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The Costs and Benefits of Home-Based Telecommuting

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This report evaluates the costs and benefits of home-based telecommuting. Combining empirical data from the literature with a Monte Carlo simulation technique, a distribution of cost-benefit ratios is produced from three perspectives: the employer, the telecommuter, and the public sector.... Depending on the underlying assumptions, the results indicate that telecommuter benefit-cost ratios are generally above one if the employer bears the majority of the equipment cost burden. ...Even when parking and office space benefits are included, productivity lies at the heart of the telecommuting cost-benefit analysis from the employer's perspective, and in almost all cases, the employer's case relies on some assumed maintenance or increase in productivity as the primary benefit. It is also shown that the potential for office and parking space benefits are high, although these benefits remain somewhat questionable. ...Based on our analysis, we conclude that the public sector air quality and construction avoidance benefits remain somewhat questionable based on the current knowledge, and difficult to justify.... Keywords: telecommuting, cost-benefit analysis, simulation, telecommunication

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THE COSTS AND BENEFITS OF HOME-BASED TELECOMMUTING

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ABSTRACT

This report evaluates the costs and benefits of home-based telecommuting. Combining empirical data from the literature with a Monte Carlo simulation technique, a distribution of cost-benefit ratios is produced from three perspectives: the employer, the telecommuter, and the public sector. The study develops a new framework that identifies costs and benefits associated with telecommuting. As part of this new framework, we allow the quantification of many of the uncertainties associated with telecommuting, such as air quality benefits or productivity benefits.

Depending on the underlying assumptions, the results indicate that telecommuter benefit-cost ratios are generally above one if the employer bears the majority of the equipment cost burden. If the telecommuter is required to purchase new equipment (i.e., a computer and software), it is probable for the telecommuter to experience benefit-cost ratios less than one – the “break-even” point – even when the telecommuter is faced with long commute distances.

For the employer, the cost-effectiveness of telecommuting is dependent largely on productivity benefits. Still, employers need only to experience a reasonable gain in total productivity – approximately 15% or more on telecommuting days, for an employee earning $35,000 per year – to balance the costs. Even when parking and office space benefits are included, productivity lies at the heart of the telecommuting cost-benefit analysis from the employer’s perspective, and in almost all cases, the employer’s case relies on some assumed maintenance or increase in productivity as the primary benefit. It is also shown that the potential for office and parking space benefits are high, although these benefits remain somewhat questionable.

Based on our analysis, we conclude that the public sector air quality and construction avoidance benefits remain somewhat questionable based on the current knowledge, and difficult to justify. The only plausible scenarios with significant public sector benefits occur 1) over a small, localized area (such as along a single transportation corridor) or 2) within a single non-attainment air quality basin where the air quality benefits can be aggregated and used toward meeting attainment goals. Still, given these conditions, the measurable public sector benefits are negligible because conservative input assumptions prevent the benefits from exceeding the losses caused by reduced fuel tax revenues.

This report identifies situations during which telecommuting is most attractive as a travel demand measure to its primary stakeholders: the telecommuter and the employer. Also included with this report is the TELESIMM (telecommuting economic simulation model) spreadsheet and program that can be used to perform Monte Carlo simulations on critical input values. The spreadsheet can be customized by individual users or modified by other researchers as better data become available.

Keywords: telecommuting, cost-benefit analysis, simulation, telecommunication

1.0 INTRODUCTION

1.1 Preface

Recent technological advances in the personal computer and telecommunications sectors have made information more accessible and telecommuting more viable than ever. Yet despite continued claims of great potential for mitigating urban traffic congestion and improving air quality, important questions remain unanswered regarding the cost-effectiveness of telecommuting as a business operations strategy. The question of cost-effectiveness, however, depends on the perspective (Handy & Mokhtarian, 1995):

- Transportation planners, along with other segments of the public sector, see telecommuting as a solution for mitigating urban traffic congestion, and as a way to conserve energy and improve air quality;
- Businesses, along with other segments of the private sector, see telecommuting as a way to increase productivity while decreasing overhead costs;
- Individual workers see telecommuting as a flexible work arrangement that (among other potential advantages) helps to alleviate travel expenses, delay, and stress associated with most urban commute trips.

Ideally, telecommuting would be both an attractive public transportation policy and a cost-effective business strategy for companies and individuals. Telecommuting probably will not be an acceptable work alternative to the telecommuter or the employer if it is not cost-effective. The transportation benefits of telecommuting depend on the extent to which it is adopted and that extent can be best identified by objectively evaluating telecommuting and outlining the conditions under which it is most attractive to participants.

While the need for examining the cost-effectiveness of telecommuting has been acknowledged since the 1970s (see the quotation at the beginning of Chapter 2), the most notable research regarding the specific economic factors associated with telecommuting did not occur until the early 1990s, largely because of the uncertainties involved in quantifying costs and benefits. By the early 1990s, however, transportation planners in federal, state, and local governments were identifying telecommuting as an important transportation demand management (TDM) strategy. Additional recognition came, in part, from the ability of telecommuting to help meet federal Clean Air Act requirements. The Clean Air Act Amendments (1990) required states to include employer-based trip reduction programs in their state implementation plans.

In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) provided even greater flexibility for state and local governments to meet these requirements through travel demand measures (TDMs), such as telecommuting. Moreover, TDMs such as telecommuting became eligible for funding through the Congestion Mitigation and Air Quality (CMAQ) Program, as well as through the Surface Transportation Program (STP) (DOT, 1997).

1.2 Definitions

Telecommuting is defined as "the partial or total substitution of telecommunications ... for the commute to work" (Nilles, 1988, p. 301). There are two types of telecommuting: *home-based telecommuting* and *center-based telecommuting*. As the name suggests, home-based telecommuting involves working from home with communication to the office, while center-based telecommuting involves work from a local or regional satellite office. From a transportation perspective, home-based telecommuting is likely to *eliminate* entire commute trips, while center-based telecommuting is likely to *reduce* commute trip lengths. For the purpose of this study, only home-based telecommuting will be considered; however, some of the conclusions may apply to both forms of telecommuting.

1.3 Defining the Project: Research Objectives and Hypotheses

The purpose of this study is to conduct a cost-effectiveness analysis of home-based telecommuting using simulation methods. The primary objectives of this research include:

- Developing a suitable framework for future economic analysis of telecommuting;
- Identifying key known and unknown data inputs;
- Simultaneously assessing the economic impact of home-based telecommuting from the public and private perspectives;
- Identifying and conducting sensitivity analyses for key variables;
- Providing policy and implementation recommendations on the general conditions under which telecommuting benefits may be maximized.

Starting with a null hypothesis of no *net* difference in costs and benefits to an individual – or a company, or the public sector – on a telecommuting day compared to a non-telecommute day, we address the following questions:

- Under what conditions is the business case for telecommuting supported or weakened?
- What are the potential public sector impacts of telecommuting?
- How realistic are the estimates of public sector telecommuting impacts, and what public policy considerations arise regarding telecommuting at the federal, state, regional, and local levels?

1.4 Contributions of This Report to the Literature

This report fills a gap in the telecommuting literature by defining a formal framework for the economic evaluation of telecommuting. Using the framework, empirical results from past telecommuting research are collected and utilized as input values in a cost-benefit simulation. This study also contributes to the literature by clearly documenting important assumptions and identifying unknowns – thereby advancing the "benchmarking" of necessary inputs until better data become available. The identification of key factors that have dramatic importance to the final outcome (as well as the identification of negligible factors that have little impact on the final outcome) is also an important contribution to the literature.

This report also implements the new methodological framework, combining economic and statistical theory, with a modifiable, spreadsheet model. Moreover, some effort has been invested in advancing previous research that addresses the growth of telecommuting. This report appears to be one of the first studies to take into account the impact of telecommuting attrition, and its associated costs, on the cost-benefit calculation. New contributions have also been made by proposing and evaluating theoretical scenarios that affect the costs and benefits. Finally, this report identifies gaps in the literature and presents suggestions for future research. Altogether, this study offers a rigorous analysis of both public and private costs and benefits of telecommuting and addresses the role of the public sector in supporting or facilitating telecommuting programs.

1.5 Report Organization

This report is organized into seven chapters. Chapter 2 contains a brief review of the relevant literature. Particular attention is paid to those studies that have provided the foundation for this report. In Chapter 3, the cost-benefit analysis methodology is discussed in detail. First, justification is provided for selecting cost-benefit analysis as the economic evaluation criterion. Next, the major analysis steps are identified, along with methodological limitations. One of the major limitations, uncertainty, is addressed by using a Monte Carlo simulation technique, using the *Visual Basic for Applications* programming language. Both the simulation technique and the programming language are also briefly discussed in this section.

In Chapter 4, each calculation is explained and presented along with a discussion of inputs and a sample calculation – as performed in the cost-benefit analysis spreadsheet. After the inputs and assumptions have been fully discussed, results are presented in Chapter 5 with additional sensitivity analysis in Chapter 6. Sensitivity analysis is conducted on key inputs and assumptions as well as on exploratory hypothetical scenarios. This report concludes with a review of major findings and limitations, as well as a discussion of areas for future research.

2.0 BACKGROUND

> Existence of this economic advantage is a necessary, if not sufficient, condition for the decision by an individual or agency to engage in telecommuting. (Nilles, *et al.*, 1976, p. 5)

In the early 1970s researchers realized the importance of establishing and promoting the economic benefits of telecommuting. Since that time, however, telecommuting literature has largely focused on the implementation or adoption of telecommuting (Bernardino, *et al.*, 1993; Gordon, 1986; Gray, *et al.*, 1993; Kugelmass, 1995; Nilles 1994; Mahmassani, *et al.*, 1993; Mokhtarian and Salomon, 1996; Mokhtarian and Salomon, 1997) and the advantages and disadvantages of telecommuting (Bernardino and Ben-Akiva, 1996; Duxbury, *et al.*, 1987; Katz, 1987; Yen, *et al.*, 1994). While substantial contributions have been made to understanding the advantages and disadvantages of telecommuting, as well as the individual behavioral aspects of adoption and implementation of telecommuting, serious attempts were not made to examine the costs and benefits of telecommuting until the early 1990s.

In particular, this report extends the 1993 U.S. Department of Transportation report entitled, *Transportation Implications of Telecommuting* (DOT, 1993). In that report, a spreadsheet model is presented that takes a public, macro-scale approach to evaluating home- and center-based telecommuting and their direct transportation impacts, such as vehicle-miles saved, avoided air pollution, avoided fatalities, time savings, and gasoline savings.

In 1994, a U.S. Department of Energy (DOE) report, entitled *Energy, Emissions,* *and Social Consequences of Telecommuting,* extended the DOT report by adding a new set of assumptions and by expanding the results to address some of the indirect impacts, such as energy use and emissions. Aside from further documenting the uncertainty associated with telecommuting growth and quantifying its impacts, the primary contribution of that study was a discussion of methods for monetizing air quality and construction benefits. Another major contribution was the attempt to quantify the impacts of latent demand and land use changes due to telecommuting.

Prior to these two macro-scale reports, several micro-scale evaluations had been conducted by local or regional governments. In 1990, the Southern California Association of Governments (SCAG, 1990) and the County of San Diego Department of Public Works (CSD-DPW, 1990) published reports based on telecommuting pilot projects. Additional reports on telecommuting demonstration projects by the State of California (JALA Associates, 1990) and the City of Los Angeles (JALA International, 1993) are prominent micro-scale studies that contributed to this report. From these reports, we are able to see some of the micro-scale, telecommuter and employer costs and benefits, such as additional training costs, communication costs, equipment costs, home energy costs, and miscellaneous telecommuter benefits.

Both theory and data from these micro- and macro-scale studies have been combined and used as a foundation for this report to develop a new and more comprehensive telecommuting cost benefit model. For critical analysis of these and other studies mentioned in this chapter, the reader is encouraged to see the previous work by Shafizadeh, *et al. (*1998) and Shafizadeh, *et al. (*2000).

3.0 STUDY METHODOLOGY

In this chapter, a new telecommuting cost-benefit framework is presented. Discussion then turns to the selection and justification of cost-benefit analysis as the economic evaluation method. We then review the major stages of a typical CBA and discuss its limitations. Next, Monte Carlo simulation is discussed as a tool to quantify the uncertainty in the CBA. Finally, the advantages and disadvantages of the *Visual Basic for Applications* (VBA) programming language are briefly discussed.

3.1 A New Telecommuting Cost-Benefit Framework

As noted in previous sections, the uncertainty involved with quantifying certain aspects of telecommuting has limited the scope of past cost-benefit evaluations of telecommuting. Although this study faces many of the same limitations, the uncertainty associated with assigning a single value to each critical unknown is addressed by the analysis framework. That is, critical unknowns are identified and allowed to vary *over a range of acceptable values*. These ranges are then input into a cost-benefit spreadsheet. Thus, the results of this analysis yield a *range of possible outcomes.* This allows us to identify the factors that most contribute to a higher yield of benefits to costs, or a higher yield of costs to benefits, as the case may be.

3.2 Selecting and Applying CBA as the Evaluation Criterion

Cost-benefit analysis was chosen as the evaluation technique for this analysis. First of all, CBA seems to be the preferred methodology in several of the telecommuting studies reviewed for this report (e.g., Southern California Association of Governments, 1988; County of San Diego Department of Public Works, 1990; State of California, 1990; City of Los Angeles, 1993).[1] Additionally, CBA appears to have a firm role within public policy decisions. In the federal government, formal CBA techniques have been required to support environmental regulation since the early 1970s, and in 1981 Presidential Executive Order 12291 explicitly required the application of CBA to new regulations (Hanley and Spash, 1993). CBA was also selected because the results in dollars should allow for the comparison of similar results for other TDMs. In general, various limitations of CBA have been recognized (and these will be discussed), yet it remains an endorsed economic evaluation criterion in public policy (as noted in Hanley and Spash, 1993; Hurter, *et al.*, 1982; Halvorson and Ruby, 1981; Swartzman, *et al.*, 1982).

The theory and methodology of cost-benefit analysis as presently employed is well-documented (Dasgupta and Pierce, 1972; Maass, 1966; Mishan 1976; Sassone and Schaffer, 1978; Zerbe and Dively; 1994). In general, six stages should be present in any cost-benefit analysis (Hanley and Spash, 1993)[2]:

1. defining the project,
2. identifying impacts (costs and benefits) that are economically relevant,
3. quantifying the relevant impacts,
4. calculating monetary valuation,
5. discounting and determining the net present value, and

---

[1] Although the studies often did not show cost-benefit spreadsheets or even their calculations, results were typically presented in terms of a benefit to cost ratio.
[2] As Hanley and Spash note, “whilst many will disagree on how these steps are identified, the following structure provides a guide to the essential steps” (Hanley and Spash, 1993, p. 8).

6. sensitivity analysis.

Stage 1: Defining the Project

The project definition step sets the boundaries of the analysis. Simply put, "the main reason for defining is that a project cannot be appraised unless what is to be appraised is known" (Hanley and Spash, 1993, p. 8). Additionally, clear project definition facilitates the identification of all relevant impacts (Walshie and Daffern, 1990).

When defining a telecommuting cost-benefit analysis, it is necessary that the scale, scope, and perspective of the telecommuting project be identified (Shafizadeh, *et al.*, 1998). As mentioned previously, this report will focus on home-based telecommuters, both full-time and part-time, and will ignore center-based telecommuters. Additionally, we combine both micro- and macro-scale elements into a comprehensive analysis of telecommuting, looking at both the specific (micro-scale) economic assessments for an individual telecommuter and generalizing (macro-scale) impacts for populations of telecommuters. This analysis should be applicable to both public- and private-sector telecommuters and employers.[3]

Stage 2: Identifying Impacts

Once project limits have been clearly defined, the next major step is to properly identify factors that impact economic evaluation of the project. For the most part, these

[3] It should be pointed out that there have not been any notable private sector contributions to the literature, mostly because the data collected by most private companies are considered proprietary and usually not released to the general public. Nonetheless, there is little indication that the costs and benefits of telecommuting in the public sector are substantially different than in the private sector.

impacts have already been identified in the literature (see for example, Shafizadeh, *et al.*, 1998; DOT, 1993; and Katz, 1987). Table 1 illustrates the wide range of costs and benefits that have been traditionally associated with telecommuting.

While Table 1 represents those factors commonly associated with telecommuting, not all of the factors are included in this analysis because their economic implications are difficult to quantify. For example, factors such as reduced stress or increased satisfaction experienced by an individual, or improved public relations experienced by a company, are excluded. As a result, only those factors that are underlined are included in this report.

