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THE EFFECTIVENESS OF TELECOMMUTING AS A TRANSPORTATION CONTROL MEASURE

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ABSTRACT

This paper examines the potential of telecommuting as a strategy for managing travel demand. In particular, the paper focuses on the travel and air quality implications of telecommuting. A study of travel impacts has been carried out using data obtained from the State of California Telecommuting Pilot Project. This paper presents preliminary findings from the first known empirical study of the emission impacts of telecommuting.

Previously-reported travel-related findings include significant reductions in work trips, peak-period travel and distance travelled due to telecommuting, while no increase was found in non-work trips. New emission-related findings include substantial reductions in the number of cold starts (60% fewer), and emissions of organic gases (64% lower), carbon monoxide (63% lower), and oxides of nitrogen (73% lower) on telecommuting days. These reductions are nearly proportional to the decrease in distance travelled by auto (76%). Work is ongoing to refine and extend the analysis of emissions impacts.

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INTRODUCTION

Transportation Control Measures (TCMs), strategies for reducing travel or improving the flow of traffic, form an important component of plans designed to improve air quality in non-attainment areas. One TCM that is still fairly novel is telecommuting, defined as "the partial or total substitution of telecommunications, with or without assistance of computers, for the twice daily commute to/from work" [Nilles, 1988]. While early treatments of telecommuting envisioned it to involve computer-based information employees, working from home, full time, it is now widely acknowledged that none of those characteristics are essential [Mokhtarian, 1991a]. In a number of telecommuting programs, the average participation rate is 1-2 days a week. A large variety of jobs deal with information to the extent that part-time telecommuting at those levels is feasible. And while telecommuting today is predominantly home-based, several telecommuting center demonstrations are currently taking place throughout the country.

This paper presents preliminary findings from the first known empirical study of the emission impacts of telecommuting. The organization of the paper is as follows: the next section describes several public policy documents in which telecommuting plays a role as a TCM. The following section reviews some of the commonly-raised hypotheses about the transportation-related impacts of telecommuting. Next, travel-related factors affecting the air quality impacts of telecommuting are described. The succeeding three sections present the empirical research on emission impacts of telecommuting, including a description of the study setting and data collection, travel findings, and emissions findings. The closing section discusses conclusions and directions for future research.

TELECOMMUTING IN PUBLIC POLICY

There is growing interest among planners, researchers and policy makers in telecommuting as a strategy for reducing travel demand. No one suggests that telecommuting alone will provide the solution to congestion and pollution problems, but it does have appeal as one among many measures for addressing these problems. This appeal can be traced to several factors: First, *telecommuting can be implemented now*, as it does not require any lengthy planning, design and construction lead times. Second, *it is relatively inexpensive to* *implement,* and third, *it expands personal choices* rather than restricting them, by offering more flexibility in workstyle and lifestyle. Finally, *it addresses a variety of public- and private-sector concerns*. For businesses, it offers the potential for improved productivity, recruitment and retention, savings in space costs, and other benefits. For public policy makers, telecommuting can contribute to issues dealing with the American family, employment for people with disabilities, rural economic development, global competitiveness, health care, and community involvement -- in addition to transportation, energy and air quality.

On the basis of this multi-dimensional appeal, telecommuting has found its way into a number of public policy statements -- especially as a transportation control measure, but also addressing other policy concerns. For example:

> The 1989 Air Quality Management Plan for the South Coast (California) Air Basin sets the goal of reducing work trips by 30% in the year 2010, due to the combined impacts of telecommuting and alternative work schedules (SCAQMD and SCAG, 1989).

> Regulation XV of the South Coast Air Quality Management District (SCAQMD, 1990) includes telecommuting on a menu of strategies large employers must use to decrease peak-period vehicle trips.

> California Governor George Deukmejian issued Executive Order D-82-89 on October 30, 1989, which directed state agencies to include telecommuting in their emergency response to the Loma Prieta (Northern California) earthquake.

