TRF Student Paper Contest

Josephine E. Olson, Academic Vice President

Over twenty papers were submitted to the 1990 TRF Student Paper Contest. The winners in the graduate division were the following. First prize went to Konstadinos G. Goulias and Ram Pendyala of the University of California at Davis for their paper, "Innovations in Transportation: The Case of Telecommuting." The second prize winner was Joseph Harr of the University of Maryland; his paper was "Economies of Scale in Postal Operations: Evidence From An International Comparison." Chandra Bhat of Northwestern University won third prize for his paper, "An Aircraft Routing Model with Departure Time Windows for a Hub and Spoke System." The undergraduate paper winner was Annette Ohuche, a 1990 graduate of Iowa State University. Her paper was entitled "Alliance, Cooperation Pacts, and Mergers in the European Airline Industry: Implications For 1992."

All the students attended the Annual Meeting and presented their papers. They were awarded their prizes by Douglas T. Smalls, Vice President, United Parcel Service. UPS generously provided funds to pay for the student prizes and their travel expenses to the Annual Meeting. The winning student papers all appear in this *Proceedings*.

The following TRF members were kind enough to serve as reviewers of the student papers during the past summer: James G. Beierlein, Penn State; John P. Carter, University of California at Berkeley; Thomas M. Corsi, University of Maryland; Curtis M. Grimm, University of Maryland; Louis LeBlanc, University of Arkansas at Little Rock; Carl D. Martland, MIT; James R. Matthews, Southern Pacific; Wayne Talley, Old Dominion University; and David Vallenga, Arizona State University.

Student Paper Awards

- *Innovations In Transportation: The Case of Telecommuting*

by Konstadinos G. Goulias and Ram M. Pendyala,
University of California, Davis

Abstract

Telecommuting has been proposed as a trip reduction measure to alleviate traffic congestion and reduce energy consumption and air pollution. Hypotheses on the potential impacts of telecommuting are conflicting. This paper offers empirical evidence on the short term impacts of telecommuting on travel demand using results from the State of California Telecommuting Pilot Project. Extensive discussions are provided on its possible long term impacts and on how innovations such as telecommuting should be implemented by stages. In this paper, we argue that technological and institutional innovations such as telecommuting, staggered work hours, etc., should be implemented jointly within a unified legislative and planning framework. Regulation XV of the South Coast Air Quality Management District has been used as a case study to illustrate a possible implementation strategy within a planning context to obtain desired results.

Introduction

Effective management of travel demand is a growing concern among transportation planners, engineers, local governments and business establishments. Most of the industrialized countries have realized that increasing transport capacity to satisfy travel demand is not a viable option for meeting future needs [AASHTO, 1988]. This realization was the result of growing energy, environmental, and air quality considerations which discouraged the expansion of existing transport systems supply. Transportation consumes 63% of all petroleum used in the United States [EIA, 1988a] and over 70% in California [CEC, 1987]. United States oil imports are forecast to increase from 5.8 million barrels per day in 1987 to between 7.6 and 11.6 million barrels per day by the year 2000 [EIA, 1988b] and the single greatest opportunity for reducing petroleum consumption lies in the transportation sector. On the environmental front, continued reliance on the private automobile continues to raise serious questions about our air quality. In 1987 the Environmental Protection Agency reported that 107 metropolitan areas in the U.S. violated the primary health standard for ozone, carbon monoxide or both [Sperling and Deluchi, 1989] – 12 of these regions were in California. On-road mobile sources are forecast to emit 61% of the total CO and 47% of NOx (an ozone precursor) in California [CARB, 1988]. Thus, the focus of transportation planning has shifted from the construction of new facilities to the application of efficient travel demand management techniques.

In response to these urgent problems, the California State South Coast Air Quality Management District (SCAQMD) adopted Regulation XV in December 1987. This regulation requires all business establishments of 100 employees or more to provide a plan to reduce employees' commute trips. This is the first regulation of its kind in the United States that provides an administrative structure to support trip reduction. One of the trip reduction measures suggested as a feasible strategy is Telecommuting which involves the use of telecommunications equipment to perform work at home [SCAQMD, 1987].