Table 1. Costs and Benefits Associated with Telecommuting

		COSTS	BENEFITS
Public	Start-up	• marketing/training development • evaluation	(none)
	Ongoing	• ongoing marketing/training • latent demand realization • urban sprawl	• travel reduction • emission reduction • improved highway safety • increased economic development (employment opportunities for underemployed/mobility-limited labor segments) • increased neighborhood safety
Private	Start-up	• planning • marketing/training • equipment	(none)

	Ongoing	• internal program administration
		• marketing/recruitment
		• training
		• equipment maintenance/ replacement (less salvage)
		• communications
		• decreased workplace interaction/ immediate access
		• security of data
			• space cost savings (office and parking)
			• recruitment (access to best talent and broader labor markets)
			• improved retention
			• increased productivity
			  ◦ less absenteeism
			  ◦ less sick leave
			  ◦ longer hours
			  ◦ fewer distractions (greater productivity per hour)
			• improved customer service
			• disaster recovery
			• public relations
			• compliance with air quality/trip reduction regulations

Individual	Start-up	• equipment • software • stress to perform	(none)
	Ongoing	• communication costs • energy costs • space costs • decreased workplace interaction • loss of support services • loss of boundary between work and home	• travel time savings • travel cost savings • misc. cost savings • personal flexibility • reduced stress • ability to get more/better work done • ability to work while mobility limited or physically distant from workplace • more time with family

Source: Shafizadeh, *et al.*, 1998

Stage 3: Quantifying Impacts

After being identified, impacts must be quantified and valued before they can be placed into the cost-benefit analysis. While the quantification and valuation of impacts are sometimes accomplished together, the two stages are distinguished in this project so that the reader can understand how results were obtained and can assess each set of factors individually.

The quantification of impacts involves determining the cost and benefit flows of a project and the time at which they occur. In this stage the analyst often begins to encounter serious uncertainties involved in estimating cost-benefit flows over an entire population at different points in time (Hanley and Spash, 1990). For example, the impacts of forgone travel due to telecommuting can be difficult to quantify when the average commute trip length for telecommuters (in comparison to non-telecommuters) continues to be another source of uncertainty. If an attempt is made to adjust for the effects of urban sprawl and latent demand, the situation quickly becomes saturated with uncertainty. As a result, many assumptions are made to simplify the analysis. For instance, in this report it is assumed that telecommuters and non-telecommuters exhibit identical commute trip lengths, on average.

Stage 4: Valuing (Monetizing) Impacts

For different impacts to be comparable they must be converted into common units, and the common unit in a cost-benefit analysis is dollars. Goods and services are converted into dollar values using marginal market prices, which represent the price at which consumers exhibit a *willingness to pay* (WTP) in a competitive market. In general, prices are very useful in translating goods and services into common units and assessing their "worth" for cost-benefit analyses.

Unfortunately, competitive markets do not exist for all goods and services. As a result, a primary challenge in a cost-benefit analysis is often the estimation of market prices for goods and services not traded directly in the market and for which no obvious market price exists. Often, a value must be estimated, and valuations may be inferred from *shadow prices* in related markets.[4] Inevitably, the estimation of marginal dollar values of proposed impacts can be a formidable challenge, subject to debate and criticism (see Zerbe and Dively, 1994 for a complete discussion of this issue).

Stage 5: Discounting and Applying the Net Present Value (NPV)

Once all relevant impacts have been valued in monetary terms and expressed as annual cost and benefit flows, it becomes necessary to convert them into present value terms to reflect the "time value of money." Simply put, money can be used to generate more money (e.g., through interest payments) so the sooner it is received, the more it is worth. For this reason, we realize that benefits are more highly valued the sooner they are received. By the same token, money that must be paid out is less onerous when paid out at a point in the future than when paid out in the present.

In this project, the loss or gain during future flows of costs and benefits are "discounted to the present," using the standard formula to find the present value of a single payment made at another point in time (Zerbe and Dively, 1994):

---

[4] Other methods of valuation include cost savings, transaction cost method, related market-pricing methods, and stated preference methods (Walshie and Daffern, 1990).

$$P = \frac{F_t}{(1+r)^t}$$

where

P = present amount
F = future value after t time periods
r = interest (discount) rate
t = number of time periods

Once all monetary flows are discounted into present value terms, costs and benefits can be compared using either the *benefit-cost ratio* (B/C) or the *net present value* (NPV) criterion. The discounted B/C formula is characterized by the following expression:

$$B/C = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}}$$

where

B_t = the benefit in time period t
C_t = the cost in time period t
r = interest rate
n = the total lifespan of the project

The NPV is the sum of the discounted benefits less costs over all time periods t, and is represented as:

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}.$$

If benefits exceed costs (NPV > 0, B/C > 1), then the project is acceptable by either criterion.[5] The NPV and the discounted B/C ratio should yield identical decisions.[6] While both criteria are used in this report in the discussion of results, B/C is the preferred criterion on which to compare results because it is simple to interpret, regardless of the magnitude of cost and benefit flows – which are a function of size of the telecommuting population. So while NPV is widely accepted as the preferred criterion guiding project investment (Lewis, 1991), the B/C ratio serves as a measure that allows projects to be compared without discriminating against projects with higher cost flows (i.e., those projects with a larger number of telecommuters).

Stage 6: Sensitivity Analysis

In most cost-benefit analyses, forecasts must be made to estimate "physical flows" (such as the number of telecommuters) and future values (such as the price of a gallon of gasoline) (Hanley and Spash, 1993). As a result, a large portion of this report examines issues of uncertainty and develops plausible scenarios. Sensitivity analysis is the simplest and most commonly used method for dealing with uncertainty in data, and it measures how "sensitive" the result is to a change in one of the input variables.

Before sensitivity analysis can be performed, however, the CBA must be performed on a "base case" set of assumptions. This base case is usually taken as the status quo, or the current condition in which no changes are proposed. For home-based

[5] A NPV > 0 is equivalent to a B/C > 1, and the only difference is the operation used to compare costs and benefits – NPV uses subtraction while B/C uses division (Zerbe and Dively, 1994, p. 190).

[6] The NPV and discounted B/C ratio should yield the same decision to either accept or reject a project, however, the two methods could yield different results when ranking a group of potential projects. In this report, the choice is whether or not to accept telecommuting, based on the economic evaluation.

telecommuting, the status quo (and thus our deterministic base case) is a situation in which no additional telecommuting exists beyond current levels, and no additional costs would be invested toward telecommuting.

Beginning with a base case, variables are systematically adjusted, one at a time, and the changes in results are documented. This approach is known as the “variable-by-variable” approach. Groups of variables also can be systematically changed, known as the “scenario” approach, and is recommended if variables are interdependent (Zerbe and Dively, 1994). Both approaches are used in this report.

3.3 Monte Carlo Simulation

Monte Carlo simulation is a common but powerful technique that allows combinations of variables to fluctuate simultaneously over a given range of values. The disadvantage of this method, however, is that it requires that a variable distribution be assumed and defined with parameters (e.g., normal distribution with its mean and variance). Essentially, a single unknown input requirement is replaced by a requirement for a set of distribution parameters. While the distribution parameters may also be unknown, this approach allows the input value to incorporate variability.

Often an input value can be considered to be unknown if a consensus value has not been reached in the literature. Still, documentation may exist that reveals a range of values that can be used to characterize the distribution parameters. For example, telecommuting frequency has been estimated in empirical studies as having values around 1.2 days per week, but studies also estimate the average value to be as low as 1.1 and as high as 2.0 days per week. So rather than assume a fixed value of 1.2 days per week for a critical parameter such as telecommuting frequency, we can let the frequency vary as a normally distributed random variable with a mean of 1.2 and a standard deviation of 0.2.

In general, most variables in this report are assumed to be normally distributed when expected values (mean values) have been identified in the empirical research literature. In most cases, standard deviations are chosen depending on the desired level of variability and based on values documented in the literature. For example, in the case of telecommuting frequency, research indicates that a mean telecommute frequency may deviate as much as 0.5 days per week on average. If we let the mean be 1.2 and the standard deviation be 0.2, then almost all random values will fall between 0.6 and 1.8 days per week – or three standard deviations away from the mean. If we wanted to let this variability increase for exploratory purposes, we could set this standard deviation at 0.3 or 0.4.

When there is little or no empirical data to guide setting the expected value for an input, the input variable is assumed to be uniformly distributed – with a specified minimum value and maximum value. With a uniform distribution, we assume that any value within the range is *equally-likely* to be chosen. For example, if we let the value of parking space savings vary uniformly between $3.50 and $9.50 per day, then any value within that range has an equal likelihood of being selected.

When the random variables are selected to produce a set of input values, the result of the Monte Carlo simulation is a distribution of results from which we can estimate an overall expected value. In this report, we will produce distributions of benefit-cost (B/C) ratios. Additionally with this approach, we can estimate a probability associated with any point on the distribution – for example the "break even" point of the cost-benefit analysis where the B/C ratio is equal to one. Overall, this type of simulation coupled with sensitivity analysis can be best characterized as a "non-confrontational way to handle controversy about key assumptions, calculation methods, and projected data" because it allows both optimistic and pessimistic scenarios to be explored (Merrifield, 1997, p. 82).

3.4 Visual Basic for Applications (VBA)

Visual Basic for Applications (*VBA*) is used in the TELESIMM program to perform the Monte Carlo simulation within a Microsoft® Excel™ spreadsheet. VBA is a programming language developed by Microsoft for use with its applications.[7] *VBA* must be used in conjunction with another compatible application, such as Microsoft® Excel™. VBA is a tool that can be used to develop programs (or macros) that extend the functionality of the Microsoft® Office™ applications.

VBA is a flexible and relatively user-friendly programming environment that we used to customize and extend the functionality of Excel™. It was used for automating

[7] *VBA* is often confused with the stand-alone version of *Visual Basic™* (*VB*) which is a programming language that allows for the development of independent, stand-alone applications. While there are many similarities between *VBA* and *VB*, they are two different development tools.

repetitive tasks in the simulation model by replacing changing input values in a static calculation spreadsheet. Essentially, VBA allowed us to introduce a dynamic element to a traditional cost-benefit framework.

Another advantage of VBA with Excel™ is that it allows for the use of Excel's myriad of analytical tools. In particular, the *Random Number Generation Tool* and the *Histogram Tool* are evoked by the VBA program. The *Random Number Generation Tool* fills a range of cells with independent random numbers, given a distribution and its parameters. The *Histogram Analysis Tool* calculates individual or cumulative frequencies for a set of data and can generate a corresponding histogram chart. These tools can only be used when the Analysis Tool Pack (ATP) add-in is available to Microsoft Excel®.

The disadvantage of using VBA is that it is a new and growing language. Consequently, it is subject to constant change, and many of the tools used in this version of Excel® and VBA are not compatible or available in earlier versions of Excel® and VBA. Overall, however, we found VBA to be an easy, low-cost, and useful application that we could use to customize and extend the functionality of Excel™ for our academic research purposes.

4.0 INPUTS, ASSUMPTIONS, AND CALCULATIONS

After defining the scope of the project and identifying the costs and benefits in the previous chapter, the impacts of telecommuting must be quantified and monetary valuations computed. In this chapter, we: 1) document and justify the inputs to this cost-benefit analysis, and 2) document and detail the equations used to quantify and monetize each factor. This chapter establishes the travel impacts resulting from telecommuting and converts them into dollar values for the cost-benefit analysis.

This chapter is organized into five sections. The first section discusses telecommuting growth and how this growth can be modeled in a cost-benefit context. Telecommuter attrition, or turnover, is also a major input deserving special discussion and is discussed in the second section. The remaining three sections detail specific inputs and calculations in the cost-benefit spreadsheets. Along with separate sections for cost and benefit factors, there also is a section dedicated to *general* factors that are used in the calculation of both costs and benefits. For each of these three sections, equations and inputs, or assumptions are provided both to quantify and to monetize factors. Throughout these sections, Monte Carlo variables are distinguished from other input variables and discussed with respect to assumed distributions and parameters. Additionally, inputs for the deterministic base case scenario are set and justified. A list of the calculations presented in this chapter is shown in Table 2 below.

Table 2. List of Model Inputs

Section	Model Input
Growth Function (Section 4.1)	• logistic function based on "curves of technological substitution" theory • linear function as a simplified option
General Inputs and Equations (Section 4.2)	• Annual telecommuting events • Annual vehicle trips saved • Annual vehicle miles saved
Cost Inputs and Equations (Section 4.3)	• Additional home energy expenses • Telecommuting training • Equipment and software • Telecommunications services
Benefit Inputs and Equations (Section 4.4)	• Avoided miscellaneous costs • Avoided travel costs • Avoided vehicle maintenance and insurance costs • Travel time savings • Increased employee productivity • Avoided parking space benefits • Avoided office space benefits • Avoided road construction or maintenance costs • Avoided vehicle emissions

Whenever possible, empirical data are drawn from past micro-scale or macro-scale telecommuting studies. Nonetheless, many instances remain where certain fundamental relationships have not yet been established in the literature. This report has identified gaps in the telecommuting cost-benefit literature regarding these relationships and some assumptions remain necessary to perform this analysis. As the results from continued empirical research become available, inputs can be adjusted or modified to improve the models.

4.1 Modeling the Growth of Telecommuting

Before telecommuting costs and benefits can be quantified, current numbers of telecommuters and expected growth must be estimated. This requirement alone continues to be a fundamental challenge in telecommuting research, because there remains debate about the current number of telecommuters. It is also not clear that sufficient research has been undertaken to validate past hypotheses regarding the functional form of telecommuting growth. As a result, we take two approaches in quantifying the number of telecommuters – a microscopic approach and a macroscopic approach. As will be discussed, the macroscopic approach may be more suitable for large regional assessments where the number of telecommuters is unknown and must be derived from workforce estimates, while the microscopic approach will be more suitable for known populations of telecommuters, such as within a company or firm.

The (Theoretical) Macroscopic Approach: A Logistic Growth Function

On a macroscopic scale, Nilles initially hypothesized that the telecommuting population was primarily a subset of the growing number of "information workers" in this country.[8] Assuming that 50% of the civilian workforce was composed of "information workers" and that 80% of information workers were potential telecommuters, Nilles proposed that 40% of all workers were potential telecommuters

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[8] Nilles cited a report by Porat (1977) as providing the definition of an "information worker" in which the U.S. workforce is classified as comprising four sectors: agriculture, industry (manufacturing), service, and information.

(Nilles, 1988).

Later, researchers concluded that the population of potential telecommuters included workers other than just information workers (Mokhtarian and Salomon, 1994). There was also the realization that not all information workers were capable of telecommuting due to job restrictions (Mokhtarian and Salomon, 1994). Because the extent to which these effects cancel each other is unknown, estimates of the telecommuting workforce will be characterized as a function of the total workforce. Theoretically, this approach can be used to define any telecommuting population, whether it be a national population or a population within a state, region, city or a large company.[9]

To obtain a telecommuting growth function, we follow work by Blackman in 1974, and later applied to telecommuting by Handy and Mokhtarian in 1996. According to Handy and Mokhtarian, the telecommuting growth function can be approximated by assuming that telecommuting is a new technology and that its adoption follows an "S-shaped" curve, characterized by low initial growth rates, high rates of growth near the midway point, and low growth rates again near the maximum adoption level.[10,11]

Blackman's general substitution model for technological innovation is given by

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[9] For micro-scale situations, such as a small company, this model also allows for a number of telecommuters to be entered directly with an average annual growth rate. Only in cases where the number of telecommuters is completely unknown is the macro-scale approach necessary.

[10] In 1988, Nilles suggested that the "key" to modeling the adoption of telecommuting was based in "the nature of technological substitution and social change. . . Telecommuting constitutes a classic example of a substitution of a new technology (in this case an evolving complex of technologies) for an older one (primarily private automobile transportation)" (Nilles, 1988, p. 305).

[11] The *adoption level*, also referred to as *penetration* by Handy and Mokhtarian, represents the "percentage of telecommuters who telecommute, without regard to frequency" (Handy and Mokhtarian, 1996, p. 166).

the equation:[12]

$$\ln\left[\frac{f}{F-f}\right] = c_1 + c_2(t - t_0) \quad (1)$$

where

f = market share captured at time t,

F = upper limit of the market share which the innovation can capture in the long run,

t_0 = the year when the innovation first captures a portion of the market,

c_1, c_2 = constants.

In our case, telecommuting is the “innovation” substituting for traditional commuting to work; f represents the adoption level of telecommuting in year t, and F represents the maximum level of telecommuting adoption achievable by the workforce. The unknown constants c_1 and c_2 are parameters that are used to calibrate the model using historical data.