> The statement of National Transportation Policy (USDOT, 1990) has a short but positive section on telecommuting, and President Bush has publicly endorsed the concept.

> Legislation supportive of telecommuting has recently been enacted by the States of California (Chapter 1389, 1990), Washington (Chapter 202, 1991), Florida (Chapter 90-291, 1990) and Virginia (HJRs 77 [1990] and 339 [1991]). In particular, the State of Washington statute requires trip reduction plans to be prepared and provides a "20% bonus" for work-at-home and alternative work schedule strategies. That is, a vehicle trip

reduced by one of those measures counts as 1.2 trips reduced.

POTENTIAL TRAVEL RELATED IMPACTS OF TELECOMMUTING

Telecommuting leads to a certain amount of change in the lifestyle and hence travel behavior of the telecommuter. Furthermore, it may also lead to changes in the travel behavior of other household members [Garrison and Deakin, 1988]. These potential impacts are not always positive from a transportation policy maker's point of view. A comprehensive assessment of the possible impacts of telecommuting is therefore important to an evaluation of the effectiveness of telecommuting as a travel demand reduction strategy.

Many different hypotheses have been formulated regarding the impacts of telecommuting on household travel [Jovanis, 1983; Salomon, 1986]. They can be classified into short-term, medium-term and long-term hypotheses.

First, consider hypotheses regarding short-term travel behavior. One of the more obvious results of telecommuting should be the *reduction of commute trips*. A direct consequence of this will likely be the *reduction of peak hour trips*, as most often work trips are made during peak hours. However, due to factors such as a psychological need for mobility, the availability of a vehicle to other household members, or the need to engage in work-related activities directly because of telecommuting (e.g., trips to the office supply store or post office), *non-commute trips may increase*.

The eliminated need to travel to work may increase flexibility in activity scheduling. Given the flexibility to do so, the *timing* of trips may change. Trips may be shifted to off-peak periods to avoid congestion delays, and/or to different days of the week.

The flexibility and lower frequency of work trips brought about by telecommuting may have negative impacts on *mode choice*. Carpools and vanpools might dissolve if telecommuters drop out, and transit operators may lose revenue. On the positive side, trips made closer to home may shift to non-motorized modes such as bicycle and walk. Another consequence might be *changes in destination choice*. Work trips may now be made to a local center rather than to a more distant office building; non-work trips may be made closer to home rather than closer to work. This may have negative impacts on the local street networks (although it should have positive economic impacts on local businesses).

Elimination of the work trip may *break up efficiently-linked activity patterns*, creating several one-stop trips instead of one multi-stop trip. Finally, telecommuting might cause *reallocation of activities among household members*, resulting in changed travel patterns.

In the medium term, telecommuting might lead to *changes in vehicle ownership*. The ability to telecommute may eliminate the need for a car altogether, or more likely the need for a second car. In the long term, telecommuting reduces the need to reside close to the work site. Hence, a long-term impact of telecommuting might be a *shift to housing in more desirable and/or more affordable outlying locations*. This may or may not lead to increases in travel. *Job location may change* as well. Once the ability to telecommute has been established, the worker may change jobs, moving to a more distant employer. Or, telecommuting may make it feasible to move a corporate facility without either relocating or losing some employees.

FACTORS AFFECTING POTENTIAL AIR QUALITY IMPACTS OF TELECOMMUTING

The air quality impacts of telecommuting can either be direct or indirect. *Direct* impacts are those resulting from changes in transportation due to telecommuting. *Indirect* impacts include the net air quality effects of non-transportation energy consumed while telecommuting (see CEC, 1983 and JALA Associates, 1990 for hypothetical and empirical evaluations of direct and indirect energy impacts of telecommuting. These findings obviously have implications for air quality). This paper only addresses the direct air quality impacts of telecommuting.

The transportation-derived air quality impacts of telecommuting may or may not be as favorable as the underlying transportation impacts themselves. A number of factors affect the direct air quality impacts of telecommuting. These include: distance travelled by auto, number of cold starts, number of hot starts, speed, type of vehicle, and ambient temperature [Horowitz, 1982]. Each of these is discussed below.

