Southwest Region University Transportation Center

# Telecommunications-Transportation-Energy Interaction: The Potential for Telecommuting to Reduce Urban Network-Wide Fuel Consumption

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Center for Transportation Research
University of Texas at Austin
3208 Red River, Suite 200
Austin, Texas 78705-2650

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16. Abstract

The substitution of transportation by telecommunications has long been advocated as an approach that might eventually alleviate the demand placed on transportation facilities and thereby reduce fuel consumption and air pollutant emissions. With increasing penetration of telecommunications in individual homes and businesses, coupled with the widespread availability of computing equipment, facsimile capabilities and the like, there is renewed interest in exploring and encouraging telecommuting arrangements. These include work-at-home schemes and workplace decentralization with satellite work centers, as well as many other non-traditional approaches to structuring workplace activities and worker responsibilities.

The aim of this project is to address the travel behavior implications of telecommuting, and determine the potential of telecommuting to improve urban mobility and reduce fuel consumption. The following objectives will be addressed: (1) prepare a synthesis of existing experience with telecommuting from the standpoint of travel behavior and fuel consumption; (2) characterize telecommunications-tripmaking-energy interactions at the individual and household levels, focusing on travel behavior within a dynamic activity-based framework; (3) develop a predictive approach to assess the energy consumption consequences of telecommuting; and (4) develop recommendations for possible implementation strategies and for future travel and energy demand forecasting.

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# Telecommunications-Transportation-Energy Interaction: The Potential for Telecommuting to Reduce Urban Network-Wide Fuel Consumption

by

Mark Sullivan

Hani S. Mahmassani

and

Robert Herman

## RESEARCH REPORT SWUTC/93/60018

Southwest Region University Transportation Center
Center for Transportation Research
The University of Texas at Austin
Austin, Texas 78712

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# ABSTRACT

Telecommuting has achieved recognition in several states and foreign countries as a means to reduce trip-making during the peak period. Evidence to date suggests that telecommuting can effectively eliminate commute trips without creating new travel. If true, telecommuting holds vast potential to mitigate urban traffic congestion. Decreased network fuel consumption and improved air quality are two primary benefits associated with reduced automobile use.

In light of Federal Clean Air Act Amendment of 1990 standards, telecommuting has been mentioned in legislative policy as a transportation demand management (TDM) strategy in non-attainment areas. Where firms are required to reduce peak hour commuting by its employees, telecommuting is an effective strategy, along with staggered work start times, the four day work week, and other programs. This development in the legislative arena lends an urgency to all aspects of telecommuting research.

The literature on telcommuting is evolving away from broad theoretical work based on a technological substitution perspective toward a system of behavioral models with better represent the compound decisions involving employer adoption, employee participation, tripmaking effects, and long-term location decisions. Researchers will have a better idea to what extent telecommuting is occurring at present as definitional issues are resolved. The vast literature on factors affecting adoption and participation decisions has fostered attempts to model these complex phenomena, utilizing stated preference techniques.

Pilot studies have provided valuable insight into the necessary ingredients to a successful telecommuting experience. The first indications of the impact of telecommuting on tripmaking have been reported recently. Observations of ongoing projects will be helpful in identifying long-term effects on auto ownership, residential location, and office location that constrain broad implications for land use and transportation networks. The first satellite telecommuting experiments have begun in Washington and California, promising a better understanding of the costs, benefits, management of, and transportation impact of satellite work centers.

This study presents a model of network fuel consumption savings due to telecommuting that incorporates the direct effect of removing vehicles from the network and the indirect effect of their removal on vehicles remaining in the network. The indirect effect is present only during the peak performance and along arterial streets where benefits are derived from increased average speeds up to about 40 MPH. The model's primary inputs are system supply and demand assumptions, two-fluid model parameters, fuel consumption characteristics, and current estimates of the effect

of telecommuting on tripmaking at the individual and household level. Several scenarios of telecommuting participation have been applied to obtain estimates of potential fuel savings for different levels of telecommuting activity in Austin, Dallas, and Houston.

The results of the model's execution indicate a more-or-less linear relationship between the percentage of information workers per day who choose to telecommute and the network percentage fuel savings. This is due to the fact that peak period arterial travel, in which the nonlinear indirect effect on vehicles remaining on the network is introduced, accounts for only about ten percent of all VMT. Only where average flows approach capacity are the nonlinear effects noticeable. Certainly there are several areas nationwide suffering congestion at or near capacity today and several more just a few years away. In these cities telecommuting can be particularly effective at reducing congestion and network fuel consumption. Further analysis, illustrates the amount of time that telecommuting can extend the sub-capacity lifetime of networks aided by little or no growth in the number of lane-miles.

Additionally, an employee participation choice model was presented herein. Several factors are identified that contribute to individual telecommuting decisions, based on stated preference responses to a cost-neutral telecommuting scenario. This exploratory analysis points toward an integrated set of choice models to enhance the scenario approach used here. Indeed, the anticipated number of people who will telecommute is a central element of the fuel consumption savings model developed in this study.

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# CHAPTER 1
# INTRODUCTION

## MOTIVATION

Powerful and complex forces are contributing to profound social, organizational, and economic changes characteristic of the "information age". These changes have relaxed considerably strict restrictions on time and place in production and consumption fundamental to the evolution of the "industrial age". This freedom is facilitating a restructuring of the economy, the workforce, the lifestyles of individuals, and potentially, the form of cities. Developments in the telecommunications industry over the last two decades have motivated inquiry into tradeoffs between telecommunications and transportation. Each industry maintains a system of networks which compete in the supply of transportation for the purpose of information transfer. In anticipation of a) accelerating diffusion of current telecommunications technologies, b) introduction of new technologies, and c) continued cost decreases relative to transportation, telecommunications networks are expected to capture an increasingly larger share of information activities. For transportation professionals, this presents the challenge of transforming the planning process to include a new set of variables affecting both supply and demand. The widespread diffusion of telecommunications technologies also offers a potential demand management strategy in the form of telecommuting in the interminable crusade against urban automobile traffic congestion.

Telecommuting, in the transportation environment, refers to the complete or partial substitution for the work commute through the use of telecommunications and/or computing equipment. It may involve work from home or from a satellite office (presumably one nearer employees' homes than the central office) and may take place on a full-time basis or part-time. Telecommuting is a subset of a broad group of telecommunications alternatives to transportation including teleconferencing (a competitor to business travel) and teleshopping (a competitor to shopping travel). Credit for the term is generally given to Jack Nilles, who began researching the topic in the early 1970s (e.g. Nilles et al., 1976). Since then, a vast body of literature has developed in the contexts of management issues, worker issues, program implementation, and transportation impacts. Recently, focus has shifted away from the identification of advantages and disadvantages of telecommuting and simple calculation of positive effects on travel under a broad array of scenarios toward an effort to understand the decision processes of employers and employees which influence the adoption of telecommuting as a work arrangement and to document the effect on trip-making at the individual, household, firm, and network levels.

The population of potential telecommuters among current workers is derived from the number of telecommutable jobs; that is, jobs whose duties do not require frequent face-to-face communication. These positions exist mainly in the growing information economy (e.g. communications, consulting, and programming; Schepp, 1990). Reported estimates of the percentage of the U.S. workforce employed in information-oriented positions generally refer to a study published in 1976 by Porat. Porat estimated that 46.2% of GNP in 1967 was produced in information sectors of the economy (in Naisbitt, 1982). Considering the growth experienced in information industries in the last 25 years, it is believed that about half of all U.S. workers hold information-oriented jobs and are potential telecommuters (e.g. Schneider, 1989). How many actually will participate depends on the evolution of relative costs, employee propensity to telecommute, and to a large extent, on the ability of management to adapt to supervising a remote workforce. In the longer term, the amount of telecommuting will depend also on the evolution of jobs specifically designed for telecommuting.

Early forecasts of the anticipated amount of telecommuting and the effect on travel have been comprised almost exclusively of the substitution effect of eliminating corresponding work trips. It has become clear that telecommunications activities will not only substitute for work trips, but will generate new trips and significantly modify the position of trips over time and space. It is uncertain to what extent telecommuting will induce new travel; e.g. travel to a satellite office, travel that had been linked previously to the work commute, travel generated by increased leisure time or the desire to spend time away from home, or travel performed by other household members due to the availability of a vehicle. Furthermore, it has been hypothesized that teleconferencing and teleshopping will extend the activity bases that motivate travel for the purposes of business meetings and shopping, thereby creating additional travel despite capturing a greater share of the demand for transportation of information (Salomon, 1986). In addition, technologies such as vehicle-based mobile phones and real-time information systems may stimulate travel by making it more attractive, conflicting with the goals of telecommuting as a trip reduction measure (Mokhtarian, 1990a). Most important, telecommunications alternatives to transportation increase the flexibility of scheduling activities over space and time. This flexibility poses critical consequences for future planning of transportation systems.

In recent years, telecommuting has gained popularity as a transportation demand management (TDM) policy based on the assumption that the benefits of eliminating work trips will far outweigh any induced travel. Certainly any mechanism that removes vehicles from crowded urban roadways during peak travel hours merits consideration. Evidence is only beginning to trickle in that identifies factors relevant to the adoption of telecommuting and the short-term effects on travel behavior. Virtually no data exists with which to analyze long-term impacts on automobile ownership and location decisions. In any case, in light of Federal Clean Air Act legislation and implications for transportation funding under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), telecommuting has already found its way into environmental legislation in several states as one means of reducing peak hour work trips at the firm level in "non-attainment" urban areas (Mokhtarian, 1991). The potential to reduce network-wide fuel consumption provides further impetus to include telecommuting in transportation legislation. In addition, the flexibility telecommuting provides may prove to be extremely valuable in crisis management of transportation in response to natural disasters, oil supply shocks, or similar disruptive events.

Thus, transportation professionals must prepare for the next few decades under considerable uncertainty with regard to the impact of telecommunications on transportation. The problem demands a comprehensive framework for analyzing the complex relationships among human, organizational, and economic variables. Within this framework, the need for quantifiable results requires analysis of telecommuting attitudes and preferences, and of observed changes in travel activity patterns of telecommuters leading toward an integrated system of behavioral models.

## OBJECTIVES AND OVERVIEW

The objectives of this report are 1) to present a conceptual framework for analyzing the impact of telecommuting on vehicle-miles traveled and fuel consumed on the network level in a metropolitan area, 2) to operationalize this framework under a set of assumptions so as to obtain quantitative estimates of potential fuel savings from telecommuting in 1990, 2000, and 2010 in Austin, Dallas, and Houston, and 3) to obtain insights into the factors affecting employee participation in telecommuting through the calibration of a choice model using stated preference data procured from a survey of workers in information-oriented occupations in the same three Texas cities. The theoretical framework incorporates mathematical relations among network-based traffic variables and estimates of model parameters derived from the "two-fluid model" of town traffic (Herman and Prigogine, 1979, and Ardekani and Herman, 1987). The translation into fuel savings estimates utilizes a linear model of fuel consumption as a function of travel time (Evans et. al., 1976) and applications to urban traffic flow (Evans and Herman, 1976).

Chapter Two contains a review of the literature on telecommuting including issues related to definitions and measurement, an inventory of factors expected to influence employer adoption and employee participation, an examination of results to date detailing short-term effects on travel behavior, a look at some theories on the impact of telecommunications on urban form and the spatial distribution of activities, and other current directions of research. The analytic framework is introduced in Chapter Three. Results from the analysis of fuel consumption consequences appear in Chapter Four. Chapter Five describes a choice model of employee participation in telecommuting. Finally, conclusions and recommendations are presented in Chapter Six.

# CHAPTER 2
# LITERATURE REVIEW

## OVERVIEW

Instigated by rapid expansion in the communications and computer industries, the "Information Revolution" is having a profound effect on the behavior of organizations and individuals. Declining emphasis on the centralization of labor and capital in production is presenting opportunities for remote work alternatives and flex-time arrangements which could serve transportation professionals as demand-reducing and peak-spreading strategies. In recognition of the above changes and opportunities, a considerable body of literature has developed in the last decade which addresses telecommunications/transportation interactions, the likelihood of widespread adoption of telecommuting, and the subsequent travel impacts.

Publications promoting the potential benefits of telecommunications substitutions for travel have appeared in the transportation literature since the early 1960s (Memmott, 1963). Memmott categorized interactions between people, machines, and information underscoring the anticipated greater role of machines in information interactions. He classified various activities that motivate transportation of people and information according to substitutability. Memmott also described an approach by which to analyze the potential for substitution in an urban area, with an emphasis on the need for commercial and individual economic advantages.

Instability in the oil industry in the 1970s provoked the first quantitative reports on the potential for national fuel savings from telecommuting. These studies consisted mostly of technology assessments which have, in retrospect, proven to be overly optimistic forecasts of the penetration of telecommunications technologies. Through the 1980s a vast theoretical body of research has emerged across the transportation, management, sociology, and geography disciplines. Recently, pilot studies in California and Europe have provided the first evidence, albeit limited, of telecommuting's impact on businesses, individuals, and transportation systems.

This review is structured as follows: Section 2.2 discusses definition issues, presents examples of some specific telecommunications activities that compete with transportation, and describes problems inherent to the measurement of telecommuting from census information. Section 2.3 examines the social, managerial, economic, legal, and political factors that influence employer adoption and employee participation. Section 2.4 contains results of research on the short-term effects of telecommuting on travel. The literature on telecommuting's long-term effects on spatial distribution is summarized in Section 2.5. Finally, current directions for research are discussed in Section 2.6.

## DEFINITION ISSUES IN TELECOMMUNICATIONS/TRANSPORTATION INTERACTIONS

Telecommunications activities have displayed substitution potential for a variety of travel purposes (Mokhtarian, 1990b). Table 2.1 defines these demand substitutes and provides specific examples of each. This table illustrates the broad-based changes in lifestyle made possible by the progress in telecommunications industries.

Telecommuting research has suffered from inconsistent definitions, creating a barrier to theoretical development and actual measurement. Mokhtarian (1990b) proposed two standards for determining whether or not a particular work arrangement qualifies as telecommuting: 1) the employee is subject to remote supervision and 2) the journey-to-work is reduced or eliminated. These criteria exclude self-employed business owners and branch office workers subject to on-site management, the objective being to include only those arrangements designed specifically with travel reductions for employees in mind.

Telecommuting takes many forms, each affecting travel behavior in a distinctive manner. Nilles (1988) defined four categories, displayed here in Table 2.2, characterized by location and proprietorship. These options can be utilized full-time or part-time, and in any combination. For example, a programmer might work from home twice a week, travel to a satellite office twice a week, and commute to a central office the remaining day. Telecommuting may also be performed for part of the day, thereby shifting a work trip off-peak. Each permutation has different implications for urban networks. Mokhtarian (1991) provided an inventory of various forms of remote work, their classification (telecommuting or not), and their expected impact on traffic.

Kraut and Grambsch (1987) examined 1980 census data and concluded that 1.6% of the white-collar workforce primarily worked at home. How many of these workers meet the conditions proposed by Mokhtarian is uncertain. Their analysis of the typical homeworker identified unmarried nonblack men, married nonblack women, and persons physically constrained to the home most likely to work at home. Homeworkers were also found to earn substantially less income than office workers. Kraut (1989) separated homeworkers into three types: substitutors (telecommuters), self-employed, and income supplementers. He touted evidence suggesting that telecommuters make up a very small portion of homeworkers.

TABLE 2.1: APPLICATIONS OF TELECOMMUNICATIONS SUBSTITUTIONS FOR TRAVEL

| Application | Definition | Examples |
|---|---|---|
| telecommuting | work performed at a remote worksite so as to reduce the work commute | work from home, work from a satellite office |
| teleconferencing | Meeting held at multiple locations linked by audio, video, or data equipment | conference call, video conference |
| teleshopping | Shopping activities performed with computer or television services | Home shopping, telemarketing |
| telebanking | Banking transactions performed with computer or telephone | ATM machine |
| tele-entertainment | Transmission of entertainment events to multiple locations | Cable TV movies and sporting events, videocassettes |
| tele-education | Classroom instruction transmitted to remote locations | Home instruction, college instruction at the worksite |
| tele-medicine | Transmission of information between medical professionals via video and/or data links | X-ray diagnosis, closed-circuit televised operations |
| tele-justice | routine legal functions performed remotely via video or audio links | remote witness testimony, depositions, arraignments |

TABLE 2.2: CATEGORIES OF TELECOMMUTING

| Category | Definition | Example |
|---|---|---|
| Home telecommuting | work performed at home rather than a centralized worksite | Control Data Corporation in Bloomington, MN was one of the first firms to employ home telecommuters (Schepp, 1990) |
| Regional telecommuting | work performed at a regional office nearer the home than the central office | see below |
| -Satellite center | a regional worksite owned and operated by one firm so as to reduce the commute times of its employees | Washington State Telework Center opened in March 1991 (Mokhtarian, 1991) |
| -Local center | a regional worksite owned and operated by several public and/or private organizations | Hawaii Telework Center (Hirata and Uchida, 1991) |
| -Neighborhood center | a local center specifically created to utilize a workforce within walking distance | Ballard (WA) Neighborhood Telework Center (Mokhtarian, 1991) |

Gordon (1988) estimated that there were about 10,000 telecommuters in 1988. Link Resources has reported that the number of home telecommuters has increased from 2.2 million in 1988 to 5.5 million in 1991 (Mokhtarian, 1991). However, in their study a telecommuter was defined simply as a company employee who worked from home some during traditional work hours. Definitional uncertainties and methodological difficulties ensure tremendous variation between estimates of the homeworker and telecommuter populations. If telecommuting is to become a viable regulatory policy, these inconsistencies and measurement problems must be addressed further.

## FACTORS INFLUENCING EMPLOYER ADOPTION AND EMPLOYEE PARTICIPATION

Clearly telecommuting's impact on transportation systems depends on the rate at which it is adopted by firms and accepted by individuals as a workplace alternative arrangement. Firms first encounter the higher-order decision whether or not to offer telecommuting to its employees, and if so in which form. Interested and qualified individuals then would be allowed to telecommute on a case-by-case basis. These decisions are contingent on a host of factors: economic, social, organizational, legal, and legislative issues all influence telecommuting decisions as do the specific tasks involved in a particular job. A report by the Southern California Association of Governments (SCAG) contains lists of possible advantages and disadvantages to workers, employers, and society as a whole (SCAG, 1985). Tables 2.3-2.5 summarize these ideas.

TABLE 2:3: POSSIBLE ADVANTAGES AND DISADVANTAGES TO EMPLOYEES OF WORKING FROM HOME

| Advantages | Disadvantages |
|---|---|
| -eliminated commute time, cost, stress | -less social & professional interaction |
| -increased flexibility | -decreased visibility to management |
| -increased autonomy | -lack of support services |
| -only means of keeping or getting job | -loss of benefits |
| -reduced distractions from the office | -management exploitation |
| -more comfortable environment | -increased home utility costs |
| -cost savings on clothes and food | -increased telephone costs |
| -evaluation based on performance | -need for workspace in the home |
| -increased home, neighborhood safety | -difficulty separating work from home |
| -closer bonds w/ family & community | -loss of perceived credibility |

TABLE 2.4: POSSIBLE ADVANTAGES AND DISADVANTAGES TO EMPLOYERS OF TELECOMMUTING

| Advantages | Disadvantages |
|---|---|
| -increased productivity | -start-up, operating costs |
| -decreased turnover | -changes in managerial style |
| -competitive hiring advantages | -difficulty with data security |
| -access to new labor pools | -decreased employee availability |
| -decreased overhead | -loss of corporate identification |
| -public relations | -loss of perceived credibility |

TABLE 2.5: POSSIBLE ADVANTAGES AND DISADVANTAGES OF TELECOMMUTING TO SOCIETY

| Advantages | Disadvantages |
|---|---|
| -decreased congestion, air pollution, and fuel consumption | -increased withdrawal and isolation |
| -decreased transportation capital and operating costs | -labor exploitation |
| -increased productivity | -spread of urban sprawl |
| -employment for the mobility-limited | -widened socioeconomic class gap |
| -stronger family and community ties | |
| -decreased crime | |
| -more flexible lifestyles | |
| -ability to reshape land-use patterns | |

A firm's decisions hinge on its assessment of the benefits and costs of a telecommuting program, the attitudes of managers and decision-makers, and the nature of its tasks; i.e. the telecommutability of its work. In non-attainment areas, the adoption of telecommuting also will depend on its perceived value relative to other trip reduction measures to meet government mandated restrictions. For individuals, the decision involves an evaluation of the cost/flexibility/visibility tradeoffs. In the future, governments could assume a vital role in these decisions by promoting telecommuting legislation.

### The employer's adoption decision

In absence of government mandates, the cost effectiveness of telecommuting is of paramount importance to firms, particularly in today's risk-averse markets. Benefits to employers, directly in the form of decreased office overhead costs, and indirectly due to postulated increased productivity and hiring advantages, must exceed costs of starting and maintaining a telecommuting program. For example, Gordon (1988) estimated the cost of retraining lost employees at between 30 and 100 thousand dollars per employee. Telecommuting programs may necessitate capital expenditures, higher operating costs due to loss of scale, the costs of manager and employee training, and in the case of non-home-based telecommuting, the costs associated with the addition of a satellite or local center. In today's risk-averse markets, cost uncertainties pose a significant barrier to telecommuting programs.

