the figure it is clear that most of the reduction observed in the TOG emissions is due to reductions, on TC days, in running exhaust and running losses which are dependent mainly on VMT. Also, there was a slight decrease in cold start exhaust notwithstanding the marginal increase in cold starts on TC days. Since cold start emissions depend not only on number of cold starts but also on the ambient temperatures, the observed reduction could be the result of more cold starts taking place during the middle of the day, when the temperatures are higher, on TC days. Higher temperatures result in lower cold start emissions. This issue is further explored below. The reduction in the CO emissions on TC days is mainly due to the reduction in running exhaust, with again a marginal decrease in cold start exhaust. And the substantial reductions observed in NO_x and PM emissions are clearly due to the sizable decrease in VMT-based running exhaust on TC days.

The distribution of cold starts by time of day was further studied to understand why cold start exhaust actually decreased (for TOG and CO) on telecommuting days despite the increase in the number of cold starts. Table 4 shows the distribution of cold starts throughout the day. It can be seen that telecommuting was effective in compressing cold starts towards the middle of the day, with reductions in the numbers of cold starts occurring during the early morning (12 midnight–6 a.m.) and late evening (6 p.m.–12 midnight) periods. This reduction in the number of cold starts at lower ambient temperatures is probably the main reason for the slight decreases observed in cold start exhausts for TOG and CO.

The TOG, CO and NO_x emission values obtained here are lower (by more than 50% for some pollutants) than those reported in some earlier studies (Henderson *et al.*, 1996; Koenig *et al.*, 1996). There could be a number of reasons for this, including air basin modeled and fleet mix.

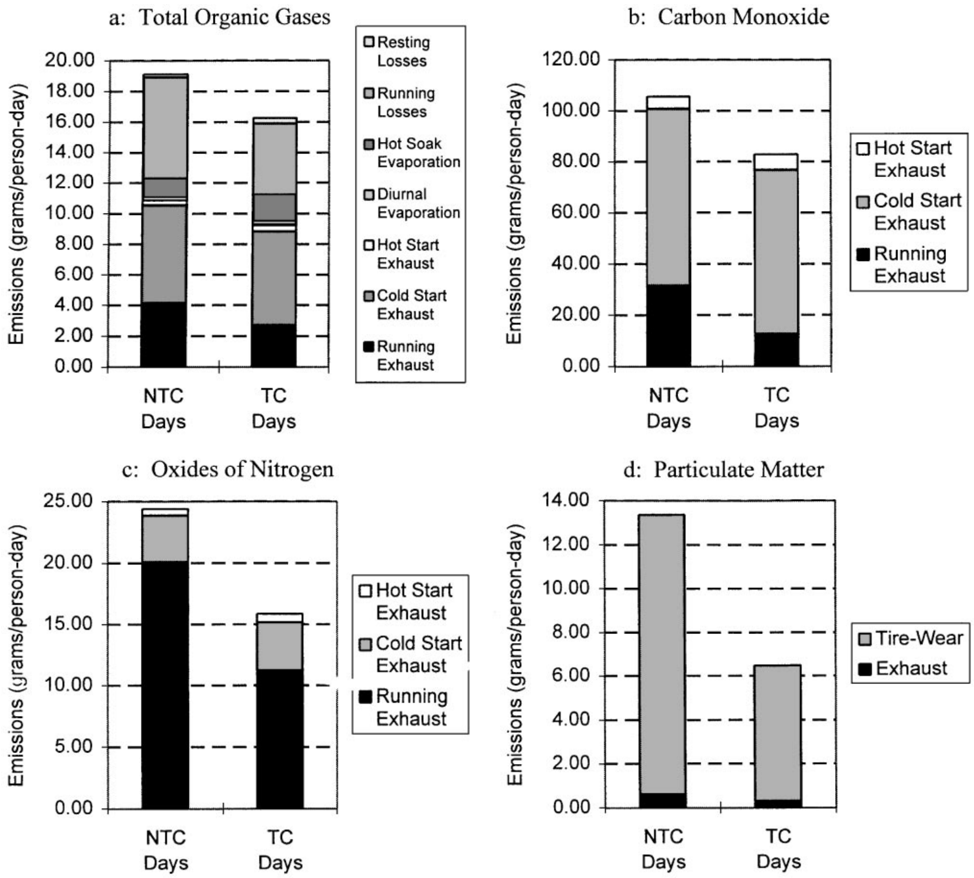

Fig. 1. Disaggregation of emissions by process.

Table 4. Distribution of cold starts by time of day (per person-day averages)

	Non-telecommuting days ($N = 207$)	Telecommuting days ($N = 116$)
12 midnight–6 a.m.	0.27 (12.6%)	0.07 (3.1%)
6 a.m.–9 a.m.	0.60 (27.6%)	0.69 (30.6%)
9 a.m.–12 noon	0.17 (7.6%)	0.32 (14.4%)
12 noon–3 p.m.	0.21 (9.5%)	0.35 (15.5%)
3 p.m.–6 p.m.	0.70 (32.0%)	0.70 (31.0%)
6 p.m.–12 midnight	0.23 (10.7%)	0.12 (5.4%)
Total	2.18 (100%)	2.26 (100%)

These potential effects were further explored. It was found that by changing the air basin from San Diego (used for this study as representing a plurality of trips) to Sacramento Valley (used in an earlier study), the emission value for TOG increased by 20%, CO increased by 10%, and there were no significant increases in NO_x and PM. Also, five years was subtracted from the model year of each of the vehicles in the sample, to simulate a fleet mix closer to the time that data were collected for the previous studies. The resulting emissions obtained showed that, with the older fleet, TOG values increased by 100%, CO by 40%, NO_x by 80% and PM did not increase significantly. This is not surprising since EMFAC7F attempts to reflect improvements in technology that result in newer vehicles polluting less. Hence, the differences between this study and earlier ones are plausible given the newer vehicle fleet seen here and the different air basin in which most trips took place.