The *distance travelled by auto* is important since, other things being equal, the lower the distance travelled, the lower the emissions. Thus, if telecommuting results in a reduction of distance travelled through the elimination of commute trips, positive impacts on emissions will result. Conversely, if increased non-work trips or a move to a more distant location leads to a net increase in auto distance travelled, the impact on emissions will be undesirable.

The number of *cold starts* is important because cold starts have higher emission rates than warmed-up vehicles. (A vehicle's engine is cold if it has been turned off for more than one hour for vehicles with a catalytic converter, and four hours for vehicles without a catalytic converter). If telecommuting were to generate additional trips or more unlinked trips, then the number of cold starts could increase, resulting in higher emissions. The number of *hot starts* or the number of stops in a trip is also a factor to be considered, as the emissions during a hot start are higher than during the stabilized phase.

In general, there is a U-shaped relationship between *speed* and emissions [California Air Resources Board, 1990]. That is, emissions decline as speed increases, up to about 80-96 kilometers per hour (50-60 miles per hour), then increase with higher speeds. Further, trips with more accelerations and decelerations result in higher emissions than those with constant speed. If telecommuting promotes off-peak travel, with fewer accelerations and decelerations at higher (but not too high) average speeds, it can be beneficial for air quality.

Cold start emissions are sensitive to the surrounding air *temperature*. In general, the lower the ambient temperature, the higher the emissions. If telecommuting reduces trips in early morning and late evening hours and induces trips to be made later in the daytime, it may have a significant positive effect on air quality.

Emissions are also somewhat dependent on the *type of vehicle* used in trip-making. For example, the presence or absence of a catalytic converter affects the emissions from a vehicle. Emissions are different between diesel engines and gasoline-powered engines. Diesel engines tend to have lower hydrocarbon (HC) and carbon monoxide (CO) emissions and considerably higher particulate emissions than gasoline engines. Telecommuting may prompt a reassignment of vehicles within households. For example, the telecommuter may use a less fuel-efficient vehicle for the shorter trips being made on telecommuting days, leaving the more efficient vehicle to be used by the spouse for commuting. If the two vehicles belong to different classes, changes in emissions may result. Thus, all the vehicles in the household should be considered to fully analyze the transportation-related impacts of telecommuting on air quality.

SETTING FOR THE EMPIRICAL ANALYSIS

Many of the hypotheses discussed above have been tested in the context of the two-year State of California Telecommuting Pilot Project (see JALA Associates, 1990 for an overall evaluation of the project). The sample for this study included more than 200 state workers as telecommuters and control group members.

Three-(consecutive)-day travel diaries were completed by all state participants and their driving-age household members. These diaries were completed in two waves (i.e, at two points in time). In the first wave, which spanned from January to June 1988 (due to the gradual phasing-in of telecommuting), all employees commuted to work conventionally. In the second wave, which covered April-June 1989, telecommuting had been in effect for about a year. For the telecommuters in the sample, the wave 2 diaries were specified to contain at least one telecommuting day.

The empirical findings reported below pertain to the 73 "stayer" telecommuters for whom before and after trip diaries were available. Additional transportation findings, including an analysis of 65 control group employees, 54 telecommuter household members and 36 control group household members are reported in Kitamura, et al., (1991) and Pendyala, et al. (1991).

Two types of data files were created with the travel diaries. The first one contains personal and household information and the other contains trip information. The *person file* contains information such as the participant status (telecommuter, control group member, telecommuter household member, or control group household member), age, gender, home and work locations, locations frequently visited, transit lines used and household car ownership.

The *trip files* contain the trip characteristics for every trip reported by the respondents. The information for each trip includes the origin and destination, beginning and ending trip times, purpose, approximate trip length as reported by the respondent, mode used, beginning and ending odometer readings if a car were used, the number of passengers and the percentage of time spent on the freeway for each trip. The complete trip files contain 2706 first wave trips and 2235 second wave trips. For the 73 telecommuters, the files contain 874 trips in wave 1 and 680 trips in wave 2.