Unfortunately, not all relevant variables.are easily quantifiable, particularly telecommuting's effect on productivity. Blue Cross/Blue Shield of South Carolina performed a productivity comparison of keyers and coders who telecommuted full-time on a contract basis against those who worked in-office (National Research Council, 1985). On a scale based on optimal performance, home telecommuters scored 102% versus 76% for in-office workers. Flexibility with regard to absenteeism and paid leave received much of the credit for the disparity. A 1982 study of the productivity of employees of Control Data Corporation in Minnesota reported an average of 35% estimated improved productivity when telecommuting according to the workers and a 20% improvement according to their managers (National Research Council, 1985). F International, a diversified British company among the pioneering employers of telecommuters, estimated 30% more productive work from its telecommuters than they would have expected from office workers (Kinsman, 1987). These figures are consistent with other published estimates in the literature (Huws et al., 1990).

In addition, one quantitative assessment of worker effectiveness improvement appears in the cost/benefit analysis of the California Telecommuting Pilot Project (JALA Assoc., 1990). The report indicated an average annual benefit of $3,815 per telecommuter based solely on job performance according to management survey responses. The analysis predicted that telecommuting had paid for itself in less than three years, due mainly to increased employee effectiveness. Thus, there is ample evidence of productivity benefits from telecommuting in the literature. Of course, the absence of negative results may be attributed at least partially to a positive reporting bias.

Attitudes of management are certainly critical to a firm's decision to offer a telecommuting program. Resistance from management and the inflexibility of current organizational structures within which they supervise are often cited as the major barriers to the spread of telecommuting. Evidence in the literature suggests clearly that today's managers are uncomfortable with the prospect of remote supervision. Huws et al. (1990) reported that interest in telecommuting in Europe varies with company size and distribution of tasks, but that in general, most managers objected due to "organizational difficulties" and "no need to change from the current situation". In addition, the authors referenced two studies performed in the U.S. ; one by Phillips Business Systems in which sixty percent of managers surveyed were opposed to telecommuting compared to less than ten percent in favor, and another survey conducted by the Management Sciences Department at the University of Minnesota in which 53 percent of managers questioned said they believed telecommuting to be difficult to manage.

However, the attitudes of project participants have tended to be more positive. In the California Telecommuting Pilot Project (JALA Assoc., 1990) supervisors reported improvements in effectiveness for both themselves and their telecommuters, though nearly thirty percent thought that the program had increased their workload (only 16 percent indicated a decreased workload). The report also provided evidence that managers who participated in a pre-telecommuting training program generally experienced more positive results.

In the SCAG Pilot Project (SCAG, 1988), managers generally reported feeling comfortable with the arrangement despite negative impacts on communication and management effectiveness. Several trends were observed in the project analysis that pointed to an unfounded pessimism on the part of employees with regard to management acceptance. Managers considered lack of availability for meetings a problem and stressed the need for more training. They did recognize the potential for competitive advantages in hiring and worker retention.

Huws et al. (1990) surveyed managers in Europe currently involved in organized telecommuting. The most important reasons for introducing telecommuting included recruiting and retaining skilled workers, coping with surplus work, improving productivity, and reducing absenteeism. In general, they reported being satisfied with telecommuting in their organizations.

Problems cited included organizational difficulties, training needs, and insufficient infrastructure and equipment. Union resistance was frequently mentioned as a potential problem. Gordon (1988) has suggested reward incentives for managers of telecommuters.

The explosion of how-to articles in recent years serves as testimony to the importance of managerial adaptation and acceptance to the success of telecommuting programs. Telecommuting consultant agencies have begun forming in response to demand for training. Evidence suggests telecommuting can be very successful given interested, informed, well-trained managers. One would expect that opposition from management will decrease if pilot programs continue to succeed and information on telecommuting continues to be disseminated.

Firms considering telecommuting must first assess the telecommutability of tasks within their operations. Schepp (1990) catalogs a list of seventy-five jobs suitable for telecommuting and their relative ranking on an arbitrary scale. For example, programmer and translator score a 10.0; desktop publisher a 9.0; lawyer an 8.75; analyst an 8.25 (a complete list is reproduced in the Appendix). The rating system is based on several factors: requirements for face-to-face interaction, computer use, performance measurability, need for access to centralized work materials, current levels of telecommuting, and future outlook. Many of the jobs listed are accompanied by examples of U.S. companies who employ telecommuters in those positions. Nilles estimated that 20% of all information workers, or 12% of all workers in California were at least potential part-time home telecommuters (JALA Assoc., 1990). In the California Pilot Project it was determined that 30% of state "infoworkers" were potential home telecommuters, and that 55% of the rest were candidates for satellite telecommuting.

In addition to the telecommutability of the position in terms of its duties, the telecommutability of the employee must be assessed. Research in the area of character suitability is thin. Appropriate telecommuters should be chosen from a pool of willing employees based on characteristics such as experience, performance, motivation, and gregariousness (Gordon and Kelly, 1986). Salomon (1992) uses a figure of 70 percent as an estimate of the percentage of personally suitable employees in a study projecting the amount of telecommuting to expect in Tel Aviv.

Technological constraints, though evaporating gradually, have been noted in the literature. In the SCAG project, lack of necessary equipment was mentioned as a primary deterrent to telecommuting (SCAG, 1988). Absence of certain basic computing skills could also theoretically prohibit telecommuting in some instances.

**The employee's participation decision**

Like firms, employees also face a set of economic variables in their participation decisions. Cost savings in terms of commuting costs and other daily expenses must be considered against increased home utility costs and possible forfeiture of wages and benefits. Possible long-term adjustments in rent and commute costs also factor into decisions where relocation is an option. Many employee advantages and disadvantages from Table 2.3 are not easily quantifiable. In economic terms, the employee participation decision involves a complex tradeoff among variables representing actual dollars and less tangible variables such as flexibility, autonomy, and visibility to management. A recent study by Bernardino et al. (1992) reported that cost allocation and salary played very significant roles in employee stated preference participation "decisions".

The role of commute cost in employee participation decisions is of particular importance to transportation planning. Gordon (1988) calculated that the average commuter spent $1355 in 1985 to travel 24.4 miles to and from work each day. Salomon and Salomon (1984) reported that 43% of those surveyed with a one-way commute of at least thirty minutes would like to work from home at least part-time, compared to only 28% of those with a commute of less than thirty minutes. In the California project, telecommuters had longer round-trip commute times than the control group: 95 minutes compared to 70 minutes (JALA Assoc., 1990). However, the Bernardino et al. (1992) survey showed no significance of commute time in stated preference telecommuting decisions. The relationship is still unclear.

There are considerable social issues influencing the acceptance of telecommuting. The upsurgence of women into the workforce and subsequent redefining of the women's role in the household has led to the widespread conclusion that telecommuting allows the female telecommuter to combine work and child care. Indeed, Huws et al. (1990) cites several surveys of telecommuters which are comprised largely of women with children. In the study by Bernardino et al. (1992) both the gender indicator variable and number of children under 18 living at home variable significantly affected the hypothetical telecommuting decision. However, Christensen (1988) argues that female home workers with children actually separate work and child duties, that they derive benefits from the flexibility afforded by home work, but that promoting home work as a child care policy is unjustified.

Employment opportunities for mobility-limited persons is often touted as a major advantage of telecommuting. Raney reported on Project Homebound, a project involving ten employees of American Express in New York City who were mobility-limited (National Research Council, 1985). Schepp (1990) describes several organizations that assist mobility-limited individuals locate opportunities to apply communications technologies in work.

One of the most commonly cited disadvantages of telecommuting is loss of social contact. Huws et al. (1990) documents several surveys of full-time home telecommuters in which social isolation is mentioned as a disadvantage by a majority of respondents. SCAG (1988) surveyed the home telecommuters in its pilot program and discovered that though they missed social interactions at the office, the problem was not serious. Apparently, social interactions at the office will discourage some individuals from working from home. Presumably, part-time home telecommuting or satellite telecommuting relieves or eliminates this difficulty.

A related issue involves visibility to management with regard to career advancement as a barrier to telecommuting, particularly the full-time home variety. Huws et al. (1990) found that 35% of telecommuters surveyed thought their chances for promotion had diminished, while 11% actually thought they had increased. The SCAG study reported anecdotal evidence that workers were concerned that *too much* telecommuting would adversely affect career advancement (SCAG, 1988).

The need for access to centralized clerical support services and short-notice meetings are other areas of concern related to physical presence at the office. In the SCAG project, one of managers' loudest complaints involved the difficulty in organizing meetings where everyone could attend, and the unavailability of telecommuters for short-notice meetings (SCAG, 1988). The consensus is that these difficulties can be overcome as organizations become more familiar with the management of telecommuting.

### The role of government

Without question, the actions of governments will affect profoundly the future of telecommuting. As public demand for environmental regulation increases, governments figure into the telecommuting decision process in the form of legislative regulatory policy.

In the United States, telecommuting has been recognized in several legislative documents as a means of reducing peak-period work trips at the firm level (Mokhtarian, 1991), particularly in California and Washington. The legislation has been introduced primarily in response to Federal Clean Air Act standards. Environmental benefits from travel reduction are not the only forces propelling telecommuting into public policy. Telecommuting could also support legislation dealing with telecommunications infrastructure, energy policy, unemployment, rural economic development, emergency response, opportunities for the disabled and a legion of other issues. Besides establishing mandates for travel reduction, governments could create economic incentives in the form of corporate income tax credits and real estate tax breaks for firms who set up formal programs to reduce work trips or create satellite offices or neighborhood work centers (Gordon, 1988).

Whatever legislation occurs will do so in the face of union opposition. In 1983 the AFL-CIO passed a resolution calling for a ban on computer homework because of the potential for worker exploitation (National Research Council, 1985). Recently, however, the AFSCME and CLUW unions have adopted more flexible positions, displaying a willingness to negotiate equitable agreements (duRivage, 1992). In reality, union positions constrain certain telecommuting agreements to ensure fair compensation, but do not inherently prohibit telecommuting from occurring.

Legal and contractual issues regarding zoning, insurance, liability, and employee status continue to present barriers to home telecommuting. Since zoning regulations vary across jurisdictions, telecommuters must be aware of any restrictions and take proper action to eradicate them. These restrictions date back to the 1940s "sweated industries" era and do not necessarily bear on modern telecommuting agreements.

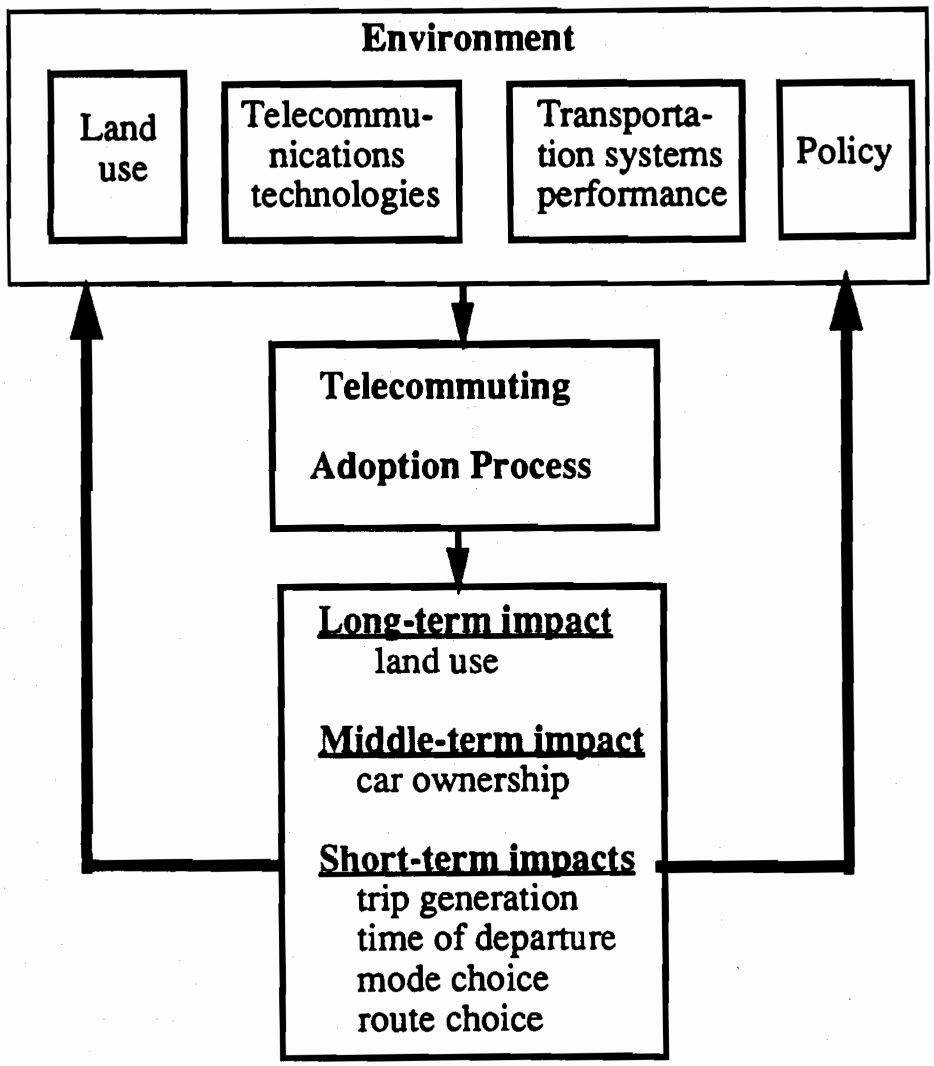
Clear contractual agreements can alleviate any potential legal problems resulting from accidents. Gordon and Kelly (1986) suggest keeping home offices separate from the rest of the home to help clarify workmen's compensation liability issues. Program participants must be aware of their insurance coverage with respect to office equipment in the home. Several options exist to protect against misunderstandings in this area.

In full-time home telecommuting, perhaps the most controversial legal issue is that of employee status; i.e. is the telecommuter to be treated as a regular employee subject to normal compensation and benefits or as contract labor? With part-time home telecommuting and regional arrangements, regular employment is the only option, although the possibility exists for the introduction of performance pay incentives. Employers seeking flexibility in handling peaks might be inclined toward part-time contract telecommuters such as the Blue Cross/Blue Shield of South Carolina project (National Research Council, 1985). In any case, a detailed agreement covering duties and responsibilities, compensation and benefits, and rights can ease these potential problems.

## TELECOMMUTING'S IMPACTS ON TRAVEL

Figure 2.1 identifies the principle categories of environmental factors which influence participation decisions of individual employees and their firms, including transportation system performance, supply of telecommunications technologies, area land use patterns, labor market conditions, and public policy with regard to telecommuting as a travel demand management strategy. The outcomes of these individual decisions correspond to short-term, medium-term, and long-term effects on travel as shown. Telecommuting has immediate impact on trip-making in terms of frequency, mode choice, and distribution over time and space. Eventually, telecommuting influences decisions on automobile ownership, residential location, and firm location, creating feedback effects on the environment and travel behavior. In this aspect, interactions between telecommunications and transportation extend beyond the work commute to affect shopping and recreational travel.

**Figure 2.:** The relationship between telecommuting and the environment



**Short-term travel impacts**

In the short-term, telecommuting will have direct, immediate changes on travel behavior, excluding location shifts and auto ownership decisions. These effects can be categorized as substitutive, complementary or modificatory. The success of telecommuting as a demand management policy depends on the net effect resulting from changes in trip activity patterns at the individual and household levels.

Interest in telecommuting kindled among transportation researchers because of the possibility for substitution of telecommunications activities for physical presence at a central worksite requiring a commute trip. In the 1970s and early 1980s, various attempts to estimate the potential for substitution placed upper bounds between 14 and 47 percent of all work trips. Criticism of this work began to appear in the early 1980s as the complexity of interactions between telecommunications and transportation became clearer.

There have been several more recent attempts to quantify the potential for reduced travel and fuel use. Gordon and Van Arsdale (1986) integrated a set of telecommuting scenarios into the planning process in Columbus, Ohio. The scenarios included home and satellite telecommuting. Costs were compared using a figure of 22 cents per mile and an average annual CBD parking cost. Annual cost savings per driver were estimated to lie between $241 for a scenario of 40% satellite telecommuters 6 days out of 7 and $422 for a scenario in which 30% of the workforce are satellite telecommuters and 20% work from home every day. These scenarios led to a 20% to 36% reduction in total fuel consumed by commuters.

Schneider (1989) devised three scenarios representing low, medium, and high levels of progressive adoption of telecommuting from 1980 to 2020 in the Seattle area. Five different categories were included that consisted of different percentages of home and satellite telecommuting. Total daily VMT reductions achieved by 2020 ranged from 6% to 16% to nearly 30% under assumptions of 18%, 63%, and 98% of all information workers telecommuting at least part-time.

New trips could arise from a telecommuting situation in the form of increased shopping or recreational travel. Salomon (1986) analyzed the problem from a perspective of travel fulfilling certain needs, some of which may be substitutable. He hypothesized that when individuals' needs are satisfied at home they will travel simply to satisfy a need for travel. Salomon also suggested that it may be misleading to assume that individuals perceive the work commute negatively. He provides evidence that some perceive the work commute as a necessary division between home life and work.

Trips that were previously linked to the work trip might be replaced by new trips from the home that offset savings from the eliminated commute. In the case of regional centers, their suburban location will relieve CBD traffic but increase stress on suburban roads, possibly creating a new class of problems. In fact, theoretically, a satellite office could actually lengthen some individuals' commutes. Also, it is unclear to what extent telecommuting will alter mode choice.

Evidence concerning the effect of telecommuting on travel behavior has begun to appear in the literature. Two pilot projects in California, the SCAG project and the California Telecommuting Pilot Project, have provided trip diary information for analysis. In the SCAG project, conducted for six months in 1986 with 18 participants who worked from home an average of once every two weeks, the data indicated a travel savings of 46 miles per telecommuting occasion per individual (SCAG, 1988). Taking into account the mode of travel replaced, the system savings equated to 31 miles per telecommute occasion. Information regarding travel generated showed an average of five miles generated per telecommuting occasion, for a net savings of 26 miles per day. However, participants indicated that 95 percent of travel generated during peak hours on a telecommuting day would have occurred at another time anyway making 26 miles per day a lower bound, depending on the relative magnitudes of new travel and travel formerly linked to the commute.

The California project has produced the most detailed travel data to date. The study involved two waves of diaries from 66 telecommuters and 39 telecommuter household members, and a control group consisting of 57 state workers and 32 household members. The diaries consisted of three consecutive days approximately one year apart where the telecommuters worked from home an average of 1.25 days per three-day period in the second wave. Kitamura et al. (1990b) reported no increase in non-work travel on telecommuting days by either the telecommuter or other household members. However, temporal shifts to other days of the week could not be captured by the three-day survey instrument. The report estimated a savings of 40 miles per telecommuting occasion per person.

The study also revealed a constricted activity space for nonwork travel by telecommuters both on telecommuting days and on days when they did commute to work, suggesting an adaptation to destinations closer to home (Pendyala et al., 1991). Consequently, telecommuters traveled a smaller percentage of vehicle-miles on freeways; in fact a 90 percent reduction. A temporal analysis of nonwork trips showed no significant changes due to telecommuting. There was also some evidence that telecommuters increased their percentage auto use on telecommuting days for nonwork purposes (Kitamura et al., 1991b). The authors proposed this effect may be a result of fewer work trips, a higher proportion of which are made by transit relative to nonwork trips.

The net effect of telecommuting on trip-making in the short-term results from individual dynamic decisions regarding mode, route, and departure time as well as the decision whether or not to telecommute. The net result is a network user pattern that has a very different appearance than that which would have existed if no telecommuting were possible. Attempting to forecast the real impact on VMT and fuel consumption becomes even more complex when long-term decisions involving auto ownership, residential location, and firm location are added to the model.

### Medium and long-term impacts on urban form

Telecommunications' long-term impacts on transportation systems have received a good deal of attention in Europe and Australia among researchers in geography and regional science. The literature examines the likelihood of activity decentralization due to changes in urban form brought on by telecommunications technologies and the relaxation of spatial-temporal requirements. Teleconferencing is the main focus of this work though certainly telecommuting could affect office and residential location decisions in the long run.

Daniels (1981) studied mode choice in conjunction with office decentralization in the London area and found a trend toward increased automobile use resulting from office location changes. This type of observation supports the theory that telecommuting would have adverse effects on suburban traffic congestion.

After reviewing the literature, Mandeville (1983) concluded that telecommunications technologies encourage both centralization and decentralization and thus have no explicit effect on location decisions. Salomon (1987) reached a similar conclusion from evidence in Israel that the supply of telecommunications infrastructure in rural regions could not support wide-scale decentralization of office activities. At the same time, demand for telecommunications services in rural areas was not sufficient to support growth of the supply, resulting in status quo.

A paper by Kobayashi and Okada (1990) introduces the notion of knowledge as a public good in the firm's production function, depending on the firm's accessibility to information labor and knowledge networks. The implications are the extensive substitution of telecommunications for transportation in routine knowledge transfer and decentralized goods production. However, research and development activities that require a high percentage of face-to-face communication will tend to concentrate according to their model.

In the California project, it was reported that the ability to telecommute from home was a significant factor in about 30% of all household relocations occurring during the study period

(JALA Assoc., 1990). Nearly 17% of telecommuters questioned had relocated since the study began and an additional 11% reported to be considering a move. Two thirds moved farther away from work, and the median distance moved was one mile farther away, though several respondents moved more than 45 miles farther away from their central office site.

A theoretical basis is emerging for understanding telecommunications impact on urban form. At present one can only speculate on future effects of telecommuting in the long run. Location decisions by firms in the "Information Age" depend on a series of factors far more complex than the introduction of new work arrangements. Many researchers believe telecommuting will occur most frequently in the form of regional centers to allow firms to take advantage of local labor supplies while decreasing overhead costs by decentralizing routine duties.

