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Telecommuting and urban sprawl: mitigator or inciter?

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Abstract. There is some evidence to the effect that as cities become increasingly congested new housing starts occur at greater distances from urban centers while jobs tend to remain center-concentrated or develop in other suburbs. In either case, mean commute distances tend to increase. Telecommuting is seen as a means of increasing the jobs-housing balance in urban and suburban areas by enhancing the ability to move work to, or closer to, the workers' residences rather than requiring workers to commute to work daily. This has the immediate side effect of decreasing automobile congestion and associated energy consumption and air pollution. There is a possible longer term adverse impact of telecommuting resulting from its ability to decrease constraints on household location, thereby enhancing the rate of spread of suburbia. This paper reviews evidence concerning the possible effects of telecommuting on urban sprawl, as derived from a two-year test of telecommuting in California, and describes two scenarios of urban form development made more feasible by telecommuting.

Introduction

In recent years growing attention has been focused on the problems of urban traffic congestion. The fundamental trends are familiar to most of us who are urban dwellers. Population growth is increasing in many cities. The transportation infrastructure is not keeping pace. Traffic congestion increases proportionately. For many years commuting has accounted for from 30% to 40% of urban vehicle-miles (Hirst 1973; Transportation Association of Southern California 1971; Pisarski 1987; SCAQMD & SCAG 1989). Automobiles are by far the dominant mode of travel for commuting. Rising housing costs, even in so-called depressed housing markets, are forcing new homeowners to buy at increasing distances from their workplaces (Pisarski 1987; CTS 1991; JALA Associates 1991). One consequence is a combination of increased commuting distance and more time spent commuting.

Another consequence of this phenomenon is so-called *urban sprawl*: the continuing urbanization of formerly rural areas. Urban sprawl is a positive feedback process in its transportation implications. The process as new highways are completed, for example, runs roughly as follows in regions of economic attractiveness:

1. The improved transportation infrastructure is a major inducement for businesses and households to move to areas that are both served by the infrastructure and have lower land prices. The goal in individual household move decisions is to achieve an attractive, affordable, generally low population density residence location.
2. The expanded movement to the newly developing area acts to increase land prices and congestion, increasing population density (and decreasing step 1 attractiveness) as population growth continues in the area.
3. The increasing congestion and improving tax base spur demand for further expansion of the transportation infrastructure either by increasing capacity, often at the expense of removal of local residences, or by extending the infrastructure to more rural areas, or both. Go to step 1.

Continuing repetition of this cycle ultimately results in the wide scale suburbanization of the area and elimination of formerly rural areas. Often these areas were originally forested, agricultural or wildlife habitat land. Los Angeles is often cited as the archetypical example of this process.

In addition to the gross effects in this process, there are some phasing phenomena. In particular, residence location decisions can be made by a single individual or a small number of individuals. Such decisions generally can be made fairly rapidly in response to changing market conditions. Business and government enterprise location decisions, involving concordance of numerous individuals, usually take significantly longer to make. Hence, newly developing areas tend to begin as residence-only communities. It usually takes from one to several years before there is significant interpenetration of business oriented building, other than retail shops, in such areas. One consequence of this is the so-called *jobs-housing imbalance*: the location of employee residences changes while worksite location either does not change, or follows the housing trends only slowly.

In recent years in certain high growth areas this phenomenon has been particularly significant. In the Los Angeles area, for example, new affordable housing development has tended to occur at distances of more than 20 miles from the major business centers in Los Angeles and Orange counties. In the late 1980's many newspaper accounts have appeared describing the multi-hour daily commutes of area residents. One of the major items in the area's regional plans is the need significantly to reduce the jobs-housing imbalance problem without inducing yet more urban sprawl (SCAQMD & SCAG 1989).

The focus of this paper is on the relationship, if any, between teleworking in general, and telecommuting in particular, on urban sprawl. In general, teleworking is the substitution of telecommunications technology for work related travel. Telecommuting, a subset of teleworking, is the partial or total substitution of telecommunications and/or computer technology for the daily commute to and from work. There are two generic forms of telecommuting: working from home and working from a regional office close to home: a regional telework center (Nilles et al. 1974; Nilles 1988; Mokhtarian 1991). In the latter case telecommuting still involves some form of worker travel although, in cases where the regional office is within a mile or two of employee residences, the travel may not involve fuel consuming vehicles. In recent years several tests have been made of the practicability of telecommuting (teleworking has been in widespread use since the diffusion of telephone technology into business use). In fact, neither teleworking nor telecommuting require the active use of telecommunications technology in order to be practical, since workers can carry their information with them on the reduced number of occasions that they travel to their employer's office. Nevertheless, telecommunications and computer technologies both act to broaden the scope and variety of tasks amenable to teleworking and telecommuting.

Contemporary teleworking in general, and telecommuting in particular, is strongly influenced by the three-decade period of intense and continuing growth of information technology. Of primary importance to teleworking are developments in microcomputers and digital telecommunications. The rate of these developments (25% to 30% annual improvement in performance per dollar invested) is likely to continue into at least the early 21st century (Nilles 1982). The primary implication of this is that substantial information processing and transmission power (including transmission of high resolution images) is available, or soon will be, to anyone within reach of a telephone line. Hence, teleworking and telecommuting may become major factors in both future home and office location decisions.