The person and trip files formed the basis for analyzing the travel impacts of telecommuting, reported in the following section. To analyze emission impacts, however, the information was needed in a different form. Emissions are vehicle-based, not person-based. While the person-trip files indicated which vehicle was being used for each trip, it would not be possible to determine with certainty from them whether a certain trip involved a hot start or a cold start for the vehicle used.

Thus, it was necessary to create *vehicle movement profiles*, itemizing the trips made by each household vehicle in the sample throughout the three-day diary period. The "vehicle profile" contains the following information for every trip made by every household vehicle: trip duration; the trip length; the time parked; origin and destination coordinates; the average speed; vehicle make, model and year; vehicle class (light-duty auto, light-duty truck, medium-duty truck, heavy-duty truck, and motorcycle); participant status (for the driver of the vehicle); the trip purpose; and percentage of freeway use. The vehicle profiles contain 2061 trips in wave 1 and 1726 trips in wave 2 for the full sample of 219 stayers. For the sample of 73 telecommuters, the vehicle profiles contain 722 wave 1 trips and 549 wave 2 trips.

TRAVEL IMPACTS

Table 1 summarizes some travel-related indicators before and after telecommuting began. All the statistics in the second wave (after telecommuting) are further divided into days on which the employee telecommuted and days on which the employee commuted conventionally. Any characteristic in the second wave that is marked with an asterisk is significantly different (at a 5% level of significance) from the first wave. It is observed that on average, telecommuters eliminated two trips on

TABLE 1

TRAVEL IMPACTS OF TELECOMMUTING

	BEFORE	AFTER (telecom)	AFTER (commute)
Number of trips in sample	874	184	496
Total trips	3.99	1.94*	4.00
Work trips	1.02	0.09*	1.11
Car trips	3.25	1.77*	3.25
AM Peak	0.89	0.24*	0.82
PM Peak	0.99	0.46*	1.16
Total km (miles), all modes	85.9 (53.7)	21.1* (13.2*)	89.8 (56.1)

AVERAGE PER PERSON PER DAY FOR SAMPLE OF 73 TELECOMMUTERS

*** SIGNIFICANTLY DIFFERENT FROM "BEFORE" WITH 95% CONFIDENCE**

Source : Pendyala, <u>et al</u>., 1991.

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telecommuting days (the trips to and from work) while showing no significant change on non-telecommuting days. They made almost no work trips on telecommuting days. Also, telecommuters made significantly fewer car trips on telecommuting days. Thus, the hypothesis that the telecommuter may make additional trips due to "cabin fever" or work-related requirements is not supported by the data. While household-level impacts are not discussed in detail here, the evidence shows that household members did not increase their travel, either [Pendyala, <u>et al</u>., 1991].

Large reductions in peak period travel are observed on telecommuting days, more so for the AM peak but significant for both peaks. There is no significant change in peak-period travel on non-telecommuting days. There is also more than a 75% reduction in total distance travelled (by all modes) on telecommuting days, while there is no significant increase on non-telecommuting days. The reduction in total distance travelled, along with the reductions in car trips and peak-period trips, suggest that telecommuting has promise as a strategy for reducing congestion and improving air quality. The air quality implications of these positive transportation findings are examined below.

EMISSION IMPACTS

Table 2 summarizes some emissions-related indicators before and after telecommuting. The first four rows of figures present travel factors relevant to emissions; number of cold starts, number of hot starts, average speed, and auto kilometers travelled. The last three rows of numbers present actual average emissions, taking into account the effects of those travel indicators. For the four travel factors, the statistics in the second wave which are significantly different from those in the first wave are marked with an asterisk.