While it is possible to obtain values for c_1 and c_2 by solving two simultaneous equations using two points of historical market share data, this method does not maximize our use of the available data and only looks at the growth at two points on the growth function. Instead, Blackman suggests approximating the unknown constants by fitting a regression line to the historical market share data.[13] To simplify this process, Equation (1) is rewritten as Equation (2) where t' equals $t - t_0$.

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[12] The Blackman substitution model was originally developed in 1971 to characterize the dynamics in the commercial airline jet engine market (see Blackman, 1974 for details).

[13] Blackman suggests plotting Equation (1) on semi-logarithmic paper so that “a straight line will result, and the constants may be estimated by determining the slope of the line and the zero intercept” (Blackman, 1974, p. 43). This report takes a similar approach, but instead of plotting $f/(f-F)$ on semi-log paper, we achieve the same linear approximation by plotting $\ln[f/(F-f)]$ on an ordinary scale.

$$\ln\left[\frac{f}{F-f}\right] = c_1 + c_2(t') \tag{2}$$

If the left hand side of the equation is treated as a single dependent variable, then Equation (2) is in the form y = b + mx. A line can be fit to the historical data, and the unknown constants (c_1 and c_2) can be obtained directly from the plot.

Once the model is calibrated using the given data, we can solve for the market share, f, in Equation (2), and plot f versus time, t'. It is this constrained logistic function that exhibits the "S-shaped" curve typical of rates of technological substitution, given by Equation (3).

$$f = \frac{F \cdot e^{(c_1 + c_2 t')}}{1 + e^{(c_1 + c_2 t')}} \tag{3}$$

Blackman's suggested method for calibrating the model is applied here using telecommuting market share data obtained from Find/SVP Inc. (formerly Link Resources, Inc.) along with figures from the U.S. Census.[14] Telecommuting market share is taken to represent the adoption of telecommuting in the workforce, and is calculated by dividing the estimated number of telecommuters in the U.S. (shown in column 1 of Table 3) by estimated number of individuals in the U.S. workforce (shown in column 2 of Table 3). The resulting levels of adoption (shown in column 3 of Table 3) are the f values needed to plot Equation (3) versus time.

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[14] Although Handy and Mokhtarian applied the Blackman model to telecommuting, they did not use the regression approach when calibrating their model. Instead, they solved two equations simultaneously for c_1 and c_2, using data from 1991 and 1992.

Table 3. Data on the Estimated Levels of Telecommuting in the United States

Year	Telecommuters[1]	Workforce[2]	Adoption[3]
1988	2.5	121.7	2.05%
1989	3.5	123.9	2.82%
1990	3.5	125.8	2.78%
1991	6.0	126.3	4.75%
1992	7.0	128.1	5.46%
1993	8.5	129.2	6.58%
1994	9.1	131.1	6.94%
1995	8.5	132.3	6.42%
1996	11.1	133.9	8.29%

1. Telecommuters in millions. Source: FIND/SVP, Inc. and Link Resources, Inc (1997).
2. Workforce in millions. Source: 1997 U.S. Statistical Abstracts.
3. Adoption was calculated as telecommuters divided by workforce.

Along with market share data, Equations (2) or (3) require that we assume a value for the maximum level of telecommuting adoption exhibited by the workforce (F) and for the year in which telecommuting first captured a portion of the market (t_0). If we assume that telecommuting first captured a portion of the market in 1980 ($t_0 = 1980$) and that the maximum market share of telecommuting is 20% ($F = 0.20$), then we obtain the regression function shown in Figure 1.[15] The regression line is transformed into Equation (5) below, which is plotted in Figure 2. Additionally, we can see that the linear approximation fits the data well, yielding a coefficient of determination, R^2, value of 0.91.

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[15] Handy and Mokhtarian assumed that telecommuting first captured a portion of the market in 1980 (t_0 = 1980) and that the maximum telecommuting market share would be 40% (F = 0.40) (Handy and Mokhtarian, 1996). While the assumption that t_0 = 1980 is maintained here, an F value of 20% was selected instead of 40%, because it is believed that 20% represents a more realistic and conservative assumption (see, e.g., Mokhtarian, 1998). However, the TELESIMM (telecommuting economic simulation model) program allows the user to customize this function by inputting new values for F and t_0 to obtain a new function, if appropriate.

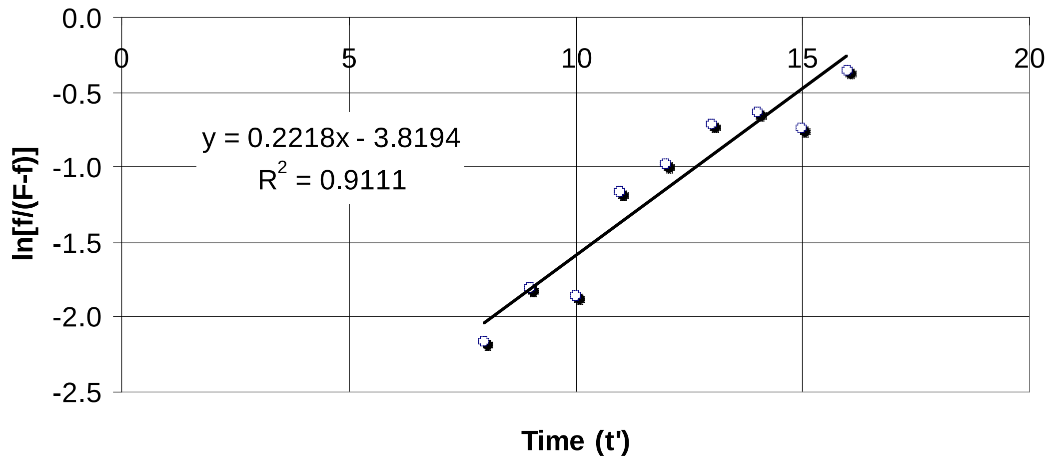

Figure 1. Telecommuting Growth Function Calibration Based on Historical Data

Based on the current body of data, we find that the national telecommuting growth model can be characterized by Equations (4) and (5) below. The resulting growth function is plotted in Figure 2.

$$\ln\left[\frac{f}{0.20 - f}\right] = -3.82 + 0.22(t') \qquad (4)$$

or

$$f = \frac{0.20 \cdot e^{(-3.82 + 0.22t')}}{1 + e^{(-3.82 + 0.22t')}} \qquad (5)$$

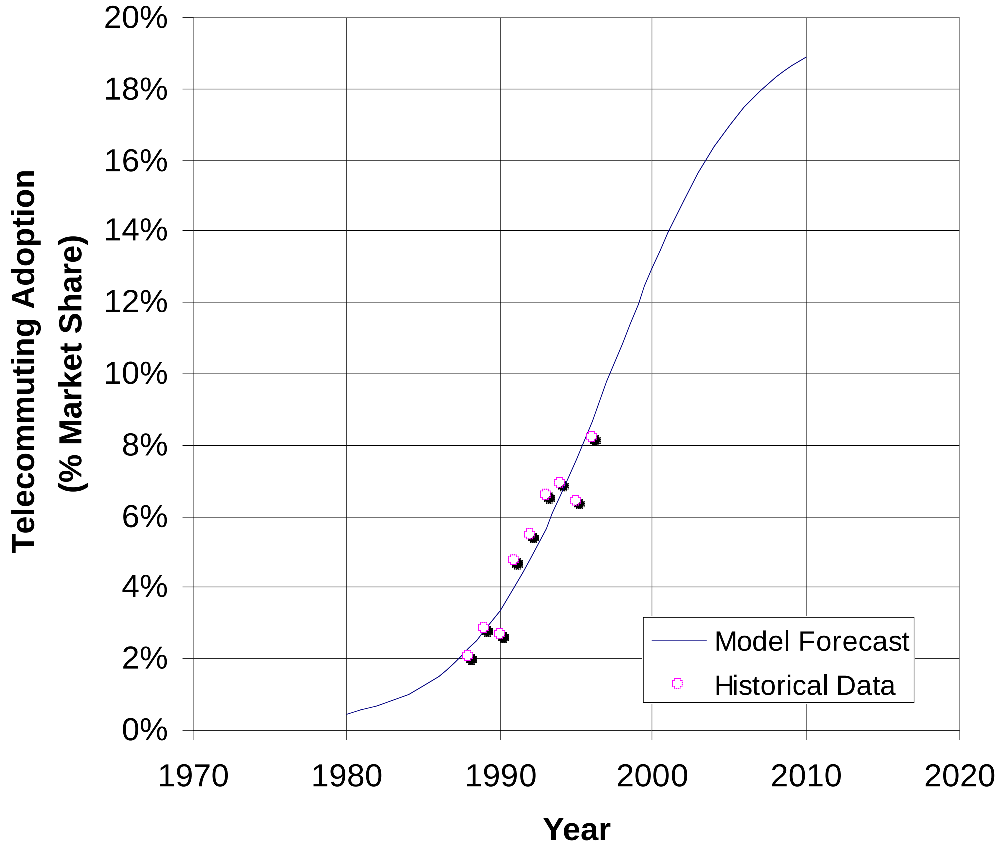

Figure 2. Forecasted Telecommuting Growth Function

Although we can define the telecommuting growth function at the national level, application of this function at smaller scales could pose a challenge because of the input data requirements. Since the telecommuter population is derived from the workforce population and workforce population is derived from the general population, we must rely on population and workforce statistics as well as projections. Table 4 is taken directly from the TELESIMM (<u>tel</u>ecommuting <u>e</u>conomic <u>sim</u>ulation <u>m</u>odel) spreadsheet and illustrates that the total number of telecommuters is derived from estimates of the total population, total workforce, and adoption of telecommuting by the workforce.[16] (Appendix B contains the actual spreadsheet from which Table 4 is taken.)

Table 4. Telecommuting Population: The Macro-Scale Approach

Year	1996	1997	…
Total Workforce	133,943,000	135,842,189	…
TC Adoption by Workforce	8.68%	9.78%	…
Total Telecommuters	11,621,107	13,287,542	…
Existing Telecommuters	10,058,669	11,621,107	…
Net New Telecommuters	1,562,438	1,666,435	…
(Replacement Telecommuters)	4,067,387	4,650,640	…
Total Telecommute Events	658,219,500	752,606,379	…

Note: *Net new telecommuters* are those employees who add to the total telecommuting population. *Replacement telecommuters* represent those who stop telecommuting and who are replaced during the year. This does not affect the total number of telecommuters and hence they are included within the number of *existing telecommuters* rather than added to them. (*Total telecommuters* = *Existing telecommuters* + *Net new telecommuters)*. However, for some elements of the model (e.g. phone service installation), the number of replacement telecommuters is important. Attrition of telecommuters is discussed later in this chapter.
Note: Some values in this table (e.g. adoption by the workforce in 1996) may be slightly different from the values in Table 3, because the values in this table are based on predicted values (not actual values).

The Microscopic Approach: A Linear Growth Function

While the macro-scale approach can be used to estimate the number of potential telecommuters within a single company or organization if the data are available, it may not be desirable to derive the number of telecommuters from all employees if the number of participating telecommuters is known directly. In response to this simplified situation, the TELESIMM spreadsheet and program allows for a *linear* growth function to be assumed where the number of telecommuters is entered directly along with an average annual growth rate. Simply put, the micro-scale approach is a practical approach that requires the least possible input and is completely separate from the theoretical macro-

[16] In the TELESIMM spreadsheet and program, a linear regression model is fit to the telecommuting adoption rates shown in Table 3 to obtain parameters for the S-shaped growth function before the cost-benefit analysis is performed.

scale approach, which assumes an "S-shaped" growth function.[17]

Table 5 is taken directly from the TELESIMM spreadsheet, and we can compare the inputs of the micro-scale approach with those in Table 4 from the macro-scale approach. We see that the TELESIMM spreadsheet does not require population, workforce, or adoption inputs. In this example, it is known that 1,000 employees started telecommuting during 1996 and comprise the current telecommuting population. An annual growth rate of 5% is assumed. The telecommuting growth function is the only part of this report that is given special attention by providing separate micro-scale and macro-scale approaches.

Table 5. Telecommuting Population: The Micro-Scale Approach

Year	1996	1997	…
Total Population	-	-	…
Total Workforce	-	-	…
TC Adoption by Workforce	-	-	…
Total Telecommuters	1,000	1,050	…
Existing Telecommuters	0	1,000	…
Net New Telecommuters	1,000	50	…
(Replacement Telecommuters)	500	525	…
Total Telecommute Events	56,640	59,472	…

4.2 General Inputs, Assumptions, and Calculations

Along with the growth and duration of telecommuting, there are other fundamental assumptions that will affect multiple calculations in the cost-benefit analysis. Of particular interest are those assumptions used to characterize the "traditional" peak-hour, journey-to-work trip made by a typical employee in this country. In other words, before we can compare the costs and benefits of a "forgone" commute on

[17] While the analyst must use judgement to assign a reasonable linear growth rate, a ceiling has been implemented in the model to ensure that the proportion of telecommuters does not exceed a predetermined level.

a telecommuting day with a "traditional" commute trip on a non-telecommute day, we need to define a traditional commute trip. These general factors include:

- Mode choice,
- Trip characteristics – average distance, time, speed, and
- Vehicle characteristics – average fuel economy.

To calculate telecommuting implications, several general inputs and calculations must be applied:

- Telecommuting attrition,
- Telecommuting frequency,
- Conversion of telecommuters into annual telecommute events,
- Conversion of annual telecommute events into saved vehicle trips, and
- Vehicle characteristics – average fuel economy.

The vehicle-related assumptions that will be discussed in detail in this section are summarized in Table 6 below.

Table 6. Summary of General Assumptions about the Telecommuting Population

Item	**Value**	**Source**
Average Commute Distance (one-way)	11.6 mi	NPTS, 1995
Average Commute Travel Time	20.7 min	NPTS, 1995
Average Work Trip Speed	33.6 mph	NPTS, 1995
Average Vehicle Fuel Economy	24.4 mpg	NHTSA, 1997
Average Retail Gasoline Price	$1.29/gal	API, 1998
Average Gasoline Tax	$0.43/gal	API, 1998
Gasoline Grade Type	All	API, 1998
Percent of Telecommute Occasions That Eliminate a Drive-Alone Automobile Commute Trip	76%	Mokhtarian, 1998

Commute Mode Choice

When we think of a "traditional" contemporary commute trip, we almost always think of the automobile as the primary mode choice. A major assumption in this report is that all transportation-related benefits stem from forgone trips made in single-occupant, light-duty vehicles. In other words, benefits from forgone trips by other modes, such as transit, bicycling, walking, or carpooling, are neglected. From a social benefit standpoint, this is a reasonable simplification because an eliminated transit, walking, or carpool trip (assuming the carpool vehicle still makes the trip with one less passenger) does not improve congestion or air quality. However, individuals presumably benefit financially by eliminating transit or carpool trips, and it is these benefits that are neglected.

While it is conceivable to have separate modules in the cost-benefit analysis program to account for separate modes given the proportional mode split for the telecommuting population, this approach was not incorporated into this report due for simplicity. Furthermore, the assumption to account only for drive-alone passenger vehicle benefits is conservative, because it underestimates the benefits attributable to telecommuting.[18] Additionally, it appears to be a safe assumption, given the dominance of the passenger automobile for commute trips.[19] Future extensions of this work, however, could incorporate these other benefits.

Commute Trip Characteristics: Distance, Time, Speed

Another important set of assumptions in the characterization of the non-telecommute journey-to-work trip involves assessing how far, how fast, and how long, on

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[18] According to the 1995 NPTS, the average vehicle occupancy for work trips is 1.14 (FHWA, 1997).

[19] The 1995 NPTS indicates that the "private vehicle [drive alone and carpool] accounts for 91 percent of all person commute trips and 93 percent of all person commute miles" (FHWA, 1997, p. 21).

average, each commute vehicle travels. While this report assumes that traditional commute trips for telecommuters resemble those of non-telecommuters, this assumption remains a key point of uncertainty in the study of telecommuting impacts on travel. To date, research suggests that early adopters of telecommuting tend to live farther from their place of work, even twice as far, on average, compared to non-telecommuters (Mokhtarian *et al.*, 1995). On the other hand, it is argued that the average commute distance of telecommuters is likely to approach (but perhaps not achieve) the average commute distance for conventional workers, as telecommuting becomes more mainstream.

For simplicity and to be conservative in estimating the impacts of telecommuting, this report assumes an average commute distance of telecommuters equal to that of non-telecommuters. According to data from the 1995 Nationwide Personal Transportation Survey (NPTS), the average commute distance is 11.6 miles. The average travel time is 20.7 minutes, and the average commute speed is 33.6 miles per hour, as shown in Table 6 (FHWA, 1997).