The use of telecommunications to substitute for the commute to work has recently drawn extensive attention as a strategy for reducing travel demand. This came to be known as telecommuting, broadly defined as "the performance of work outside the traditional central office, either at home or at a neighborhood center close to home" [Kitamura, et al., 1990a]. Telecommuting is becoming increasingly feasible due to the rising proportion of information workers in the U.S. labor force [Kitamura, et al., 1990a]. Nilles [1988] provides a conservative estimate of 1 million for the number of workers in the work force who telecommute at least a portion of a day each week. Thus the potential for telecommuting as a means to mitigate urban traffic congestion, reduce transportation energy consumption, and improve air quality is substantial. However, the strategy adopted for implementing telecommuting is crucial for its success as a trip reduction measure. The need for the development of a flexible implementation strategy motivated this paper.

The State of California Telecommuting Pilot Project conducted in 1988 and 1989 offered the first opportunity to gather non-proprietary data on household travel behavior to assess the impact of telecommuting. The sample of the study comprises 222 State employees who participated in the

Pilot Project on a voluntary basis, and 189 of their household members of driving age. The participants recorded trip characteristics in three-day travel diaries both in 1988 and 1989. Thus, their travel characteristics were measured before and after the introduction of telecommuting in order to assess the differences in travel. It was found that, in a one year time period, telecommuting substantially reduced travel while virtually eliminating the commute trip.

The assessment of short term benefits does not, however, provide conclusive evidence regarding the possible long term impacts. There are other contributing factors such as human adjustment over time to imposed changes, acceptability by public and private employers and institutional and technological barriers that may determine the ultimate impacts.

Since changes in travel making are dependent upon a multitude of factors and telecommuting is just one among many trip reduction measures that can be implemented, a plan for the introduction of telecommuting, and any transportation innovation in general, has to be devised. This plan must provide flexibility to recover from any setbacks and prepare the platform for the introduction of innovations on a large scale. Also, the different innovations must be coordinated and implemented jointly to realize the maximum possible benefit.

In the next section, the different types of trip reduction measures and their objectives are presented. In the third section, the results of the telecommuting experiment conducted by the State of California Department of Transportation are outlined. Discussion on the possible long-term effects of telecommuting are provided in the following section. A stage-wise implementation plan of telecommuting is provided in the penultimate section. The last section contains a summary of our findings, recommendations, and conclusive remarks.

Trip Reduction Measures

Management of travel demand can be achieved by influencing demand through traffic control measures. These measures may be subdivided into direct and indirect measures. The direct measures involve imposing restrictions on travel or devising incentive structures for reducing travel, for example, car/van pool incentive structures, road and parking pricing, telecommuting, etc. These direct measures are implemented through Regulations. The indirect measures would include new road construction, HOV lane provision, closure of existing roads, and provision of alternative modes such as light rail. The adequacy and impact of each measure depends on the objectives at hand, the traffic problem itself and the constraints (economic or other). The evaluation of the success of each measure must be comprehensive to include possible primary and secondary effects.

A trip reduction measure is a strategy to reduce congestion, energy consumption and air pollution by modifying administrative and regulatory mechanisms surrounding travel. This paper is mainly concerned with telecommuting which is a direct trip reduction measure as it influences travel demand at its genesis.

An example of an institutional backbone of trip reduction measures is Regulation XV adopted in December, 1987 by the California State South Coast Air Quality Management District (SCAQMD). This regulation aims at reducing peak hour travel (6:00 am to 10:00 am) by decreasing the number of commute trips. The regulation provides a basis for the mandatory design and implementation of comprehensive trip reduction plans by all employers with 100 or more employees by the end of 1991. In particular, employers have to develop incentives for their employees' adoption of ride sharing, mass transit, lesser polluting vehicles, staggered work hours and finally, telecommuting.

The assessment of the impact of telecommuting on travel demand is a highly complex task. An issue of particular importance is whether telecommunications technologies act as substitutes for travel or whether a complementary relationship exists between telecommunications and travel [e.g., Salomon, 1986; Mokhtarian, 1988; Nilles, 1988]. Little empirical evidence appears to exist at present on the interaction between the two [Salomon, 1988].

Many hypotheses can be formulated on the impact of telecommuting on household travel (for related discussions, see Nilles, 1988 and Kitamura, et al., 1990a). It is convenient to classify these hypotheses according to a time frame into short-term and long-term hypotheses.