## OTHER CURRENT DIRECTIONS IN THE LITERATURE

Recently, Sampath et al. (1991), using the same California Project diary information, examined the effect of telecommuting on air quality. From an analysis of speeds, VMT, and distributions of hot and cold starts, a telecommuting occasion was shown to decrease various emissions by 63-73 percent per person per occasion. The decrease due to less travel and fewer starts was partially offset by lower average speeds and a higher proportion of travel made in the start modes.

One area currently receiving a great deal of attention is the travel impact of local work centers. The state of Hawaii opened a public/private neighborhood telework center in 1989 with 14 full-time telecommuters in a Honolulu suburb (Hirata and Uchida, 1991). Response from participants was overwhelmingly positive. The telecommuters reported savings of $13/week in transportation costs. Productivity and employee satisfaction were improved and support for continuing the telework centers was unanimous among employees. Managers who were involved were also very positive in their assessments. Meanwhile two telework centers are currently in operation in the Seattle area, and in California legislation was passed in 1990 to fund two centers there (Mokhtarian, 1991).

# CHAPTER 3
# CONCEPTUAL FRAMEWORK

## INTRODUCTION

The adoption processes of firms and individuals directly influence short-term travel decisions, the collective results of which alter the transportation environment and lead to long-term decisions concerning location and automobile ownership. Within this broad framework, under a set of assumptions, this chapter proceeds to describe the approach used to compare the effects of various levels of telecommuting on vehicle-miles traveled and fuel consumption.

The analysis focuses on peak-period travel on streets classified as major and minor arterials. It is during peak hours (generally defined as 7-9 A.M. and 4-6 P.M.) that interactions between vehicles are most common and most critical to system performance. When vehicles are removed from the network, remaining vehicles benefit in the form of decreased travel times due to reduced interactions with other drivers. Both removed and remaining vehicles contribute to the overall system benefit. In this analysis, vehicles removed during off-peak hours do not affect remaining vehicles.

The analysis is restricted to arterial streets because the fuel consumption benefits of increased average speed (the reciprocal of trip time per unit distance) are realized only within a realm of speeds below about 40 MPH (Chang et al., 1976). Beyond this threshold higher average speeds actually increase fuel consumption. Of course many urban freeways experience speeds below 40 MPH during peak hours. The overall impact of removed vehicles on fuel consumption in these systems depends on the effect on the probability of disturbances occurring in the traffic stream which preclude travel at the freeway speed limit. No research exists that facilitates the inclusion of freeway travel in this analysis. For this reason only the direct effect of removed vehicles is considered on freeways, the assumption being that the indirect effects of reduced instances of delay and increased average speeds negate each other with respect to fuel consumption. Local and collector street travel are similarly restricted to the direct effect of removed vehicles because of the low levels of driver interactions even during peak hours.

This work is concerned only with primary level short-term impacts. Since so little is understood about them, long-term impacts on urban form are outside the scope of this analysis. In addition, the highly complex effects of induced travel behavior changes on network user equilibrium are not addressed.

For a given scenario in terms of overall traffic levels, commuting characteristics, and telecommuting penetration, the approach described in this chapter provides estimates of the corresponding savings in fuel consumed. The key inputs include regional labor force, vehicle-miles traveled (VMT) per capita, mode choice, vehicle occupancy, and average commute length, network characteristics, average vehicle MPG estimates, and projections of this information for the years 2000 and 2010 for the urban areas under consideration. Assumptions are made regarding temporal and directional distributions of traffic and the fraction of telecommutable workers, as described in the next section. Relationships among the macro-scale traffic variables (flow, density, and speed) derive from the two-fluid model of town traffic (Herman and Prigogine, 1979). Fuel consumption implications are based on a linear fuel consumption model (Evans and Herman, 1979). The various modeling elements are discussed in Section 3.3.

## THE TELECOMMUTING SCENARIOS

Tables 3.1-3.3 illustrate the spreadsheet format for calculating the number of telecommuters according to various scenarios of employee participation. Three Texas cities: Austin, Dallas, and Houston are represented for the years 1990, 2000, and 2010. A set of scenarios are defined by varying the daily fraction of home and satellite telecommuters from the pool of telecommutable workers who would normally have been physically commuting.

TABLE 3.1: SPREADSHEET FOR DETERMINING THE NUMBER OF TELECOMMUTERS IN AUSTIN

| **AUSTIN**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Population | 543000 | 727570 | 951280 |
| Labor force | 377920 | 485790 | 612830 |
| Fraction of telecommutable employees i.e. "information workers" | 0.5 | 0.52 | 0.54 |
| Fraction of labor force commuting per day | 0.9 | 0.9 | 0.9 |
| Fraction of home telecommuters per day | 0.05 | 0.05 | 0.05 |
| Fraction of satellite telecommuters per day | 0 | 0 | 0 |
| Number of home telecommuters per day | 8503 | 11367 | 14892 |
| Number of satellite telecommuters per day | 0 | 0 | 0 |

TABLE 3.2: SPREADSHEET FOR DETERMINING THE NUMBER OF TELECOMMUTERS IN DALLAS

| **DALLAS**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Population | 3030000 | 3696810 | 4093230 |
| Labor force | 2028060 | 2521590 | 2746450 |
| Fraction of telecommutable employees i.e. "information workers" | 0.5 | 0.52 | 0.54 |
| Fraction of labor force commuting per day | 0.9 | 0.9 | 0.9 |
| Fraction of home telecommuters per day | 0.05 | 0.05 | 0.05 |
| Fraction of satellite telecommuters per day | 0 | 0 | 0 |
| Number of home telecommuters per day | 45631 | 59005 | 66739 |
| Number of satellite telecommuters per day | 0 | 0 | 0 |

TABLE 3.3: SPREADSHEET FOR DETERMINING THE NUMBER OF TELECOMMUTERS IN HOUSTON

| **HOUSTON**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Population | 2798000 | 3036190 | 3185280 |
| Labor force | 1752860 | 1958760 | 2026890 |
| Fraction of telecommutable employees i.e. "information workers" | 0.5 | 0.52 | 0.54 |
| Fraction of labor force commuting per day | 0.9 | 0.9 | 0.9 |
| Fraction of home telecommuters per day | 0.05 | 0.05 | 0.05 |
| Fraction of satellite telecommuters per day | 0 | 0 | 0 |
| Number of home telecommuters per day | 39439 | 45835 | 49253 |
| Number of satellite telecommuters per day | 0 | 0 | 0 |

The number of home telecommuters, HTC, is simply determined by:

$$HTC = LABOR \times TCABLEF \times COMMF \times HTCF$$

where LABOR is the total labor force, TCABLEF is the fraction of those workers holding telecommutable jobs, COMMF is the fraction of workers who commute per day, and HTCF is the fraction of those who could telecommute from home that do. The number of satellite telecommuters is similarly determined using the fraction of those who could telecommute from a satellite office that do.

The scenarios evolve from statistical forecasts of metropolitan area population and labor force (Woods and Poole, 1990). Given the labor force estimate, the fraction of telecommutable workers is assumed to be 0.5 in 1990, rising to 0.52 in 2000, and 0.54 by 2010 in anticipation of an increase in the percentage of information-oriented jobs in the labor market. In order to account for part-time employment and work days missed, a fraction of workers commuting per day of 0.9 is assumed. The result of multiplying the number of commuters per day under this assumption by the average commute length more closely approximates the expected total area-wide commute miles per day as estimated by NCHRP Report 187 methodology (Sossiau et al., 1978).

The variable portion of the scenarios consists of the fraction of home and satellite telecommuters per day from the number of telecommutable workers who normally would have been commuting, yielding the number of home and satellite telecommuters. Fifteen different scenarios are considered, each consisting of a different combination of the fraction of home telecommuters (ranging from 5% to 25% in 5% increments) and the fraction of satellite telecommuters (0, 5%, and 10%). The scenarios are displayed in Table 3.4 below.

## CALCULATING FUEL CONSUMPTION SAVINGS

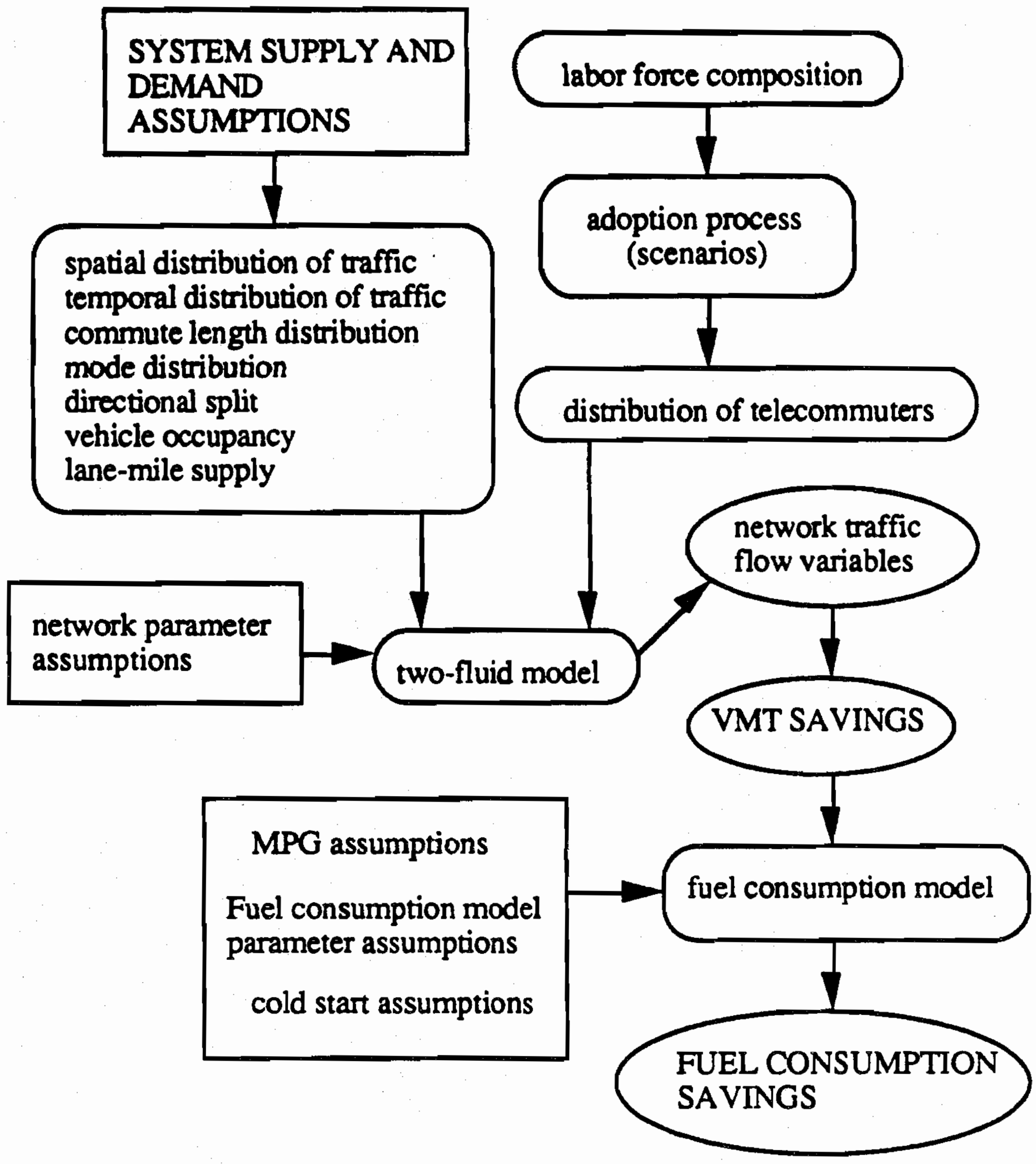
Figure 3.1 depicts the process by which fuel consumption savings result from telecommuting. Assumptions regarding demand for automobile travel and the supply of capacity determine the spatial and temporal characteristics of automobile travel and of commuting in particular. Average flows resulting from these assumptions, combined with estimates of the two-fluid model parameters, yield average values for speed and concentration. The number of telecommuters is determined by the composition of the labor force and the scenario of telecommuting penetration. The effect on VMT of removing vehicles from the network by telecommuting is measured by comparing output from the two-fluid model in the telecommuting scenario against that of the base case with no telecommuting.

TABLE 3.4: THE FIFTEEN TELECOMMUTING SCENARIOS

| Scenario number | % home telecommuters | % satellite telecommuters |
|---|---|---|
| 1 | 5 | 0 |
| 2 | 10 | 0 |
| 3 | 15 | 0 |
| 4 | 20 | 0 |
| 5 | 25 | 0 |
| 6 | 5 | 5 |
| 7 | 10 | 5 |
| 8 | 15 | 5 |
| 9 | 20 | 5 |
| 10 | 25 | 5 |
| 11 | 5 | 10 |
| 12 | 10 | 10 |
| 13 | 15 | 10 |
| 14 | 20 | 10 |
| 15 | 25 | 10 |

To calculate fuel consumption savings, assumptions are needed concerning average miles per gallon (MPG) and the fuel consumption model parameters. The model determines the effect on fuel consumption of removing vehicles from the arterial network during the peak periods. Savings for off-peak or non-arterial travel are simply calculated from the VMT savings estimate. Additionally, the effect of telecommuting on the frequency of cold starts must be included.

Figure 3.1 : The conceptual framework for analyzing the effect of telecommuting on fuel consumption



**System supply and demand assumptions**

First a set of assumptions regarding the demand for automobile travel must be made. These include the following variables: daily VMT per capita, fraction of arterial VMT occurring in the peak period, fraction of VMT on arterials, fraction of commutes made by car, average commute auto occupancy, fraction of commuting VMT occurring in the peak period, fraction of commuting VMT on arterials, average round-trip commute length, and fraction of peak period VMT moving in the major and minor directions. In addition, a supply-side assumption is necessary regarding the growth in the number of lane-miles of arterials over time. These variables will later be used to calculate average values of network traffic variables: flow, concentration, and speed for peak period arterial traffic. The arterial system is assumed to be homogeneous. Tables 3.5-3.7 show examples of these values for Austin, Dallas, and Houston.

Daily VMT per capita is assumed to grow at a rate of 1% annually between 1990 and 2000, then drop off to 0.5% annually from 2000 until 2010. An expected increase in commute vehicle occupancy due to carpooling is reflected here. In absence of any clear trend either way, the fraction of workers commuting by car is assumed to remain steady. In all three cities, the average round-trip commute length is assumed to increase at a rate of 1% annually. Initially, the number of arterial lane-miles is presumed to rise at a rate of 1% annually, a reflection of the current trend in the three cities (Lomax, 1986). This assumption is relaxed in the sensitivity analysis in the next chapter.

It is assumed that the distribution of commuting VMT over space (i.e. arterials vs. non-arterials) is identical to the corresponding distribution of total VMT. When applying this model, this assumption could be altered in favor of local information regarding road category use during the work commute. Finally, the model assumes that commute distance has no effect on the distribution of telecommuters.

1990 data on VMT, lane mileage, and road categories are taken from Highway Statistics (U.S. D.O.T., 1990). Estimates of fractions of peak travel, peak commute travel, and directional split are from NCHRP Report 187 (Sosslau et al., 1978). Information concerning mode split, commute vehicle occupancy, and commute length were derived from various sources (U.S. D.O.T., 1985; Ward, 1990; Lomax, 1986).

TABLE 3.5: SAMPLE SPREADSHEET WITH SYSTEM DEMAND AND SUPPLY ASSUMPTIONS FOR AUSTIN

| AUSTIN<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Daily VMT per capita | 21.4 | 23.6 | 24.8 |
| Fraction of arterial VMT in peak period | 0.3 | 0.3 | 0.3 |
| Fraction of VMT on arterials | 0.29 | 0.29 | 0.29 |
| Fraction of commutes made by car | 0.9 | 0.9 | 0.9 |
| Average commute vehicle occupancy | 1.15 | 1.2 | 1.25 |
| Fraction of commuting VMT in peak period | 0.6 | 0.6 | 0.6 |
| Fraction of commuting VMT on arterials | 0.29 | 0.29 | 0.29 |
| Avg. round-trip commute length (miles) | 20 | 22 | 24 |
| Fraction of peak period traffic moving in major direction | 0.6 | 0.6 | 0.6 |
| Lane-miles in arterial system | 788 | 870 | 962 |

TABLE 3.6: SPREADSHEET WITH SYSTEM DEMAND AND SUPPLY ASSUMPTIONS FOR DALLAS

| DALLAS<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Daily VMT per capita | 25.5 | 28.2 | 29.6 |
| Fraction of arterial VMT in peak period | 0.3 | 0.3 | 0.3 |
| Fraction of VMT on arterials | 0.26 | 0.26 | 0.26 |
| Fraction of commutes made by car | 0.9 | 0.9 | 0.9 |
| Average commute vehicle occupancy | 1.15 | 1.2 | 1.25 |
| Fraction of commuting VMT in peak period | 0.6 | 0.6 | 0.6 |
| Fraction of commuting VMT on arterials | 0.26 | 0.26 | 0.26 |
| Avg. round-trip commute length (miles) | 26 | 29 | 32 |
| Fraction of peak period traffic moving in major direction | 0.6 | 0.6 | 0.6 |
| Lane-miles in arterial system | 5943 | 6565 | 7252 |

TABLE 3.7: SPREADSHEET WITH SYSTEM DEMAND AND SUPPLY ASSUMPTIONS FOR HOUSTON

| **HOUSTON**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Daily VMT per capita | 25.9 | 28.6 | 30.1 |
| Fraction of arterial VMT in peak period | 0.3 | 0.3 | 0.3 |
| Fraction of VMT on arterials | 0.32 | 0.32 | 0.32 |
| Fraction of commutes made by car | 0.9 | 0.9 | 0.9 |
| Average commute vehicle occupancy | 1.15 | 1.2 | 1.25 |
| Fraction of commuting VMT in peak period | 0.6 | 0.6 | 0.6 |
| Fraction of commuting VMT on arterials | 0.32 | 0.32 | 0.32 |
| Avg. round-trip commute length (miles) | 26 | 29 | 32 |
| Fraction of peak period traffic moving in major direction | 0.6 | 0.6 | 0.6 |
| Lane-miles in arterial system | 4953 | 5471 | 6043 |

**Two-fluid model parameters**

The two-fluid model of network traffic flow provides the basis of the procedure to translate the fraction of vehicles "removed" by telecommuting into savings in the overall VMT in the network. The VMT savings then form the basis for estimating the savings in fuel consumed. The detailed mathematical relations by which the demand and supply characteristics described in the previous subsection are transformed into the variables of interest and converted into VMT estimates are described in subsection 3.3.3. In this subsection, the two-fluid model and its underlying assumptions are described.

The two-fluid model is an extension of the kinetic theory of multilane traffic flow (Prigogine and Herman, 1971). The two fluids refer to moving vehicles and stopped (not parked) vehicles in an urban street system. Simple relationships are developed among network traffic variables and additional parameters are included relating to the quality of traffic service provided by the network. The traffic variables involved are averages over the entire system.

The basic postulate of the two-fluid theory is

$$V_r \sim f_r^n \qquad (f_r + f_s = 1)$$

where $V_r$ is average running speed, $f_r$ is the average fraction of vehicles running, $f_s$ is the average fraction of vehicles stopped, and n represents a network performance parameter. Thus, a relationship exists between the average running speed and the average fraction of vehicles stopped that reads

$$V_r = V_m(1-f_s)^n,$$

where $V_m$ is the average maximum speed in the network. Since $V=V_r f_r=V_r(1-f_s)$ by definition, where V is the average speed of all vehicles in the network,

$$(1) \qquad V = V_m(1 - f_s)^{n+1}.$$

In addition, a relation between $f_s$ and concentration has been proposed of the form

$$f_s \sim (K / K_m)^p$$

where K is the average concentration, $K_m$ is the average maximum or jam concentration, and p is an additional parameter measuring network performance.

In later work (Herman and Ardekani, 1984; and Ardekani and Herman, 1985), experiments performed in Austin, Texas generally supported the model's assumptions and network performance parameter values were compared in several cities around the world. Further analysis taking boundary conditions into consideration (Ardekani and Herman, 1987) gives the relationship

$$(2) \qquad f_s = f_{s,min} + (1 - f_{s,min})(K / K_m)^p$$

where $f_{s,min}$ is a lower bound on the fraction of vehicles stopped in the network and p replaces p as a traffic quality parameter.

Equations (1) and (2) imply a speed-concentration relation of the form

$$V = V_m(1 - f_{s,min})^{n+1}[1 - (K / K_m)^p]^{n+1}.$$

Assuming that Q=KV for average flow Q then

$$Q = KV_m(1 - f_{s,min})^{n+1}[1 - (K / K_m)^p]^{n+1}.$$

The reasonableness of the assumption Q=KV for a network is supported by aerial observations of speeds and concentrations compared with ground observations of flows in Austin. Furthermore, NETSIM simulation experiments have shown the product KV to be an accurate measure of Q within at worst two or three percent in repeated trials on a representative CBD network (Mahmassani et al., 1984).

Arterial system traffic parameters for the two-fluid model equations used in the present analysis are based on observations made in the three cities (Herman and Ardekani, 1984). It is assumed that these parameters remain unchanged over the 20 year period. These parameters are shown in Tables 3.8-3.10.