Because commute distance is a critical parameter and because some research has suggested that telecommuters have on average longer commute distances, commute distance is treated as a Monte Carlo variable – meaning that we let distance vary randomly with specified distribution and parameters. Based on a brief analysis of the 1995 NPTS data, we concluded that the commute distance was approximately normally distributed – with a mean of 11.6 miles as noted above. This input parameter remains customizable by the user in the TELESIMM program.

While we could also take the standard deviation from the available data, consideration must be taken to avoid unrealistic scenarios (i.e., *negative* commute distances) when it is applied to the Monte Carlo simulation. Because a randomly selected value from a normal distribution can yield extreme values as much as three standard deviations above or below the mean value, it is possible that the Monte Carlo simulation will generate a negative commute distance and yield invalid results if the standard deviation is too large (i.e., greater than one-third of the mean value). Consequently, the standard deviation was reduced to avoid negative commute distances while achieving a desired level of variability. This aspect of the Monte Carlo simulation is recognized as being somewhat subjective and is discussed in the last chapter.

Average Vehicle Fuel Economy and Gasoline Prices

Another aspect in quantifying the benefits from forgone travel, specifically operating expenses, requires assuming an average fuel economy. An average fuel economy, together with travel distance, allows us to estimate average annual fuel savings. An average value of 24.4 mpg was used for the deterministic base case assumption and was obtained from a 1997 NHTSA report, as shown in Table 7. This table also illustrates that the overall fleet fuel economy average is declining, due to the increasing share of light duty trucks. While we might expect fuel economies to increase in the future, it appears that any improvement in fuel economy could be offset by continued growth in the proportion of light duty trucks in the vehicle fleet.

Table 7. Light Duty Vehicle Fuel Economy Averages

Model Year	Passenger Cars (mpg)	Light Duty Trucks (mpg)	Total Fleet (mpg)	Light Duty Truck Share of Fleet (%)
1987	28.5	21.7	26.2	28.1
1988	28.8	21.3	26.0	30.1
1989	28.4	20.9	25.6	30.8
1990	28.0	20.8	25.4	30.1
1991	28.4	21.3	25.6	32.2
1992	27.9	20.8	25.1	32.9
1993	28.4	21.0	25.2	37.4
1994	27.3	20.7	24.7	40.2
1995	28.6	20.5	24.9	37.4
1996	28.7	20.8	24.9	39.4
1997	28.6	20.4	24.4	42.8

Source: U.S. National Highway Traffic Safety Administration, 1997.

Along with fuel economy, we also estimated the out-of-pocket cost to the user for gasoline at the pump. According to the American Petroleum Institute (API), gasoline prices in the United States are among the lowest (after adjusting for inflation) in the 79-year history of recorded pump prices, as shown in Figure 3. According to the API, the average annual pump price for gasoline was $1.29 per gallon in 1997 (in real, inflation-adjusted 1997 dollars).[20,21] For the purposes of this report, we did not assume that a higher percentage of vehicles used by telecommuters use less-expensive, lower-grade gasoline even though this may be the case (in view of their longer commutes). Ideally, in computing an average fuel price we would use the retail price for each grade weighted by the proportion of each grade of gasoline consumed by those who telecommute.

[20] This value appears to be an average that has been weighted by the proportion of each grade of gasoline purchased. In 1997, the average pump prices were as follows: $1.23 for regular unleaded, $1.32 for midgrade unleaded, and $1.42 for premium unleaded (API, 1998).

[21] In March of 1998, the national retail price for all grades of gasoline reached an all-time record low of $1.01 per gallon (API, 1998). This value does not appear to be a weighted average.

Furthermore, the API values represent the average for the entire U.S. population, not the average among U.S. telecommuters.

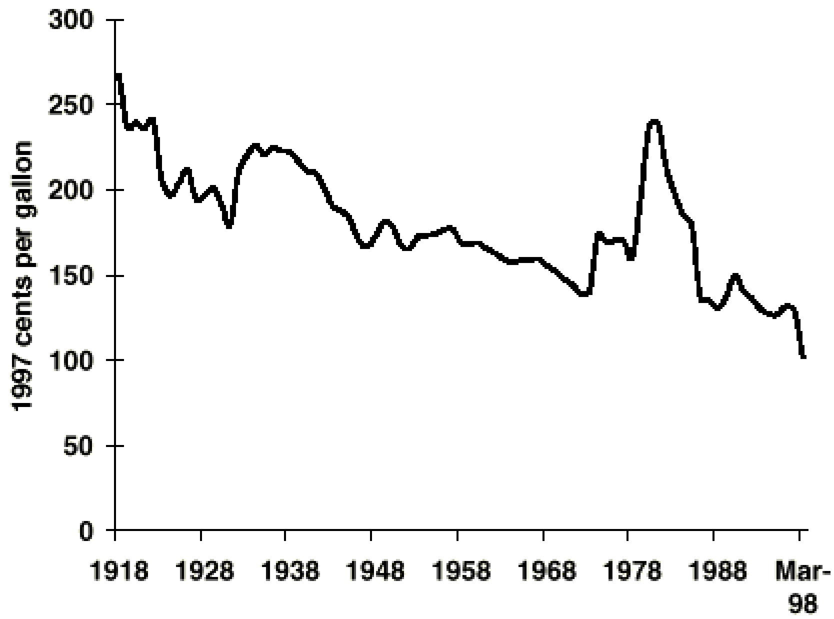

Figure 3. U.S. Retail Gasoline (Pump) Prices
Source: American Petroleum Institute, 1998.

Part of the out-of-pocket cost to the user is a transfer to the public sector through gasoline taxes. According to the API, the average combination of federal, state and local taxes varies from 26.4 cents per gallon in Alaska to 54.8 cents per gallon in Hawaii. Americans pay about 43 cents per gallon in federal, state, and local gasoline taxes on average, where 18.4 cents per gallon goes to the federal government, an average of 22.6 cents per gallon goes to state governments, and about 2 cents per gallon goes to local governments (API, 1998). For the purpose of this report, we assumed that the average gasoline tax is 43 cents per gallon, although averages are available for individual states. The assumption of a high gas tax is conservative because it tends to overestimate lost gasoline tax revenue (as a result of decreased gasoline consumption) for the public sector.

Telecommuting Frequency

Before we can begin to make cost-benefit comparisons between traditional commuting and telecommuting (which involves fewer commute trips), it is important to make some general assumptions regarding the levels of telecommuting. One of the most critical parameters in the cost-benefit analysis is the assumption made with respect to the average telecommuting frequency – how often employees telecommute in relation to how often a traditional commute is made. It is commonly assumed that telecommuting occurs approximately two days per week on average, however some evidence suggests that this assumption may be too high and thus, overestimates the benefits of telecommuting.

A recent study by UC Davis researchers examined the telecommuting frequencies of the users of various telecommuting centers and found that the average telecommuting frequency across the sample was 22%, or about 1.1 days per week (Varma, *et al.*, 1998).[22] An earlier study found an average telecommuting frequency of 24%, or 1.2 days per week, across eight different home-based telecommuting programs (Handy and Mokhtarian, 1995). Because this report focuses on home-based telecommuting, a mean telecommuting frequency of 1.2 days per week, or 24%, was assumed.

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[22] According to Varma, *et al.*, a telecommuting center is defined as "an office facility shared by remotely-supervised staff of multiple employers, generally on a part-time basis" (Varma, *et al.*, 1998, p. 5). These centers are usually furnished with computers and office equipment and are "much closer to participants' homes than the regular workplace" (Varma, *et al.*, 1998, p. 5).

Telecommuting Attrition

To accurately model telecommuting, we must also include the effects of telecommuting attrition, or turnover, in our model. It is conceivable that the tendency for telecommuters to stop telecommuting can have a significant impact on project effectiveness if additional resources are required to train replacement telecommuters without receiving any additional benefit. In other words, when a telecommuter quits and is replaced, two individuals are trained, but only one individual is providing increased productivity at any given time. Other non-transferable start-up costs include communications start-up costs, and equipment costs when telecommuters pay for their own equipment.

While attrition has been identified in micro-scale pilot projects (e.g. JALA Associates, 1990, 1993), it is not well understood and has not been fully researched. Still, research suggests that attrition can be considerable (Ho, 1997). UC Davis researchers studied attrition in past home-based telecommuting pilot projects and concluded that "attrition can be conservatively estimated to run 32-41% (based only on those who start telecommuting)" (Varma, *et al.*, 1998, p. 3). In the same report, data from telecommuting pilot projects indicated that over half of all participants stopped telecommuting within the first nine months of starting and that there was only a 57% chance that an individual would telecommute for longer than six months (Varma, *et al.*, 1998). Consequently, the study pointed out that attrition is worthy of additional research and that it could be a serious problem for sustaining telecommuting projects.

In this report, we assume an average annual attrition rate between 20% and 50%, with a deterministic base case attrition rate of 35%. It is assumed that telecommuters quit and are replaced each year and that this replacement process is distinct from the addition of new telecommuters attributed to the growth in telecommuting.[23] In the stochastic portion of the TELESIMM model, this variable is treated as a Monte Carlo variable with a uniform distribution.

Converting Telecommuters into Telecommute Events and Forgone Vehicle Trips

The last procedure that is necessary before a telecommuting scenario can be compared to the traditional commute scenario is converting an estimated number of *telecommuters* into an estimated number of *telecommute events* and an estimated number of *forgone vehicle trips*. It is important to calculate the estimated number of telecommute events as an intermediate step because some telecommuting costs and benefits are determined on a "per event" basis (e.g. miscellaneous benefits), while others are determined on a "per trip" basis (e.g. travel cost savings).

The number of telecommute events is determined for an annual period and is based on the proportion of the total number of workdays on which telecommuting occurs, as shown in the equation below.

[23] Despite the observed attrition rates from pilot studies, national statistics indicate that the total number of telecommuters in this country continues to grow, as shown in Table 3. This leads us to believe that telecommuting as a whole continues to grow despite the high turnover rate.

$$Annual\ Telecommute\ Events = TC\ Frequency \times Work\ Days \times TCers \qquad (6)$$

On average we might expect there to be 236 workdays per year, of which 24% (1.2 days per five-day workweek) are telecommute days.[24] In other words, 57 of the 236 workdays per year, on average, will be telecommute days while 179 workdays will be traditional commute days, assuming that an individual either commutes or telecommutes on any given work day and that only one telecommute event occurs on any given telecommute day. In the example below, we can see how 1,050 telecommuters yield 59,472 telecommute events per year:

example Annual Telecommute Events
= (1.2 TC events/workweek) ÷ (5 workdays/workweek) × (236 workdays/year) × (1,050 TCers)
= 59,472 TC events per year for all 1,050 telecommuters

The annual number of vehicle trips that is saved or forgone by telecommuting each year is calculated based on the estimated number of annual telecommute events.[25] As mentioned earlier in this chapter, an adjustment is made to count only the fraction of telecommute events that eliminate *drive-alone* commute trips. Research indicates that only 76% of telecommute events actually translate into forgone *drive-alone* vehicle trips (Mokhtarian, 1998).[26] Simply put, telecommuters who carpool, bicycle, walk, or use

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[24] This value of 236 working days per year is obtained by assuming that there are 104 weekend days, 10 federal holidays, and 15 days of vacation per year in the 365 day year (365 – 104 – 10 – 15 = 236).

[25] In this report, a "trip" is considered travel one-way from one location to another. The return would be considered an additional trip.

[26] The estimated 76% factor takes two factors into account: 1) modes other than drive alone, as well as 2) partial-day telecommuting. See Mokhtarian (1998) for details.

transit do not eliminate drive-alone vehicle trips, and approximately 6-14% of telecommute events are only for partial days and are still accompanied by a traditional commute (Mokhtarian, 1998). The addition of this adjustment factor results in a more conservative and realistic estimate of forgone vehicle trips attributable to telecommuting. As with other inputs in this report, this parameter can be customized by the user for areas where transit or non-motorized vehicle mode choice is higher on average.

$$\textit{Annual Forgone Vehicle Trips} = \textit{(annual TC events)} \times \textit{(2 potentially saved trips/event)} \times \textit{(\% of events that eliminate drive-alone veh. trips)} \qquad (7)$$

For example, if we use the previous example and assume that 76% of telecommuting events eliminate drive-alone vehicle trips, we see that the same 1,050 telecommuters (that generated 59,472 telecommute events) saved almost 90,400 vehicle trips during the year.

example Annual Vehicle Trips Avoided
= (59,472 TC events/year) × (2 potentially saved commute trips/event) ×
(76% of events that eliminate drive-alone vehicle trips)
= 90,397 vehicle-trips/year saved for all 1,050 telecommuters

It will be shown later that this calculation is modified further to account for any additional local, non-commute travel that may be generated during the telecommute day to run errands, for example. In other words, we model the scenario in which some short, local vehicle trips are *generated*, while a greater number of longer, commute trips are *eliminated*.

4.3 Cost Inputs, Assumptions, and Calculations

In this section, the cost inputs and calculations are discussed. We begin by addressing the telecommuter's cost perspective, which is based primarily on additional home energy costs. Next, the majority of the costs are realized when we address the employer's perspective. As will be discussed, typical employer costs include equipment purchases and telecommunications installation and service, as well as additional training costs.

Additional Home Energy Expenses

For the telecommuter's additional home energy costs, we can combine typical appliance energy costs (shown in Table 8) with estimates for additional energy usage to yield the average additional home utility costs for a typical telecommuter, as shown in Table 9. While this is only an estimate, we see that total additional utility cost could be between $50 and $150 per year per telecommuter, depending on heating and cooling requirements.

Table 8. Typical Office Appliance Energy Costs

Appliance	Cost
Personal Computer	1¢ - 2¢/hr
Lighting – Incandescent 100 watt bulb	1¢/hr
Lighting – Fluorescent 27 watt bulb	1¢/4 hr
Microwave Oven	15¢/hr
Rangetop Burner – Electric	15¢/hr
Rangetop Burner – Gas	4¢/hr
Cooling – Fan	1 – 7¢/hr
Cooling – Window System	18 – 33¢/hr
Cooling – Air Conditioning (3-ton)	55¢/hr
Portable Heater	9¢ - 20¢/hr
Heating – Gas Furnace	$16 - $200/mo
Heating – Electric Central Heater	$56 - $400/mo

Figures based on 1994 average residential rates of 12.3 cents per kilowatt-hour (kwh) and 61.5 cents per therm. Source: PG&E, 1994.

Table 9. Additional Energy Costs Per Year

Appliance	Assumed Usage and Cost
Personal Computer	454 hrs @ 2¢/hr
Lighting – Incandescent 100 watt bulb	3 lights @ 454 hrs @ 1¢/hr
Microwave Oven	4.75 hrs @ 15¢/hr
Cooling – Air Conditioning	113.5 hrs @ 55¢/hr
Heating – Gas Furnace	113.5 hrs @ 28¢/hr
TOTAL	**$117.62/year**

Assuming: 236 work days per year, 1.2 days/week telecommuting frequency, and an 8 hour work day – which yields approximately 454 hours of additional utility usage in 57 days working at home. Assumes one computer is on continuously, three incandescent lights are on continuously, a gas furnace heater is on 25% of the time, air conditioning is on 25% of the time, and the microwave is on for 5 minutes per day. It is important to stress that this table represents energy usage that is in addition to what would normally be used without telecommuting.[27]

Empirical data from the 1988 SCAG pilot project indicate that these additional home energy costs would be approximately $132 per telecommuter per year, so this value is

[27] The gas furnace cost in Table 9 is obtained by converting the $200 per month value in Table 8 into an hourly value by assuming that there are 30 days in a month ($200/month ÷ 30 days/month ÷24 hours/day = $0.28/hour).

used as the deterministic base case value. Because additional energy usage is proportional to time spent telecommuting, this value of $132 per year is divided by the 57 telecommute events per year (as noted earlier in this chapter) to obtain an average energy cost of approximately $2.40 per telecommute event.[28]

$$\textit{Home Energy Costs} = \textit{(average energy cost/event)} \times \textit{(annual TC events)} \qquad (8)$$

For example, if 1,050 telecommuters generate 59,472 telecommute events per year (as in prior examples) and spend an additional $2.40 per telecommute event on energy costs, then the net resulting cost is almost $143,750 annually.

example Additional Home Energy Costs
= (59,472 TC events/year) × ($2.40 /event)
= $142,733 per year for all 1,050 telecommuters

Equipment Expenses

Although past research indicates that employees are often required to pay for telecommuting equipment without reimbursement (SCAG, 1988; CSD-DPW, 1990), it remains possible for the equipment costs to be the responsibility of the employer, and in this report both scenarios are addressed. While it is possible for the costs to be shared by both the telecommuter and the employer, the shared-cost situation becomes rather complex to model if telecommuting attrition is an issue. In other words, it would be difficult to reconcile equipment ownership if the equipment costs are shared and an

[28] A value of $2.32 is obtained and rounded up to $2.40 to be conservative.

employee stops telecommuting.