The historical development of urban sprawl can be attributed largely to the combined influence of the automobile (as a facilitator) and the motivation of families to have their own house in the suburbs. It seems plausible that telecommuting, with its ability to make work at least partly location-independent, could have equal or even greater impacts on residence location decisions. Such decisions might be constrained only by the need for at least occasional personal visits to the "central" office location. As videoconferencing and advanced forms of "groupware" become more widely available, as a result both of steadily decreasing technology costs and technology performance increases, even the office visits may become largely unnecessary for some workers.

Hypothesis

This paper concerns the following hypothesis:

> Telecommuting can be structured so that it does not influence residence location decisions that result in net long term increases in travel.

That is, urban sprawl is a real phenomenon, but the undesirable side effects of urban sprawl can be reduced significantly by telework alternatives, *provided that some complementary modifications of growth patterns occur concurrently*. The counter hypothesis is that teleworking has significant potential for exacerbating urban sprawl in a manner similar to that of expansion/improvement of the transportation infrastructure. This is of little consequence if the number of telecommuters in the world is small. However, if telecommuting becomes widespread, then it may be of vital importance to transportation planners.

The evidence to date

Since we are still at the relative beginning of the major growth curve of telecommuting it is not possible to make definitive forecasts. In fact, there is a growing literature supporting the allegation that *definitive* forecasts of complex, chaotic phenomena are impossible for other than very short periods into the future. That does not diminish the importance of understanding the major forces at work so that the scope of alternative outcomes can be suitably restrained.

This paper is based primarily on data derived from a two year test of telecommuting by the State of California (JALA Associates 1990; Kitamura et al. 1990). The California Telecommuting Pilot Project ran from July, 1987 through June, 1990 with active telecommuting beginning in January 1988 and ending, for measurement purposes, in December 1989. At least 150 State employees were telecommuting through that active period. Surveys of telecommuter automobile use were taken at intervals during the two-year test period, although not all of the participants answered all of the survey questionnaires. Telecommuting has continued at the participating agencies and is now an official transportation management option throughout California State government. All of the 150 State telecommuters telecommuted part-time from home, spending the rest of their work days at their formerly full-time office locations. The project also included a control group of comparable size, comprising employees with job characteristics similar to those of the telecommuters. The telecommuters were from State agencies with principal office locations either in the Sacramento, CA or San Francisco, CA metropolitan areas.

In addition to the primary California telecommuting project data there are more recent, but not longitudinal, results from a group of employees of the City of Los Angeles, California, most of whom began telecommuting in the first half of 1991.

Two issues will be addressed. First, are telecommuters somehow different from their co-workers, with respect to commute travel behavior, and, if so, are the differences significant in estimating future behavior? Second, have residence move decisions by telecommuters had net negative effects on commute distances?

Commute trip patterns

Recent values

The first issue is approached by examining the commute patterns of the telecommuters and comparing them with non-telecommuters. Figure 1 shows the distribution of one-way commute distances for the State telecommuter and control groups, the initial set of telecommuters for the City of Los Angeles, a random sample of State of California information workers and a random sample of Southern California commuters (JALA Associates 1990, 1991a, b). All the State and regional samples shown in the figure were taken in late 1989 to early 1990. The City of Los Angeles sample was made in the first quarter of 1991.

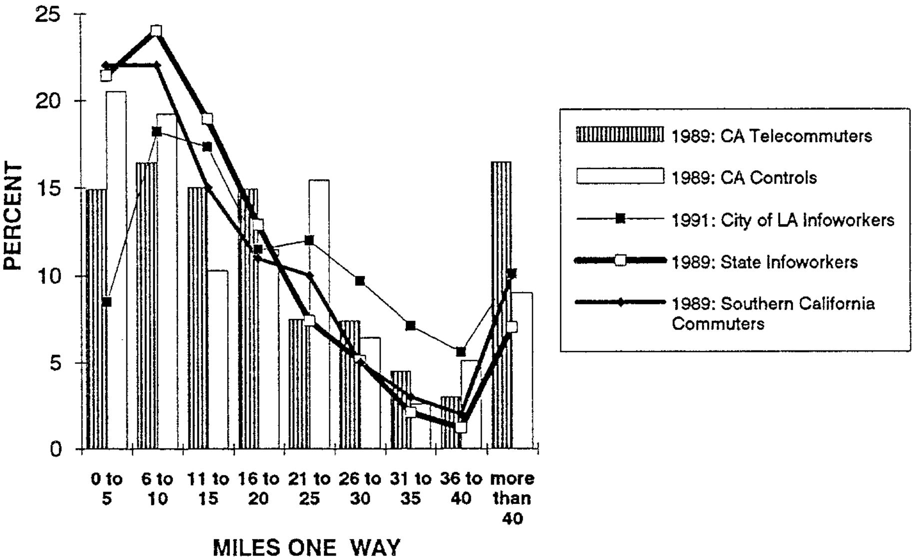

Fig. 1. Recent one-way commute distance distribution.

The California project control group (N=141) and the State information workers have similar commute patterns, with mean commute distances of 17.2 and 16.0 miles, respectively and identical median commute distances of 12.0 miles one way. The State information worker sample (N=513) was taken from locations all over the state, both urban and rural, while the control group was largely from the Sacramento and San Francisco metropolitan areas. The Southern California sample from among all commuters (N=1,169), conducted by Commuter Transportation Services in collaboration with the Southern California Association of Governments, showed mean and median one-way commutes of 16 and 10 miles, respectively.