TABLE 3.8: TWO-FLUID MODEL PARAMETERS TO CALCULATE NETWORK TRAFFIC VARIABLES FOR AUSTIN

| **AUSTIN**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Maximum average speed on arterial system (MPH) | 40 | 40 | 40 |
| Maximum avg. conc. on arterial system (Veh/lane-mile) | 100 | 100 | 100 |
| Two-fluid model parameter n (dimensionless) | 1.25 | 1.25 | 1.25 |
| Parameter f (avg. min. fraction of stopped vehicles) | 0.1 | 0.1 | 0.1 |
| Two-fluid model parameter p (dimensionless) | 1.5 | 1.5 | 1.5 |

TABLE 3.9: TWO-FLUID MODEL PARAMETERS TO CALCULATE NETWORK TRAFFIC VARIABLES IN DALLAS

| **DALLAS**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Max avg. speed on arterial system (MPH) | 40 | 40 | 40 |
| Maximum avg. conc. on arterial system (Veh/lane-mile) | 100 | 100 | 100 |
| Two-fluid model parameter n (dimensionless) | 1.25 | 1.25 | 1.25 |
| Parameter f (avg. min. fraction of stopped vehicles) | 0.1 | 0.1 | 0.1 |
| Two-fluid model parameter p (dimensionless) | 1.25 | 1.25 | 1.25 |

TABLE 3.10: TWO-FLUID MODEL PARAMETERS TO CALCULATE NETWORK TRAFFIC VARIABLES IN HOUSTON

| **HOUSTON**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Max avg. speed on arterial system (MPH) | 40 | 40 | 40 |
| Maximum avg. conc. on arterial system (Veh/lane-mile) | 100 | 100 | 100 |
| Two-fluid model parameter n (dimensionless) | 1 | 1 | 1 |
| Parameter f (avg. min. fraction of stopped vehicles) | 0.1 | 0.1 | 0.1 |
| Two-fluid model parameter p (dimensionless) | 1.25 | 1.25 | 1.25 |

**Using the two-fluid model to calculate values of network traffic variables**

The effect of removing vehicles from the network due to telecommuting is reflected through the three major network traffic variables: average flow (Q), average concentration (K), and average speed (V). These variables must be calculated for both the base case of no telecommuting as well as the particular telecommuting penetration scenario. The information available for this purpose for the base case is the average daily VMT by road category (U.S. D.O.T., 1990). Average flow per lane during the peak period on arterial streets in the major direction in the case of no telecommuting, $Q_{paj1}$, is given by

$$Q_{paj1} = POP \times VMTPC \times PEAKF \times ARTF \times MAJF \; / \; PKHRS \; / \; MILES \; / \; LANES$$

where POP is the area population, VMTPC is daily VMT per capita, PEAKF is the fraction of all VMT that occurs in the peak period, ARTF is the fraction of all VMT that occurs along arterials, MAJF is the fraction of VMT that occurs in the major direction, PKHRS is the number of peak hours per day, MILES is the number of arterial miles in the system, and LANES is the number of lane-miles per mile. Here and throughout this analysis, values for the minor direction are calculated by an analogous process.

Applying the flow-concentration relation described previously, which incorporates the two-fluid parameters, the average network concentration in the major direction, $K_{paj1}$, is the value that solves

$$Q_{paj1} = K_{paj1} V_m (1 - f_{s,min})^{n+1} [1 - (K_{paj1} / K_m)^p]^{n+1}.$$

The solution is obtained using a Newton-Raphson approach. The average network speed in the major direction follows from

$$V_{paj1} = Q_{paj1} / K_{paj1}.$$

Sample spreadsheets with pre-telecommuting network traffic variable values are shown in Tables 3.11-3.13

The telecommuting scenario is now applied. In accordance with evidence reported in the literature thus far, it is assumed that no new travel is generated by the adoption of home-based telecommuting (Kitamura et al., 1990a). For satellite telecommuters, it is assumed that an average incidence of telecommuting eliminates half the original commute. The new peak hour average network flow along arterials in the major direction, $Q_{paj2}$, is calculated by subtracting the VMT saved by telecommuting from the initial average flow $Q_{paj1}$. The equation is as follows

$$Q_{paj2} = Q_{paj1} - (HTC + 0.5STC) \times 1/OCCUP \times DISTANCE \times AUTOF \times COMPEAKF \times ARTF \times MAJF \; / \; PKHRS \; / \; MILES \; / \; LANES$$

where HTC is the number of home telecommuters, STC is the number of satellite telecommuters,

TABLE 3.11: INITIAL VALUES OF NETWORK VARIABLES BY DIRECTION IN AUSTIN

| **AUSTIN**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| *Major direction peak arterial variables* | | | |
| Peak hour average flow per lane, Q (veh/hr) | 385.17 | 515.71 | 641.63 |
| Peak hour average concentration, K (veh/lane-mile) | 13.73 | 20.27 | 31.49 |
| Peak hour average speed, V (MPH) | 28.06 | 25.45 | 20.37 |
| *Minor direction peak arterial variables* | | | |
| Peak hour average flow per lane, Q (veh/hr) | 256.78 | 343.80 | 427.75 |
| Peak hour average concentration, K (veh/lane-mile) | 8.62 | 11.98 | 15.65 |
| Peak hour average speed, V (MPH) | 29.79 | 28.69 | 27.33 |

TABLE 3.12: INITIAL VALUES OF NETWORK VARIABLES BY DIRECTION IN DALLAS

| **DALLAS**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| *Major direction peak arterial variables* | | | |
| Peak hour average flow per lane, Q (veh/hr) | 304.76 | 371.17 | 391.08 |
| Peak hour average concentration, K (veh/lane-mile) | 11.24 | 14.53 | 15.64 |
| Peak hour average speed, V (MPH) | 27.13 | 25.54 | 25.00 |
| *Minor direction peak arterial variables* | | | |
| Peak hour average flow per lane, Q (veh/hr) | 203.18 | 247.45 | 260.72 |
| Peak hour average concentration, K (veh/lane-mile) | 6.99 | 8.75 | 9.30 |
| Peak hour average speed, V (MPH) | 29.06 | 28.28 | 28.03 |

TABLE 3.13: INITIAL VALUES OF NETWORK VARIABLES BY DIRECTION IN HOUSTON

| **HOUSTON**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| *Major direction peak arterial variables* | | | |
| Peak hour average flow per lane, Q (veh/hr) | 422.36 | 457.30 | 456.52 |
| Peak hour average concentration, K (veh/lane-mile) | 16.19 | 18.17 | 18.12 |
| Peak hour average speed, V (MPH) | 26.09 | 25.17 | 25.19 |
| *Minor direction peak arterial variables* | | | |
| Peak hour average flow per lane, Q (veh/hr) | 281.57 | 304.86 | 304.35 |
| Peak hour average concentration, K (veh/lane-mile) | 9.72 | 10.67 | 10.65 |
| Peak hour average speed, V (MPH) | 28.98 | 28.57 | 28.58 |

OCCUP is average commute vehicle occupancy, DISTANCE is the average round-trip commute length, AUTOF is the fraction of commutes made by automobile, COMPEAKF is the fraction of commuting VMT occurring in the peak period, ARTF is the fraction of commuting VMT occurring along arterials, MAJF is the fraction of commuting VMT occurring in the major direction, PKHRS is the number of peak hours per day, MILES is the number of arterial miles, and LANES is the number of lane-miles per mile.

The new peak hour average network concentration in the major direction, $K_{paj2}$, is the solution to the aforementioned flow-concentration relation

$$Q_{paj2} = K_{paj2}V_m(1 - f_{s,min})^{n+1}[1 - (K_{paj2} / K_m)^p]^{n+1},$$

and the new peak hour average network speed in the major direction, $V_{paj2}$, follows from

$$V_{paj2} = Q_{paj2} / K_{paj2}.$$

An example of the calculations of the network traffic variables under a telecommuting scenario for each of the three cities are shown in Tables 3.14-3.16.

TABLE 3.14: NEW VALUES OF NETWORK VARIABLES BY DIRECTION IN AUSTIN

| **AUSTIN**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| *New major direction variables* | | | |
| New peak hour average flow, Q (veh/lane) | 376.36 | 504.41 | 627.42 |
| New peak hour average concentration, K (veh/lane-mile) | 13.35 | 19.61 | 29.36 |
| New peak hour average speed, V (MPH) | 28.20 | 25.72 | 21.37 |
| *New minor direction variables* | | | |
| New peak hour average flow, Q (veh/lane) | 250.90 | 336.27 | 418.28 |
| New peak hour average concentration, K (veh/lane-mile) | 8.40 | 11.68 | 15.21 |
| New peak hour average speed, V (MPH) | 29.85 | 28.79 | 27.50 |

TABLE 3.15: NEW VALUES OF NETWORK VARIABLES BY DIRECTION IN DALLAS

| **DALLAS**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| *New major direction variables* | | | |
| New peak hour average flow, Q (veh/lane) | 297.45 | 362.11 | 381.24 |
| New peak hour average concentration, K (veh/lane-mile) | 10.90 | 14.05 | 15.09 |
| New peak hour average speed, V (MPH) | 27.28 | 25.78 | 25.27 |
| *New minor direction variables* | | | |
| New peak hour average flow, Q (veh/lane) | 198.30 | 241.41 | 254.16 |
| New peak hour average concentration, K (veh/lane-mile) | 6.80 | 8.50 | 9.03 |
| New peak hour average speed, V (MPH) | 29.14 | 28.39 | 28.15 |

TABLE 3.16: NEW VALUES OF NETWORK VARIABLES BY DIRECTION IN HOUSTON

| **HOUSTON**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| *New major direction variables* | | | |
| New peak hour average flow, Q (veh/lane) | 413.03 | 446.90 | 445.80 |
| New peak hour average concentration, K (veh/lane-mile) | 15.70 | 17.56 | 17.49 |
| New peak hour average speed, V (MPH) | 26.31 | 25.45 | 25.48 |
| *New minor direction variables* | | | |
| New peak hour average flow, Q (veh/lane) | 275.35 | 297.93 | 297.20 |
| New peak hour average concentration, K (veh/lane-mile) | 9.47 | 10.38 | 10.35 |
| New peak hour average speed, V (MPH) | 29.09 | 28.69 | 28.71 |

**Fuel consumption model parameters**

A linear relationship between fuel consumed per unit distance, f, and average trip time per unit distance, t, was first proposed in 1976 (Evans et al. 1976). Multivariate analysis of experiments performed in Detroit in the early 1970s indicated a correlation of nearly 0.85 between f and t at speeds under about 40 MPH. The equation can be expressed as

$$f = k_1 + k_2 t$$

where $k_1$ and $k_2$ are constants representing vehicle-specific parameters. The parameter $k_1$ is proportional to vehicle mass and is associated with fuel consumed in order to overcome rolling resistance. The coefficient $k_2$ represents the vehicle fuel flow rate while idling.

If $u=k_2/k_1$ is introduced, aggregating the above equation over all vehicles in the system yields

$$F = Sf_i = K_1(1 + U / V)$$

where $K_1$, U, and V all represent system-wide averages of $k_1$, u, and v, respectively. The percentage reduction D in fuel consumed per vehicle due to a reduction in average speed from $V_1$ to $V_2$ ($V_1$ and $V_2$<40 MPH) can be written as:

$$D = -100[K_1(1 + U / V_2) - K_1(1 + U / V_1) \; / \; K_1(1 + U / V_1)],$$

which simplifies to:

$$D = -100(V_1 / V_2 - 1)U / (V_1 + U).$$

In order to include the effect of reducing the volume, the overall system-wide fuel savings $D_{total}$ is given by:

$$D_{total} = -100 \{[1+D/100][1+(Q_2/Q_1-1)]-1\}.$$

An example of the fuel consumption parameters necessary for the model is shown in Table 3.17. The numbers are identical in all three cities.

TABLE 3.17: FUEL CONSUMPTION MODEL PARAMETERS

| | 1990 | 2000 | 2010 |
|---|---|---|---|
| Average MPG of all traffic | 16 | 17 | 18 |
| Average MPG of commuter traffic | 20 | 22 | 24 |
| Fuel consumption model parameter, U (MPH) | 25 | 26 | 27 |

Current MPG data are from the Highway Statistics report (U.S. D.O.T., 1990). Future estimates are based on the assumption that the pool of commuter vehicles will continue along the current trend of improving vehicle fuel consumption performance. The disparity between all traffic and commuter traffic stems from the inclusion of truck fuel consumption in the figures for all traffic.

Evans and Herman (1976) estimated the fuel consumption parameter U at 33.4 KPH or 20.7 MPH. Their figure was arrived at from an average of seven tested mid-70s model vehicles commonly found in urban traffic. Here U=25 MPH is used to reflect the changes in traffic mix that have occurred in the last 20 years. Future projections are based on the assumption that the vehicle-dependent parameters that make up U will continue to evolve in such a manner that U will increase gradually over time.

**Implementing the linear fuel consumption model**

The linear fuel consumption model is used here to calculate the peak hour arterial fuel savings due to telecommuting. The initial amount of fuel consumed during peak hours on the arterial network in the major direction, $FUEL_{paj1}$, is found by:

$$FUEL_{paj1} = POP \times VMTPC \times PEAKF \times AUTOF \times MAJF / MPG_{all}$$

where POP is the population, VMTPC is daily VMT per capita, PEAKF is the fraction of VMT occurring during the peak period, AUTOF is the fraction of VMT occurring along arterials, MAJF is the fraction of VMT occurring in the major direction, and $MPG_{all}$ is the average miles per gallon of all traffic.

The amount of fuel saved during the peak period on arterials in the major direction is found by applying the equation described earlier to calculate the percentage reduction, D, per vehicle in fuel consumed due to a change in average network speed, namely:

$$D = -100\ (V_{paj1} / V_{paj2}-1) \times U / (V_{paj1}+U).$$

The system-wide percentage savings follows as:

$$D_{total} = -100\ \{[1+D/100][1+(Q_{paj2}/Q_{paj1}-1)]-1\}.$$

Therefore, $G_{paj}$, the number of gallons saved during the peak period along arterials in the major direction per day is given by:

$$G_{paj} = FUEL_{paj1} \times D_{total}$$

The total peak period arterial fuel saving is the sum of savings in the major and minor directions. Spreadsheet examples of this procedure in its entirety are shown in Tables 3.18-3.20.

**Including off-peak or non-arterial fuel savings**

As mentioned previously, in the case of off-peak or non-arterial traffic, only the direct effect of removing vehicles is considered. This is a much simpler procedure consisting of the following equation that calculates $G_{on}$, the number of gallons saved daily either during off-peak hours or along non-arterial roads due to telecommuting.

$$G_{on} = (HTC + 0.5STC) \times 1 / OCCUP \times DISTANCE \times AUTOF \times OFFPKF \times NONARTF / MPG_{com}$$

where HTC is the number of home telecommuters, STC is the number of satellite telecommuters,

TABLE 3.18: SPREADSHEET TO CALCULATE THE PEAK ARTERIAL FUEL SAVINGS IN AUSTIN

| **AUSTIN**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| *Major direction peak arterial values* | | | |
| Peak hour avg. flow per lane, Q (veh/hr) | 385.17 | 515.71 | 641.63 |
| Peak hour avg. conc., K (veh/lane-mile) | 13.73 | 20.27 | 31.49 |
| Peak hour average speed, V (MPH) | 28.06 | 25.45 | 20.37 |
| *Minor direction peak arterial values* | | | |
| Peak hour avg. flow per lane, Q (veh/hr) | 256.78 | 343.80 | 427.75 |
| Peak hour avg. conc., K (veh/lane-mile) | 8.62 | 11.98 | 15.65 |
| Peak hour average speed, V (MPH) | 29.79 | 28.69 | 27.33 |
| *New major direction values* | | | |
| New peak hour avg. flow, Q (veh/lane) | 376.36 | 504.41 | 627.42 |
| New pk hr avg. conc., K (veh/lane-mile) | 13.35 | 19.61 | 29.36 |
| New peak hour average speed, V (MPH) | 28.20 | 25.72 | 21.37 |
| % savings per vehicle on network, D (major) | 0.23 | 0.55 | 2.65 |
| % network fuel savings, $D_{total}$ (major) | 2.52 | 2.73 | 4.81 |
| PEAK PERIOD ARTERIAL GALLONS SAVED PER DAY IN THE MAJOR DIRECTION | 955 | 1440 | 3297 |
| *New minor direction values* | | | |
| New peak hour avg. flow, Q (veh/lane) | 250.90 | 336.27 | 418.28 |
| New pk hr avg. conc., K (veh/lane-mile) | 8.40 | 11.68 | 15.21 |
| New peak hour average speed, V (MPH) | 29.85 | 28.79 | 27.50 |
| % fuel savings per vehicle on network, D (major) | 0.10 | 0.18 | 0.31 |
| % network fuel savings, $D_{total}$ (major) | 2.39 | 2.36 | 2.52 |
| PEAK PERIOD ARTERIAL GALLONS SAVED PER DAY IN THE MINOR DIRECTION | 604 | 832 | 1150 |

TABLE 3.19: SPREADSHEET TO CALCULATE THE PEAK ARTERIAL FUEL SAVINGS IN DALLAS

| **DALLAS**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| *Major direction peak arterial values* | | | |
| Peak hour avg. flow per lane, Q (veh/hr) | 304.76 | 371.17 | 391.08 |
| Peak hour avg. conc., K (veh/lane-mile) | 11.24 | 14.53 | 15.64 |
| Peak hour average speed, V (MPH) | 27.13 | 25.54 | 25.00 |
| *Minor direction peak arterial values* | | | |
| Peak hour avg. flow per lane, Q (veh/hr) | 203.18 | 247.45 | 260.72 |
| Peak hour avg. conc., K (veh/lane-mile) | 6.99 | 8.75 | 9.30 |
| Peak hour average speed, V (MPH) | 29.06 | 28.28 | 28.03 |
| *New major direction values* | | | |
| New peak hour avg. flow, Q (veh/lane) | 297.45 | 362.11 | 381.24 |
| New pk hr avg. conc., K (veh/lane-mile) | 10.90 | 14.05 | 15.09 |
| New peak hour average speed, V (MPH) | 27.28 | 25.78 | 25.27 |
| % savings per vehicle on network, D (major) | 0.28 | 0.46 | 0.56 |
| % network fuel savings, $D_{total}$ (major) | 2.67 | 2.89 | 3.06 |
| PEAK PERIOD ARTERIAL GALLONS SAVED PER DAY IN THE MAJOR DIRECTION | 6040 | 8287 | 9655 |
| *New minor direction values* | | | |
| New peak hour avg. flow, Q (veh/lane) | 198.30 | 241.41 | 254.16 |
| New pk hr avg. conc., K (veh/lane-mile) | 6.80 | 8.50 | 9.03 |
| New peak hour average speed, V (MPH) | 29.14 | 28.39 | 28.15 |
| % fuel savings per vehicle on network, D (major) | 0.13 | 0.19 | 0.22 |
| % network fuel savings, $D_{total}$ (major) | 2.53 | 2.63 | 2.73 |
| PEAK PERIOD ARTERIAL GALLONS SAVED PER DAY IN THE MINOR DIRECTION | 3813 | 5017 | 5734 |

TABLE 3.20: SPREADSHEET TO CALCULATE THE PEAK ARTERIAL FUEL SAVINGS IN HOUSTON

| **HOUSTON**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| *Major direction peak arterial values* | | | |
| Peak hour avg. flow per lane, Q (veh/hr) | 422.36 | 457.30 | 456.52 |
| Peak hour avg. conc., K (veh/lane-mile) | 16.19 | 18.17 | 18.12 |
| Peak hour average speed, V (MPH) | 26.09 | 25.17 | 25.19 |
| *Minor direction peak arterial values* | | | |
| Peak hour avg. flow per lane, Q (veh/hr) | 281.57 | 304.86 | 304.35 |
| Peak hour avg. conc., K (veh/lane-mile) | 9.72 | 10.67 | 10.65 |
| Peak hour average speed, V (MPH) | 28.98 | 28.57 | 28.58 |
| *New major direction values* | | | |
| New peak hour avg. flow, Q (veh/lane) | 413.03 | 446.90 | 445.80 |
| New pk hr avg. conc., K (veh/lane-mile) | 15.70 | 17.56 | 17.49 |
| New peak hour average speed, V (MPH) | 26.31 | 25.45 | 25.48 |
| % savings per vehicle on network, D (major) | 0.42 | 0.57 | 0.59 |
| % network fuel savings, $D_{total}$ (major) | 2.62 | 2.83 | 2.93 |
| PEAK PERIOD ARTERIAL GALLONS SAVED PER DAY IN THE MAJOR DIRECTION | 6860 | 8327 | 8977 |
| *New minor direction values* | | | |
| New peak hour avg. flow, Q (veh/lane) | 275.35 | 297.93 | 297.20 |
| New pk hr avg. conc., K (veh/lane-mile) | 9.47 | 10.38 | 10.35 |
| New peak hour average speed, V (MPH) | 29.09 | 28.69 | 28.71 |
| % fuel savings per vehicle on network, D (major) | 0.17 | 0.21 | 0.22 |
| % network fuel savings, $D_{total}$ (major) | 2.38 | 2.48 | 2.56 |
| PEAK PERIOD ARTERIAL GALLONS SAVED PER DAY IN THE MINOR DIRECTION | 4140 | 4858 | 5235 |

OCCUP is the average commute vehicle occupancy, DISTANCE is the average commute length, AUTOF is the fraction of commutes made by automobile, OFFPKF is the fraction of VMT occurring during off-peak periods, NONARTF is the fraction of VMT that occurs along non-arterial facilities, and $MPG_{com}$ is the average miles per gallon for commuter vehicles. Examples of the result of these calculations appears in Tables 3.21-3.23.