Instead of a shared-cost situation, we focus on the two "all-or-nothing" situations in which either the telecommuter or the employer pays all of the equipment costs. When the employer bears the burden, it is clear that the company would retain ownership of the equipment, and that it could be redistributed to a replacement telecommuter when one employee stops telecommuting.

When the telecommuter bears the equipment burden, however, it is assumed that each new telecommuter will purchase new equipment to telecommute. Clearly, this assumption is conservative, as many telecommuters may already own personal computers at their homes and may opt to use their equipment before deciding to purchase new equipment to telecommute, thereby cutting down on actual costs. Furthermore, because it is assumed that each new telecommuter would be required to purchase new equipment, we can see that under this approach equipment costs can become a large component of the overall cost of the project when attrition is high.

In either "all-or-nothing" situation, we assume that equipment is required for each telecommuter and that the net sum of costs for all telecommuters is obtained simply by multiplying the unit cost of the equipment by the total number of telecommuters:

$$\textit{Equipment Costs} = (\textit{unit equipment cost}) \times (\textit{TCers}) \qquad (9)$$

Based on retail computer equipment prices in the U.S. and previous research (e.g. JALA International, 1993), it was assumed that a value of $1,800 would represent the deterministic base case purchase price of a new desktop computer system for each telecommuter. Using the same 1,050 telecommuters from previous examples, we see that the total equipment costs for all telecommuters would be almost $1.9 million.

example Telecommuter Equipment Costs
= ($1,800/TCer) × (1,050 telecommuters)
= $1,890,000 for all 1,050 telecommuters in year 0, and replacement years

While the example above illustrates the equipment costs if they were paid as a lump sum, TELESIMM amortizes the equipment costs over the life of the computer equipment, which is assumed to be five years for computer equipment according to the current federal tax code.[29] In other words, equipment costs are translated into equal annual payments before the equipment is replaced. It is also assumed that equipment is continuously replaced after reaching its projected life during the project.

While the equal annual payment plan requires additional calculations, this payment method is preferred because it allows companies or individuals to avoid large lump payments at the beginning of the project. The equal annual payment method is also preferred because it simplifies the calculation of equipment costs when additional telecommuters are added to the system; all telecommuters pay the same unit costs (in current year dollars). For example, if the $1,800 per telecommuter cost is amortized over five years, the resulting annual payment of $450.82 will be the required payment for each telecommuter for each year over the equipment life. Once the equipment becomes “obsolete,” the payment process starts over but maintains a constant annual payment for

[29] The federal government determined a computer's useful life to be five years as part of the 1986 Tax Act (Frankel, 1996). Depreciation and salvage values could be included in with the capital equipment costs. As a simplified and conservative estimate, however, it was assumed that the salvage value of computer equipment would be negligible due to obsolescence.

each telecommuter.

example Telecommuter Equipment Costs
= ($450.82/yr/telecommuter) × (1,050 telecommuters)
= $473,361 per year for 1,050 telecommuters

While the amortized payment plan has its advantages and disadvantages, we recognize the fact that it may be preferable to account for these capital costs at the start of the project. Nonetheless, we expect the final results to be similar regardless of the payment method selected because the net present value of the equipment costs are equal regardless of the payment method selected. In other words, the discount rate that is used to bring future cost and benefit flows to the net present value is the same discount rate used to amortize the equipment payments.

Finally, it should be pointed out that our equipment cost estimates are conservative (i.e., potentially on the high side). As mentioned earlier, some telecommuters may have their own equipment and not require a computer (especially when asked to purchase it themselves). Additionally, it is possible for a company to purchase a single computer that the employee uses both at home and at work – such as a laptop or notebook computer. Finally, it is possible that in some situations it is not necessary to have a computer to telecommute. Especially at lower frequencies, telecommuting activities may be limited to those involving reading or processing hard copy documents, telephoning, and other “low-tech” activities.

Software Expenses

Software expenses, like computer expenses, are considered start-up expenses and occur during the project start-up, and again at each replacement year. For simplicity, in this report software costs are included as part of computer equipment costs, because software often is pre-installed and bundled with the purchase of a new computer. While combining software with computer expenses was done to simplify the situation, we recognize that there may be instances in which it is appropriate to distinguish equipment costs from software costs. For example, software is subject to different tax restrictions and regulations. Furthermore, while it may be appropriate to have a salvage value for a piece of computer equipment, it might not be appropriate to combine the original equipment/software cost in this salvage value. Still, as an initial approach, computer and software expenses remain combined in equipment costs.

Equipment Service and Maintenance Expenses

Along with equipment and software costs, there are additional costs associated with the service and maintenance of this equipment. In this report, it is assumed that these costs are borne by the employer and that they may involve both technical support and/or related services to facilitate telecommuting. Based on the 1990 State of California telecommuting pilot project, the cost of these services was assumed to be approximately $250 per telecommuter per year (JALA Associates, 1990). For 1,050 telecommuters, these services would represent a cost of $262,500 per year as shown below.

$$\textit{Equipment Service \& Maint. Expenses} = (\textit{TCers}) \times (\textit{cost/year}) \qquad (10)$$

example Telecommuter Equipment Service Costs
= ($250/TCer) × (1,050 telecommuters)
= $262,500 for all 1,050 telecommuters

Telecommunications Installation and Service

Telecommunications costs involve the installation of an additional phone line for new and replacement telecommuters, as well as annual service costs for all telecommuters. While not all telecommuters may require an additional phone line, this remains a conservative assumption that may overestimate costs. The total telecommunications cost package includes both start-up installation and on-going service payments. Installation costs are assumed to be $100 per telecommuter, while on-going service costs are estimated to be an additional $360 per telecommuter per year on average. These start-up values were obtained from a review of the micro-scale literature which indicate startup costs between $85 and $91 (SCAG, 1988; County of San Diego, 1990; JALA International, 1993). The on-going service costs were assumed to be $30 per month, or $360 per year, based on the 1988 SCAG study. A similar value of $400 to $500 is also noted in the Puget Sound Demonstration Case Studies for the total start-up costs (Kunkle, 1992), and Finlay estimated this start-up cost to be $360 Canadian (Finlay, 1991). (For additional discussion, see Shafizadeh, *et al.*, 2000.)

$$\textit{Telecommunications Costs} = (\textit{net new \& repl. TCers}) \times (\textit{one-time install costs}) + (\textit{all TCers}) \times (\textit{annual service costs}) \qquad (11)$$

For example, if we have 50 net new telecommuters and 525 replacement telecommuters who require phone service installation and 1,050 total telecommuters who require on-going phone service, then we see that the total telecommunications costs are $435,500 – of which $57,500 (13%) represents start-up costs and $378,000 (87%) represents ongoing costs.

example Telecommunications Costs
= (575 TCers) × ($100/ TCer) + (1,050 TCers) × ($360/ TCer)
= $435,500 for all 1,050 telecommuters

Telecommuting Training

As part of any telecommuting program, it is assumed that some training is necessary for telecommuters and their supervisors. This training is expected to cost $300 per supervisor-telecommuter pair, based on the value reported by the 1990 State of California telecommuting evaluation. Additional training costs will be incurred whenever a new employee starts telecommuting. However, some cost savings can occur if a trained supervisor manages more than one telecommuter at a time.

$$\textit{Training Costs} = (\textit{net new and replacement TCers}) \times (\textit{one-time training costs}) \quad (12)$$

In the example in which we have 50 net new telecommuters and 525 replacement telecommuters (out of 1,050 total telecommuters) who require training, then we see that the total training costs are $172,500 as shown below.

example Training Costs
= (575 net new and replacement TCers) × ($300/TCer-supervisor pair)
= $172,500 for 575 telecommuters (out of 1,050 total TCers)

To review, most of the employer costs (e.g. equipment, software, communications, service/maintenance costs) are simply unit costs multiplied by the total number of telecommuters. Care must be taken in estimating costs, to distinguish between existing, net new, and replacement telecommuters.[30] In general, replacement telecommuters will incur new startup costs while resuming ongoing costs. So while equipment can usually be transferred (if the employer paid for it), other start-up expenses such as training or telecommunication installation cannot. For this reason, attrition can impact the project budget, especially if non-transferable expenses are high and the project life is short.

4.4 Benefit Inputs, Assumptions and Calculations

In this section, the inputs, assumptions, and calculations associated with the benefits of telecommuting are discussed in detail. Notable benefits include avoided travel costs and miscellaneous savings by the telecommuter. For the employer, productivity benefits as well as office and parking space benefits are possible. For the public sector, air quality and construction benefits are explored.

Avoided Travel Costs

One of the principal benefits to telecommuters is the avoided cost of travel – excluding parking costs, which are classified as a benefit to the employer (see discussion later in this chapter). The cost of avoided travel stems primarily from gasoline cost savings, based on average fuel consumption over an average commute distance. As noted earlier in this chapter, avoided travel cost calculations are made more complicated by assuming that telecommuters make a local, non-commute trip during the telecommute

[30] While both subpopulations of net new and replacement telecommuters require similar start-up costs (e.g. training, telecommunication installation, etc.), it may be assumed that, when the employer bears the equipment cost, the *replacement telecommuters* receive equipment that once belonged to the telecommuters who were replaced.

day. In 1998, Mokhtarian used the findings of four previous studies to summarize the impacts of telecommuting on travel (Mokhtarian, 1998). While three of the four studies concluded that non-commute travel VMT decreased between two and five miles, one study concluded that non-commute travel VMT increased by two miles, on average (Mokhtarian, 1998).

This report assumes that telecommuters make one local, non-commute vehicle trip during the telecommute day that averages two miles in total distance. While a distance of two miles is not much, it is important to include this variable because the potential for non-commute travel during telecommute days exists. Furthermore, non-commute travel remains an important aspect in the potential travel impacts of telecommuting, especially when a large portion of benefits stem from avoided travel. As with other inputs, this value represents an area deserving of additional research and can be adjusted in the TELESIMM model, if necessary.[31]

Avoided travel cost is calculated by estimating the saved fuel from each telecommute event, based on an average commute distance. The estimated travel distance per event takes into account both the forgone commute trips and the generated local, non-commute trip. Avoided travel cost is also a function of fuel economy and retail gasoline prices.

$$\textit{Avoided Travel Cost} = \textit{(Annual TC Events)} \times \textit{(\% of events that eliminate drive-alone veh. trips)} \times \textit{(net travel distance saved per event)} \div \textit{(fuel economy)} \times \textit{(fuel cost)} \quad (13)$$

[31] A review of previous studies also revealed that three of the four studies produced an average of 0.2 and 0.5 additional non-commute vehicle trips, while one study indicated that non-commute vehicle trips decreased by 0.4, on average (Mokhtarian, 1998). In other words, it may be worthwhile for future versions of TELESIMM to assume that additional trips are only generated for a small percentage of telecommute occasions.

Thus, a sample of 1,050 telecommuters results in a total savings of \$50,660 per year for all telecommuters – which translates into over \$48 per year for each telecommuter.

example Avoided Travel Cost
= (59,472 TC events) × (76% of events that elim. drive-alone veh. trips) × ((2 × 11.6 mi/trip) – 2.0 mi/trip) ÷ (24.4 mi/gal) × (\$1.29/gal)
= \$50,660 per year for all 1,050 telecommuters

Because avoided travel cost is calculated directly from both fuel economy and commute distance, it is expected that those individuals with the greatest commute lengths or those with the lowest fuel-economy vehicles may realize the greatest avoided travel costs. As a result, it can be argued that telecommuting most benefits those individuals who exhibit above-average commute distances or who drive vehicles with below-average fuel economies, all else being equal. Furthermore, it should be pointed out that any other avoided road user-fees such as tolls would also benefit the telecommuter. However, as with taxes collected from gasoline consumption, it will be shown that these travel cost savings to the telecommuter come at the expense of public sector revenues.

Miscellaneous Benefits (Avoided Costs)

Miscellaneous benefits can result from cost savings attributed to eating at home instead of dining out for lunch, or from wearing casual clothes instead of "business" attire that may require frequent dry cleaning. Subtle savings such as these have been noted in many of the past micro-scale studies. For this report, we assume that an average of \$2.15

is saved by each telecommuter during each telecommute event, as documented in the SCAG (1988) study.

$$\textit{Misc. Benefits} = \textit{(Savings per event)} \times \textit{(Annual TC Events)} \tag{14}$$

If we assume that 1,050 telecommuters result in 59,472 telecommute events per year, then we see that the miscellaneous benefits reach almost $128,000. This translates into over $121 per telecommuter per year.

example Miscellaneous Benefits
= $2.15/event _ 59,472 events/year
= $127,865 per year for all 1,050 telecommuters

Avoided Vehicle Insurance and Maintenance Costs

In addition to direct fuel savings benefits from forgone travel, the telecommuter also experiences benefits from forgone travel attributable to avoided vehicle insurance and maintenance costs. As indicated by a 1992 FHWA study, fuel costs represent only a fraction of the total cost of owning and operating an automobile (FHWA, 1992). According to the report, the average cost for automobile ownership was approximately 39.5 cents per vehicle-mile, of which insurance and maintenance costs were approximately 26% and 15%, respectively, while fuel costs (with taxes) were only 15%. Thus, by those figures the combined insurance and maintenance costs would be estimated to be 16.2 cents per vehicle mile.

In this report, a more recent and conservative estimate of five cents per vehicle mile is used, as documented in a 1995 Washington State Department of Transportation

Study (Reed, *et al.*, 1995). A similar value is also noted by the American Automobile Association (AAA, 1998). Avoided insurance and maintenance benefits are a function of travel distance and are calculated similar to avoided travel costs.

$$\textit{Avoided Insurance \& Maint. Cost} = \textit{(annual TC events)} \times \textit{(\% of events that eliminate drive-alone trips)} \times \textit{(net travel distance/event)} \times \textit{(M\&I cost/mile)} \quad (15)$$

For example, we see that the avoided insurance and maintenance costs for 1,050 telecommuters is just under $48,000 which is over $45 per telecommuter per year.

example Avoided Vehicle Maintenance and Insurance Costs
= (59,472 TC events) × (76% of events that eliminate drive-alone veh. trips) × ((2 × 11.6 mi/trip) – 2.0 mi/trip) × ($0.05/mi)
= $47,911 per year for all 1,050 telecommuters

Travel Time Savings

By allowing the telecommuter to avoid the commute to and from work, additional benefits from the travel time savings are available. Unfortunately, it can be difficult to determine: 1) how the travel time is valued and 2) who accrues the benefit of the saved travel time. Depending on how it is used, the travel time savings due to telecommuting can be considered either saved “work time” or saved “leisure time.” If the saved time is applied to work purposes, then the travel time savings can be considered a benefit to the employer (as will be discussed in the next section) and can be valued as a function of an individual’s hourly wage rate. If the saved time is applied to leisure purposes, however, then the travel time savings would be considered a benefit to the telecommuter and would be valued at a lower rate.[32]

In transportation studies, the value of travel time is generally taken to be one-third to one-half of the average hourly wage rate. The estimated value of travel time has been documented to be as low $6.30 per hour, based on a Washington State project prioritization report (Reed, *et al.*, 1995; also see Dowling Associates, 1999). A 1986 study by the Texas Transportation Institute (TTI) valued travel time at $10 per hour (Chui and McFarland, 1986), and TTI's Annual Mobility Study cited a value of $11.70 when estimating the cost of congestion (Schrank and Lomax, 1999). In April of 1997, the U.S. DOT released a memorandum on the valuation of travel time for the use of all federal agencies conducting economic analyses, entitled "Departmental Guidance for the Valuation of Travel Time for Economic Analysis," in which a minimum range of $6.00 to $10.20 was given for personal, local travel as shown in Table 10 below (Krusi, 1997). The values of time in this memo were recommended for "cost-benefit and cost-effectiveness analyses that employ measures of the value of travel time lost or saved" (Krusi, 1997).

[32] For the case where the time is invested in additional leisure time, the ideal value of time to the telecommuter would be equal to the average telecommuter's willingness-to-pay for additional time. While this value is probably greater than zero, it is also probably below the individual's wage rate.