The final (at project end) group of State telecommuters (N=107) had mean and median one-way commute distances of 28.1 and 20.0 miles, respectively, while the comparable figures for the group of telecommuting applicants for the City of Los Angeles (N=447) are 22.0 and 18.5 miles one way. The maximum post-1988 reported commute distances were 200, 123, 210, 150 and 90 miles one way for the control group, the State information workers, the State telecommuters, Southern California commuters and the City of Los Angeles applicants, respectively. Clearly, the urban Los Angeles information workers have longer commutes than do the workers in the state in general or in smaller metropolitan areas. Both the State telecommuters and the Los Angeles applicants have significantly longer commutes than either the northern California control group or the average worker, with median commute distances in excess of 50% greater.

Changes over time

The data just quoted are for single, annual sample sets. For example, all respondents to any of the questionnaires throughout the California Project

Table 1. Commute distance summary.

Commute distance (miles one way)	Mean	Median
1989: Telecommuters	23.0	17.0
1989: Controls	19.0	16.0
1989: State Infoworkers	16.0	12.0
1989: Southern California Commuters	16.0	10.0
1991: City of LA Infoworkers	22.0	18.5
1988: Telecommuters	22.4	16.0
1988: Controls	19.6	15.5
1987: Telecommuters	21.0	16.0
1987: Controls	19.3	16.5

are included. As is the case with most longitudinal change investigations, not all respondents answer the questionnaires at all points of the investigation. Therefore, the remainder of the California Pilot Project data reported here are for the group of telecommuters (N=67) and controls (N=78) for whom a complete set of data exists. Table 1 reflects those restrictions, and summarizes mean and median commute distances for each group.

Figure 2 shows the variation in commute distance distribution for the State telecommuter group from the inception of the project at the end of 1987 to the termination of the data collection phase in December 1989. The mean and median one way commute distances reported by the telecommuters in 1988 were 22.4 and 16.0 miles, respectively, with a maximum reported commute distance of 75 miles. The mean and median one way commute distances reported by those telecommuters in 1987 were 21.0 and 16.0 miles, respectively, with a maximum reported commute distance of 69 miles.

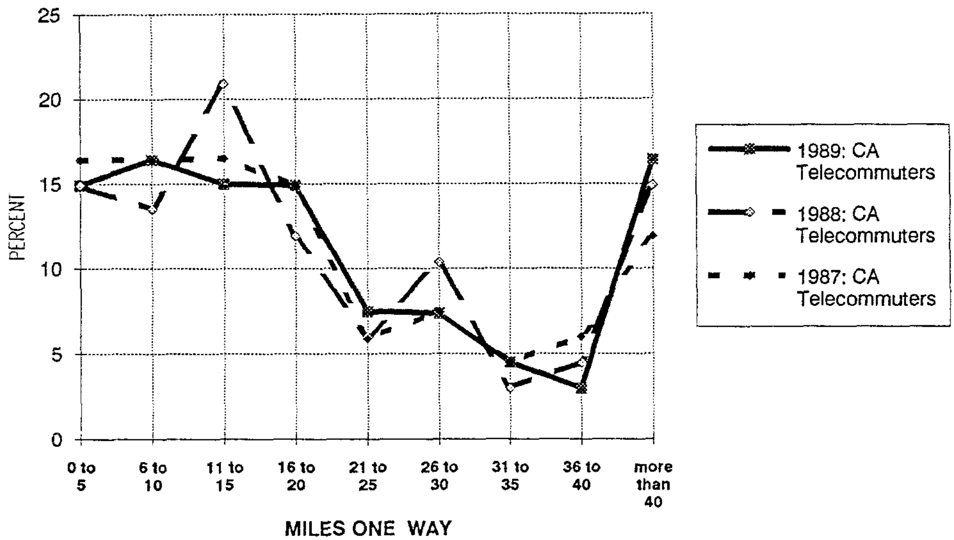

Fig. 2. Longitudinal analysis of California telecommuter commuting patterns.

Taken together, these data show two primary features. First, the telecommuters in the State project live farther from work than do the either the controls or the average State information worker. This is partially due to the selection criteria for the project, which included a bias in favor of those applicants who lived at great distances. Second, the telecommuters, as a group, appear to have moved somewhat farther from work in succeeding years of telecommuting, while the mean reported commutes of the control group fluctuated 0.3 miles about 19.3.

Figure 3 compares the net move distances for the telecommuters and the control group for the years 1988 and 1989, excluding moves greater than 110 miles. In the interval 1987 to 1988, 95.6% of the telecommuters remained in the same location or moved closer to work, compared with 97.2% of the controls. For the 1988–1989 interval the rates were 95% and 99%, respectively. Analysis of variance of the telecommuter and control group means, including the long distance moves, gives a significance, p', of 0.107 for the 1987–1988 change and p'=0.415 for the 1988–1989 change. With the long distance moves eliminated the analysis gives p'=0.90 and p'=0.24, respectively. Consequently, the hypothesis is not rejected: *at least in the first two years, there was no significant difference between the control group and the telecommuters in household move patterns.*