The most direct short-term hypothesis is that the number of trips generated by telecommuters will decrease due to the reduction in commute trips to and from work. Because work trips are most often made during the peak period, a decrease in peak-hour trips will follow as a direct consequence. In addition, the eliminated need to travel to work would lead to savings in both time and money. This in turn might result in an increased availability of discretionary time, flexibility in activity scheduling, and some monetary savings. One may then hypothesize that these changes could prompt new, discretionary trips such as social and shopping trips. Indeed, if the assumption is true that a person budgets a fixed amount of time for travel [Zahavi, 1974; Wigan and Morris, 1979], then those commute trips, eliminated

by telecommuting, may be replaced by new trips; or, the time spent previously commuting will now be spent pursuing other activities in or around home. As a result, new trip destinations may be chosen to reach more desirable locations. Trips could be made by alternate modes of travel and scheduled at more convenient times. For example, shopping which used to be done on the weekends at a regional shopping center far from home may now be done at a neighborhood store near home on a telecommuting weekday. Thus one long trip may be substituted by numerous short home-based trips. This could, in turn, increase the feasibility of using alternatively fueled vehicles such as short range electric vehicles for trip making.

One may conjecture that the spatial distribution of trip ends may be concentrated around the home location rather than the work location when the worker telecommutes. This redistribution of trips may affect (suburban) congestion and air quality of telecommuting is widely implemented. Another important consequence of telecommuting is the removal of some of the work-related constraints. Relaxation of these constraints is likely to reduce the need to link trips, i.e., consolidation of several stops into one home-to-home journey. In fact a recent analysis of trip linking behavior under different conditions [Goulias, et al., 1990a] has shown that people increase their linking of trips under tighter constraints. If this in fact is the case, then telecommuting may lead to an increased number of sporadic home-based trips, leading to less efficient travel patterns and more cold starts. It is also conceivable that the flexibility and irregularity in work schedule brought about by telecommuting may lead to a change in mode use. For example, participating in a carpool may not be convenient to a telecommuter who does not commute every day, therefore he may choose to use his personal car when he commutes.

At the household level, it is conceivable that the presence of a telecommuter at home with his flexible work schedule may result in a reallocation of tasks among the household members [for example, Koppelman and Townsend, 1988]. This may streamline the distribution of travel patterns of the entire household, making possible more efficient engagement in out-of-home activities. On the other hand, the household members may choose to use the car left at home by the telecommuter who would otherwise take it to commute, possibly leading to increased proportion of car trips.

Thus, many changes are conceivable even within a short time frame. Some changes will be beneficial while others may not. The timing of these changes is also uncertain. A telecommuter and his household members would go through a process of experimentation and learning before they adopt a new pattern that best takes advantage of telecommuting. Adaptation to telecommuting thus involves a certain time lag whose length is not known.

Further impacts of telecommuting are conceivable in the long term. The reduced need to commute may prompt a household to own fewer cars. At the same time, telecommuting reduces the need to reside close to the work location. Hence, some telecommuters may use telecommuting "as the basis for moving farther away from work, which has possible negative effects on travel patterns" [Telecommuting Review, The Gordon Report, September 1, 1989]. Even though the testing of such long term hypotheses is not possible within the results of the pilot study, we will provide a discussion on how telecommuting can be implemented while keeping possible long term impacts in mind. However, many of the short-term hypotheses have been tested using the empirical evidence provided by the State Pilot Project. These hypotheses guided the statistical analysis performed in Kitamura, et al. [1990b]. In this paper an outline of the salient findings on the impact of telecommuting on household travel is offered.

Other potential benefits of telecommuting (e.g., reduced office space requirements, increased worker productivity) are being examined in detail by JALA Associates [1989] and will be briefly discussed in this paper to assess the potential for the penetration of telecommuting in private business establishments and occupational tasks other than those involving information processing.

Results of the State of California Pilot Project

The impact of telecommuting on travel demand was examined using three-day travel diary data obtained from State employees, participating in the State of California Telecommute Pilot Project, and from their household members of driving age. Travel data were collected twice, before and after telecommuting started, facilitating a before-and-after comparison of various aspects of household travel. The pilot project had involved 222 state employees from 14 agencies. Approximately half of these employees telecommuted on an experimental basis. The rest constituted a control group and commuted to work conventionally. The latter group reflected changes in the general travel environment and the comparison of the two groups allowed the isolation of the effects of telecommuting on travel. In this paper, results are presented on the travel characteristics of telecommuter households only. Results on the travel patterns of control group households and the comparison between the two groups of households can be found in Kitamura, et al. [1990b].