Table 10. Recommended Ranges for Value of Time for Personal Autos

Category	Low Value	High Value
Local Travel		
Personal	$6.00	$10.20
Business	$15.00	$22.60
All Purposes	$6.40	$10.70
Intercity Travel		
Personal	$10.20	$15.30
Business	$15.00	$22.60
All Purposes	$10.40	$15.70

Note: Values are in 1995 $ per person-hour for surface modes.
Source: U.S. DOT (Krusi), 1997.

Based on this recommendation, we let travel time value vary between $6.00 and $10.20 per hour by treating it as a Monte Carlo variable with a uniform distribution. In other words, we let the value of travel time take on any value between $6.00 and $10.20 with equal probability.

It is important to acknowledge that travel time benefits are certainly more complicated than we have indicated here and that there are many notable subtleties that accompany this assumption. For example, it is certainly possible that travel time benefits are actually spent as both leisure time and as additional work time. It is possible that the telecommuter absorbs a smaller portion of the travel time benefit, while a greater portion is given to the employer. Further, it can be argued that even when the saved time is devoted to work, the employee yields a psychological benefit from of getting more work done and feeling productive and that there is some unobserved value in that feeling of productivity. In any event, all benefits to the employer from increased work are considered increases in employee productivity and are discussed below.

Increased Employee Productivity

Employee productivity remains a key, yet formidable, factor to quantify. In this report, it was assumed that telecommuters would be between 0% and 15% more productive on telecommute days than the same individual on a non-telecommute day.[33] While specific claims of even higher productivity increases have been made (e.g., JALA Associates, 1990; JALA International, 1993; County of San Diego, 1990), we chose to be conservative when estimating these benefits.[34] It is important to note that, for simplicity, productivity is considered to be an amalgamation of many of the factors highlighted in Table 1, including (but not limited to): increased quality or quantity of work, increased time spent working, decreased sick-leave, decreased employee turnover, and increased employee retention.

Additional productivity is valued proportionally to the telecommuter's annual salary. Using the employee's annual wage rate, we can calculate the theoretical value that additional productivity due to telecommuting would have to the employer, based on the average amount of time spent for the amount compensated. A similar approach was used in the State of California Telecommuting Pilot Project (JALA Associates, 1990).

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[33] While it is possible that some loss in productivity could occur initially (due to the setup requirements at home or due to the loss of support services), we assume this loss in efficiency to be a short-term issue that presumably would be quickly replaced with increased efficiency from travel time savings and increases in productivity. Telecommuting arrangements with sustained detrimental impacts to productivity will presumably be terminated.

[34] Some studies have quantified increased productivity through attitudinal surveys; typically, telecommuters are asked before and after the survey how productive they are and the difference (less the responses by a control group) are thought to indicate the increase in productivity. This approach, however, remains highly

$$\textit{Productivity Benefit} = (\textit{TCers}) \times (\textit{productivity change}) \times (\textit{annual salary}) \times (\textit{TC frequency} \div 5\ \textit{workdays/week}) \qquad (16)$$

In this report, an average employee salary of $35,000 was assumed. While Census figures and 1995 NPTS data indicate that the average individual income is closer to $25,000 per year,[35] the value of $25,000 was thought to be lower than the average telecommuter annual salary in this country. The national income estimates include part-time and hourly wage earners – not just full-time salaried workers as most telecommuting participants are expected to be. Furthermore, these national figures are for all employment sectors, and it is believed that most telecommuters work in office environments and exhibit above-average incomes. For these reasons, the average telecommuter salary was assumed to be $35,000 per telecommuter per year.

If an employee receives an annual salary of $35,000 per year and is 10% more productive when telecommuting 1.2 days per week (24%), then the additional benefit to the employer is worth approximately $840 per telecommuter per year. For a population of 1,050 telecommuters, this productivity benefit becomes worth over $882,000 annually.

example Productivity Benefits
=(1,050 TCers) × (10% productivity) × ($35,000/yr) ×
(1.2 TC days ÷ 5 day workweek)
= $882,000 per year for all 1,050 telecommuters

It should be noted that because productivity impacts and the telecommuter salary

subjective and qualitative.

[35] U.S. Census figures indicate that the mean personal income in 1996 was almost $24,300 (1997 Statistical Abstracts), while the 1995 NPTS data indicate that the mean individual income among respondents who normally drive to work was approximately $23,500.

are both highly variable and because they are key inputs to this analysis, they were both treated as Monte Carlo variables and allowed to vary in the stochastic cost-benefit simulations. Annual salary is assumed to have a normal distribution with a mean of $35,000, while productivity increases were allowed to vary uniformly between 0% and 15%. (For additional discussion on productivity, see Westfall, 1997.)

Avoided Parking Space Expenses

In April 1991, a commuter parking cost study was completed by the Metropolitan Washington Council of Governments. In that study, average daily parking ranged between $2.50 and $7.40 per day (Washington Council of Governments, 1991). For the present study, those values, adjusted for inflation, equate to approximately $3.50 and $9.50 per day in 1998 dollars, respectively. Still, these values are believed to be conservative estimates for most major metropolitan areas. It is difficult to assess parking costs in major urban areas around the country, in part because parking costs are often internalized within building costs. Moreover, parking costs can vary from city to city or within a city. For example, the 1993 market rate for parking in Seattle, Washington ranged from $60 to $150 per month, while in nearby suburban Bellevue, Washington the market rate for parking is about $75 per month (Municipality of Metropolitan Seattle, 1993).

Based on parking-related research, this report treats parking as a cost to the employer because employers are often required to provide parking for their employees (Shoup, 1998; Municipality of Metropolitan Seattle, 1993). Again, this assumption represents a simplification, as some employees must pay for their own parking, in which case the avoided cost is a benefit to the employee – not the employer.[36] Still, the assumption that parking costs are paid by the employer is supported by empirical research that indicates that at least nine out of ten American automobile commuters do not pay for parking at work (Shoup and Breinholt, 1997). The 1995 NPTS data confirm that over 93 percent of all automobile commuters park for free at work.

In this report, parking cost savings are calculated based on the daily parking costs per vehicle for the fraction of telecommute events that save drive-alone vehicle trips:

$$\textit{Avoided Parking Costs} = \textit{(TC events)} \times \textit{(\% events elim. drive alone trips)} \times \textit{(daily parking costs)} \quad (17)$$

If we continue to follow our example with 1,050 telecommuters and let parking costs be $6 per day, then we see that the resulting parking benefit is over $271,000 per year for all telecommuters – which is approximately $258 per telecommuter per year.

example Avoided Parking Costs
= (59,472 TC events) × (76% events elim. drive-alone veh. trips) × ($6.00/veh)
= $271,192 per year for all 1,050 telecommuters

Avoided Office Space Expenses

The office space benefit remains one of the most enigmatic factors in this report, because it is both difficult to quantify and difficult to value. It is not clear *how much* space is saved per telecommuter, nor how much that space is valued by the employer.

[36] Future versions of the TELESIMM model could allow the split to be customized for contexts in which it is important.

Moreover, marginal space savings from telecommuting on a part-time basis may not result in direct cost-savings; there must be a market for that marginal space. For these reasons, there is scarce research addressing the marginal benefits of office space savings, and this remains one of the largest gaps in telecommuting cost-benefit literature.

In an attempt to capture the potential benefit of office space savings, we approximate the potential office space benefit of an average telecommuter. According to an annual survey of industrial and office real estate markets in the U.S., office space rental rates can vary from around $5 per square foot per month ($60 per square foot per year) in suburban areas to as much as $65 per square foot per month ($780 per square foot per year) in downtown urban areas (Society of Industrial and Office Realtors, 1998). While these survey results provide a wide range of office space values, they also allow us to arbitrarily assume a reasonable office space value of $15 per square foot per month (or $180 per square foot per year). To accompany the valuation of office space, we arbitrarily assume the size of a typical telecommuter office to be 100 square feet (a conservative ten-foot by ten-foot office).

Before calculating office space benefits, we also apply an arbitrary “efficiency factor” that indicates the percentage of time that the vacated office space is utilized. If we assume an 100 square-foot office rental rate of $180 per square foot per year and an “efficiency factor” of 50% (to represent the fraction of time that space vacated by a telecommuter is utilized for other purposes), then we calculate an average office space benefit of $2,160 per telecommuter per year.

$$\textit{Office Space Savings} = (\textit{TCers}) \times (\textit{avg space savings/TCer}) \times (\textit{avg. value of space}) \times (\textit{“efficiency factor”}) \times (\textit{TC frequency} \div 5 \textit{ workdays/week}) \quad (18)$$

If we apply these average office space benefits to a population of 1,050 telecommuters, then we see that office space benefits total $2,268,000 as shown below.

<u>example</u> Office Space Savings
= (1,050 TCers) × (100 ft^2 office) × ($180/$ft^2$ per TCer) × (50% “efficiency factor”) × (1.2 TC days ÷ 5 day workweek)
= $2,268,000 per year for all 1,050 telecommuters

From this calculation, we can see that office space benefits can be significant – even though they are not supported by much empirical data. Still, even if we assume that the employer can only utilize the telecommuter’s space half of the time it is available, the employer essentially has the opportunity to save one month of rent (28 days in an average work year) for an office belonging to an employee who telecommutes at least 1.2 days per week. Of course, it is quite possible that employers will not be able to efficiently use the available office space, given its limited and intermittent availability. If the employer is unable to utilize the space savings, then there is no resulting benefit. Moreover, an employer’s ability to use available office space could decrease as the number of telecommuters increases, and marginal office space savings become abundant. As is the case with travel time savings, it can be argued that a point is reached where little or no additional utility is gained from the incremental availability of resources at the margin – whether the resource be time or space.

Because office space benefits are capricious, its valuation is treated as a Monte Carlo variable to account for some of the variations in rents in different locations and settings (e.g., suburban versus central business district). Other inputs, such as office space size and the "efficiency factor", can be adjusted with other TELESIMM input variables.

Avoided Road Construction Benefits

In general, public sector benefits resulting from telecommuting are debatable. In this section, we discuss the rationales for both including and excluding the impacts of telecommuting on the physical transportation network into the cost-benefit analysis. Although a method for calculating potential impacts was explored, it will be shown that telecommuting is unlikely to significantly impact the physical transportation system.

In 1994, a Department of Energy report suggested that benefits from telecommuting could result if construction of additional freeway or arterial lanes could be avoided (DOE, 1994). Hypothetically, it is conceivable that public sector benefits could be realized if commute trips were highly concentrated in an isolated corridor at a time when traffic were at or near capacity (e.g. during the morning and afternoon peak commute periods). For example, if a large office park located close to an urban freeway served a sizeable telecommuting workforce, telecommuting could impact the travel demand on the freeway segment and arterials and ramps during the peak commute periods. In most situations, however, telecommuters may be dispersed throughout an urban area having minimal impact on any particular roadway, and the physical effects of telecommuting would probably be dispersed throughout the transportation system. Because telecommuting occurs less than two days per week on average and because it may occur on varying days of the week, telecommuting alone would probably not have a significant and consistent enough impact on the traffic demand during the peak (design) hour in which capacity is measured to avoid adding additional roadway capacity. Simply put, telecommuting can be expected to contribute to an overall reduction in travel demand, but it is more likely to produce a regional, system-wide improvement in travel rather than preventing the construction of additional lanes. Moreover, it remains plausible that any benefit that would be achieved through telecommuting programs would be filled by suppressed latent demand.

Simple calculations indicate that a large number of vehicles would need to be removed during the peak travel period before telecommuting would have the same effect on the demand side that the addition of a lane on a typical freeway would have on the supply side. To explore the impacts of telecommuting on a specific roadway corridor, we can use analysis methodology recommended by the 1997 Highway Capacity Manual (HCM). We can show that telecommuting would need to be responsible for the removal of almost 2,000 vehicles per hour in order to have the same effect as adding a lane to a three-lane freeway under highly congested conditions.

According to the Highway Capacity Manual, the number of lanes required for a freeway segment, N, is determined using the following formula:

$$N = \frac{V}{v_p \times PHF \times f_w \times f_{HV} \times f_P} \qquad (19)$$

where

v_p = service flow rate (passenger vehicles per hour per lane),

V = hourly volume during the design hour (vehicles per hour),

PHF = peak-hour factor adjustment for variability within the design hour,

f_w = lane width and/or lateral clearance adjustment factor,

f_{HV} = heavy-vehicle adjustment factor, and

f_P = driver population adjustment factor.

This equation is commonly used by traffic engineers to calculate the number of lanes (in one direction) that must be supplied, given the hourly traffic demand during the design hour, V, and the desired level of service indicated by the maximum service flow rate, v_p. The remaining variables are simply adjustment factors that take into account 1) the effect of "less than ideal" lane widths and clearances on the roadway, 2) the effects of heavy vehicles in the traffic stream (f_{HV}), and 3) the effects of driver characteristics (e.g. commuter versus recreational motorists) using the roadway (f_P). The peak-hour factor, PHF, is another adjustment that takes into account the effects of variability of traffic during the peak hour. (For additional details regarding this equation and its variables, the reader is referred to Chapter 3 of the 1997 Highway Capacity Manual.)

Table 11. Typical Maximum Service Flow Rates

	Free Flow Speed				
LOS	**55 mph**	**60 mph**	**65 mph**	**70 mph**	**75 mph**
A	550	600	650	700	750
B	880	960	1,040	1,120	1,200
C	1,320	1,440	1,548	1,632	1,704
D	1,744	1,856	1,984	2,048	2,080
E	2,250	2,300	2,350	2,400	2,400
F	Variable	Variable	Variable	Variable	< 2,400

Note: Values are in units of passenger vehicles per hour per lane.
Source: Highway Capacity Manual (TRB, 1997).

By assuming typical adjustment factors for urban freeway conditions, we can find the traffic demand for a typical three-lane freeway section at capacity. Then we can determine the number of vehicles that could occupy the roadway if another lane were added to determine the number of vehicles that would need to be omitted from the same roadway (due to telecommuting) to have the same effect.

The maximum service flow rates and corresponding levels of service are taken from the Highway Capacity Manual and are shown in Table 11.[37] If a freeway has a free-flow speed of 65 mpg but operates at LOS D during the peak period, then we can assume a service flow rate of 1,984 passenger vehicles per lane per hour, as indicated in Table 11. For the purpose of these calculations, we can make simple assumptions regarding the adjustment factors as might be expected for a typical urban freeway during the peak period: PHF = 0.90, f_w = 0.95, f_{HV} = 0.95, f_p = 0.95.[38] With three lanes, we see that capacity is almost 4,600 vehicles per hour.

$$V_3 = v_{p_{\text{LOS D}}} \times N \times PHF \times f_w \times f_{HV} \times f_p = 1{,}984 \times 3 \times 0.9 \times 0.95 \times 0.95 \times 0.95 = 4{,}593 \text{ veh/hr}$$

With an additional lane (four lanes), we see that the supply increases to almost 6,130 vehicles per hour:

$$V_4 = v_{p_{\text{LOS D}}} \times N \times PHF \times f_w \times f_{HV} \times f_p = 1{,}984 \times 4 \times 0.9 \times 0.95 \times 0.95 \times 0.95 = 6{,}123 \text{ veh/hr}$$

For telecommuting to maintain a level of service equal to that of adding a freeway lane, it would need to be responsible for removing more than 1,530 vehicles from the peak hour on a single freeway section. If 76% of telecommute events result in drive-alone trips as discussed earlier, we would need to ensure that more than 2,013 employees

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[37] According to the Highway Capacity Manual, LOS A represents free-flow conditions, under which individual motorists are virtually unaffected by other vehicles present. LOS E represents operating conditions at or near capacity, while LOS F represents a breakdown in flow.

[38] These adjustment factors correspond to a freeway with: level terrain, 11-foot lane widths, 6-foot lateral clearance, containing a 10% mix of trucks and buses with no RVs, and consisting primarily of commuter drivers. While the percentage of heavy vehicles in the vehicle population may increase when telecommuter passenger vehicles are eliminated, we will assume that this effect is negligible for the purposes of this example.

who would have used that freeway section during the peak hour telecommute *each day* (requiring 8,388 employees to telecommute 1.2 days a week on average) to achieve a 1,530-vehicle reduction in demand. Depending on the length of the peak, this reduction may need to be sustained for more than one hour. Simply put, it seems unlikely that these concentrated reductions in demand can be consistently achieved at a localized level. If this 1,530-vehicle per hour reduction is not achieved, then any reduction in demand would simply result in an improved level of service, and the forgone cost of adding a lane would not be justified. While there may be some quantifiable public sector benefit that can be obtained from an improvement in the level of service due to a general reduction in travel demand, these benefits are not explored in this report.