5. SUMMARY AND DIRECTIONS FOR FURTHER RESEARCH

Several travel indicators were compared between telecommuting days and non-telecommuting days for a sample of 72 center-based telecommuters in California. As expected, distance traveled decreased significantly on TC days, with average reductions of 51 person-miles (58%) and 35 vehicle-miles (53%). When individual travel patterns were weighted by the individual frequency of occurrence of each type of day, average reductions of 11.9% in PMT and 11.5% in VMT were found over a five-day work week.

The more interesting result was that person-trips and vehicle-trips increased slightly (but not significantly) on TC days. Surprisingly, this was not due to increased non-commute travel, as has frequently been hypothesized, but due to statistically significant increases in commute trips by telecommuters who more often went home for lunch on their TC days. The drive-alone mode share increased on TC days, both for all trips, and for commute trips in particular. Walking and biking shares also increased modestly on TC days, but shares of transit and ridesharing declined.

Vehicle emissions declined as a result of telecommuting, with TC days showing a 15% reduction for total organic gas emissions, 21% for carbon monoxide, 35% for the oxides of nitrogen, and 51% for particulate matter over NTC days. The primary reason for the decrease in emissions of all pollutants was the 53% reduction in VMT which more than compensated for the marginal increase in number of trips (and consequently, cold starts) on telecommuting days. Also, the analysis of the distribution of cold starts by time of day revealed that on telecommuting days the number of cold starts at lower ambient temperatures (early morning and late evening) decreased. This was the main reason for the decreases observed even in cold start exhausts for TOG and CO.

There are several productive directions for future research. To measure the effects of telecenter use on household travel, it is important to study the travel patterns of all members of the telecenter user household. The analysis of travel at the household level could help determine whether reductions in travel by the telecommuter are partially compensated for by increases in travel on the part of household members. Also, the emissions analysis would be more rigorous if all uses of a household vehicle were accounted for, thus allowing each particular trip to be more accurately classified as either a hot or cold start. To the extent that vehicle ownership approximates one per licensed driver (as is the case for this sample), it is likely that little swapping of vehicles occurs. But when vehicles are frequently shared, person-based trip information should be transformed to vehicle-based trip logs for an emissions analysis.

Where vehicle trips are the primary travel measure of interest, it would be desirable to take advantage of new automatic data collection devices using Global Positioning System (GPS) technology to record numbers, locations, and lengths of trips (Murakami and Wagner, 1997). This method would yield more accurate reporting than manually completed diaries, but the technology is not currently practical for non-vehicular trips, nor does it distinguish between a carpool and a drive-alone trip.

The travel diary (or comparable GPS-based) data also allow for a spatial analysis of the travel impacts of telecenter use. Such an analysis would examine the extent to which new locations are visited after telecommuting and the spatial orientation of those locations relative to home, telecenter, and regular workplace. Saxena and Mokhtarian (1997) have conducted such a study for home-based telecommuting; an interesting difference from that previous study is the introduction of the telecommuting center as a frequently-visited destination. This may lead to the identification of new destinations near the center, which has implications for the local economic development impacts of telecenters.

Future studies on emissions impacts of telecommuting will benefit from improvements to the EMFAC/BURDEN models. It is expected that the new (7G) versions of the models will increase predicted emissions levels to be more consistent with field-measured pollutant concentrations (Washington, 1994). These improvements will provide a more accurate assessment of the emissions benefits of telecommuting.

The results presented here are based on the travel characteristics of a relatively small sample of the early adopters of center-based telecommuting. Future center-based telecommuters may exhibit trip-making behavior that is different from the current sample. This could result from a number of factors, including selection and response biases in the current sample, the location and density of future telecenters, and changes in telecommuting frequency and duration.

The telecommuters studied here had longer-than-average commute distances; this may not persist as telecommuting moves past the early adopter stage. That would mean that *per capita* distance reductions due to telecommuting may shrink in the future. As noted earlier, the typical commute mode choice affected the results—center-based telecommuting may have a much smaller impact on *vehicle*-trips and -distances traveled in metropolitan areas for which transit use is more prevalent than the ones studied here.

As for response bias, it is possible that the trip-making behavior of the early dropouts differs from the 'stayers' who were analyzed here (e.g. early dropouts may tend to live closer to work and hence receive fewer travel-related benefits from telecommuting; such a tendency was identified in Mokhtarian *et al.*, 1997, but it was not statistically significant). If that is the case, then the impacts seen here would not apply on the average to all center-based telecommuters as long as they were telecommuting, but rather only to longer-term telecommuters. Also, presumably those who travel more would be less likely to complete the travel diaries (both since they are away more and since the diary would be more burdensome). Although this may bias the estimates of *per capita* travel indicators downward, if there is a differential effect on NTC vs TC days, the likely nature of that effect is difficult to identify, since the NTC-TC differences between distance traveled and between trips are in opposite directions.

The density of the current demonstration telecenters is very low, and most of them are located in suburban areas of metropolitan regions. As the density of telecenters increases it is possible that the commute distance to the center may further decrease, resulting in additional travel savings. On the other hand, as more telecenters are set up in urban areas (where the average commute distance to the regular workplace would be shorter than in suburban areas), the reductions in travel as a result of center-based telecommuting may turn out to be less dramatic than those currently observed. Finally, changes in average telecommuting frequency would affect the impacts on trips and distance traveled over the period of the five-day work week, and changes in duration would affect the aggregate system-level impacts of telecommuting. Therefore, continuing to monitor the travel characteristics of center-based telecommuters should provide useful insights that can either confirm or counter the current results.

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