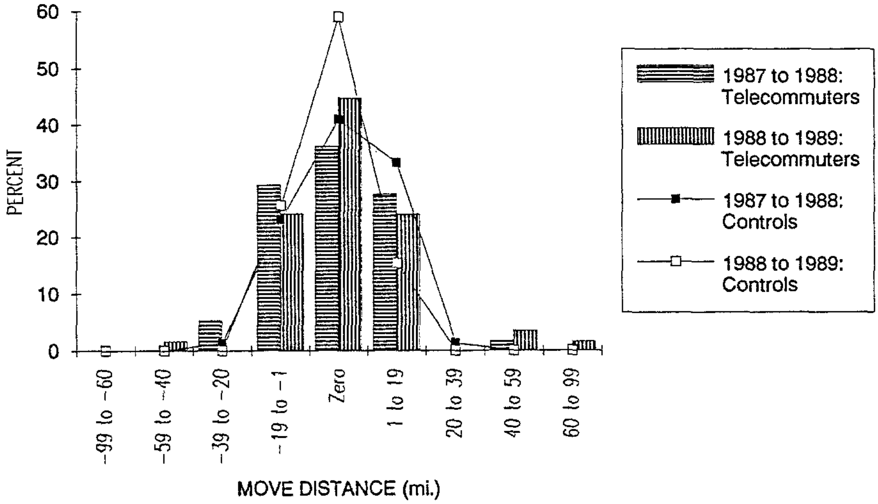

Fig. 3. Net residence move distances.

It is important to note that failure to reject the hypothesis on the basis of these data does not preclude its rejection in the future, as a later section will discuss. It simply means that the dynamics of household move decisions are such that no such trend is evident in a two year initial period. It is entirely conceivable that such a trend might take ten or more years to become evident.

Impacts on commuting

A related issue is whether household moves farther from the principal office produce a net increase in commuting. One possibility is that a household move may be related to a change in telecommuting patterns. That is, if a move farther from work is accompanied by a corresponding increase in telecommuting, the effect of the move is nullified. Table 2 shows the entire-day telecommuting distribution for the telecommuters. Although some of these individuals also telecommuted partial days, to avoid rush hour traffic, only the completely non-commuting days are counted here.

Note a key factor: *the number of entire telecommuting days per month increased by 25% from 1988 to 1989*, while the number of partial days decreased 33%. This can be considered a clear improvement in trip reduction since partial telecommuting days have a smaller positive effect on reducing energy consumption and air pollution, and no effect on trip reduction. This can be interpreted as another indication of continued learning and adaptation on the part of the telecommuters and their supervisors. The number of full-time telecommuting days per month may continue to increase somewhat in the future.

Table 2. Telecommuting-specific patterns.

Factor	Mean		Median		Percent	
	Mid-term	Final	Mid-term	Final	Mid-term	Final
Number of *entire* days/month telecommuting from home:	5.2	6.5	4.0	5.0		
0					12.5	1.9
1 to 4					52.5	45.3
5 to 8					16.7	23.6
9 to 13					11.7	18.8
14 to 17					4.2	9.5
18 to 23					2.5	0.9

Net travel effects

In order to assess the overall impact of telecommuting on travel the impact of household moves must be used to mediate the gross effects of telecommuting. That is, if a telecommuter moves farther from the central office, while still telecommuting only part time, then the increase in commute distance during the non-telecommuting work days should be subtracted from the telecommuting account. Table 3 shows the data for the 67 telecommuters who completed all of the necessary questionnaires for the entire two-year test period.

Table 3. Annual trip mileage savings per telecommuter.

Estimated annual savings (mi per telecommuter)	Mean	Median
1988: Gross savings	2437	1584
1988: Net savings	1752	1628
1989: Gross savings	3531	2640
1989: Net savings	2964	2046
Percent change, gross, 1988–89	45%	67%
Percent change: net: 1988–89	69%	26%

Gross savings are simply the product of the commute round trip distance and the estimated annual full days of telecommuting. Net savings include the penalty for household location moves away from the main office (as well as some increases resulting from moves closer to the office). That is, the extra miles generated on commute days due to moving farther away are deducted from the gross savings achieved on telecommuting days. (Or, in a few individual cases, the miles saved by moving closer are added to the miles saved due to telecommuting.) The savings shown in Table 3 refer to the commute distance stated by the telecommuters before they began telecommuting. The 69% increase in net savings from 1988 to 1989 is largely the result of increased telecommuting frequency. The proportional effect, the residence relocation penalty, is the ratio between net and gross savings: a 28% reduction of gross savings in 1988 and a 16% reduction by the end of 1989. Thus it can be said that residence relocations may have resulted in a 16% average decrease in the commute savings that would have occurred had there been no moves, and had the observed changes in telecommuting frequency still taken place.

Telecommuting influence on household location changes

The next issue is that of the factors influencing home relocation decisions. Of the telecommuters who responded to all the questionnaires, 85.1% had *not* relocated during the two-year test period (although 7.5% were considering it) and 14.9% did relocate. Of those who either relocated or were thinking about it, 52.6% said telecommuting had no influence whatever on their decision (one did not indicate the level of influence), 21.1% said it had a slight influence, 10.5% indicated a moderate influence, 21.1% a significant influence and 5.3% said that telecommuting was decisive in their move decision. In 50% of the completed move cases the move was farther from the central office, with 30% moving nearer; 10% of the moves had no change in commute distance. The median move distance was zero; the average was 13.8 miles farther. In both the "considering moving" and the "have moved" groups 78% of the moves changed (or would change) the commute by 15 miles or less. The remaining 2 actual moves were 47 and 80 miles farther away. Tables 4 and 5 show the distributions.

Telecommuting appears to be prompting some of these individuals (3% of all the telecommuters) to move entirely out of town, not just a little farther (or closer)! The relationship between absolute value of distance moved (for those who have actually done it) and the influence of telecommuting is significant at the $p'=0.02$ level.