So while telecommuting remains a viable general travel demand strategy, it is difficult to justify the assertion that it can impact construction costs, even along a localized corridor. Even if construction benefits were to be realized, many assumptions would need to be made to identify *when* and *where* the impact would occur.[39]

Avoided Vehicle Emissions

Quantifying air quality impacts depends on a series of factors, such as: vehicle miles of travel (VMT), engine starting conditions (i.e., cold or hot starts), average speed, vehicle type (including emissions equipment), ambient air temperature, and driver

[39] The impact of telecommuting on latent demand (that is, the possibility that newly-available capacity will be partially or completely exhausted by previously-existing demand that had been suppressed due to lack of capacity) is recognized as an additional complication to the issue of increased roadway capacity but is neglected in this report.

behavior (California Air Resources Board, 1996). As a result, it remains difficult to fully capture all of the pollution benefits from a telecommuting program. Nonetheless, we can reach a conservative approximation by calculating 1) start emissions based on start emission factors along with 2) running exhaust emissions by using VMT estimates, assuming a constant running speed and using emission factors from California's EMFAC emission model as shown in Table 12.[40,41]

To be conservative, it was also assumed that the forgone commute would have been made in a light-duty, gasoline-powered automobile with a catalytic converter. Because a growing portion of the vehicle fleet in this country comprises light duty trucks or sport-utility vehicles with lower fuel economies than light-duty automobiles, these assumptions will underestimate the air quality impacts of telecommuting.[42] In other words, the current vehicle fleet almost certainly consumes more gasoline per mile and produces more emissions per gallon of gasoline than that which is assumed here. Furthermore, because a constant running speed is assumed, we are neglecting any sudden acceleration and deceleration episodes which also result in higher emission rates than those assumed.

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[40] The average travel speed was assumed to be 35 mph, as the average commute speed was determined to be 33.6 mph as shown in Table 6.

[41] While we recognize that EMFAC emission factors are based on California vehicle fleet characteristics, we assume that these factors represent reasonable vehicle emission rates.

[42] Approximately 21% of the national vehicle fleet is light-duty trucks or sport-utility vehicles, according to the 1995 NPTS.

Table 12. EMFAC7G Mobile Emission Factors for Light Duty, Gasoline Autos

Speed (mph)	**ROG (grams/mile)**	**CO (grams/mile)**	**NO_X (grams/mile)**	**CO_2 (grams/mile)**	**PM_{10} (grams/mile)**
5	0.91	17.09	1.07	936.69	0.00
10	0.43	9.71	0.80	602.96	0.00
15	0.30	6.67	0.64	432.17	0.00
20	0.26	5.17	0.53	340.44	0.00
25	0.24	4.30	0.46	290.95	0.00
30	0.22	3.72	0.44	266.27	0.00
35	0.20	3.30	0.45	257.59	0.00
40	0.17	3.01	0.49	260.01	0.00
45	0.14	2.88	0.57	270.30	0.00
50	0.13	3.01	0.69	285.68	0.00
55	0.14	3.63	0.84	302.99	0.00
60	0.21	5.46	1.03	318.30	0.00
65	0.58	11.52	1.25	326.96	0.00

Source: California Air Resources Board, 1996, pp. 57-58.
Note: These values are for vehicles equipped with catalytic converters (vehicles produced after 1975).
Note: These values are for summertime, running enhanced inspection and maintenance exhaust emission factors at 75 degrees F for light duty autos, assuming 1976 to 2010 model years.
Note: "Composite emission factors listed are for warmed-up (i.e., the engine is fully warmed up to operating temperature) vehicles operating in an ambient temperature of 75 degrees Fahrenheit for summer and 50 degrees for winter. There are composite emission factors for each of the 17 type/technology groups for average speeds from 5 – 65 miles per hour. Exhaust emissions include both tailpipe emissions, as well as engine blowby from the crankcase" (CARB, 1996, p. 56).
Note: In this report, the value for reactive organic gases (ROG) is assumed to be approximately equal to that for hydrocarbons (HC). Both terms are used to represent volatile organic compounds (VOCs).

If one or more cold-starts are eliminated, additional air quality benefits can be counted using the start emission factors from California's EMFAC model, indicated in Table 13. In this report, a hot soak time of 120 minutes was assumed to obtain values from Table 13.[43]

[43] While SO_x is included among the criteria vehicular pollutants, it is primarily the product of diesel engines and, thus, is not included among the pollutants from light duty gasoline autos, shown in Table 12 and Table 13.

Table 13. EMFAC7G Start Emission Rates for Light Duty, Gasoline Autos

Soak Time (minutes)	ROG (grams/start)	CO (grams/start)	NO_x (grams/start)	CO_2 (grams/start)
1	0.04	0.44	0.30	2.81
5	0.20	2.15	0.46	6.21
10	0.40	4.21	0.65	10.47
20	0.75	8.08	0.97	18.97
40	1.34	14.78	1.44	35.99
60	1.77	20.10	1.67	53.01
90	2.10	25.47	1.69	78.55
120	2.18	27.69	1.69	94.49
180	2.31	28.57	1.68	110.87
300	2.57	30.38	1.66	141.10
480	2.92	33.21	1.60	180.18
720	3.33	37.19	1.46	220.54

Source: California Air Resources Board, 1996, pp. 59-60.

Once the quantities of pollutants are calculated, they are monetized using values shown in Table 14 below. These monetizing values were estimated using two different approaches, so a range of values is available. For the deterministic base case, it will be indicated in Chapter 5 that the lowest, most conservative estimates were used in the majority of cost-benefit analysis calculations.[44] For the stochastic base case analysis, the monetizing values were allowed to vary and the ranges were used as the minimum and maximum allowable values.

[44] Two general methods were originally used by Wang and Santini (1994) to estimate monetary valuations for emissions. Damage estimates were obtained by "simulating air quality, identifying health and other welfare impacts of air pollution, and valuing the identified impacts," while control costs estimates are obtained to "represent the opportunity cost offset by avoiding the need for spending on emission reductions from the most costly emission control measures previously considered to meet regulatory requirements" (Wang & Santini, 1994, p. 40).

Table 14. Emission Value Estimates (1997 dollars, $/ton)

Pollutant	Damage Value Method	Control Cost Method
HC	0 – 8,945	1,450 – 27,311
CO	0 – 4	1,061 – 12,038
NO_x	272 - 18,746	3,184 –34,171
PM_{10}	713 – 61,637	1,165 – 7,378
SO_x	362 – 9,611	780 – 24,463

Source: Wang and Santini, 1994, adjusted for inflation.
Note: This study did not include a valuation for CO_2.

The general equation used to quantify and monetize air pollution benefits is shown below. Additionally, an example based on a telecommuting population of 1,050 telecommuters is shown.[45] As we can see from the example calculation, low quantifying factors coupled with low valuation factors result in small air quality benefits for the public sector. From the example, we can see that only NO_x has both a non-zero emission factor and a non-zero valuation.

$$\textit{Avoided Pollution Benefits} = (\textit{TC events}) \times (\textit{\% events that eliminate drive-alone trips}) \times [(\textit{saved distance/event}) \times (\Sigma_p(\textit{running emissions from pollutant p/mile} \times \textit{\$/pollutant p})) + (\textit{avoided cold starts/event}) \times (\Sigma_p(\textit{pollutant p/cold start} \times \textit{\$/pollutant p}))] \quad (20)$$

[45] A conversion factor is needed to convert tons into grams so that the emission factors and the valuation factors are in common units (1 ton = 907,184.74 grams).

example Avoided Pollution Benefits
= (59,472 TC events) × (76% events that elim. drive-alone veh. trips) × [(2 × 11.6 mi) – 2.0 mi/trip)) × (1 ton/ 907,185 gm) × ((0.20 gm ROG/mi × \$0/ton ROG) + (3.30 gm CO/mi × \$0/ton CO) + (0.45 gm NO_x/mi × \$272/ton NO_x) + (0 gm PM/mi × \$713/ton PM) + (257.59 gm CO_2/mi × \$0/ton CO_2) + (0 gm SO_x/mi × \$362/ton SO_x)) + (1 saved cold start/event) × (1 ton/ 907,185 gm) × ((2.18 gm ROG/start × \$0/ton ROG) + (27.69 gm CO/start × \$0/ton CO) + (1.69 gm NO_x/start × \$272/ton NO_x) + (94.49 gm CO_2/start × \$0/ton CO_2) + (0 gm SO_x/start × \$362/ton SO_x))]
= \$152 per year for all 1,050 telecommuters

Summary of Non-Monte Carlo Input Values

The tables below list a summary of input values used in the calculation of cost and benefits. While most of these values were used in the equations above, some may not have been listed explicitly. These tables are presented to fully account for any inputs that have not been discussed in previous sections. Table 15 lists values that are used to quantify various factors, while Table 16 lists values that are used to monetize the quantified results for the cost benefit analysis.[46] Along with each value, a source is cited as a reference indicating the origin of the value. These input values do not change in the analysis (unlike the Monte Carlo variables, which change and are discussed preceding the deterministic and stochastic base case results). The tables below will be referenced later in this report for comparison when the results from the sensitivity analysis are discussed.

[46] All of these values can be adjusted in the TELESIMM spreadsheet model.

Table 15. Quantifying Inputs and Assumptions

Input	Value	Source
Work Days Per Year (days/yr)	236	(assumed)
Local Non-Commute Trip Distance (mi)	2.0	Mokhtarian (1998)
One-Way Commute Trip Distance (mi)	23.2	1995 NPTS
One-Way Commute Trip Travel Time (min)	20.7	1995 NPTS
Commute Trip Speed (mph)	33.6	1995 NPTS
Fuel Economy (mpg)	24.4	NHTSA, 1997
Computer Equipment Life (yrs)	5	Frankel (1996)
Percent Telecommuting Events That Eliminate Drive-Alone Auto Trips	76%	Mokhtarian (1998)
Running Emissions - ROG (gm/veh-mile)	0.20	CARB (1996)
Running Emissions – CO (gm/veh-mile)	3.30	CARB (1996)
Running Emissions – NO_x (gm/veh-mile)	0.57	CARB (1996)
Running Emissions – PM (gm/veh-mile)	0.00	CARB (1996)
Running Emissions – CO_2 (gm/veh-mile)	257.59	CARB (1996)
Running Emissions – SO_x (gm/veh-mile)	0.00	CARB (1996)
Avoided Cold Starts (#/event)	1.0	based on Mokhtarian (1998)
Start Emissions - ROG (gm/veh-trip)	2.18	CARB (1996)
Start Emissions – CO (gm/veh-trip)	27.69	CARB (1996)
Start Emissions – NO_x (gm/veh-trip)	1.69	CARB (1996)
Start Emissions – CO_2 (gm/veh-trip)	94.49	CARB (1996)

Table 16. Monetizing Inputs and Assumptions

Input	Value	Source
Fuel Costs ($/gal)	$1.29	API (1998)
Auto Insurance & Maint. ($/mi)	$0.05	Reed, *et al*. (1995)
Misc. Cost Savings ($/event)	$2.15	SCAG (1988)
Add'l Energy Costs ($/event)	$2.40	est. from SCAG (1988)
Equipment/Software Start-Up Cost ($)	$1,800.00	JALA (1993)
Equipment Service/Maint. Cost ($/yr)	$250.00	JALA (1990)
Communications Start-Up Cost ($)	$100.00	JALA (1993)
Communications Service Cost ($/yr)	$360.00	SCAG (1988)
Training Costs ($/TCer-sup. pair)	$300.00	JALA (1990)
Emissions – ROG ($/ton)	$0.00	Wang and Santini (1994)
Emissions – CO ($/ton)	$0.00	Wang and Santini (1994)
Emissions – NO_x ($/ton)	$272.00	Wang and Santini (1994)
Emissions – PM ($/ton)	$713.00	Wang and Santini (1994)
Emissions – CO_2 ($/ton)	$0.00	no information available
Emissions – SO_x ($/ton)	$362.00	Wang and Santini (1994)
Fuel Tax ($/gal)	$0.43	API (1998)

5.0 OUTPUTS: SUMMARY OF RESULTS

This chapter is divided into five sections. The first section is devoted to a discussion of the *deterministic base case* scenario and a review of its input values, while the second section sets up the *stochastic base case* input values. In the second section, the stochastic base case procedure is distinguished from the deterministic base case procedure, and some discussion is devoted to the base case parameters, specifically the Monte Carlo variables and the scenario assumptions.

The third section is a brief overview of the stochastic base case output generated by the TELESIMM model. An overview of the output allows for easier interpretation of the stochastic base case results, as well as the sensitivity analysis results in the next chapter. This overview also highlights how the changes in input parameters can be matched with changes in results. The simulation mechanics and parameters are presented along with a discussion on interpreting the output.

In the last two sections of this chapter, the stochastic base case results are presented and compared to the deterministic results. Together, the deterministic and stochastic base case components provide a complementary discussion of TELESIMM model results.

5.1 The Deterministic Base Case

As noted in earlier sections, the deterministic base case scenario represents current conditions. It is used as a benchmark to which other scenarios are compared by making adjustments to input values and documenting changes in the results. In this section, the deterministic base case values set for both the Monte Carlo variables and the three scenario assumptions are discussed.

Monte Carlo Variables

Although most of the input parameters were discussed in the previous chapter, here special attention is given to the key parameters treated as the Monte Carlo variables. In the previous chapter, these variables were discussed with respect to the type of distribution from which a range of values could be randomly generated for the stochastic simulation process. Also, we discussed the parameters that defined the variable distributions. For example, we allowed *changes in productivity* to vary uniformly between 0% and 15%. For the deterministic base case, however, the Monte Carlo variables are set to a single value (based on their defined distributions) to represent current conditions. For example, we take the average change in productivity among current telecommuters to be 7.5%, halfway between 0% and 15%.[47]

The deterministic base case value for each Monte Carlo variable is shown in

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[47] It is important to emphasize that the increase in productivity only occurs on telecommute days, as indicated in Section 4.4. The 7.5% assumed increase in productivity occurs on 24% of all work days, yielding a *net* increase in productivity of 1.8% of the telecommuter's annual salary.

Table 17 below. Along with each value, a reference is provided to inform the reader where the value was obtained. While some values are taken directly from the literature, some values are the result of minor modifications (as has been explained for telecommuting frequency), which were made based on experience and/or competing values in the literature. Other values without references were wholly assumed and are subject to debate. These assumptions were necessary to characterize current conditions or to fill gaps in the empirical research literature. All of the values used in this report can be altered by a user of the TELESIMM model, if desired.

Table 17. Monte Carlo Variable Deterministic Base Case Values

Variable	Value	Reference
Discount (Interest) Rate (%)	8.0%	(assumed)
One-Way Commute Distance (mi)	11.6	1995 NPTS
Annual Salary ($/yr)	$35,000	(assumed)
Value of Travel Time ($/hr)	$0.00	WA DOT (1995)
TC Attrition (%/yr)	35%	(assumed)
TC Frequency (days/wk)	1.2	Handy and Mokhtarian (1995)
Productivity Change (%)	7.5%	(assumed)
Parking Space Value ($/day)	$3.50	Met. Wash. COG (1991)
Office Space Value ($/yr)	$0	(assumed)
Emission Costs – ROG ($/ton)	$0	Wang and Santini (1994)
Emission Costs – CO ($/ton)	$0	Wang and Santini (1994)
Emission Costs – NO_x ($/ton)	$272	Wang and Santini (1994)
Emission Costs – PM ($/ton)	$713	Wang and Santini (1994)
Emission Costs – CO_2 ($/ton)	$0	(assumed)
Emission Costs – SO_x ($/ton)	$362	Wang and Santini (1994)

Scenarios

In addition to the fixed values on the Monte Carlo variables, a set of scenarios helps to define the deterministic base case. Three scenario indicator variables allow the user to decide on the following factors:

1) including or excluding office and parking space benefits,

2) including or excluding air quality benefits, and

3) choosing the bearer of the equipment cost burden.

Like the Monte Carlo variables, these scenarios were allowed to vary for the stochastic base case but remained fixed for the deterministic base case calculations.

In the TELESIMM model, each scenario was set using "dummy" indicator variables where each variable could only take on a discrete value of 0 or 1, representing two distinct scenarios. For example, the equipment cost burden indicator is defined as:

0 = the *employer* bears the equipment cost burden, and

1 = the *employee* bears the equipment cost burden.