TABLE 3.21: OFF-PEAK OR NON-ARTERIAL FUEL CONSUMPTION SAVINGS IN AUSTIN

| **AUSTIN**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Off-peak or non-arterial gallons saved per day | 5497 | 7072 | 9005 |

TABLE 3.22: OFF-PEAK OR NON-ARTERIAL FUEL CONSUMPTION SAVINGS IN DALLAS

| **DALLAS**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Off-peak or non-arterial gallons saved per day | 39183 | 48759 | 53610 |

TABLE 3.23: OFF-PEAK OR NON-ARTERIAL FUEL CONSUMPTION SAVINGS IN HOUSTON

| **HOUSTON**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Off-peak or non-arterial gallons saved per day | 32421 | 36261 | 37877 |

**Adjusting fuel savings to account for less frequent cold starts**

The reduction of cold-start trips implies further reductions in fuel consumption than those produced by VMT reductions. Evidence in the literature states that a telecommuting occasion reduces cold starts by 1.3 per day (Sampath et. al., 1991). The same report found no significant change in the number of hot starts which would also have required an adjustment. It is assumed that the average cold start consumes 350 ml of fuel, about one tenth of a gallon (Chang et. al., 1976). The cold start adjustment, CSADJUST, is calculated in the equation below as

$$CSADJUST = HTC \times 1 / OCCUP \times AUTOF \times COLDSTART$$

where HTC is the number of home telecommuters, OCCUP is the average commute vehicle occupancy, AUTOF is the fraction of commutes made by automobile, and COLDSTART is the reduction in fuel consumed by cold starts due to a telecommuting occasion (1.3 starts/day x 0.1 gallons/start). Examples of these adjustments are shown in Tables 3.24-3.26.

TABLE 3.24: EXAMPLE OF COLD START ADJUSTMENT IN AUSTIN

| **AUSTIN**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Fuel savings adjustment for reduced cold starts | 865 | 1108 | 1394 |

TABLE 3.25: EXAMPLE OF COLD START ADJUSTMENT IN DALLAS

| **DALLAS**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Fuel savings adjustment for reduced cold starts | 4642 | 5753 | 6247 |

TABLE 3.26: EXAMPLE OF COLD START ADJUSTMENT IN HOUSTON

| **HOUSTON**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Fuel savings adjustment for reduced cold starts | 4013 | 4469 | 4610 |

**Total fuel consumption savings due to telecommuting**

The total fuel consumption saving is the sum of the peak period arterial savings, the off-peak or non-arterial savings, and the cold start adjustment. The percentage savings is found by comparing the amount of fuel saved to the system-wide fuel consumed per day in absence of telecommuting, $FUEL_{initial}$. This is simply

$$FUEL_{initial} = POP \times VMTPC / MPG_{all}$$

where POP is population, VMTPC is daily VMT per capita, and $MPG_{all}$ is average miles per gallon of all traffic. Tables 3.27-3.29 display the process for determining total fuel consumption savings due to telecommuting per day and annually.

TABLE 3.27: TOTAL SYSTEM-WIDE FUEL SAVINGS DUE TO TELECOMMUTING IN AUSTIN

| **AUSTIN**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Peak period arterial gallons saved per day in the major direction | 955 | 1440 | 3297 |
| Peak period arterial gallons saved per day in the minor direction | 604 | 832 | 1150 |
| Off-peak or non-arterial gallons saved per day | 5497 | 7072 | 9005 |
| Fuel savings adjustment for reduced cold starts | 865 | 1108 | 1394 |
| Total fuel saved per day due to telecommuting | 7920 | 10452 | 14846 |
| Fuel consumed per day without telecommuting | 726813 | 1011704 | 1313179 |
| Fuel consumed per day with telecommuting | 718892 | 1001252 | 1298333 |
| % total fuel savings due to telecommuting | 1.09 | 1.03 | 1.13 |
| Annual workdays | 250 | 250 | 250 |
| Annual fuel savings in gallons | 1980057 | 2612913 | 3711534 |

TABLE 3.28: TOTAL SYSTEM-WIDE FUEL SAVINGS DUE TO TELECOMMUTING IN DALLAS

| **DALLAS**<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Peak period arterial gallons saved per day in the major direction | 6040 | 8287 | 9655 |
| Peak period arterial gallons saved per day in the minor direction | 3813 | 5017 | 5734 |
| Off-peak or non-arterial gallons saved per day | 39183 | 48759 | 53610 |
| Fuel savings adjustment for reduced cold starts | 4642 | 5753 | 6247 |
| Total fuel saved per day due to telecommuting | 53678 | 67817 | 75245 |
| Fuel consumed per day without telecommuting | 4837625 | 6125367 | 6732993 |
| Fuel consumed per day with telecommuting | 4783947 | 6057550 | 6657749 |
| % total fuel savings due to telecommuting | 1.11 | 1.11 | 1.12 |
| Annual workdays | 250 | 250 | 250 |
| Annual fuel savings in gallons | 13419531 | 16954195 | 18811181 |

TABLE 3.29: TOTAL SYSTEM-WIDE FUEL SAVINGS DUE TO TELECOMMUTING IN HOUSTON

| HOUSTON<br>Scenario 1 | 1990 | 2000 | 2010 |
|---|---|---|---|
| Peak period arterial gallons saved per day in the major direction | 6860 | 8327 | 8977 |
| Peak period arterial gallons saved per day in the minor direction | 4140 | 4858 | 5235 |
| Off-peak or non-arterial gallons saved per day | 32421 | 36261 | 37877 |
| Fuel savings adjustment for reduced cold starts | 4013 | 4469 | 4610 |
| Total fuel saved per day due to telecommuting | 47433 | 53914 | 56698 |
| Fuel consumed per day without telecommuting | 4539375 | 5109678 | 5321686 |
| Fuel consumed per day with telecommuting | 4491942 | 5055764 | 5264987 |
| % total fuel savings due to telecommuting | 1.04 | 1.06 | 1.07 |
| Annual workdays | 250 | 250 | 250 |
| Annual fuel savings in gallons | 11858374 | 13478588 | 14174581 |

## SUMMARY

This chapter describes an analytic approach to obtain estimates of fuel savings due to telecommuting in urban areas. Scenarios are used to represent various levels of telecommuting that can be expected to occur over the next twenty years in Austin, Dallas, and Houston. The two-fluid model of town traffic is employed in conjunction with estimates of current traffic condition variables to calculate values of flow, concentration, and speed. Similar estimates are obtained for each scenario of telecommuting penetration for comparison to the base case of no telecommuting in order to estimate the VMT savings possible from flow reductions due to telecommuting. Subsequently, a linear model of fuel consumption is used to determine fuel savings on arterial streets during peak hours. Savings for off-peak or non-arterial travel reductions are calculated directly from VMT savings estimates. Finally, a factor is included to represent additional savings from telecommuting in the form of fewer cold starts, based on findings in the literature (Sampath et al., 1991).

In Chapter Four, this framework is executed and fuel savings are reported for Austin, Dallas, and Houston for the various scenarios of telecommuting penetration under both realistic capacity improvement projections and more optimistic projections, including a sensitivity analysis around arterial capacity growth rates as functions of population growth rates.

# CHAPTER 4
# RESULTS OF FUEL CONSUMPTION ANALYSIS

## INTRODUCTION

The model framework was applied to the set of scenarios of home and satellite telecommuting participation in Austin, Dallas, and Houston that were described in the previous chapter. Each scenario produced a fuel consumption saving relative to the amount that would have been consumed region-wide had no telecommuting occurred. The model was applied to a base year, 1990, and two future years, 2000 and 2010, that required extensive assumptions regarding both the demand for automobile transportation and the supply of facilities.

Initially, it is assumed that the supply of urban arterial lane-miles grows at a rate of one percent annually, consistent with current trends in the three cities. Later this assumption is relaxed in favor of a more optimistic scenario in which lane-mileage keeps pace with population growth. In order to capture the potential value of telecommuting to a network as average flows approach capacity along urban arterials during peak hours of travel, a sensitivity analysis is performed. Selected scenarios are analyzed for cases where the supply of arterial lane-miles grows at a rate ranging from 33% to 67% of the ten-year population growth rate. The average flows resulting at the 33% rate are very close to the theoretical maximum average flows in the flow-concentration relation used to derive average speed.

Finally, in another exercise to demonstrate the value of telecommuting to a network approaching capacity, the growth rate of the supply of arterial lane-miles is fixed at the 1990 level and selected Austin scenarios are applied annually until capacity is reached. This exercise provides insight into the ability of telecommuting to ward off impending gridlock under continuing population growth in the coming years in Austin, Dallas, and Houston. Results of these experiments are reported in this chapter followed by a discussion of the results and the limitations of the model.

## NETWORK-WIDE FUEL CONSUMPTION SAVINGS MADE POSSIBLE BY TELECOMMUTING

The fifteen telecommuting scenarios for the three cities in the three years and their respective percentage fuel consumption savings are shown in Tables 4.1- 4.3 for Austin, Dallas, and Houston, respectively. The savings are expressed as a percentage of consumption under the base case scenario of no telecommuting. Again, the original supply assumption is that lane-mileage grows at a one percent annual rate. The differences in the three cities' percentage savings simply reflects the differences in their average commute characteristics and anticipated growth in population.

TABLE 4.1: FUEL CONSUMPTION SAVINGS IN AUSTIN POSSIBLE FROM TELECOMMUTING UNDER A REALISTIC ARTERIAL CAPACITY EXPANSION SCENARIO (AS A PERCENTAGE OF FUEL CONSUMED IF NO TELECOMMUTING OCCURRED)

| Home telecommuter % | Satellite telecommuter % | Savings % 1990 | Savings % 2000 | Savings % 2010 |
|---|---|---|---|---|
| 5 | 0 | 1.09 | 1.03 | 1.13 |
| 10 | 0 | 2.18 | 2.05 | 2.22 |
| 15 | 0 | 3.27 | 3.09 | 3.28 |
| 20 | 0 | 4.35 | 4.11 | 4.32 |
| 25 | 0 | 5.44 | 5.13 | 5.35 |
| 5 | 5 | 1.57 | 1.49 | 1.62 |
| 10 | 5 | 2.66 | 2.52 | 2.70 |
| 15 | 5 | 3.75 | 3.55 | 3.75 |
| 20 | 5 | 4.84 | 4.57 | 4.78 |
| 25 | 5 | 5.92 | 5.59 | 5.81 |
| 5 | 10 | 2.06 | 1.95 | 2.11 |
| 10 | 10 | 3.15 | 2.98 | 3.17 |
| 15 | 10 | 4.24 | 4.00 | 4.21 |
| 20 | 10 | 5.33 | 5.02 | 5.25 |
| 25 | 10 | 6.41 | 6.04 | 6.27 |

TABLE 4.2: FUEL CONSUMPTION SAVINGS IN DALLAS POSSIBLE FROM TELECOMMUTING UNDER A REALISTIC ARTERIAL CAPACITY EXPANSION SCENARIO (AS A PERCENTAGE OF FUEL CONSUMED IF NO TELECOMMUTING OCCURRED)

| Home telecommuter % | Satellite telecommuter % | Savings % 1990 | Savings % 2000 | Savings % 2010 |
|---|---|---|---|---|
| 5 | 0 | 1.11 | 1.11 | 1.12 |
| 10 | 0 | 2.22 | 2.21 | 2.23 |
| 15 | 0 | 3.33 | 3.31 | 3.34 |
| 20 | 0 | 4.43 | 4.41 | 4.45 |
| 25 | 0 | 5.54 | 5.51 | 5.56 |
| 5 | 5 | 1.62 | 1.61 | 1.63 |
| 10 | 5 | 2.72 | 2.72 | 2.74 |
| 15 | 5 | 3.83 | 3.82 | 3.85 |
| 20 | 5 | 4.94 | 4.92 | 4.96 |
| 25 | 5 | 6.04 | 6.01 | 6.06 |
| 5 | 10 | 2.12 | 2.12 | 2.14 |
| 10 | 10 | 3.23 | 3.22 | 3.25 |
| 15 | 10 | 4.33 | 4.32 | 4.36 |
| 20 | 10 | 5.44 | 5.42 | 5.47 |
| 25 | 10 | 6.54 | 6.52 | 6.57 |

TABLE 4.3: FUEL CONSUMPTION SAVINGS IN HOUSTON POSSIBLE FROM TELECOMMUTING UNDER A REALISTIC ARTERIAL CAPACITY EXPANSION SCENARIO (AS A PERCENTAGE OF FUEL CONSUMED IF NO TELECOMMUTING OCCURRED)

| Home telecommuter % | Satellite telecommuter % | Savings % 1990 | Savings % 2000 | Savings % 2010 |
|---|---|---|---|---|
| 5 | 0 | 1.04 | 1.06 | 1.07 |
| 10 | 0 | 2.09 | 2.11 | 2.13 |
| 15 | 0 | 3.13 | 3.15 | 3.18 |
| 20 | 0 | 4.17 | 4.20 | 4.24 |
| 25 | 0 | 5.20 | 5.24 | 5.29 |
| 5 | 5 | 1.52 | 1.54 | 1.55 |
| 10 | 5 | 2.56 | 2.59 | 2.61 |
| 15 | 5 | 3.60 | 3.63 | 3.67 |
| 20 | 5 | 4.66 | 4.68 | 4.72 |
| 25 | 5 | 5.67 | 5.72 | 5.77 |
| 5 | 10 | 2.00 | 2.02 | 2.04 |
| 10 | 10 | 3.04 | 3.07 | 3.10 |
| 15 | 10 | 4.08 | 4.11 | 4.15 |
| 20 | 10 | 5.11 | 5.15 | 5.20 |
| 25 | 10 | 6.15 | 6.19 | 6.25 |

Figures 4.1-4.3 graphically show the results for Austin, Dallas, and Houston in 1990 for all fifteen scenarios. The network fuel consumption savings resulting from telecommuting are essentially a linear function of the percentage of telecommutable workers who choose to telecommute. Each 5% increment of home telecommuting provides about 1.1% in fuel consumption savings. Additionally, each 5% increment of satellite telecommuting yields about one half of one per cent savings. The apparent linearity of the results is not surprising considering that peak period arterial travel, the only source of the indirect effect on vehicles left on the network, makes up only about ten per cent of total VMT.

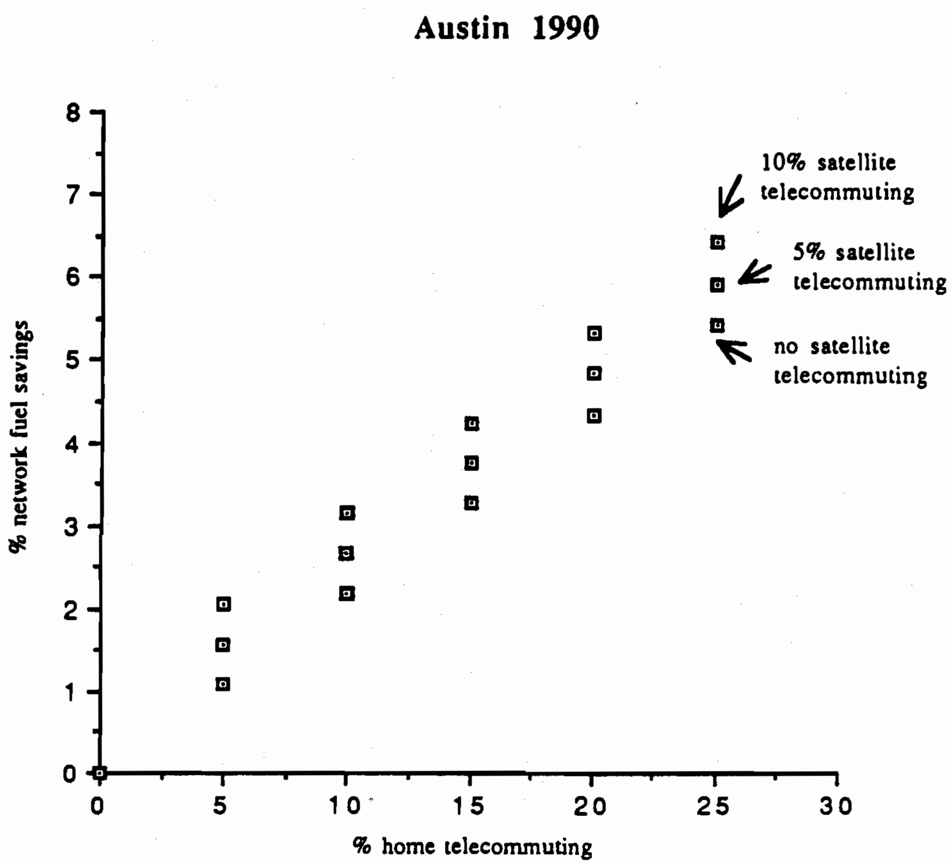



FIGURE 4.1: AUSTIN'S POTENTIAL FUEL SAVINGS IN 1990 FOR DIFFERENT LEVELS OF TELECOMMUTING PENETRATION

## Dallas 1990

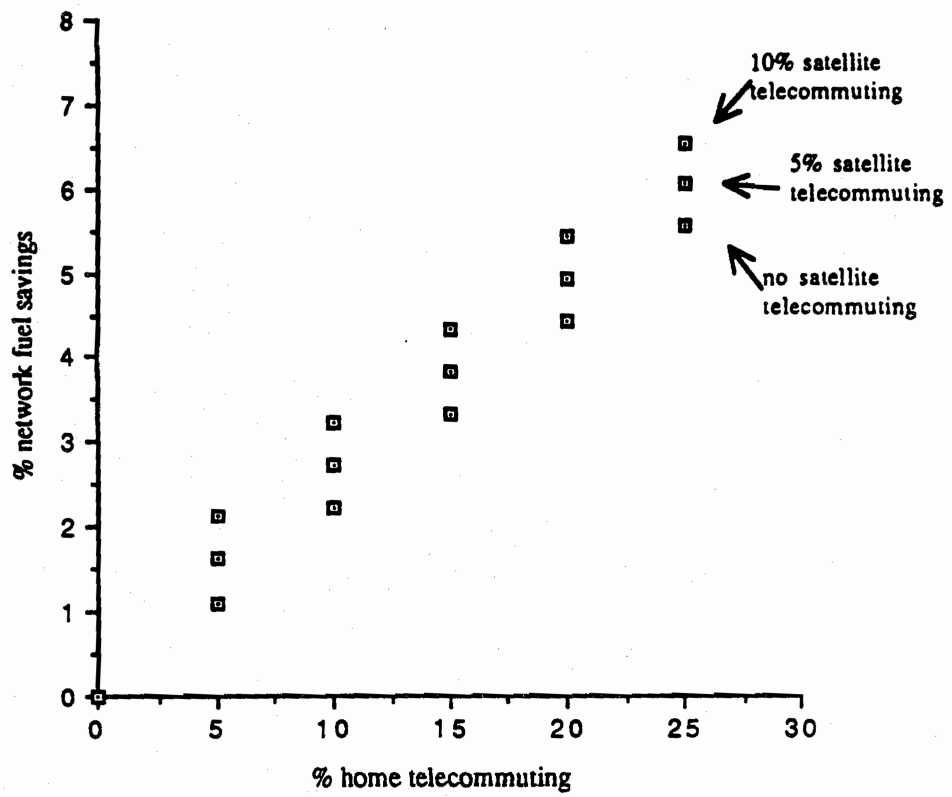



FIGURE 4.2: DALLAS' POTENTIAL FUEL SAVINGS IN 1990 FOR DIFFERENT LEVELS OF TELECOMMUTING PENETRATION

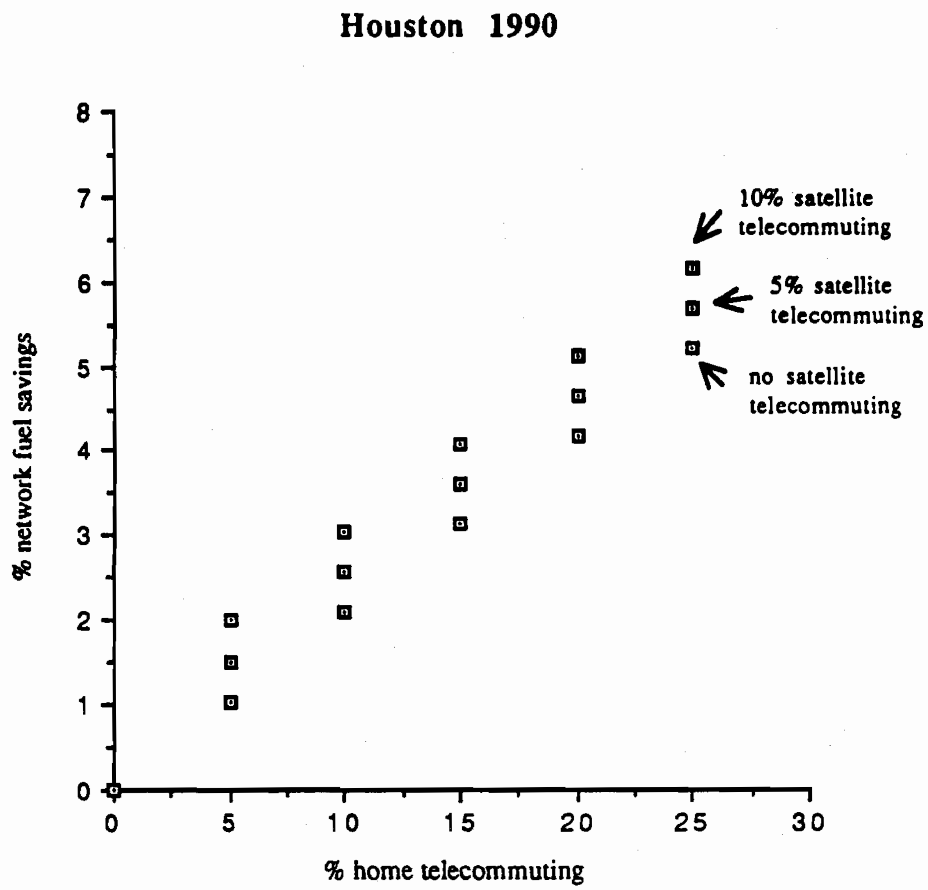



FIGURE 4.3: HOUSTON'S POTENTIAL FUEL SAVINGS IN 1990 FOR DIFFERENT LEVELS OF TELECOMMUTING PENETRATION

## THE EFFECT OF CAPACITY ON FUEL CONSUMPTION SAVINGS

Initially, the analysis assumes that arterial capacity grows at rate of one percent annually. In this section, capacity growth is set to keep pace with population growth at first, then limited to 67%, 50%, and finally 33% of the ten-year population growth rates in each city to observe the effect of telecommuting on fuel consumption savings as the arterial network approaches capacity. The results under the optimistic assumption that the arterial supply grows at a rate of 100% of the population growth rate are shown in Tables 4.4-4.6.