For those contemplating a move, but who had not yet actually made one, the average move distance contemplated was 26.7 miles farther from their current work location, while the median distance was 7 miles farther. The telecommuting influence-distance relationship in these cases is weaker,

Table 4. Telecommuter move patterns (Completed Moves, 1989).

Move distance (mi)	Telecommuting influence (number of telecommuters and column %)				Row total (no. and %)
	None	Moderate	Significant	Decisive	
-5	1 16.7%		1 50.0%		2 20.0%
-2	1 16.7%				1 10.0%
-1	1 16.7%				1 10.0%
0	1 16.7%				1 10.0%
1	1 16.7%				2 10.0%
8	1 16.7%				1 10.0%
15		1 100.0%			1 10.0%
47			1 50.0%		1 10.0%
80				1 100.0%	1 10.0%
Column total:	6 60.0%	1 10.0%	2 20.0%	1 10.0%	10 100%

however (p'=0.06), just short of what is usually considered significant ($p' \leq 0.05$).

It is important to emphasize that these moves primarily are responses to other motivating factors. Telecommuting is not the chief motivator, according to interviews with telecommuters; it simply alters the decision process by partially reducing the pain of commuting and/or opening other work arrangement alternatives. *In any case, it is clear that the availability of telecommuting will influence future household move decisions.*

Another pattern seems to be emerging from the commute data: residence moves tend to be either relatively small, a few miles one way or another, or relatively large – twenty to forty miles or more. That is, they appear to be either local or completely out of town. There was evidence during the 1970s that skilled workers, including professionals and many other information workers, were opting to move out of major cities to rural cities and

Table 5. Telecommuter move patterns (Considering Moves, 1989).

Move distance (mi)	Telecommuting influence (number of telecommuters and column %)				Row total (no. and %)
	None	Slight	Moderate	Significant	
0	3 100.0%		1 100.0%		4 50.0%
10		1 100.0%			1 12.5%
30		1 100.0%			1 12.5%
60				1 50.0%	1 12.5%
120				1 50.0%	1 12.5%
Column total:	6 37.5%	2 25.0%	1 12.5%	2 25.0%	8 100%

towns (Long & De Are 1983). If telecommuting acts to reinforce that trend, as appears to be the case from the California data, then urban sprawl may be reduced in favor of rural city/town growth. Since 1985 the author has conducted informal interviews with residents of small cities in California that further support this version of relocation growth. This mode of relocation also has serious consequences since small cities may be unprepared for the new growth and large cities may be hurt by the erosion in quality of the tax base.

Growth possibilities

Whether one should be concerned with the preceding depends on the likelihood that telecommuting will become a widespread phenomenon, and therefore of serious interest to transportation and urban planners. As discussed earlier, the precursor pressures for telecommuting – increased congestion, a growing information workforce, increased capacity, capability and use of information technology – appear to be present. Although these factors may be important, the question remains as to whether organizational structures and work patterns will support extensive telecommuting. In particular, aside from the technology sufficiency issue, there is the question of how adaptable to teleworking situations information (or other) jobs might be.

General "telecommutability"

As a test of this we surveyed State of California employees who were information workers. The questionnaire used was derived from the questionnaire used for telecommuter selection in the project. The questionnaire focused on job content and worker attitude issues and did not include some of the behavioral components of the project questionnaire. This was administered to a random sample of 996 State information workers during January 1990. Slightly more than half of those who received questionnaires returned them. The returns were subjected to the same screening criteria as were the participants in the pilot project. However, the screening was less exhaustive, both because of the reduced scope of the questions and because the direct supervisors of the employees were not included in the survey. Hence the results represent only the prospective telecommuter portion of the tests and only the job task related factors. Further, none of the participants in the general survey was given a briefing on telecommuting prior to completing the questionnaire. Therefore, there may have been some confusion on some of the fine points of job restructuring that lowered their scores.

The original selection process in 1987 and early 1988 for the active project produced responses from 614 prospective telecommuters, primarily in the Sacramento and San Francisco Bay areas. The general survey covered a broad array of agencies (more than 35 agencies) and elicited responses from 513 information workers from all over the state. One apparent difference between the two groups is in commute distance; the average one way commute for the respondents to the general survey was 16.0 miles, as contrasted to 19.8 miles for the applicants to the pilot project. Average commute speeds were not substantially different, however: 28.4 mph for the average state information worker versus 28.3 mph for the average pilot project applicant. The average State information worker had worked for the State about 6% longer than the average pilot project applicant (12.2 versus 11.6 years, respectively) and had held his/her current position about 5 months longer (4.6 versus 4.2 years).

Our evaluations of the pilot project applicants, based solely on the questions in the general survey, would have been that 15% of the applicants would not have been able to telecommute at all, 54% would have been able to telecommute from a telework center, and the remaining 31% would have been able to telecommute some or most of the time from home. The comparable results for the statewide respondents to the general survey are that 31% would not be able to telecommute at all, 52% would be able to telecommute from a telework center, and 17% would be able to telecommute part time from home. Of the no-telecommute group, 23% replied that their job required them to be in the 'regular' office every day. Of that number, more than 40% had secretarial, clerical, technician or operative jobs. It is likely that at least some of these could be performed at a telework center. A few, such as automotive mechanic and registered nurse, turned out not to have information jobs after all.

That is, the pilot project applicant group comprised 85% potential telecommuters, while the general pool of State information workers includes 69% potential telecommuters. It is important to note that the pilot project applicants were already pre-screened to some extent by their management, thereby increasing the likelihood that they would meet the selection criteria.