As would be expected from the reduction in trips shown in Table 1, a significant reduction in the number of cold starts is apparent, from more than 2 per day before telecommuting, to fewer than 1 on telecommuting days. No significant change is found on non-telecommuting days. The number of hot starts also decreased on both telecommuting and non-telecommuting days, though the change is statistically insignificant (at the 5% level).

The reduction in average speed on telecommuting days is important, and counter to the hypothesis that travel would shift to off-peak times and uncongested facilities where speeds would be higher. The observed decrease is due to the fact that trips on telecommuting days are more likely to be shorter, local trips, involving a much lower proportion of freeway usage [Pendyala, et al., 1991]. The auto distance travelled declined by 76% on telecommuting days and reduced marginally on non-telecommuting days also.

TABLE 2

EMISSION IMPACTS OF TELECOMMUTING

	BEFORE	AFTER (telecom)	AFTER (commute)
Number of trips in sample	722	163	386
Cold starts	2.26	0.92*	2.23
Hot starts	0.99	0.74	0.81
Average speed, kmph (mph)	47.0 (29.4)	37.1* (23.2)*	47.8 (29.9)
Auto VKmT (VMT)	79.5 (49.7)	19.2* (12.0)*	71.0 (44.4)
TOG (gms) **	45.2	16.1	41.7
CO (gms) **	467.7	175.0	433.3
NO_x (gms) **	49.7	13.4	44.8

AVERAGE PER PERSON PER DAY FOR SAMPLE OF 73 TELECOMMUTERS

AQAT - 3 (EMFAC7D, 24° C / 75° F , DEFAULT FLEET AGE MIX)

*** SIGNIFICANTLY DIFFERENT FROM "BEFORE" WITH 95% CONFIDENCE.**

**** NO STATISTICAL TEST PERFORMED ON THESE INDICATORS.**

The reduction in the number of cold starts and reduction in distance travelled by auto will have a beneficial impact on air quality, while the reduction in average speed will work in the opposite direction. The net impact on emissions is discussed below.

In this preliminary analysis, the emissions calculations were performed using the AQAT-3 program of the California Air Resources Board (Randall and Diamond, 1989). AQAT-3 is a microcomputer software package containing simplified versions of programs commonly used for air quality analysis in California. This analysis employed the EMFAC7D program of the package, using the program defaults for temperature (24° C / 75° F) and fleet age mix. User-specified inputs included the year in which the emissions are to occur, percentage vehicle miles traveled (VMT) by vehicle class, average speed, and the percentage of VMT in cold start and hot start modes.

The results for total organic gases (TOG), carbon monoxide (CO), and oxides of nitrogen (NO_x) are as shown in the rest of Table 2. On telecommuting days the reduction in emissions of TOG and CO are 64% and 63% respectively. There is a 73% reduction in NO_x emissions on telecommuting days. Even on non-telecommuting days there is a modest decrease in the emissions of those three classes of pollutants.

It is worth pointing out that emission rates, in grams per unit distance, are actually higher on telecommuting days than non-telecommuting days. For example, the rate for CO is 5.9 gm/km (9.4 gm/mi) before telecommuting, and 9.1 gm/km (14.6 gm/mi) on telecommuting days, a 55% increase. Rates for TOG and NO_x are 32% and 11% higher, respectively, on telecommuting days.

The rates are higher for two reasons: first, the average speeds are lower on telecommuting days, as mentioned earlier. Second, even though the number of cold starts and hot starts are lower on telecommuting days, the proportion of distance traveled in cold start and hot start modes is higher (since total distance traveled by auto is so much lower). In the EMFAC model, the emissions rate calculations (especially for CO and TOG) are a function of the proportion of distance in cold start and hot start modes. Nevertheless, even though emissions rates are higher on telecommuting days, multiplying the higher factor of grams per unit distance by the far lower distance traveled results in total emissions that are still greatly reduced due to telecommuting.

It is further of interest to compare the reductions in emissions against the reductions in vehicle distance traveled. *A priori*, no specific relationships between the two can be assumed: due to the mitigating influences already discussed (number of cold and hot starts, speed, and so on), the emissions reductions may be higher or lower than the reductions in distance.