TABLE 4.4: FUEL CONSUMPTION SAVINGS IN AUSTIN POSSIBLE FROM TELECOMMUTING UNDER AN OPTIMISTIC ARTERIAL CAPACITY EXPANSION SCENARIO (AS A PERCENTAGE OF FUEL CONSUMED IF NO TELECOMMUTING OCCURRED)

| Home telecommuter % | Satellite telecommuter % | Savings % 1990 | Savings % 2000 | Savings % 2010 |
|---|---|---|---|---|
| 5 | 0 | 1.09 | 1.02 | 1.01 |
| 10 | 0 | 2.18 | 2.03 | 2.01 |
| 15 | 0 | 3.27 | 3.05 | 3.02 |
| 20 | 0 | 4.35 | 4.06 | 4.02 |
| 25 | 0 | 5.44 | 5.08 | 5.02 |
| 5 | 5 | 1.57 | 1.47 | 1.46 |
| 10 | 5 | 2.66 | 2.49 | 2.46 |
| 15 | 5 | 3.75 | 3.50 | 3.46 |
| 20 | 5 | 4.84 | 4.52 | 4.46 |
| 25 | 5 | 5.92 | 5.53 | 5.46 |
| 5 | 10 | 2.06 | 1.93 | 1.91 |
| 10 | 10 | 3.15 | 2.94 | 2.91 |
| 15 | 10 | 4.24 | 3.95 | 3.91 |
| 20 | 10 | 5.33 | 4.97 | 4.91 |
| 25 | 10 | 6.41 | 5.98 | 5.91 |

TABLE 4.5: FUEL CONSUMPTION SAVINGS IN DALLAS POSSIBLE FROM TELECOMMUTING UNDER AN OPTIMISTIC ARTERIAL CAPACITY EXPANSION SCENARIO (AS A PERCENTAGE OF FUEL CONSUMED IF NO TELECOMMUTING OCCURRED)

| Home telecommuter % | Satellite telecommuter % | Savings % 1990 | Savings % 2000 | Savings % 2010 |
|---|---|---|---|---|
| 5 | 0 | 1.11 | 1.10 | 1.11 |
| 10 | 0 | 2.22 | 2.20 | 2.22 |
| 15 | 0 | 3.33 | 3.30 | 3.32 |
| 20 | 0 | 4.43 | 4.40 | 4.43 |
| 25 | 0 | 5.54 | 5.49 | 5.53 |
| 5 | 5 | 1.62 | 1.60 | 1.62 |
| 10 | 5 | 2.72 | 2.70 | 2.72 |
| 15 | 5 | 3.83 | 3.80 | 3.83 |
| 20 | 5 | 4.94 | 4.90 | 4.93 |
| 25 | 5 | 6.04 | 5.99 | 6.03 |
| 5 | 10 | 2.12 | 2.11 | 2.13 |
| 10 | 10 | 3.23 | 3.21 | 3.23 |
| 15 | 10 | 4.33 | 4.30 | 4.33 |
| 20 | 10 | 5.44 | 5.40 | 5.44 |
| 25 | 10 | 6.54 | 6.49 | 6.54 |

TABLE 4.6: FUEL CONSUMPTION SAVINGS IN HOUSTON POSSIBLE FROM TELECOMMUTING UNDER AN OPTIMISTIC ARTERIAL CAPACITY EXPANSION SCENARIO (AS A PERCENTAGE OF FUEL CONSUMED IF NO TELECOMMUTING OCCURRED)

| Home telecommuter % | Satellite telecommuter % | Savings % 1990 | Savings % 2000 | Savings % 2010 |
|---|---|---|---|---|
| 5 | 0 | 1.04 | 1.06 | 1.08 |
| 10 | 0 | 2.09 | 2.11 | 2.15 |
| 15 | 0 | 3.13 | 3.16 | 3.21 |
| 20 | 0 | 4.17 | 4.21 | 4.27 |
| 25 | 0 | 5.20 | 5.25 | 5.33 |
| 5 | 5 | 1.52 | 1.54 | 1.57 |
| 10 | 5 | 2.56 | 2.59 | 2.64 |
| 15 | 5 | 3.60 | 3.64 | 3.70 |
| 20 | 5 | 4.64 | 4.68 | 4.76 |
| 25 | 5 | 5.67 | 5.73 | 5.81 |
| 5 | 10 | 2.00 | 2.04 | 2.06 |
| 10 | 10 | 3.04 | 3.07 | 3.13 |
| 15 | 10 | 4.08 | 4.12 | 4.19 |
| 20 | 10 | 5.11 | 5.16 | 5.24 |
| 25 | 10 | 6.15 | 6.20 | 6.29 |

Four scenarios were selected for comparison: scenarios 1 (5% home 0% satellite),4 (20% home 0% satellite),6 (5% home 5% satellite), and 9 (20% home 5% satellite). Tables 4.7-4.10 display the resulting fuel savings. The number of arterial lane-miles for each case is shown in parentheses.

TABLE 4.7: EFFECT OF CAPACITY GROWTH RATE, AS A PERCENTAGE OF POPULATION GROWTH, ON SAVINGS: 5% HOME, 0% SATELLITE TELECOMMUTING

Austin

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 1.09 (788) | 1.09 (788) | 1.09 (788) | 1.09 (788) |
| 2000 | 1.02 (1056) | 1.02 (967) | 1.03 (922) | 1.03 (876) |
| 2010 | 1.01 (1380) | 1.02 (1167) | 1.14 (1064) | 1.12 (965) |

Dallas

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 1.11 (5943) | 1.11 (5943) | 1.11 (5943) | 1.11 (5943) |
| 2000 | 1.10 (7251) | 1.10 (6819) | 1.11 (6597) | 1.11 (6375) |
| 2010 | 1.11 (8028) | 1.12 (7309) | 1.12 (6951) | 1.13 (6600) |

Houston

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 1.04 (4953) | 1.04 (4953) | 1.04 (4953) | 1.04 (4953) |
| 2000 | 1.06 (5374) | 1.06 (5235) | 1.06 (5163) | 1.07 (5092) |
| 2010 | 1.08 (5638) | 1.09 (5407) | 1.09 (5290) | 1.10 (5174) |

TABLE 4.8: EFFECT OF CAPACITY GROWTH RATE, AS A PERCENTAGE OF POPULATION GROWTH, ON SAVINGS: 20% HOME, 0% SATELLITE TELECOMMUTING

Austin

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 4.35 (788) | 4.35 (788) | 4.35 (788) | 4.35 (788) |
| 2000 | 4.06 (1056) | 4.08 (967) | 4.09 (922) | 4.11 (876) |
| 2010 | 4.02 (1380) | 4.07 (1167) | 4.13 (1064) | 4.30 (965) |

Dallas

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 4.43 (5943) | 4.43 (5943) | 4.43 (5943) | 4.43 (5943) |
| 2000 | 4.40 (7251) | 4.41 (6819) | 4.41 (6597) | 4.47 (6375) |
| 2010 | 4.43 (8028) | 4.45 (7309) | 4.42 (6951) | 4.49 (6600) |

Houston

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 4.17 (4953) | 4.17 (4953) | 4.17 (4953) | 4.17 (4953) |
| 2000 | 4.21 (5374) | 4.22 (5235) | 4.23 (5163) | 4.23 (5092) |
| 2010 | 4.27 (5638) | 4.30 (5407) | 4.32 (5290) | 4.34 (5174) |

TABLE 4.9: EFFECT OF CAPACITY GROWTH RATE, AS A PERCENTAGE OF POPULATION GROWTH, ON SAVINGS: 5% HOME, 5% SATELLITE TELECOMMUTING

Austin

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 1.57 (788) | 1.57 (788) | 1.57 (788) | 1.57 (788) |
| 2000 | 1.47 (1056) | 1.48 (967) | 1.48 (922) | 1.49 (876) |
| 2010 | 1.46 (1380) | 1.48 (1167) | 1.51 (1064) | 1.61 (965) |

Dallas

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 1.62 (5943) | 1.62 (5943) | 1.62 (5943) | 1.62 (5943) |
| 2000 | 1.60 (7251) | 1.61 (6819) | 1.61 (6597) | 1.62 (6375) |
| 2010 | 1.62 (8028) | 1.63 (7309) | 1.63 (6951) | 1.64 (6600) |

Houston

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 1.52 (4953) | 1.52 (4953) | 1.52 (4953) | 1.52 (4953) |
| 2000 | 1.54 (5374) | 1.55 (5235) | 1.55 (5163) | 1.55 (5092) |
| 2010 | 1.57 (5638) | 1.58 (5407) | 1.59 (5290) | 1.60 (5174) |

TABLE 4.10: EFFECT OF CAPACITY GROWTH RATE, AS A PERCENTAGE OF POPULATION GROWTH, ON SAVINGS: 20% HOME, 5% SATELLITE TELECOMMUTING

Austin

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 4.84 (788) | 4.84 (788) | 4.84 (788) | 4.84 (788) |
| 2000 | 4.52 (1056) | 4.53 (967) | 4.55 (922) | 4.57 (876) |
| 2010 | 4.46 (1380) | 4.52 (1167) | 4.58 (1064) | 4.77 (965) |

Dallas

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 4.94 (5943) | 4.94 (5943) | 4.94 (5943) | 4.94 (5943) |
| 2000 | 4.90 (7251) | 4.91 (6819) | 4.92 (6597) | 4.92 (6375) |
| 2010 | 4.93 (8028) | 4.96 (7309) | 4.97 (6951) | 5.00 (6600) |

Houston

| year | 100% | 67% | 50% | 33% |
|---|---|---|---|---|
| 1990 | 4.64 (4953) | 4.64 (4953) | 4.64 (4953) | 4.64 (4953) |
| 2000 | 4.68 (5374) | 4.70 (5235) | 4.70 (5163) | 4.71 (5092) |
| 2010 | 4.76 (5638) | 4.79 (5407) | 4.81 (5290) | 4.83 (5174) |

As the tables indicate, fuel consumption savings due to telecommuting increase, at times significantly, as the network approaches capacity, that is, the theoretical maximum average flow stipulated by the flow-concentration relation

$$Q = KV_m(1 - f_{s,min})^{n+1}[1 - (K / K_m)^p]^{n+1}.$$

Figures 4.4 and 4.5 further illustrate this point in Austin's case.

FIGURE 4.4: EFFECT OF CAPACITY ON PERCENTAGE FUEL SAVINGS IN AUSTIN: 20% HOME, 0% SATELLITE TELECOMMUTING

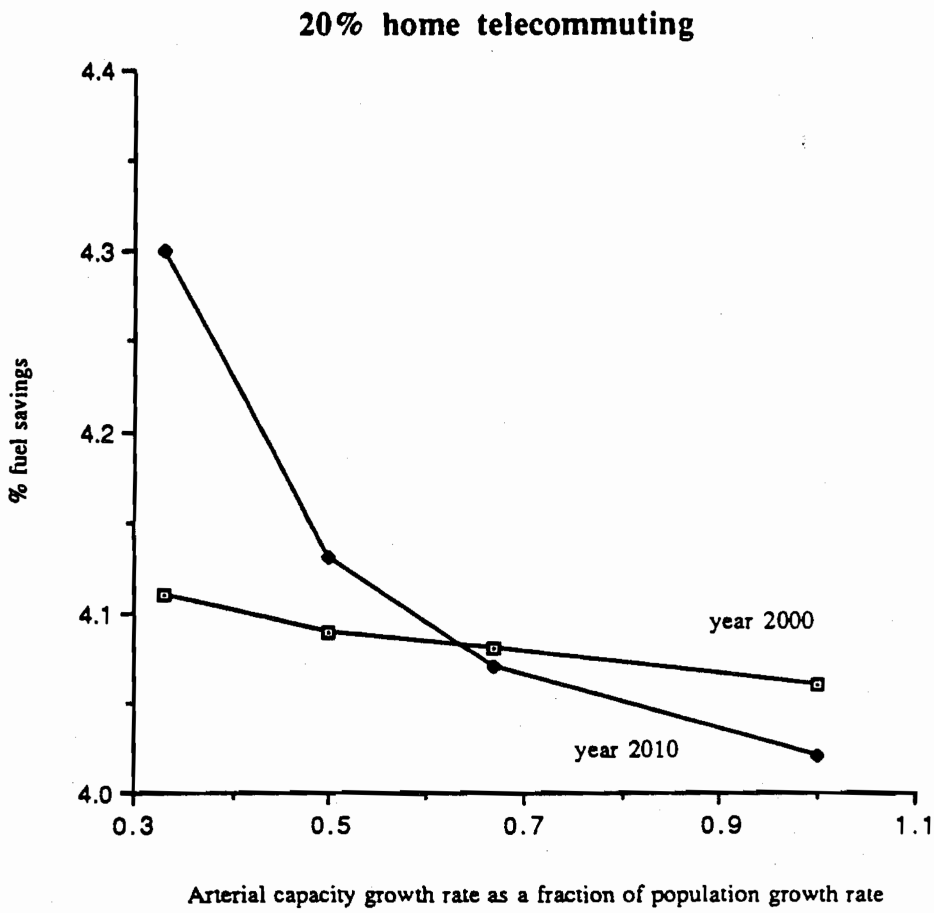
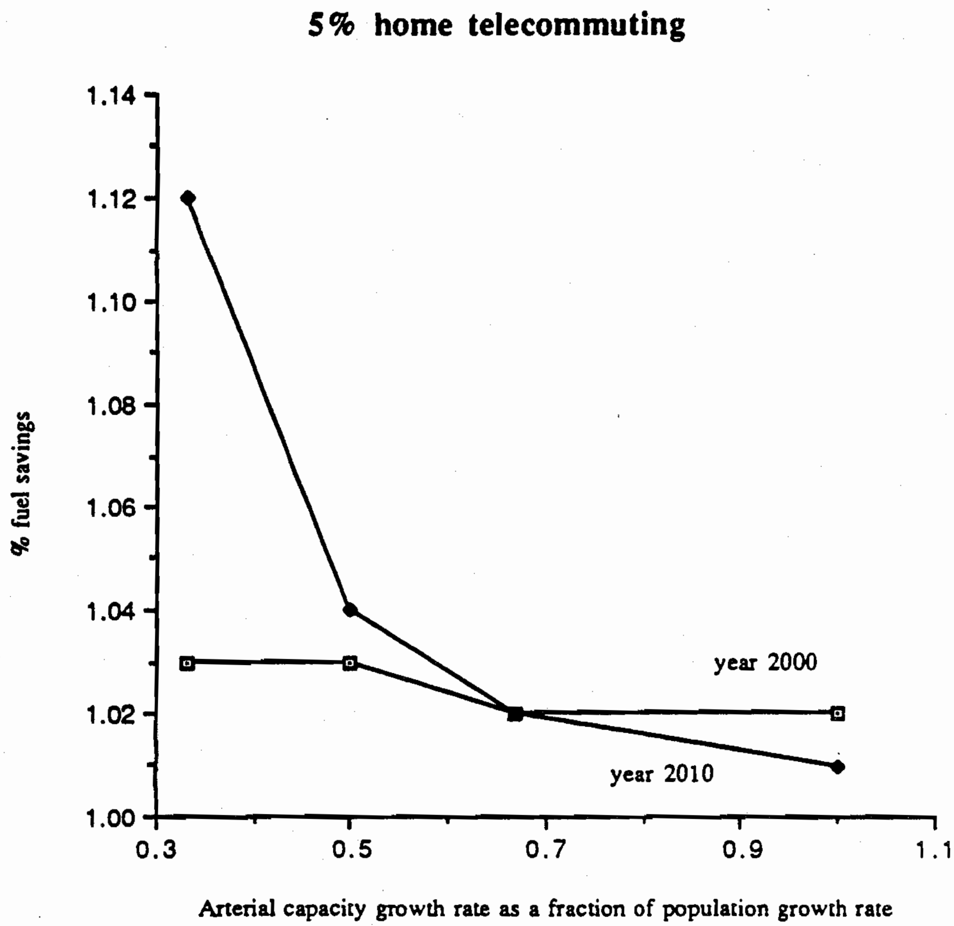


FIGURE 4.5: EFFECT OF CAPACITY ON PERCENTAGE FUEL SAVINGS IN AUSTIN: 5% HOME, 0% SATELLITE TELECOMMUTING




Figures 4.4 and 4.5 clearly illustrate that fuel savings due to telecommuting increase significantly in this model as average flows approach their theoretical limits. To further show the effect of capacity on fuel savings, an exercise was performed in which capacity is held constant over time and telecommuting scenarios are applied to observe for how many years telecommuting can ward off gridlock in absence of capacity improvements and in the face of rapid population

growth (about 3% annually in Austin). For Austin the model predicts that the theoretical limit for average flow in the major direction along arterials during peak the period will be reached by 2005 at the current level of capacity. Table 4.11 shows the results of applying home telecommuting scenarios to this situation.

TABLE 4.11: THE ABILITY OF TELECOMMUTING TO DELAY GRIDLOCK FLOW LEVELS: 1990 CAPACITY LEVEL CONSTANT

| Home telecommuting % | 0% | 5% | 10% | 15% | 20% | 25% |
|---|---|---|---|---|---|---|
| Year theoretical maximum average flow reached | 2005 | 2005 | 2006 | 2007 | 2008 | 2009 |

An additional point of interest involves comparing the number of lane-miles needed in the future to attain a certain level of average concentration with the amount of telecommuting necessary to achieve the same concentration. For example, it was determined that, in Austin, if 25% of employees with telecommutable jobs chose to telecommute between 1990 and 1993, the condition of traffic would stay about the same (average concentration increasing from 13.73 to 13.85). Alternatively, in absence of telecommuting, 106 additional lane-miles would be necessary in order to maintain similar condition of traffic over the same period. Whether this extra capacity comes from the construction of new lane-miles, the improvement of existing facilities, or the upgrading of collector streets to arterial status, 106 new lane-miles over a three year period is an extremely expensive proposition.

## DISCUSSION OF THE RESULTS AND LIMITATIONS OF THE MODEL

From this analysis, the factors most influential in determining the magnitude of telecommuting's impact on transportation include: area commute characteristics (average commute length, reliance on the automobile, and commuting VMT as a fraction of total VMT), network flows in relation to capacities, the population of telecommutable workers, and their propensity to telecommute. Of course the numbers reported here describing fuel consumption savings contain much uncertainty. For example, calculations for 1990 are based on rough estimates of the fraction of VMT occurring in the peak period which is defined as 7-9 A.M. and 4-6 P.M. In many large cities peak traffic conditions extend well beyond these hours. Several quick-response parameter estimates used in accordance with NCHRP Report 187 date back fifteen years or more. The two-fluid model parameter estimates used here to represent arterial network performance are adjusted estimates of CBD street performance. In particular, the values of the theoretical maximum average flow ("capacity") associated with the given parameter estimates are undoubtedly on the low side for several reasons including: 1) the observations on which the parameter estimates are based are very limited and did not include observations near the theoretical maximum, and 2) the average capacity of a grid network could be substantially less than that of long commuting arterials. The values of the fuel consumption parameter U are loosely based on test results from 1970s model vehicles. In the calculation of future savings the conjecture regarding model parameter values compounds the uncertainty.

Nevertheless, this model provides a reasonable and meaningful representation of the effect of realistic amounts of telecommuting based on the best data available and the behavioral evidence reported to date. The conceptual framework and model structure could be applied to any combination of demand or supply intervention strategies. In essence, the model is a simplification of an incredibly complex system, taking advantage of relationships among network traffic variables that have been shown to be remarkably robust in field observations and elaborate simulation experiments.

# CHAPTER 5
# MODELING THE EMPLOYEE TELECOMMUTING DECISION

## CONCEPTUAL FRAMEWORK

Clearly the impact of telecommuting on transportation systems in the future hinges on the rate at which telecommuting is adopted as a work arrangement. This chapter presents a disaggregate choice model of the decision to participate in a hypothetical cost-neutral telecommuting program offered to employees of information-related firms in the three Texas cities considered in this study: Austin, Dallas, and Houston. Employees were surveyed in an attempt to elicit information about their attitudes and stated preferences toward working from home.