Of the 222 employees and 189 household members originally contacted, 123 employees and 71 household members reported their trips in both survey contacts. The 123 employees included 66 telecommuters and 57 control group members. These employees were residing mostly in the Sacramento Metropolitan Area. The telecommuters work at home on the average 1.25 days during three-day diary periods. There were 39 household members associated with the telecommuter households who responded in both survey contacts while their control group counterparts numbered 32. The results of the analysis offer strong empirical evidence that telecommuting is a viable trip reduction measure.

The major findings of the telecommuting pilot study are reported in Table 1 which summarizes travel indicators before and after telecommuting was initiated. On the days when they telecommuted, no work trips were generated by the telecommuters. The savings in time due to the elimination of the commute trips does not seem to have lead to an increase in non-work trips. Even though telecommuters found themselves with an increased flexibility regarding work schedules, etc., they did not choose to make any additional trips. We observed that telecommuters decreased their total distance traveled by approximately 20% over a three day period. Further, on average one telecommuting day reduced the vehicle miles traveled by more than 40 miles. Trips made on telecommuting days were of much shorter duration and involved less freeway use.

The most encouraging result, in light of the guidelines in Regulation XV, was obtained with regard to peak period trip generation. Telecommuters tend to make their trips during off-peak periods on telecommuting days. As a result, morning peak period trips were found to be reduced on the average by over 75%, and afternoon-peak period trips by about 60% on telecommuting days. This is in contrast to previous theories postulated regarding the impacts of telecommuting. The indications obtained in this study contrast the pessimistic views of Garrison and Deakin [1988] who postulated that telecommuting will not be a major trip reduction measure.

These results also seem to indicate that telecommuting yields energy savings. However, telecommuters use their cars for a higher percentage of trips when they work at home. This may, in part, be due to the reduced number of work trips, and the more frequent use of the car for non-work trips.

In general, the telecommuter household members did not increase their trip making. The travel indicators presented in Table 2 show that there is no substantial difference in their travel patterns between the two contacts.

The apparent reduction in the number of trips may, in part, be due to decrease in trip reporting across survey contacts. A salient finding was that the household members of telecommuters increased car use by 4% which is not significant when we consider that trip reporting and other statistical issues related to surveys might have caused this spurious effect. This is particularly important since additional family cars have become available for their use. In summary, the trip making of household members described in Table 2 shows stability in their travel behavior before and after the introduction of telecommuting.

In addition, we examined the trip linking patterns of telecommuters. Telecommuting leads to somewhat fewer linked trips [Kitamura, et al., 1990b]. This is presumably because no office-based trips can be made and non-work trips cannot be linked to commute trips when a worker telecommutes. As a result, trips tend to be home-based, forming the simple pattern, home-activity-home. However, the analysis thus far is not complete for the assessment of household task reallocation and activity engagement. More information regarding the destination choice of telecommuters is currently being collected and analyzed [for example, Wissen, 1989]. The changes in activity patterns that resulted from telecommuting are being assessed by constructing daily activity profiles of all participants before and after telecommuting.

Discussion

The study results outlined in the previous section support telecommuting as a travel reduction measure. Further analysis is needed to determine the region-wide impact of telecommuting on traffic congestion, air quality, and energy consumption. Regional effects of telecommuting depend on the number of workers who can telecommute, the frequency with which they telecommute, and the contribution that telecommuting can make towards reducing traffic congestion, pollution and energy consumption.

The implications of telecommuting are both short term and long term changes in travel patterns. In the short term, telecommuting resulted in not only a reduction in peak hour trip generation, which is the requirement of Regulation XV, but also a reduction in vehicle miles traveled. An added short term advantage of telecommuting may be the release of existing pressure at the work-place (both parking space and work space).

On the other hand, it has been observed that people tend to choose locations for non-

TABLE 1

Impact of Telecommuting on the State Employees' Travel

Travel Indicators	*Before*	*After*	
		T/C day*	*Non T/C day***
Number of Trips per day	3.91	1.92	3.95
Number of Trips to Work per day	1.11	0.03	1.13
Number of non Work Trips per day	2.80	1.89	2.82
Number of Peak-Period Trips (7:00-9:00 am)	1.18	0.21	0.92
Number of Peak-Period Trips (4:00-6:00 pm)	1.39	0.45	1.15
Average Distance Travelled per day (miles)	54.5	9.4	52.6
Average Trip Duration (minutes)	21.0	4.9	13.5
Freeway Use (percentage)	32.3	8.9	43.1
Percentage of Trips by Car	83%	94%	84%

* Days on which the employees telecommuted (i.e., worked principally at home).