A major conclusion of the California project was that there was no reason to believe that telecommuting could not be widely applied throughout State government. At least at the job content and experience level, the proportion of State employees who could telecommute is high. Second, at least half of these employees had job characteristics that suggested telecommuting only from telework centers. Therefore, the developement of regional telework center telecommuting is an important factor in future growth. *In the longer term it portends a future in which residence location and "office" location are only loosely correlated for many information workers. Hence, the need for an extensive network of regional telework centers will continue to grow.* Since the conclusion of the pilot project the number of telecommuters in California State government has continued to grow as has the number of State agencies with active, formal telecommuting programs.

Alternative futures and issues

Many information workers have become, or will become, telecommuters, according to data and forecasts developed by JALA Associates and the Telecommuting Research Institute (TRI) (JALA Associates 1983; Nilles 1988; TRI 1991). Figure 4 shows the TRI nominal forecast for telecommuting in the United States. In 1991 the process is still in the early growth stages but within 20 years there could be as many as 50 million telecommuters in the U.S., saving as much as 380 billion passenger-miles of transportation use (compared to the usage if there were no telecommuting). There is no way to demonstrate the validity of this scenario except by waiting for it to happen. However, anecdotal evidence certainly points to the likelihood that acceptance of telecommuting will increase significantly in the next decade.

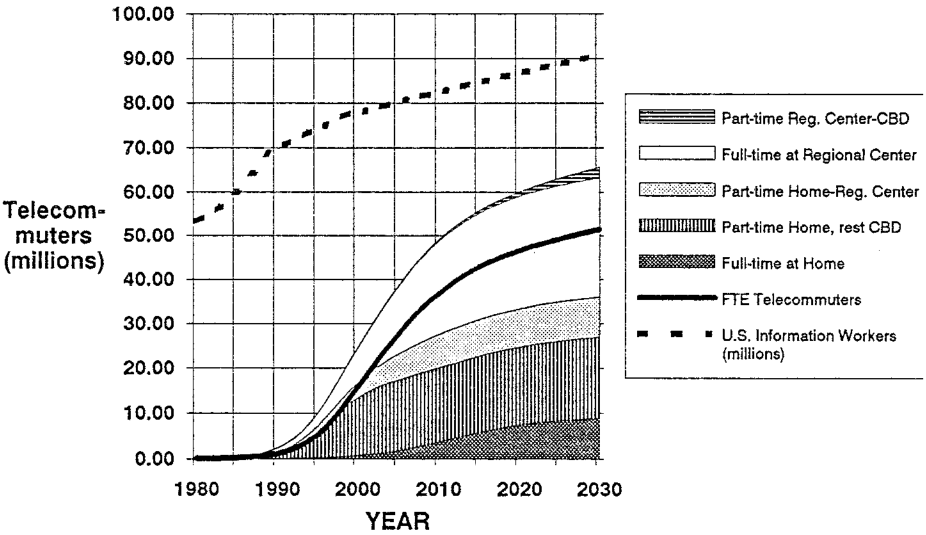

Fig. 4. U.S. telecommuting forecast.

The legend for Figure 4 indicates the following variants of telecommuting:

Part-time Reg. Center-CBD: The telecommuter spends part of the average work week at a regional telework center, the rest of the week in a Central Business District.

Full-time at Regional Center: The telecommuter always commutes to the nearest telework center.

Part-time Home-Reg. Center: On average, the telecommuter spends part of the work week telecommuting from home, the rest of the week at the nearest telework center.

Part-time home, rest CBD: The dominant form of telecommuting today, with the

telecommuter spending part of the work week at home, the rest of the week in the principal traditional office.
Full-time at home: The telecommuter (almost) always telecommutes from home.
FTE Telecommuters: Full-Time-Equivalent Telecommuters.

Note that the term *Central Business District*, as used above, does not necessarily refer to the traditional center of a large city. Since the majority of commuter traffic is now between suburban centers (Pisarski 1987), those centers are included in this definition. The primary distinction between CBD, as used here, and regional center is one of distance: the regional center is presumed to be closer than the CBD to its telecommuters' residences.

Growth issues

Although only limited population surveys are available, the number of telecommuters in the United States in 1991 was estimated at somewhere between 1.3 and 4.3 million, in keeping with the forecast values. For example, Miller estimated that there were 3.75 million telecommuting employees by mid-1991, on the basis of random surveys of 2,500 U.S. households (Miller 1991, modified by personal communication on August 13, 1991). About 40% of these households were situated within 50 miles of major cities (that is, cities with at least 1 million population) or in cities of at least 100 thousand