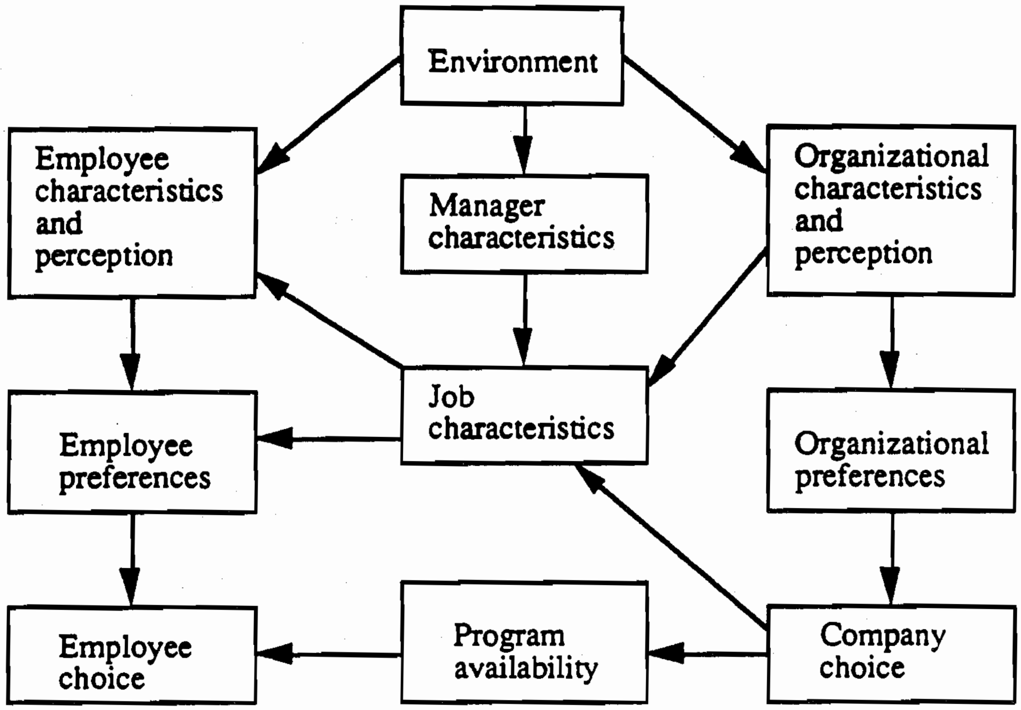
This chapter is concerned with identifying prevailing factors in the employee decision whether or not to telecommute. This choice process is illustrated in Figure 5.1 along with the organization's decision whether or not to offer a telecommuting option to its employees. In a given environment, characteristics of the employee, management, the firm, and jobs within the firm, determine attitudes and preferences concerning telecommuting. The employee is constrained by the firm's higher-order decision on program availability. Collective individual decisions produce the overall level of adoption which generates the travel impacts.

The chapter proceeds with a description of the survey instrument, including a summary of respondents' general characteristics, responses to attitudinal questions and stated preference scenarios. The third section describes the employee discrete choice model and reports the estimation results.

## THE SURVEY

The employee survey is divided into four parts. The first section contains a set of questions concerning general job characteristics, commuting habits, and communication activities at work. The second part is comprised of inquiries into attitudes toward commuting, work in general, and work at home. The next set of questions asks the respondent to select a work arrangement from a choice set consisting of various degrees of home telecommuting given a particular scenario of telecommuting cost allocation and salary. The final group of questions extracts socio-economic information and computer skill levels. This section contains a summary of the data collected from this survey. A detailed description of the survey and an exploratory analysis of the responses are presented in Mahmassani et al. (1992).

**Figure 5.1:** The telecommuting adoption process



**General characteristics of respondents**

Table 5.1 summarizes the socio-demographic characteristics of the survey respondents. A majority of 56% are female. Seventy five percent are between 18 and 40 years of age. Most of the respondents (92%) have attained a high education level, with 49% having completed college or university and 18% having attained a masters or Ph.D. degree. Household income is approximately normally distributed, with the mode in the range of $25,000 to $50,000 per year.

Employees were also asked about the number of telephone lines, FAX equipment, and personal computer availability at home, because such equipment may be of use for telecommuting. Only 13% of the respondents have more than one telephone number at home. The penetration of home FAX machines is still limited, with 98% of the respondents not owning such equipment. Personal computers are more prevalent, with 47% of respondents having at least one personal computer at home, and 5% reporting at least two units. However, only 7% use electronic databases or computer-based teleshopping.

To the extent that workers with good computer skills have been identified as a likely target group for telecommuting, the survey asked about proficiency levels in different computer-related skills. Among respondents, 76% have at least a medium level proficiency in the use of word processing packages, 50% for spreadsheets, 30% for data processing packages, 22% for computer language programming, and 33% for computer graphics packages. Overall, 84% of the respondents have at least one computer skill at medium or high level.

Thirty-four job titles were mentioned by the respondents, varying from president to engineer to clerk. These job titles are grouped into 12 categories based on three criteria: (1) power in the organizational strategic decision process, (2) schedule flexibility, and (3) suitability for telecommuting. These job titles and categories are listed in Table 5.2. Categories one (president/vice president) and two (manager/supervisor) have more power in the decision making process than others. Categories three (writer/editor), four (accountant/attorney), and five (agent) are assumed to have more schedule flexibility. Categories six (computer programmer), seven (data processing), and eight (engineer/researcher) are considered to have the most potential for telecommuting. Categories nine (field worker) and ten (receptionist/secretary), probably have the least potential for telecommuting. General employee (19%), engineer/researcher (18%), and manager/supervisor (16%) are the largest three job categories in the sample.

TABLE 5.1: INDIVIDUAL AND HOUSEHOLD CHARACTERISTICS

| Characteristics | Categories | Relative frequency (% |
|---|---|---|
| Gender | Male | 44.3 |
| | Female | 55.7 |
| Age | under 18 | 0.0 |
| | 18-30 | 35.6 |
| | 31-40 | 39.8 |
| | 41-50 | 17.4 |
| | 51-60 | 5.5 |
| | above 60 | 1.7 |
| Educational level | Finished high school | 4.2 |
| | Some college or university | 25.0 |
| | Finished college or univ. | 48.6 |
| | Master | 16.3 |
| | Ph.D. | 1.4 |
| | Other | 4.5 |
| Household income/year | Less than 25,000 | 12.7 |
| | 25,000-50,000 | 44.0 |
| | 50,000-75,000 | 28.9 |
| | More than 75,000 | 14.3 |
| Number of telephone lines at home | 0 | 2.0 |
| | 1 | 85.3 |
| | 2 | 11.5 |
| | 3 | 1.0 |
| | 4 | 0.1 |
| With FAX at home | Yes | 1.9 |
| | No | 98.1 |
| Subscription to electronic home-shopping | Yes | 6.5 |
| | No | 93.5 |

TABLE 5.1 (CONT.): INDIVIDUAL AND HOUSEHOLD CHARACTERISTICS

| Characteristics | Categories | Relative frequency (% |
|---|---|---|
| Number of personal computers at home | 0 | 53.1 |
| | 1 | 42.4 |
| | 2 | 3.5 |
| | 3 | 1.0 |
| Proficiency level in word processing | high | 40.3 |
| | medium | 35.3 |
| | low | 13.0 |
| | non-existent | 11.4 |
| Proficiency level in spreadsheets | high | 22.0 |
| | medium | 28.0 |
| | low | 22.0 |
| | non-existent | 28.0 |
| Proficiency level in data processing packages | high | 10.0 |
| | medium | 20.2 |
| | low | 25.4 |
| | non-existent | 44.4 |
| Proficiency level in computer programming | high | 13.7 |
| | medium | 8.2 |
| | low | 21.2 |
| | non-existent | 56.8 |
| Proficiency level in computer graphics packages | high | 14.5 |
| | medium | 18.8 |
| | low | 24.9 |
| | non-existent | 41.9 |

TABLE 5.2: JOB TITLE AND JOB CATEGORY

| Job category | Job title | freq* | perc* | freq** | perc** |
|---|---|---|---|---|---|
| President/vice pres. | President/vice pres. | 10 | 1.5 | 10 | 1.5 |
| Manager/supervisor | Director/administrator | 27 | 3.9 | 108 | 15.7 |
| | Senior associate | 12 | 1.7 | | |
| | Supervisor/manager | 54 | 7.9 | | |
| | Technical manager | 15 | 2.2 | | |
| Writer/editor | Writer | 7 | 1.0 | 60 | 8.7 |
| | Editor | 47 | 6.9 | | |
| | Photo research | 6 | 0.9 | | |
| Accountant/attorney | Accountant/tax consultant | 59 | 8.6 | 72 | 10.5 |
| | Attorney | 13 | 1.9 | | |
| Agent | Broker | 3 | 0.4 | 15 | 2.2 |
| | Real estate agent | 7 | 1.0 | | |
| | Travel agent | 5 | 0.7 | | |
| Computer programmer | Computer programmer | 57 | 8.3 | 57 | 8.3 |
| Data processing | Data processor | 10 | 1.5 | 14 | 2.0 |
| | Bookkeeper | 2 | 0.3 | | |
| | Typist | 2 | 0.3 | | |
| Engineer/researcher | Consultant | 12 | 1.7 | 122 | 17.8 |
| | Engineer/architect | 92 | 13.4 | | |
| | R & D scientist | 18 | 2.6 | | |
| Field worker | Clerk/general labor | 25 | 3.6 | 39 | 5.7 |
| | Registered nurse | 7 | 1.0 | | |
| | Teamster | 1 | 0.1 | | |
| | Plumber/mechanic/ carpenter | 6 | 0.9 | | |

TABLE 5.2 (CONT.): JOB TITLE AND JOB CATEGORY

| Job category | Job title | freq* | perc* | freq** | perc** |
|---|---|---|---|---|---|
| Receptionist/secretary | Receptionist | 3 | 0.4 | 49 | 7.1 |
| | Secretary | 46 | 6.7 | | |
| Coach/trainer | Coach | 1 | 0.1 | 8 | 1.2 |
| | School/community liaison | 4 | 0.6 | | |
| | Training specialist | 3 | 0.4 | | |
| General employee | Administration asst. | 37 | 5.4 | 132 | 19.2 |
| | Sales/marketing rep. | 47 | 6.9 | | |
| | General govt. employee | 1 | 0.1 | | |
| | Customer/support analyst | 36 | 5.2 | | |
| | Production coordinator | 11 | 1.6 | | |

* : for Job title

**: for Job category

**Responses to attitudinal questions**

The responses to the attitudinal questions are shown in Table 5.3. With regard to the first attitude pertaining to the transportation system, half of the commuters in the sample do not find commuting to work stressful (question 1). Thirty three percent think that the traffic is smooth from home to the workplace, while 41% think that it is congested. On the other hand, 24% of the respondents believe the traffic is smooth on the way back home, while 54% believe it is congested, confirming the finding in other studies that commuters experience a longer evening commute than in the morning (Mahmassani, Caplice and Walton, 1990).

With respect to the importance of working in the office, 60% of the respondents feel that it is essential to their work to have frequent input from their supervisor or co-workers, while less than 20% feel that it is not. In response to question 5, 44% believe that it is important for them to attend short-notice meetings during the work hours, while fewer respondents (36%) believe that it is not important. Seventy percent of the respondents find it is important to have immediate access to information or references available only at the office, while only 14% feel it is not important.

The responses to the questions that address the importance of social interaction with co-workers indicate that 50% of the respondents feel it is important to have social interactions with their co-workers at work (question 10), but only 13% feel it is important outside of work (question 11).

With regard to the job's suitability for telecommuting, only 21% of the respondents feel that their jobs are suitable for working from home everyday. This number increases to 38% when working from home is limited to several days per week. Interestingly, employees believe that their assessment of this matter is not likely to be shared by their supervisor: only 4% of respondents feel that their supervisors will approve of their working from home everyday. This percentage increases to 9% when working from home takes place only several days per week. Clearly, employees overwhelmingly perceive their supervisors as not likely to approve of their working from home. Furthermore, working from home several days per week is more acceptable than every day.

For the effects of telecommuting on job performance, 34% of the respondents feel that they could get more work done if they worked from home, while 40% feel that they could not (question 16). The response to question 18 indicates that 65% of the respondents feel that working from home will decrease their chances for promotion, while only 4% feel it will increase these chances. This is an important element that needs to be carefully addressed in efforts and programs to encourage telecommuting. Not surprisingly, 47% of the respondents feel that the flexibility of one's work schedule is important for accomplishing household duties, while 28% feel that it is not important (question 4). In response to question 17, 43% of the respondents feel that working from home will benefit their relationships with other household members, while 15% feel that it will affect these relationships adversely.

With regard to the seventh attitude, preference towards working independently, most of the respondents (70%) like to work independently, while only 8% dislike it (question 5). The response to question 6 also shows that most people (87%) would like to learn how to use new office equipment for their jobs.

TABLE 5.3: RESPONSES TO ATTITUDINAL QUESTIONS

| Questions | Responses (relative freq., in %) *1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Do you find commuting to work stressful? | 19.7 | 27.6 | 22.4 | 16.1 | 14.2 |
| 2. On a typical day, how would you describe the traffic you encounter on your way from home to your workplace? | 14.7 | 26.7 | 26.1 | 19.7 | 12.8 |
| 3. On a typical day, how would you describe the traffic you encounter on your way from your workplace to home? | 25.9 | 27.7 | 22.8 | 14.7 | 8.8 |
| 4. How important is flexibility of your work schedule for accomplishing your household duties? | 16.3 | 11.8 | 25.5 | 23.1 | 23.4 |
| 5. Would you like to work independently during more of your work time? | 2.8 | 5.2 | 21.8 | 24.3 | 45.9 |
| 6. How do you feel about learning to use new office equipment for your job? | 1.4 | 2.6 | 8.7 | 23.0 | 64.3 |
| 7. How essential to your work is frequent input from your supervisor or co-workers? | 5.7 | 12.9 | 21.3 | 25.8 | 34.3 |
| 8. How important is it for you to attend short-notice meetings during work hours? | 15.3 | 21.0 | 19.8 | 19.9 | 24.0 |
| 9. How important is it for you to have immediate access to information or references which are available only at work? | 4.5 | 9.1 | 16.6 | 22.1 | 47.7 |
| 10. How important to you are social interactions with your co-workers at work? | 11.0 | 12.9 | 26.0 | 27.6 | 22.5 |
| 11. How important to you are social interactions with your co-workers outside of work? | 35.6 | 29.9 | 21.8 | 9.2 | 3.5 |

TABLE 5.3 (CONT.): RESPONSES TO ATTITUDINAL QUESTIONS

| Questions | Responses (relative freq., in %) | | | | |
|---|---|---|---|---|---|
| 12. Do you think your job is suitable for working from home every day? | 45.3 | 18.3 | 15.2 | 12.7 | 8.5 |
| 13. Do you think your job is suitable for working from home several days per week? | 31.9 | 15.0 | 14.9 | 17.2 | 21.1 |
| 14. Do you think your supervisor would approve your working from home every day? | 71.6 | 16.5 | 8.3 | 2.8 | 0.9 |
| 15. Do you think your supervisor would approve your working from home several days per week? | 51.5 | 21.1 | 18.2 | 6.1 | 3.0 |
| 16. If you could work from home, do you think you could get more work done? | 24.5 | 15.1 | 26.0 | 15.5 | 18.9 |
| 17. If you could work from home, how do you think this would affect your relationship with other household members? | 5.9 | 9.0 | 42.1 | 18.8 | 24.2 |
| 18. If you could work from home, what effect do you think this would have on your chance for promotion? | 39.4 | 25.7 | 31.2 | 1.8 | 1.9 |

*With the exception of question No. 1, responses range from negative to positive

**Responses to stated preference scenarios**

Seven telecommuting program scenarios were defined in terms of 1) who assumes costs incurred in order to work from home, and 2) corresponding salary changes. These scenarios are as follows: (1) salary stays the same and employer pays all costs, (2) salary stays the same but the employee pays the cost of adding a new telephone number, (3) salary stays the same but the employee needs to buy a personal computer, (4) salary increases 5% and employer pays all costs, (5) salary increases 5% and the employee pays part of the costs, (6) salary decreases 5% but employer pays all costs, and (7) salary decreases 10% but employer pays all costs. For each alternative scenario, the employee was asked to state his/her preference in the form of one of the following responses: (1) working from home everyday, (2) working from home several days per week, (3) possibly working from home and (4) not to work from home. The third response option ("possibly") was not available for scenario (4). The responses to these alternative scenarios are summarized in Table 5.4.

Scenario 4 was designed to dominate all others (salary increases, no cost to employee), as confirmed by the results, with 86.1% of the respondents interested in telecommuting at least several days per week. Scenario 1 reflects the "status quo" (same salary, no cost to employee). Under this scenario, about 66% of the respondents will opt to work from home at least several days per week, with 22% indicating they do not rule it out. The desire to telecommute is quickly dampened as employees are asked to incur some of the additional costs that may be required. The percentage of willing telecommuters drops to 38% if the employee has to pay for an additional phone line (scenario 2), and to 29% if a computer must be purchased (scenario 3). Apparently a 5% increase in salary may not be sufficient to compensate for some of these costs (scenario 5), as suggested by the 28% categorical refusal to telecommute compared to about 12% under the status quo (scenario 1).

Salary decreases certainly do not encourage telecommuting, and appear to be even less tolerated than having to assume some of the costs of telecommuting. Under scenario 6 (5% salary decrease, no additional cost to employee), the percent of willing telecommuters decreases to 20.7%, and further drops to 10.2% if one has to give up 10% of their salary (scenario 7).

These results allow us to estimate the percentage of "hard core" telecommuters at no more than 15%, and those that would not even think of telecommuting also at about 15%. This means that the participation of the vast majority of employees in a telecommuting program will be highly dependent on the specifics of the program, particularly its cost implications. Employees do not appear to value telecommuting sufficiently to take a pay cut for the privilege. Some may be willing to incur a small cost to acquire necessary equipment.

It can also be noted that under all program scenarios, more employees would rather telecommute only a few days per week rather than every single day.

TABLE 5.4: RESPONSES TO STATED PREFERENCE SCENARIOS

| Telecommuting program scenario | Responses (relative freq in %) | | | |
|---|---|---|---|---|
| | * 1 | 2 | 3 | 4 |
| 1. Salary stays the same; employer pays all costs | 21.6 | 44.5 | 22.0 | 11.8 |
| 2. Salary stays the same; employee incurs the cost of a new telephone number | 11.9 | 25.8 | 33.4 | 28.9 |
| 3. Salary stays the same; employee buys a personal computer | 9.2 | 16.0 | 31.8 | 43.0 |
| 4. Salary increases 5%; employer pays all costs | 34.0 | 52.1 | ** | 13.8 |
| 5. Salary increases 5%; employer pays part of the costs | 16.2 | 28.2 | 27.8 | 27.8 |
| 6. Salary decreases 5%; employer pays all costs | 7.9 | 12.8 | 21.2 | 58.1 |
| 7. Salary decreases 10%; employer pays all costs | 5.2 | 5.0 | 12.4 | 77.4 |

* 1: Would like to work from home everyday.

2: Would like to work from home several days per week.

3: Possibly would like to work from home.

4: Do not want to work from home.

** This scenario only allowed three responses in the questionnaire.

## MODEL SPECIFICATION AND ESTIMATION RESULTS

The employee's decision to participate in a telecommuting program with the characteristics described earlier is modeled as a choice among four discrete alternatives, corresponding to the four possible responses to the question. The intent is to relate the employee's stated preferences towards telecommuting to the factors highlighted in Figure 5.1, namely the employee's individual and household characteristics, work and work-related attributes, as well as travel-related variables. This is accomplished by formulating and calibrating a multinomial logit model that relates the discrete response variable to a set of explanatory variables. To derive the specification and interpret the model, the response can be viewed as resulting from the relative magnitudes of four continuous latent variables (corresponding to each alternative, respectively) $U_{in}$, $i=1,2,3,4$, $n=1,...N$, reflecting employee n's preferences for a given option i. Each latent variable consists of a systematic component and a random component. The former captures the systematic effects from the observable factors mentioned previously. The latter captures unobservables. By assuming that the employee's response corresponds to the latent variable with the maximum value in the choice set, and that the random components are identically and independently Gumbel distributed across the observations, the probability that individual n chooses alternative i is given by the usual multinomial logit model form, namely:

$$P_n(i)=\frac{e^{\beta X_{in}}}{\sum_{j \in C_n} e^{\beta X_{jn}}}$$

where $C_n$ is the choice set, $\beta X_{in}$ represents the systematic component of alternative i with $\beta$ a vector of coefficients to be estimated and $X_{in}$ the vector of explanatory variables.

Tables 5.5 and 5.6 respectively contain summary statistics on the characteristics of the survey respondents for the specific relevant independent variables, and the frequency distribution of responses for each city (with corresponding percentages in parentheses).