** Days on which the employees commuted to work.

TABLE 2

Impact of Telecommuting on the State Employees' Household MembersTravel

Travel Indicators	*Before*	*After*
Number of Trips per day	4.27	3.04
Number of Trips to Work per day	0.88	0.73
Number of non Work Trips per day	3.39	2.31
Number of Peak-Period Trips (7:00-9:00 am)	1.07	0.76
Number of Peak-Period Trips (4:00-6:00 pm)	1.14	0.85
Average Distance Travelled per day (miles)	37.7	31.9
Average Trip Duration (minutes)	19.8	21.9
Freeway Use (percentage)	19.9	21.1
Percentage of Trips by Car	93%	97%

* Days on which the employees telecommuted (i.e., worked principally at home).
** Days on which the employees commuted to work.

work activities along their usual commute route, with special preference given to the sites around work [Kitamura, et al., 1990c]. When people telecommute, they may choose to visit locations around their residence, thus increasing pressure on suburban transport and retail facilities. This hypothesis is being tested currently by precisely locating the destinations chosen by telecommuters.

The long term impacts of telecommuting have not been empirically studied to the knowledge of the authors. Nilles [1988] offers a descriptive analysis of some issues related to this where he offers a wide range of forecasts based on limited data. Obviously, an analysis of this type would have its limitations, but would still provide useful insights regarding the impact of a global technological change on travel.

Telecommuting should be considered only as a part of an institutional and technological revolution which could lead to drastic changes in the formation of cities, the work force composition, and the basic definition of transportation. Garrison and Deakin [1988] presented the introduction of new technologies in a historical framework. According to them, innovations have faced barriers in their adoption. These barriers were mainly due to resistance to change, the lack of knowledge of their possible impacts.

Telecommuting can be considered to be the tip of a technological iceberg the adoption of which could open the road to much more effective ways to utilize technology. For example, the increasing computer literacy and ownership offers new methods for more effective managerial supervision, task allocation, and distribution of employees' promotion and benefits. Moreover, the increase in demand for a flexible working environment may motivate the revival of the small home-based firms which will function on independent contract based task performance.

The savings in time due to telecommuting, which could amount to four hours per day (including the time spent preparing for work and relaxing after work) may be spent in performing other activities which may, in turn, improve the quality of life. The elimination of the commute related and work induced tension and anxiety is another major factor that could change the activity schedule and lifestyle of a telecommuter. Telecommuting was found to drastically shorten trip lengths and trip durations along with freeway use. This is indicative of a radical change in the destinations chosen for performing household and personal activities. Telecommuters may choose to pursue activities in the vicinity of their home location which involve a lesser use of the freeway and increased use of local urban streets. While in the short term, the increased use of local streets could lead to suburban congestion, in the long term it could lead to a reformation of our transportation system together with a better urban design. An increasing public awareness of the ill-effects of todays land-use patterns in which the car is an indispensable mode of transport is already motivating the development of alternative urban designs such as small town neighborhoods [Environmental Council of Sacramento Working Paper, 1989]. The lifestyle of small town neighborhoods is perfectly supported by a telecommuting society. The need to interact with people would induce telecommuters to interact with neighbors. This, in a large scale, would induce greater social contact and the revival of the spirit of community life. On the other hand, alienation due to telecommuting may also occur. It has been hypothesized that working at home may disrupt a persons' contacts with the work place. This in turn would result in loss of information exchange with fellow workers and promotion opportunities. Both of these theories have to be tested empirically.

Working at home opens new opportunities to persons otherwise excluded from the labor force such as handicapped people, etc. A few more social changes may also be induced. For example, people could move far away without losing their present job. Increased recreational and social visit activities could also result due to the increased discretionary time available. In addition, a telecommuter household may adopt a considerably different lifestyle. This may be due to changes in task allocation among the household members which would influence their travel patterns.