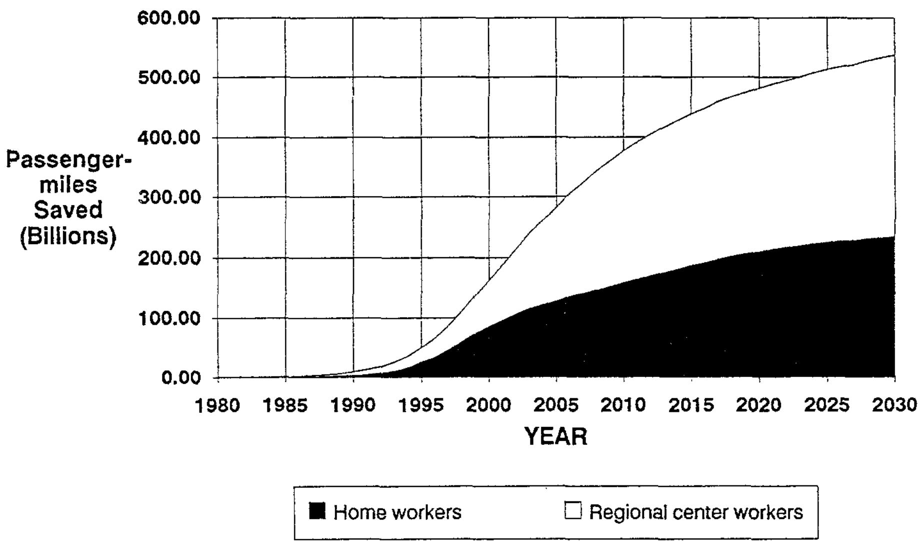

Fig. 5. U.S. nominal telecommuting impacts.

population. The TRI estimates of telecommuters for mid-1991, as embodied in Fig. 4, are a more conservative 2.9 million; the Miller survey is 29% higher than the forecast value. As they become available, 1990 census data should provide more definite answers on the nearly-full-time home-based telecommuters (about 4% of the estimated total).

If growth in telecommuting occurs as forecast in Fig. 4, then two major questions arise:

1. What will be the geographic distribution of the growth patterns?
2. What are the implications of this on development of the transportation infrastructure?

Two versions of the future serve to illustrate the possibilities. The *Nominal Future* scenario covers the most desirable case in terms of minimizing environmental impacts and is reflected in Fig. 5. The *Telesprawl Future* covers the case of exacerbation of existing trends via telecommuting and teleworking and assumes that the Hypothesis is incorrect. Both scenarios are considerably simplified in the description that follows.

Nominal future

In the nominal future case telecommuting acts as intended: as a partial or total substitute for commuter transportation. Telecommuters either work at home or at a nearby regional center, thereby reducing their commuting to zero or to a significantly shorter distance on the days they telecommute. Teleworking also reduces the amount of mid-day business related travel through increased use of teleconferencing (audio-only, audio-plus-graphics, facsimile, computer, and/or full-motion video) and electronic messaging (voice- and electronic-mail).

Home-based telecommuters typically work from home only part time, although the average number of telecommuting days per week increases over the years as technological enhancements appear and as the business culture adapts more readily to principles of telemanagement.

Although home-based telecommuting is the dominant form in the early years of the process, regional telework center telecommuting gains the ascendency in the mid-1990 s. Average commute distances to regional centers slowly diminish as the number of centers increases, to the point where neighborhood telework centers become common by 2010. (Neighborhood centers are smaller facilities, housing just a few workers, that can serve as mini-satellites or mini-local centers. The emphasis here is on neighborhood: each such center would be within a few blocks of the workers' residences.) There is also a change in mode selection for the regional center telecommuters, correlated with the decreasing commute distances: an increasing number of telecommuters get to work on foot, by bicycle, or by local mini-mass transit (buses, jitneys, car- and vanpools), although the increase is not large. Similarly, part-time home-based telecommuters switch from commuting to the urban/suburban CBD to regional telework center commutes for their commuting days.

Residence location decisions are still driven by considerations of availability of affordable housing but the decision becomes simpler for telecommuters; the stress and cost of significant commute time and distance dwindle as decision factors. The growing fraction of residents who are home during daytime hours spurs more rapid development of local service businesses. Bedroom communities become full time communities. Transportation patterns become local-center directed rather than inter-or trans-urban. Rural towns and smaller cities, with their more attractive living environments, reverse their trends of population loss. Residence move decisions are counteracted by the availability of local telework centers and home-based telecommuting so that there is no effective attrition from net increases in commute distance. Note that this scenario still implies lower numbers of telecommuters than those estimated by Miller.

Telesprawl future

The telesprawl scenario could develop if part-time home-based telecom-

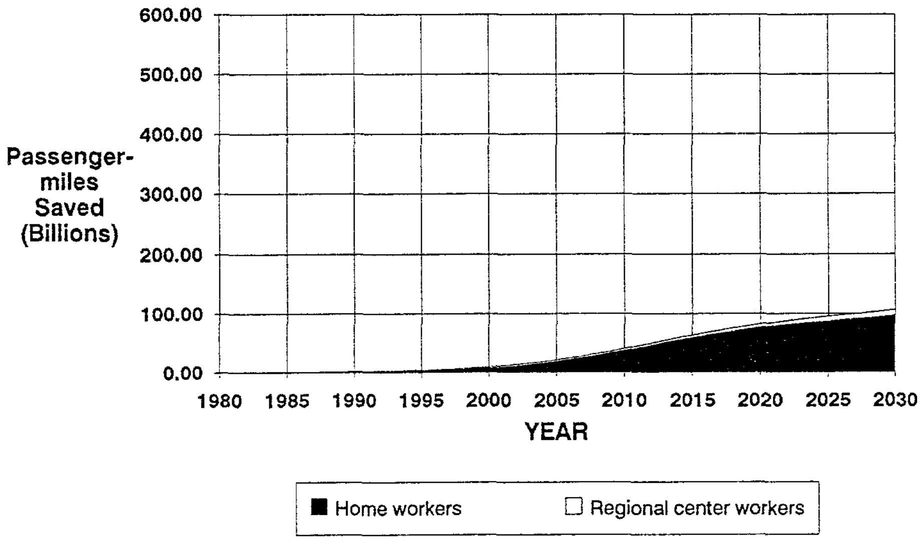

Fig. 6. U.S. urban sprawl telecommuting impact.

muting remains the dominant form. In this scenario, most organizations fail to develop telemangement techniques and continue to insist on at least part-time information worker employee presence in their central urban/suburban offices. Few regional telecommuting centers are developed.