TABLE 5.5: CHARACTERISTICS OF SURVEY RESPONDENTS

| Travel Variables | Mean | Std. deviation |
|---|---|---|
| round-trip commute time t;<br>0 if $t \leq 20$, t if $20<t<80$, 80 if $t \geq 80$ | 48.27 | 25.73 |
| commute stops per week | 5.17 | 4.57 |

| Work Variables | One | Zero |
|---|---|---|
| length of time with firm s;<br>1 if $s \geq 5$ years, 0 otherwise | 201 | 461 |
| avg. time using computer per day c;<br>1 if $c > 4$ hours, 0 otherwise | 379 | 283 |
| face-to-face communication f;<br>1 if response is several times per day with any group, 0 otherwise | 566 | 96 |
| work end time e;<br>1 if $e \geq$ 5:30 P.M., 0 otherwise | 329 | 333 |

| Socio-economic Variables | One | Zero |
|---|---|---|
| females w/ children; 1 if yes, 0 otherwise | 116 | 546 |
| males' household income y;<br>1 if y<$25,000 annually, 0 otherwise | 19 | 643 |
| gender; 1 if female, 0 if male | 366 | 296 |
| age a; 1 if $a \geq 50$ years old, 0 otherwise | 46 | 616 |
| marital status; 1 if married, 0 otherwise | 390 | 272 |

TABLE 5.6: DISTRIBUTION OF RESPONSES: A COST-NEUTRAL SCENARIO

| City | Full-time | Part-time | Possibly | No |
|---|---|---|---|---|
| Austin | 63 (18.2%) | 160 (46.2%) | 84 (24.3%) | 39 (11.3%) |
| Dallas | 43 (24.9%) | 72 (41.6%) | 35 (20.2%) | 23 (13.3%) |
| Houston | 36 (25.2%) | 62 (43.4%) | 30 (21.0%) | 15 (10.5%) |
| Total | 142 (21.5%) | 294 (44.4%) | 149 (22.5%) | 77 (11.6%) |

Table 5.7 presents the maximum-likelihood parameter estimates and corresponding to statistics for the pooled (over the three cities) employee choice model, calculated using SST software (SST User's Guide, 1988). The "No" response has been scaled to zero. As noted earlier, the explanatory variables can be grouped into three categories: travel-related, job-related, and socio-economic.

The two travel-related variables included in the model are round-trip commute time and average number of stops per week linked to the commute. The model reveals an inclination toward full-time home telecommuting associated with longer work commute times. The travel time variable, t, is defined as zero up to a round trip commute time of 20 minutes; t equals actual travel time through 80 minutes after which t equals 80. This desirable result implies that reductions in vehicle-miles traveled, fuel consumed, and pollutants emitted due to the absence of a telecommuter from an urban network will be greater relative to the average commuter. Also, the average number of stops per week along the work commute is positively related to both full-time and part-time alternatives. Presumably an individual reporting frequent stops along the work commute is predisposed toward telecommuting so as to enjoy greater schedule flexibility.

Four job-related variables appear in the model. All take the form of one-or-zero dummy variables. A length of service variable, s, equals one if the commuter has been employed by the same firm for five years or more. It is negatively related to both the full-time and part-time alternatives. It could be that employees who have maintained the same employer for five years or longer are relatively more comfortable with their jobs and with their office worksite. These employees would be less anxious to experiment with alternatives, particularly if they are in management-track positions.

TABLE 5.7: PARAMETER ESTIMATION RESULTS FOR THE POOLED MODEL

| Independent Variable | Full-time | Part-time | Possibly |
|---|---|---|---|
| constant | -0.49 (-1.20) | 0.18 (0.71) | 0.46 (1.69) |
| round-trip commute time t; 0 if t≤20, t if 20 <t<80, 80 if t ≥80 | 0.013 (3.04) | | |
| commute stops per week | 0.058 (2.66) | 0.058 (2.66) | |
| length of time with firm s; 1 if s ≥5 years, 0 otherwise | -0.58 (-3.08) | -0.58 (-3.08) | |
| avg. time using computer per day c; 1 if c ≥4 hours, else 0 | 0.80 (4.58) | 0.80 (4.58) | |
| face-to-face communication f; 1 if response is several times per day with any group, 0 otherwise | -0.54 (-2.10) | | |
| work end time e; 1 if e ≥ 5:30 P.M., 0 otherwise | -0.76 (-3.70) | | |
| females w/ children; 1 if yes, 0 otherwise | 0.86 (2.72) | 0.86 (2.72) | |
| males' household income y; 1 if y<$25,000 annually, 0 otherwise | 1.08 (2.16) | | |
| gender; 1 if female, 0 if male | 0.34 (1.79) | 0.34 (1.79) | |
| age a; 1 if a ≥50 years old, 0 otherwise | | -0.59 (-1.86) | -0.59 (-1.86) |
| marital status; 1 if married, 0 otherwise | 0.76 (3.00) | 0.76 (3.00) | 0.76 (3.00) |
| Number of Observations | 662 | | |
| Log-likelihood at zero | -917.73 | $r^2$=0.147 | |
| Log-likelihood at convergence | -782.91 | | |

A computer use variable, c, equals one where the employee spends at least four hours per day working at a computer. As expected, it is positively related both to the full-time and part-time alternatives. This variable is of particular interest to forecasting. As more jobs become computer-task-oriented and workers become more knowledgeable about and comfortable with computers one would expect more workers to become interested in home telecommuting, according to the model.

The communication variable, f, is one if the respondent replied that he/she experiences several instances per day of face-to-face communication with either supervisors, co-workers, subordinates, or customers. The coefficient is negative and significant with respect to the full-time alternative only. It appears that although the existence of regular face-to-face communication at work deters full-time home telecommuting, it does not automatically preclude its possibility, at least not in the opinion of the employee.

Finally, the variable representing work end time, e, equals one where the commuter's typical work end time is at or later than 5:30 P.M. Again, the coefficient is negative and significant with respect to the full-time alternative only. Possibly this variable represents another measure of the importance of schedule flexibility; i.e. an individual who must leave work before 5:30 might do this so as to attend to personal matters. Therefore that person would be more inclined to select full-time telecommuting than an individual who has no such constraints on work end time.

There are five socio-economic binary indicator variables in the model. First, there is a variable which equals one if the respondent is female and has children. The coefficient is positive with respect to both full-time and part-time telecommuting. In addition, gender, one where the respondent is female, is also positive and significant with regard to the same alternatives. It is clear women are much more inclined to choose telecommuting than men.

The marital status variable is positive and significant with respect to all three non-negative choices. There is also an income variable for men only, i, which is one where the respondent reported household income less than $25,000. The coefficient of the income variable is positive and related to the full-time alternative only. The age variable equals one when the respondent is over 50 years old. The coefficient of the age variable is negative and pertinent only to the part-time and possibly alternatives.

Variables that were examined in different forms but omitted due to statistical insignificance include commute mode, education, computer ownership, and various computer skill levels. The estimation results for each city separately are shown in Tables 5.8-5.10. As mentioned previously, the model is calibrated with pooled data from the three cities included in the study.

The transferability of the parameters is supported by the results of a likelihood ratio test comparing the log likelihood values of the pooled, or fully restricted model shown in Table 5.3, and an unrestricted model in which each parameter is specific to each city (Ben-Akiva and Lerman, 1985). The test statistic for this likelihood ratio test is given by

$$2[L_{pooled}(\beta) - (L_{Austin}(\beta) + L_{Dallas}(\beta) + L_{Houston}(\beta))]$$

This test statistic is $c^2$ distributed with degrees of freedom equal to the number of restrictions, that is, $(K_{Austin} + K_{Dallas} + K_{Houston}) - K_{pooled}$ where $K_j$ represents the number of coefficients on the corresponding model. Here the test statistic equals 2[782.91 - (402.93 + 207.30 + 158.83)] = 27.7. $c^2_{28,.05} = 41.3$ so the hypothesis that the coefficients are identical across cities can not be rejected.

As Figure 5.1 implies, the decision-making process involved in the telecommuting choice is rather complex. It is likely that in most cases today the process never commences from lack of awareness on the part of individuals involved: executives, managers, and employees alike. In time, as the concept spreads via various media as well as through active efforts of various agencies concerned with air quality, fuel consumption, and urban traffic congestion, perhaps more workers will be able to choose their workplace much as they would choose a commute mode. The availability of the telecommuting option is the crucial constraint to the employee decision described in the left-hand portion of Figure 5.1 and modeled in Table 5.7. Still, the Texas data indicate that the employee telecommuting decision can be modeled quite well with stated preference information. The model is a step toward a profile of the likely future telecommuter.

TABLE 5.8: PARAMETER ESTIMATION RESULTS FOR AUSTIN

| Independent Variable | Full-time | Part-time | Possibly |
|---|---|---|---|
| constant | -0.49 (-0.83) | 0.35 (0.91) | 0.69 (2.50) |
| round-trip commute time t; 0 if t≤20, t if 20 <t<80, 80 if t ≥80 | 0.012 (3.04) | | |
| commute stops per week | 0.062 (2.66) | 0.062 (2.66) | |
| length of time with firm s; 1 if s ≥5 years, 0 otherwise | -0.67 (-2.55) | -0.67 (-2.55) | |
| avg. time using computer per day c; 1 if c ≥4 hours, else 0 | 0.79 (3.24) | 0.79 (3.24) | |
| face-to-face communication f; 1 if response is several times per day with any group, 0 otherwise | -0.50 (-1.37) | | |
| work end time e; 1 if e ≥ 5:30 P.M., 0 otherwise | -0.61 (-2.01) | | |
| females w/ children; 1 if yes, 0 otherwise | 0.64 (1.48) | 0.64 (1.48) | |
| males' household income y; 1 if y<$25,000 annually, 0 otherwise | 1.59 (2.62) | | |
| gender; 1 if female, 0 if male | 0.52 (2.01) | 0.52 (2.01) | |
| age a; 1 if a ≥50 years old, 0 otherwise | | -1.21 (-2.30) | -1.21 (-2.30) |
| marital status; 1 if married, 0 otherwise | 0.31 (0.87) | 0.31 (0.87) | 0.31 (0.87) |
| Number of Observations | 346 | | |
| Log-likelihood at zero | -479.66 | $r^2$=0.160 | |
| Log-likelihood at convergence | -402.93 | | |

TABLE 5.9: PARAMETER ESTIMATION RESULTS FOR DALLAS

| Independent Variable | Full-time | Part-time | Possibly |
|---|---|---|---|
| constant | -0.99 (-1.07) | 0.081 (0.18) | -0.40 (-1.16) |
| round-trip commute time t; 0 if t≤20, t if 20 <t<80, 80 if t ≥80 | 0.014 (1.46) | | |
| commute stops per week | 0.032 (0.73) | 0.032 (0.73) | |
| length of time with firm s; 1 if s ≥5 years, 0 otherwise | -0.46 (-1.17) | -0.46 (-1.17) | |
| avg. time using computer per day c; 1 if c ≥4 hours, else 0 | 0.76 (2.15) | 0.76 (2.15) | |
| face-to-face communication f; 1 if response is several times per day with any group, 0 otherwise | -0.27 (-0.51) | | |
| work end time e; 1 if e ≥ 5:30 P.M., 0 otherwise | -0.89 (-2.27) | | |
| females w/ children; 1 if yes, 0 otherwise | 1.06 (1.78) | 1.06 (1.78) | |
| males' household income y; 1 if y<$25,000 annually, 0 otherwise | -0.39 (-0.33) | | |
| gender; 1 if female, 0 if male | -0.25 (-0.64) | -0.25 (-0.64) | |
| age a; 1 if a ≥50 years old, 0 otherwise | | -0.42 (-0.80) | -0.42 (-0.80) |
| marital status; 1 if married, 0 otherwise | 1.72 (3.44) | 1.72 (3.44) | 1.72 (3.44) |
| Number of Observations | 173 | | |
| Log-likelihood at zero | -239.83 | $r^2$=0.136 | |
| Log-likelihood at convergence | -207.30 | | |

TABLE 5.10: PARAMETER ESTIMATION RESULTS FOR HOUSTON

| Independent Variable | Full-time | Part-time | Possibly |
|---|---|---|---|
| constant | 0.071 (0.08) | -0.24 (-0.42) | 0.24 (0.58) |
| round-trip commute time t; 0 if t≤20, t if 20 <t<80, 80 if t ≥80 | 0.007 (0.81) | | |
| commute stops per week | 0.11 (1.88) | 0.11 (1.88) | |
| length of time with firm s; 1 if s ≥5 years, 0 otherwise | -0.67 (-1.62) | -0.67 (-1.62) | |
| avg. time using computer per day c; 1 if c ≥4 hours, else 0 | 1.27 (3.03) | 1.27 (3.03) | |
| face-to-face communication f; 1 if response is several times per day with any group, 0 otherwise | -1.00(-1.82) | | |
| work end time e; 1 if e ≥ 5:30 P.M., 0 otherwise | -1.00 (-2.33) | | |
| females w/ children; 1 if yes, 0 otherwise | 1.28 (1.54) | 1.28 (1.54) | |
| males' household income y; 1 if y<$25,000 annually, 0 otherwise | 8.50 (0.16) | | |
| gender; 1 if female, 0 if male | 0.60 (1.37) | 0.60 (1.37) | |
| age a; 1 if a ≥50 years old, 0 otherwise | | 0.13 (0.21) | 0.13 (0.21) |
| marital status; 1 if married, 0 otherwise | 0.86 (1.48) | 0.86 (1.48) | 0.86 (1.48) |
| Number of Observations | 143 | | |
| Log-likelihood at zero | -198.24 | $r^2$=0.199 | |
| Log-likelihood at convergence | -158.83 | | |

# CHAPTER 6
# SUMMARY AND RECOMMENDATIONS

## SUMMARY

Telecommuting has achieved recognition in several states and foreign countries as a means to reduce trip-making during the peak period. Evidence to date suggests that telecommuting can effectively eliminate commute trips without creating new travel. If true, telecommuting holds vast potential to mitigate urban traffic congestion. Decreased network fuel consumption and improved air quality are two primary benefits associated with reduced automobile use.

In light of Federal Clean Air Act Amendment of 1990 standards, telecommuting has been mentioned in legislative policy as a transportation demand management (TDM) strategy in non-attainment areas. Where firms are required to reduce peak hour commuting by its employees, telecommuting is an effective strategy, along with staggered work start times, the four day work week, and other programs. This development in the legislative arena lends an urgency to all aspects of telecommuting research.

The literature on telecommuting is evolving away from broad theoretical work based on a technological substitution perspective toward a system of behavioral models which better represent the compound decisions involving employer adoption, employee participation, tripmaking effects, and long-term location decisions. Researchers will have a better idea to what extent telecommuting is occurring at present as definitional issues are resolved. The vast literature on factors affecting adoption and participation decisions has fostered attempts to model these complex phenomena, utilizing stated preference techniques.

Pilot studies have provided valuable insight into the necessary ingredients to a successful telecommuting experience. The first indications of the impact of telecommuting on tripmaking have been reported recently. Observations of ongoing projects will be helpful in identifying long-term effects on auto ownership, residential location, and office location that contain broad implications for land use and transportation networks. The first satellite telecommuting experiments have begun in Washington and California, promising a better understanding of the costs, benefits, management of, and transportation impact of satellite work centers.

This study has presented a model of network fuel consumption savings due to telecommuting that incorporates the direct effect of removing vehicles from the network and the indirect effect of their removal on vehicles remaining in the network. The indirect effect is present only during peak driving hours where interactions between driver-vehicle units are most critical to system performance and along arterial streets where benefits are derived from increased average speeds up to about 40 MPH. The model's primary inputs are system supply and demand assumptions, two-fluid model parameters, fuel consumption characteristics, and current estimates of the effect of telecommuting on tripmaking at the individual and household level. Several scenarios of telecommuting participation have been applied to obtain estimates of potential fuel savings for different levels of telecommuting activity in Austin, Dallas, and Houston.

The results of the model's execution indicate a more-or-less linear relationship between the percentage of information workers per day who choose to telecommute and the network percentage fuel savings. This is due to the fact that peak period arterial travel, in which the nonlinear indirect effect on vehicles remaining on the network is introduced, accounts for only about ten percent of all VMT. Only where average flows approach capacity are the nonlinear effects noticeable. Certainly there are several areas nationwide suffering congestion at or near capacity today and several more just a few years away. In these cities telecommuting can be particularly effective at reducing congestion and network fuel consumption. Further analysis illustrates the amount of time that telecommuting can extend the sub-capacity lifetime of networks aided by little or no growth in the number of lane-miles.

Additionally, an employee participation choice model was presented herein. Several factors are identified that contribute to individual telecommuting decisions, based on stated preference responses to a cost-neutral telecommuting scenario. This exploratory analysis points toward an integrated set of choice models to enhance the scenario approach used here. Indeed, the anticipated number of people who *will* telecommute is a central element of the fuel consumption savings model developed in this study.

## SUGGESTIONS FOR FURTHER RESEARCH

Topics for telecommuting-related research are abundant. First, on forecasting the amount of telecommuting to expect, further analysis of the telecommutability of specific jobs and tasks within various industry sectors should help to better define the universe of potential telecommuters. Extensive data collection is still needed in order to develop an understanding of the attitudes and preferences of managers and executives. It is still uncertain to what extent the reported rise in telecommuting in recent years is due to market forces, i.e. managers implementing programs, or simply a result of manipulated definitions. More extensive cost-benefit models from current and ongoing pilot projects would be useful to firms considering telecommuting as a response to compulsory commute reduction legislation. In fact, much still needs to be resolved on the issue of the effect of cost allocation on individual telecommuting choices.

Limitations of the fuel consumption savings model presented here underscore several areas of need for additional research. More evidence is needed on the impact of telecommuting on the spatial and temporal distribution of trips. Simulation experiments present an opportunity to identify effects of behavioral changes due to telecommuting on network flows. Currently the model does not address interactive fuel consumption effects on freeways. Helpful research would include developing relationships between average freeway flows and the amount of time vehicles spend traveling in various speed ranges that have different fuel consumption implications. Freeway travel simulation experiments could lend insight into this issue.

Data from ongoing projects can provide needed information concerning long-term impacts of telecommuting. Little is understood about the dynamics of participation in a telecommuting program, such as reneging. Only limited information is available concerning personality profiles of effective telecommuters.

Opportunities to study the feasibility of satellite centers have only recently become possible. Evidence is scant regarding the presence of economic incentive for firms. A related issue, telecommunications potential in rural economic development is beginning to generate interest in the field.

Ultimately, telecommuting models must be integrated into the planning process at all levels. Telecommunications impact on location decisions must be included in land use models. The effect of telecommuting on travel behavior must be accounted for in the trip generation, trip distribution, mode choice, and traffic assignment stages of traditional transportation planning models. Then the fuel consumption and air quality impacts can be analyzed. An additional modeling challenge is presented by the implications of telecommuting for total regional energy use. Benefits to society in the form of reduced fuel consumption may be offset by the effect of work decentralization on other energy sources.

Despite the attention telecommuting has received in the last decade from researchers across disciplines, many questions remain outside the scope of the current pool of information on the subject. In spite of this, telecommuting is now recognized widely as a legitimate means of reducing peak period travel, particularly in urban areas that are in violation of Federal Clean Air Act standards. In the context of transportation research, emphasis must be placed on developing behavioral models of employer adoption and employee participation for forecasting the amount of telecommuting to expect, identifying the implications of the resulting new work arrangements on travel behavior, and integrating telecommuting decisions into transportation planning models to examine the effects on traffic congestion, energy, and air quality.

# APPENDIX

The following is a list of telecommutable jobs and their relative ratings found in Schepp (1990).

| JOB | RATING |
|---|---|
| Abstracter | 7.5 |
| Accountant | 8.5 |
| Actuary | 8.0 |
| Advertising copy writer | 7.0 |
| Advertising representative | 7.5 |
| Architect | 8.25 |
| Auditor | 8.0 |
| Bank officer | 7.5 |
| Book author | 8.5 |
| Booking agent | 7.0 |
| Bookeeper | 7.0 |
| Budget analyst | 7.5 |
| Chief executive officer | 8.0 |
| City manager | 7.0 |
| Columnist | 8.0 |
| Computer service technician | 8.5 |
| Computer systems analyst | 9.5 |
| Consultant | 8.0 |
| Copy editor | 7.75 |
| Correspondent | 8.5 |
| Cost estimator | 7.25 |

| | |
|---|---|
| Critic | 8.0 |
| Customer service representative | 7.5 |
| Data entry clerk | 8.75 |
| Database administrator | 8.25 |
| Desktop publisher | 9.0 |
| Economist | 7.75 |
| Editorial writer | 8.0 |
| Educational consultant | 7.75 |
| Educational software writer | 8.0 |
| Electronic news editor | 7.75 |
| Freelance writer | 8.75 |
| Fundraiser | 8.5 |
| Heart specialist | 6.75 |
| Illustrator | 8.0 |
| Indexer | 8.25 |
| Information broker | 8.5 |
| Insurance claims representative | 7.75 |
| Judge | 7.0 |
| Lawyer | 8.75 |
| Legal assistant | 8.75 |
| Market research analyst | 8.25 |
| Medical records technician | 8.25 |
| News reporter | 9.25 |
| Operations research analyst | 8.0 |
| Pathologist | 6.75 |
| Pollster | 7.5 |
| Probation officer | 8.25 |

| | |
|---|---|
| Professor | 7.0 |
| Programmer | 10.0 |
| Psychologist | 8.0 |
| Public relations professional | 9.25 |
| Purchasing agent | 6.75 |
| Radio announcer | 6.75 |
| Radiologist | 7.0 |
| Real estate agent | 8.25 |
| Records manager | 7.75 |
| Registered nurse | 7.75 |
| Researcher | 8.5 |
| Reservations agent | 7.5 |
| Sales representative | 9.75 |
| Secretary | 6.75 |
| Social worker | 7.5 |
| Software engineer | 9.75 |
| Speechwriter | 8.25 |
| Sportswriter | 9.25 |
| Stockbroker | 9.0 |
| Technical writer | 9.0 |
| Telemarketer | 8.5 |
| Transcriber | 8.25 |
| Translator | 10.0 |
| Travel agent | 7.75 |
| Typesetter | 7.25 |
| Urban planner | 8.0 |
| Word processor | 8.0 |

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