Telecommuting and telecommunications will change the way transportation is defined. Even the introduction of the automobile in this society may not have been as revolutionary and swift as the introduction of telecommunications in transportation. The rapid changes in transportation brought about by the introduction of telecommunications could redefine the role of transportation in the economy. Garrison and Deakin [1988] point out that "the transportation manager's question should be how transportation could be shaped to support (a) telecommunications society rather than how telecommuting might ease traffic problems".

The role played by transportation today is primarily one in which people and goods are moved from one point to another. Transportation facilities are built and managed in an attempt to achieve an efficient movement of people and goods. In transportation practice, congestion during peak period commutes is the one concern that absorbs a major portion of planning efforts. Trip reducing regulations such as SCAQMD's Regulation XV are also a part of the overall efforts in decreasing congestion, air-pollution, energy consumption, and travel times.

But what does the future look like, given the introduction of the revolutionary concept of substituting travel (and in particular, the commute trip) with telecommunications? The answer is uncertain. However, using the preliminary indications provided by the pilot project, we could put forth a few alternative possibilities. One outcome of this is the substitution of the commute trip with telecommunications by a large portion of the information work force. A consequence of this could be the increase in demand for suburban routes and recreational facilities. So planners will soon find themselves no longer solving problems related to peak period commutes, but problems related to route choices of recreational travelers and short home-based trips of telecommuters.

The changes brought about by this innovation would be experienced not only in the transportation of people and goods, but also in the transportation of information. On the people and goods side, the spatial pattern of trip making will change to one in which people make either very long business and recreational trips or very short trips (i.e., breaks in between home-based telecommuting for recreation, neighborhood grocery shopping, etc.). Increased use of telecommunications to transit and receive information would place a greater demand on the telecommunication system network. Thus a new facet of transportation will emerge; one in which transportation engineers are no longer looking after transporting people and goods but are designing telecommunication networks to manage peak period information transmission/reception. This new branch of transportation would be a blend of two specializations in engineering; telecommunications and transportation.

Yet another major change that we might see is in the development of new modes of transport-those convenient for very long trips and very short trips. The need to make long business and recreational trips could increase air transport needs. This is indeed a trend being observed in the United States and Europe. The short trips around the home-base could lead to the use of short-range alternatively fueled vehicles such as battery powered or roadway powered electric vehicles [Nesbitt and Sperling, 1990]. Telecommuters could thus provide a much needed niche for the introduction of alternative fuels in the market. It is now well known that increased use of alternatively fueled vehicles would go a long way in alleviating air pollution problems and improving energy security [Sperling and Deluchi, 1989].

Implementation

Any revolutionary innovation which entails major changes such as those described in the preceding sections must be introduced carefully and judiciously. The strategy followed in introducing the innovation could prove instrumental in its success. It has to satisfy the following requirements:

a) The formulation of the strategy should be such that both positive as well as negative aspects of the innovation are clearly seen. This will ensure a proper economic analysis of the implementation strategy and also keep us ready to face the negative aspects.

b) The strategy should be formulated in a flexible way so that we can change our direction in the innovation is proven to be non-beneficial at a certain stage.

One way to do this would be to implement a stream of coordinated short-term actions with long-term goals in mind. This may be called 'implementation by stages'. Telecommuting will be used as our case study here as one of the stages in the strategic implementation of telecommunications. In the first stage, telecommunications could be introduced on an experimental basis in public agencies which would experiment different schemes and methods of work procedures. In this way, negative and positive effects of different applications of telecommunications can be assessed. The various actors participating in the process of telecommuting will have to be identified in this stage. They may include the government, telecommunication components manufacturers, private and public agencies that will use the technology, and the households who will use the technology and become subject to change in lifestyle. Based on the outcome of this experimental phase, in the second stage, an incentive structure needed to initiate the introduction of telecommunications in private firms will have to be developed. Since the initial returns on investment for an innovation are both low and difficult to realize, the incentive structure will provide the additional benefits private firms would require. This is based on the assumption that public agencies do not need incentives as they are government controlled and do not always operate as profit maximization firms. Only after the first two stages are carried out, it would be possible to determine the potential for penetration of telecommuting in the public and private sectors. This is because the penetration of telecommuting would depend on both the results of the experimentation in the public agencies and the acceptance of the incentive structure by the private sector. The third stage would involve assessing this potential for penetration and estimating the technological requirements under a futuristic scenario. The fourth stage would involve the definition of an institutional and legislative framework,

i.e., regulations, incentives, role of public and private industry, taxation and pricing schemes, etc. It is in this stage that the role of each actor in the process is clearly defined and monitored. This is the final stage where economies of scale have been reached and the introduction of the innovation will be successful both in profit maximization and traffic reduction.