The ratio of emissions reductions (for a given class of pollutant) to distance reduction might be taken as an index of efficiency for a particular TCM oriented toward reducing travel. This ratio can theoretically take on any non-negative value, but in practice is likely to fall between zero and one. For the data presented here, the index of efficiency is 0.85 for TOG (64.4% reduction in emissions compared to 75.9% reduction in distance traveled), 0.83 for CO, and 0.96 for NO_x. The index for NO_x is close to unity because that class of pollutants is less affected by cold starts and by changes in speed, within the range of the trips in this sample. In all cases, however, the index of efficiency is quite high, indicating that emissions benefits nearly proportional to the reductions in distance traveled are being achieved.

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

The results of the empirical analysis reported in this paper present strong evidence that telecommuting is a viable transportation control measure. It appears to have beneficial transportation and air quality impacts, at least in the specific context studied here. In brief, the findings are:

> Telecommuters in the Pilot Project reported making virtually no work trips on telecommuting days.

> Counter to hypothesis, no increase in non-commute trips was observed for telecommuters (or their household members). Thus, on average two fewer trips were made by the telecommuter on telecommuting days.

> Distance traveled by auto declined by 76% (60.3 km, or 37.7 miles per telecommuter on average) on telecommuting days.

> On telecommuting days, telecommuters showed a 60% reduction in the number of cold starts per person per day, while no significant change was observed on the commuting days. The number of hot starts per person per day decreased by 25%.

> As a consequence, significant reductions in emissions were observed on telecommuting days: 64% for TOG, 63% for CO, and 73% for NO_x.

> Lower average speeds and higher proportions of travel in cold and hot start modes, had the combined effect that emissions rates (grams per unit distance) were higher on telecommuting days. However, total distance traveled was so much lower that the total emissions still declined substantially.

> The ratios of emissions reductions to reduction in distance traveled were quite high: 0.85 for TOG, 0.83 for CO, and 0.96 for NO_x. This indicates that telecommuting (at least for this study) is a relatively efficient TCM.

Several near-term extensions of this study are currently underway. Additional insight will be gained through analyzing not only trips made by telecommuters, but also trips made by their household members and by the control group households. A more refined and detailed air quality analysis will be performed by using EMFAC7E instead of the simplified EMFAC7PC version used here. By using EMFAC7E, actual fleet age mix values can be used, instead of the default fleet age mix used in this analysis.

While the travel and preliminary air quality findings presented here are encouraging, it must be remembered that they represent only one application of telecommuting, and deal only with short-term, day-to-day travel behavior. In the long term, several questions remain to be answered regarding the large-scale transportation and air quality impacts of telecommuting.

First, the impacts of telecommuting on residential location must be monitored. Preliminary evidence suggests that telecommuting will motivate at least some people to move significantly further away from the work place [Mokhtarian, 1991b]. The important question is whether these moves will be the exception (whose negative impacts will be outweighed by the travel savings for the many who do not move) or the rule.

Second, the findings presented here apply to the home-based form of telecommuting. A number of people expect to see substantial future growth in the center-based forms of telecommuting, which provide certain advantages over the home in many cases. The air quality benefits of telecommuting are likely to be lower for telecommuting centers, because a vehicle trip (although a much shorter one than a conventional commute) may still be made from home to the center. However, that trip may be combined with other trips (such as to a child care center) in such a way as to have little impact on emissions. And even if air quality benefits are lower for telecommuting centers, they may still be worth achieving. Thus, this form of telecommuting deserves additional study.

Finally, the most critical question regarding the transportation/air quality impacts of telecommuting is whether enough people will do it, often enough, to matter. It is vital, therefore, to develop causal/behavioral models of the adoption of telecommuting. Included in that effort should be identification of barriers to adoption and the likely importance of those barriers in the future.

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The University of California Transportation Center

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