Nevertheless, the attractiveness of even part-time telecommuting and the resultant reduction in commute times inspires continuing expansion of housing development into formerly rural areas. Although the number of commute trips by telecommuters is decreased, commute distances increase to more than offset the savings for 20% of the telecommuters. The current trends of urban sprawl in growth regions are continued unabated or, perhaps, accelerated as a consequence. Demands on the transportation infrastructure are correspondingly increased, as is consumption of fossil fuels and concomitant air pollution. Figure 6 shows the telecommuting portion of the impact of this scenario but does not show the additional infrastructure impacts.

The evidence to date does not support this scenario.

Some public policy issues

To date, telecommuting has developed generally in response to market forces. There has been little direct distortion of the market in favor of telecommuting, although the availability of high quality, low cost telecommunications services and the increasing proliferation of computer use by information workers are important factors. The Nominal Future of telecommuting described here and shown in Fig. 4 assumes that market forces will remain the dominant influences on the acceptance of telecommuting. However, market forces could account for either the Nominal or Telesprawl futures. Indeed, an historical viewpoint would argue that, in the long run, Telespawl is more likely unless the market is somehow distorted to favor development in regional clusters rather than as uniform geographic expansion. Thus, there remains the possibility that the growth of telecommuting can be both accelerated and guided by means of government-induced distortions of the market.

One key factor in cluster-versus-uniform development is the likelihood of development of network organizations; that is, organizations that are physically decentralized via regional offices of various sorts. If this is to be a widespread phenomenon an important growth factor may be the development of small multi-tenant regional/local telework centers made available on either a full-time, part-time or drop-in basis to local teleworkers. The success of this sort of endeavor is critical to the broadest development of telecommuting. Such development can be affected significantly by government action.

For example, government can subsidize seed efforts for telework center development. One such effort was made by the State of Hawaii, beginning in 1988 (Hirata and Uchida 1990). A similar activity has been proposed for the Los Angeles metropolitan area as a result of State of California action (California Legislature 1991b). Both involve cost-sharing on the part of the government, either as an equal or minority partner.

Zoning laws and regional development regulations can also influence the nature of telework development. For example, many communities (as well as cooperative associations) have laws or regulations that prohibit home-based work of any sort. Several cities, including the City of Los Angeles, are in the process of revising zoning laws to permit telecommuting. Other zoning restrictions, such as requiring office buildings to include a certain amount of telework space, can also motivate corporate shifts to telework. Punitive regulations, such as those promulgated by the South Coast Air Quality Management District (SCAQMD) in southern California, require organizations with facilities housing at least X employees to develop and implement comprehensive plans for reducing the number of vehicles used by their commuting employees (X=100 for the SCAQMD). Failure to comply with the regulation can result in stiff fines, as high as $25,000 per day for the non-compliance period.

Tax incentives also have been used frequently to steer investment decisions. Efforts have been underway in California to give income tax credits to employers for initiating telecommuting in their organizations (California Legislature 1991a). Increased taxes on, or elimination of tax incentives for, parking space can have similar effects, as can the conversion of major highways to toll roads. These actions are receiving increasing support in communities with traffic congestion problems.

Finally, government can play, and is playing, a major role in educating the public about telecommuting as a commuting alternative. The State of California has played a ground-breaking role in this regard, followed closely by the state governments of Hawaii, Arizona and Washington, and the local governments of Fort Collins, Colorado, Los Angeles and San Diego (both city and county governments in the latter two cases).

Summary

Evidence from the California Telecommuting Pilot Project supports the contentions that telecommuting does not, as yet, exacerbate urban sprawl and that telecommuting does produce net reductions in household travel in proportion to the intensity of telecommuting.

Analysis of the California data also produced the conclusions that telecommuting was widely applicable to State employees and that telework centers would be very desirable. It appears reasonable to assume that the presence of nearby telework centers will help reduce or eliminate increased commute distances even where workers change residence location. Therefore it is important to continue emphasizing the need for a broad array of regional centers.

On a more general note, the experience of the state government information workers is entirely consonant with similar experiences of the author in the private sector; government employees are not unique in their eligibility for, or responses to, telecommuting. In principle, the State of California experience should be generalizable to any population group in a developed country. Unfortunately, data on private sector experience are generally not available for publication.

The empirical evidence collected to date indicates that the Nominal Future telecommuting scenario is the more likely one. Telecommuting does result in decreased automobile use, both in terms of number of trips and in trip distance.

Nevertheless, telecommuting was also associated with significant moves away from the principal office location for a small percentage of telecommuters. Even though the median move distance actually made by telecommuter households is almost zero, the pattern for moves yet to come may increase that distance significantly in the long run. Hence telesprawl clearly remains a possibility, particularly if the growth of regional centers does not occur at the levels estimated for the Nominal Future scenario. Also possible is a renaissance of growth and redevelopment of cities and towns in rural areas as a viable alternative to urban sprawl.

The development of telecommuting is producing some exciting transportation infrastructure possibilities. It is also producing a rich area for further research into the dynamics of interplay of the transportation and telecommunication infrastructures on community growth.

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