The implementation by stages will help avoid CBD-like congestion in the suburbs. This would also help in avoiding rejection due to unfounded skepticism. The implementation of other supporting measures to aid the success of telecommuting will be enabled by the provision of additional time and flexibility in the plan.

Regulations such as Regulation XV of SCAQMD should form a part of the first stage. It is a regulation which provides the appropriate legislative and institutional platform on which telecommuting can be launched and its effects assessed. The monitoring of the progress may be conducted according to procedures proposed by Guensler [1989]. Briefly, he suggests improvements in the enforcement policies followed by local air pollution control districts. He provides guidelines for the evaluation of trip reduction plans, modifications to monitor compliance with regulations, procedures for record keeping and auditing. The collection and analysis of data on the impact of the trip reduction plans such as the pilot study in Kitamura, et al. [1990b] would provide a valuable source of information for assessing the progress of trip reduction measures. For example, daily trip records of all employees are collected and summaries reported to the agencies. Thus Regulation XV and other similar regulations will generate a substantial quantity of information regarding the impact of trip reduction measures. In addition, the analysis of this information will shed light on numerous unresolved issues regarding the behavior of the government, firms and people.

There are other trip reduction measures which can also be implemented in conjunction with the telecommunications revolution. These measures include staggered work hours (for e.g., Giuliano and Golob, 1990), car/van pooling [Rivckin, 1989] and restricted parking facilities. It is important to implement all these measures jointly as the coordinated implementation in a unified framework could produce more significant benefits than if they had been implemented in isolation. Also, the time available to assess the benefits of each one in an isolated setting is too limited. The need to act immediately cannot be emphasized more.

Conclusions

In this paper, we argued that even though the short term impacts of telecommuting are very favorable as shown by the results of the State of California Pilot study, the long term impacts cannot be forecasted. The early stage of the telecommuting experiment does not allow us to draw valid long term inferences regarding human travel and activity patterns. However, a well-orchestrated and concerted plan has been sketched for the introduction of telecommuting in conjunction with other traffic mitigation measures. In the short term, telecommuting was found to eliminate commute trips, largely reduced peak period trips, not increase other trips, decrease vehicle miles traveled, decrease trip times, decrease freeway use and increase the proportion of car trips. Changes in telecommuters travel patterns may also influence the travel patterns of non-telecommuters, and therefore their energy consumption. However, the travel characteristics of household members of telecommuters remained stable over a short span of time. The indications are very encouraging in that they meet the requirements of Regulation XV of SCAQMD. However, if it is to continue providing such benefits over a long duration, the strategy for the implementation of telecommuting (and other traffic reduction measures) must be drawn up very carefully. Also important for future research is the identification of socio-demographic and mobility characteristics of potential telecommuters (e.g., their residence and work locations, car ownership, work trip distance and mode, lifestyle measures) as this would allow the identification of market penetration of telecommuting.

Telecommuting could represent one possible precursor of many more telecommunication applications in transportation. In this connection, it is important to realize that the role of transportation and its definition would undergo radical modifications which could have important implications on future planning strategies.

This paper provides a strategy for the introduction of innovations in transport. Particular emphasis has been placed on the introduction of telecommuting and the institutional and legislative framework surrounding it. However, the implementation by stages could be applied to any proposed innovation as long as possible long term objectives are always clearly reflected in the planning process. Implementation by stages provides the much needed flexibility and time to respond to changes in the external environment. The authors call for a unified implementation of numerous traffic mitigation measures in order to obtain maximum possible benefits as the benefits realized from each measure implemented in isolation may not provide significant and desired results.

Acknowledgement

The authors wish to acknowledge Prof. Ryuichi Kitamura at the University of California, Davis, for his constant guidance, support and instruction without which this paper would not have been possible. Ken Kurani provided valuable information on the energy implications of increasing travel demand while Randall Guensler provided useful documentation on SCAQMD's Regulation XV. The authors are also grateful to Professors Daniel Sperling and Paul Jovanis whose instruction provided the methodological framework for this paper.

References

American Association of State Highway and Transportation Officials (1988) *Keeping America Moving: The Bottom Line.* Washington, D.C.

California Air Resources Board (1988) *Air Quality Plan.* 1988 Revision. Sacramento, CA.

California Energy Commission (1987) *California's Energy Outlook.* 1987 Biennial Report. Sacramento, CA.

Energy Information Administration (1988a) *Annual Energy Outlook 1987.* Washington, D.C.

Energy Information Administration (1988b) *Annual Review of Energy 1987.* Washington, D.C.

Garrison, W.L. and E. Deakin (1988) *Travel, Work and Telecommunications: A View of the Electronics Revolution and its Potential Impacts.* <u>Transportation Research A.</u>, 22A (4), 239-45.

Giuliano, G. and T. F. Golob (1990) *Staggered Work Hours for Traffic Management: A Case Study.* Paper submitted at the 69th Annual Meeting of the Transportation Research Board, January 7-11, 1990, Washington, D.C.

Goulias, K.G., R. Pendyala, and R. Kitamura (1990) *A Practical Method for the Estimation of Trip Generation and Trip Chaining.* <u>Transportation Research Record</u> (forthcoming). National Research Council, Washington, D.C.

Guensler, R. (1989) *Compliance Perspectives on Transportation Control Measures. South Coast AQMD Regulation XV.* <u>Transportation Research Record</u> (forthcoming). National Research Council, Washington, D.C.

JALA Associates, Inc. (1989) *The State of California Telecommuting Pilot Project: Midterm Report.* Los Angeles, California.

Kitamura, R., J.M. Nilles, P. Conroy, and D.M. Fleming (1990a) *Telecommuting as a Transportation Planning Measure: Initial Results of State of California Pilot Project.* Paper submitted at the 69th Annual Meeting of the Transportation Research Board, January 7-11, 1990. Washington, D.C.

Kitamura, R., K.G. Goulias, and R. Pendyala (1990b) *Telecommuting and Travel Demand: An Impact Assessment for State of California Telecommute Pilot Project Participants.* Research Report No. UCD-TRG-RR-90-8. Prepared for The State of California Department of Transportation.

Kitamura, R., K. Nishii and K. Goulias (1990c) *Trip Chaining Behavior by Central City Commuters: A Causal Analysis of Time Space Constraints.* In P.M. Jones (Ed.), <u>New Developments in Dynamic and Activity-Based Approaches to Travel Analysis</u>, Grower Publishing, Aldershot, England, 145-170.

Koppelman, F.S. and T.A. Townsend (1988) *Task Allocation Among Household Members: Theory and Analysis.* Draft paper unpublished.

Mokhtarian, P.L. (1988) *An Empirical Evaluation of the Travel Impacts of Teleconferencing.* <u>Transportation Research A.</u>, 22A (4), 283-89.

Nesbitt, K. and D. Sperling (1990) *An Initial Assessment of Roadway-Powered Electric Vehicles.* <u>Transportation Research Record</u> (forthcoming). National Research Council. Washington, D.C.

Nilles, J.M. (1988) *Traffic Reduction by Telecommuting. A Status Review and Selected Bibliography.* <u>Transportation Research A.</u>,22A (4), 301-17.

Rivkin, M.D. (1989) Can Transportation Management Reduce Traffic in the Suburbs? Ask the Nuclear Regulatory Commission. In TR News No. 141. National Research Council. Washington, D.C.

Salomon, I. (1986) *Telecommunications and Travel Relationships: A Review.* <u>Transportation Research A.</u>, 20A (3), 223-38.

Salomon, I. (1988) Transporting Information and Transporting People. <u>Transportation Research A.</u>, 22A (4), 237.

South Coast Air Quality Management District (1987) *Staff Report on Proposed Regulation XV (Trip Reduction/Indirect source);* El Monte, CA.

Sperling, D. and M. Deluchi (1989) *Transportation Energy Futures.* Annual Review of Energy, Vol. 14.

Wigan, M.R. and J.M. Morris (1979) *The Transport Implications of Activity and Time Budget Constraints.* Research Report AAR No. 93. Australian Road Research Board. Victoria, Australia.

van Wissen, L.J.G. (1989) *A Model of Household Interactions in Activity Patterns.* Paper presented at the International Conference on Dynamic Travel Behavior Analysis, Kyoto, Japan, July 16-17, 1989.

Zahavi, Y. (1974) *Travel Time Budgets and Mobility in Urban Areas.* Federal Highway Administration. U.S. Department of Transportation. Washington, D.C.