For the stochastic base case (discussed in greater detail in the next section), the user is allowed to input a probability corresponding to the likelihood that the scenario with dummy variable equal to one will be selected in any given simulation. As with some of the Monte Carlo assumptions, these three probabilities were not selected based on previous telecommuting literature. In fact, these scenarios were added to the cost-benefit analysis, because they represented issues that were not resolved in the telecommuting literature. For example, practice varies on whether the equipment cost burden is borne by the employer or the employee, so the user is allowed to assign a probability that the cost burden will belong to the employee for any random case. In the stochastic case, each scenario is allowed to vary independently, creating eight (2^3) possible sets of scenarios – although in reality these scenarios may not actually be independent.

The space benefit is used to allow for office or parking space benefits to be realized by the employer. In many situations, such as those outside of major metropolitan areas, the marginal space savings may be negligible, as may be the case for air quality or construction benefits. For the deterministic base case, we conservatively assume that both space benefits as well as air quality and construction benefits can be neglected when assuming current conditions as shown in Table 18. Additionally, it was assumed that the employer would bear the equipment cost burden (for details see Shafizadeh, *et al.*, 2000).

Table 18. Deterministic Base Case Scenario Assumptions

Indicator Variable	Value	Interpretation
Space Benefits	0	Space Benefits are Neglected
Air Quality Benefits	0	AQ Benefits are Neglected
Equipment Burden	0	Employer Pays for Equipment

5.2 The Stochastic Base Case

Unlike the deterministic base case where as little uncertainty is added to the model as possible, the stochastic base case analysis allows uncertainty with costs and benefits to be introduced. For each stochastic simulation, the Monte Carlo variables are allowed to take on a different, randomly generated value based on the assumed distribution of the variable. The stochastic case can easily be compared to the deterministic case because both cases assume no net growth in telecommuting so that the only difference is the changes in the Monte Carlo variables. The distinctions between the deterministic base case and the stochastic base case are summarized in Table 19 below. The rest of this section contains a brief discussion devoted to the mechanics of the actual simulation process, as well as the simulation input parameters and interpretation of the output.

Table 19. Summary of Base Case Assumptions

Assumption	Deterministic Base Case	Stochastic Base Case
Growth	No Growth	No Growth
Monte Carlo Variables	Fixed Values	Allowed to Vary
Scenarios	Fixed	Probabilistic
Results	Section 5.3	Section 5.4

The Process

The stochastic simulation involves the modification of the Excel spreadsheet used for the deterministic base case calculations, facilitated by the use of a macro program. The stochastic simulation process can be characterized in the following three steps:

Step 1. Random Number Generation. Random numbers are generated for each Monte Carlo variable, based on parameter settings and the number of trials requested. Each unique set of Monte Carlo variables represents a different simulation trial. In this report, 5,000 trials were run for each case studied, in which each of the 12 Monte Carlo variables was represented by values generated for each trial (as will be discussed in the next part of this section), and each of the three scenario indicators independently took on the value 0 or 1 for each trial with the probabilities indicated in Table 21 below.

Step 2. Simulation. Each Monte Carlo input value is copied and pasted into the cost-benefit input worksheet, and the results from each "trial" are preserved. In other words, the macro program simply "cuts and pastes" values from a sheet of randomly generated numbers on to a sheet where they are fed into the cost-benefit calculation. The results from the cost-benefit spreadsheet are calculated almost instantly before being copied and pasted with the results from other trials. The output of the simulation process is discussed in the last part of this section.

Step 3. Histogram Generation. In the last step, the frequencies of B/C ratios are compiled for the telecommuter, the employer, the public sector, and overall before being graphed as a histogram. The histogram is generated from the 5,000 trials that were simulated for each scenario.

The Input Parameters

As was done with the deterministic base case, before results can be discussed we must first set the stochastic base case parameters. In Table 20 below, we can see the parameters that were allowed to vary as either normally distributed or uniformly distributed random variables. For the normally distributed variables, the distribution is defined by a mean value that was usually found in the literature and a standard deviation that was selected based on a desired level of variability. The uniformly distributed variables are allowed to vary anywhere between the minimum and maximum values.

Table 20. Stochastic Base Case Parameters

Normally Dist. Variables	Mean	S.D.	Reference
One-Way Commute Dist.(mi)	11.6	4.0	1995 NPTS
Annual Salary ($/yr)	$35,000	$6,000	(assumed)
TC Frequency (days/wk)	1.2	0.3	Handy and Mokhtarian (1995)
Uniformly Dist. Variables	**Min**	**Max**	**Reference**
Discount (Interest) Rate (%)	3.0%	12.0%	(assumed)
Value of Travel Time ($/hr)	$0.00	$6.30	WA DOT (1995)
TC Attrition (%/yr)	20%	50%	(assumed)
Net Productivity Change (%)	0%	15%	(assumed)
Parking Space Value ($/day)	$3.50	$9.50	Washington COG (1991)
Office Space Value ($/ft^2/yr)	$0	$780	(assumed)
Emission Costs – ROG ($/ton)	$0	$8,945	Wang and Santini (1994)
Emission Costs – CO ($/ton)	$0	$4	Wang and Santini (1994)
Emission Costs – NO_x ($/ton)	$272	$18,746	Wang and Santini (1994)
Emission Costs – PM ($/ton)	$713	$7,378	Wang and Santini (1994)
Emission Costs – CO_2 ($/ton)	$0	$0	(assumed)
Emission Costs – SO_x ($/ton)	$362	$9,611	Wang and Santini (1994)

Note: These stochastic base case parameters can be compared to the deterministic base case parameters, shown in Table 17.

Along with setting the Monte Carlo variable parameters, we must assign probabilities to each scenario, shown in Table 21. Although these parameters are critical decision parameters to the outcome of the cost-benefit analysis of telecommuting, they remain subjective because there is little research to support the values listed. Instead, professional judgment is used to arbitrarily assign probabilities to these scenarios. Other values are explored, and results are compared as part of the sensitivity analysis.

Table 21. Stochastic Base Case Scenario Probabilities

Indicator Variable	Probability	Interpretation
Space Benefits (parking, office)	25%	Probability that space benefits are realized.
Scale Benefits (air quality)	20%	Probability that scale benefits are realized.
Equipment Costs	40%	Probability that telecommuters will bear the equipment cost burden.

Interpreting the Output

The TELESIMM program provides the user with a detailed spreadsheet containing the Monte Carlo input from each individual trial (as shown in Table 22) and the resulting output (shown in Table 23). By preserving the Monte Carlo variable inputs with the resulting outputs, we are able to recognize the conditions that lead to certain results. From the sample tables below, we can see that each row represents a separate trial with varying input and output values.

Table 22. Sample TELESIMM Stochastic Base Case Inputs

Trial	Disc.	Dist.	Salary	TT $	Attrition	TC Freq.	Prod.	…
1	8.52%	15.69	$37,933.01	$9.39	40.3%	1.13	5.2%	…
2	4.70%	9.61	$37,512.20	$8.98	37.7%	1.65	6.3%	…
3	4.82%	6.39	$28,582.39	$7.04	37.8%	0.74	10.9%	…
4	5.78%	8.47	$36,120.68	$8.66	26.3%	0.72	1.8%	…
5	11.64%	16.73	$42,924.40	$9.18	32.6%	1.65	10.2%	…
…	…	…	…	…	…	…	…	…
5000	3.66%	8.57	$36,150.12	$7.66	38.1%	0.81	10.4%	…

where

Disc = discount rate

Dist. = commute travel distance (miles one-way)

Salary = employee individual annual salary

TT$ = individual value of an hour of travel time

Attrition = annual telecommuting attrition

TC Freq. = average telecommuting frequency

Prod. = change in productivity due to telecommuting

Table 23. Sample TELESIMM Stochastic Base Case Results

Trial	…	Telecommuter					Employer …
		Total Discounted Costs ($)	Total Discounted Benefits ($)	NPV ($)	NPV per TCer per year ($)	B/C Ratio	…
1	…	6.07E+10	2.91E+10	-3.17E+10	($285.29)	0.48	…
2	…	1.70E+10	4.15E+10	2.45E+10	$220.67	2.44	…
3	…	7.58E+09	1.53E+10	7.70E+09	$69.37	2.02	…
4	…	7.09E+09	1.65E+10	9.41E+09	$84.81	2.33	…
5	…	6.00E+10	3.89E+10	-2.11E+10	($189.75)	0.65	…
…	…	…	…	…	…	…	…
5000	…	6.12E+10	1.94E+10	-4.18E+10	($376.48)	0.32	…

These tables also provide a glimpse of how the results can vary depending on the selected input values. As will be shown in the next section, the TELESIMM program uses this spreadsheet of trial outcomes to generate histograms for the telecommuter, the employer, the public sector, and overall. Each histogram allows us to view the *range of possible outcomes* and gives us an idea as to frequency of each potential outcome – both of which are useful when trying to determine the potential risks and rewards of a telecommuting project.

5.3 Deterministic Base Case Results

Using the inputs noted earlier in this chapter, we assume no net growth in telecommuting to obtain the deterministic base case results. The telecommuting population in each year of the telecommuting project was fixed at the current number of telecommuters (11,100,000) in the United States in 1996 (with, however, a 35% attrition rate and equivalent replacement being assumed). The results, shown in Table 24, reveal that telecommuter benefits are high with a benefit-cost ratio value greater than two, indicating that benefits are more than twice the costs. If we divide the total NPV by the total number of telecommuters, we conclude that the average benefit is more than $122 per telecommuter per year. A chart of telecommuter costs and benefits is presented in Figure 4. As we can see, the largest benefit stems from miscellaneous benefits (reduced lunch expenses, dry cleaning expenses, etc.), followed by travel time benefits.

Table 24. Deterministic Base Case Results for U.S. Telecommuters

Perspective	NPV (all telecommuters)	NPV (per TCer per year)	B/C Ratio
Telecommuter	$13.6 billion	$122.34	2.24
Employer	-$46.3 billion	-$417.42	0.52
Public Sector	-$1.3 billion	-$11.65	0.00
Overall	-$34.0 billion	-$306.733	0.69

Note: Net present value per telecommuter per year was calculated by dividing the total NPV by the total number of telecommuters in all years of the project.

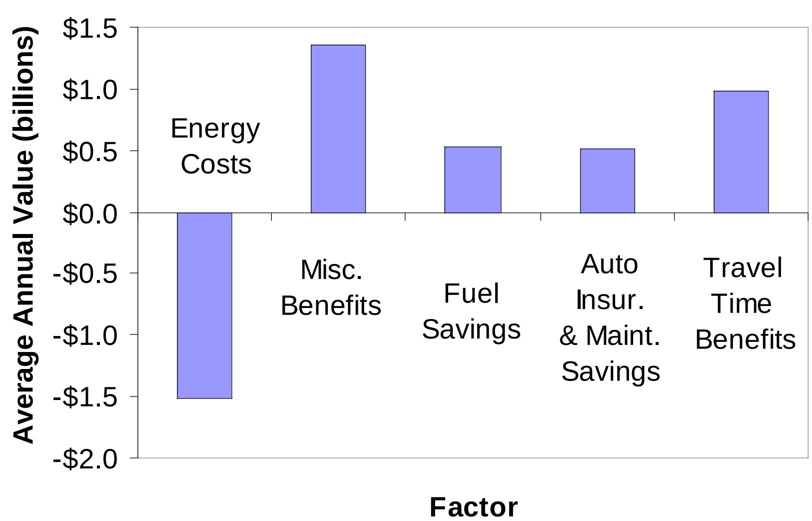

Figure 4. Telecommuter Deterministic Base Case Costs and Benefits

Also in Table 24, the deterministic base case results yield an employer B/C ratio of 0.52 – well below the break-even value of one – indicating that costs exceed benefits. In fact, this B/C ratio indicates that, for the employer, costs are twice those of benefits. We see that the employer losses (net present value equal to -$46.3 billion for all telecommuters) are more than three times greater than telecommuter benefits ($13.6 billion for all telecommuters). The results indicate that it would cost an employer (on net) almost $420 per telecommuter per year to support a telecommuting program. Furthermore, we can immediately conclude that an employer must achieve a increase in productivity greater than the deterministic base case value assumed (7.5%) to yield a net benefit, because productivity is the only employer benefit assumed under the deterministic base case scenario.[48] A chart of deterministic base case employer costs and benefits is shown in Figure 5, which illustrates that equipment costs and telecommunications costs make up the majority of costs.

Together, these results indicate that deterministic base case conditions do not encourage home-based telecommuting – except for the telecommuter. Even the public sector yields no benefits and results in a net loss of $1.3 billion in fuel tax revenue.

[48] Recall that the 7.5% productivity is assumed to apply only to telecommuting days, so that the overall productivity increase for an individual who only telecommutes 24% of the time is only 1.8% (24% × 7.5%), which translates into $630 annually for an individual with an average salary of $35,000.

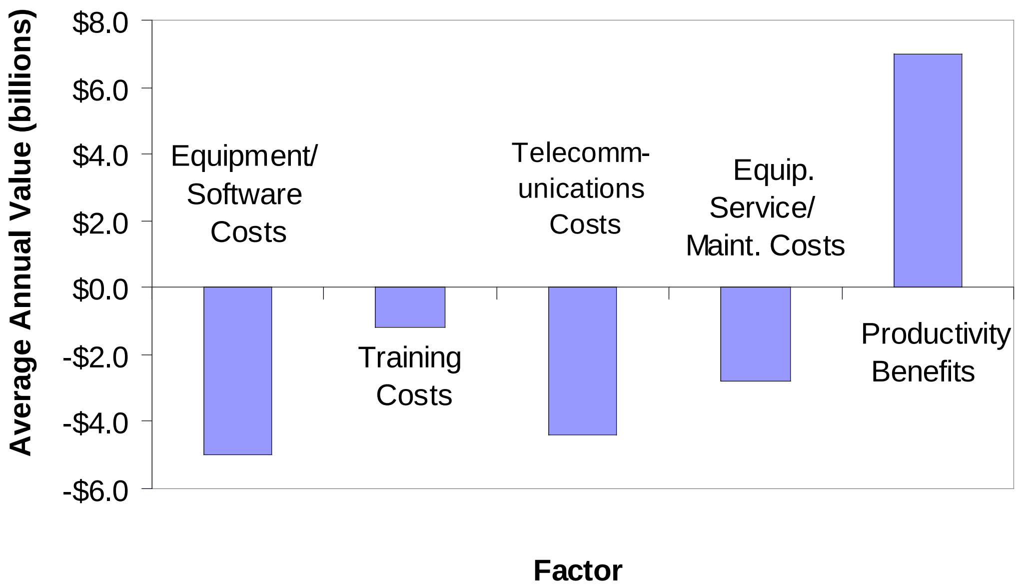

Figure 5. Employer Deterministic Base Case Costs and Benefits

These results suggest that something is wrong with the deterministic base case assumptions. It is unlikely that employers would permit *any* telecommuting if the B/C ratio were actually so unfavorable. Thus, it is likely that the employer benefits (e.g., impacts on productivity) are understated or that the costs are overstated. These results could also indicate that the model does not capture all of the elements in the decision to telecommute. Either the deterministic base case inputs need to be adjusted, or a rational explanation must exist as to why *any* telecommuting exists under these circumstances.

Another possible explanation for these results can be traced back to the assumed attrition rate of 35%. It is difficult to imagine a program that supports telecommuters on an ongoing basis when over one-third of all participants quit within their first year. It is possible that attrition rates are not actually that high or that they decrease over time for longer-term telecommuting projects. (However, anecdotal evidence and some systematic research continue to support the assumption of high attrition, or at best stagnation, for many programs; see, e.g., West Group Research *et al*., 1999). While these possible influences are merely speculative, the attrition rate assumptions will be explored in the next chapter.

5.4 Stochastic Base Case Results

In this section, we present the results obtained from the stochastic base case analysis. Histograms for each perspective are produced which yield an overall probability of "breaking even" under a given set of conditions. In other words, we present a probability of breaking even, given that certain input assumptions are met (i.e., those shown in Table 20 and Table 21). Additionally, we obtain B/C ratios and NPV results, which are compared to the base case results. Because these results are being compared to the deterministic base case results, we continue to assume "no growth" in telecommuting.[49] (In the sensitivity analysis, we will explicitly explore how a different growth assumption affects the results.)

The Telecommuter

After analyzing the deterministic base case results, we might be led to believe that the telecommuter would have a positive economic outcome from telecommuting in the stochastic base case analysis. By introducing a 40% probability that telecommuters will

[49] In this chapter, we assume no growth in telecommuting but we allow the Monte Carlo variables in Table 21 to vary by the assumed probabilities.

pay for their own equipment costs, however, we find a much different conclusion. The simulation histogram, illustrated in Figure 4, indicates that the introduction of that factor involves a large cost component that makes the economic evaluation for the telecommuter less than optimistic.

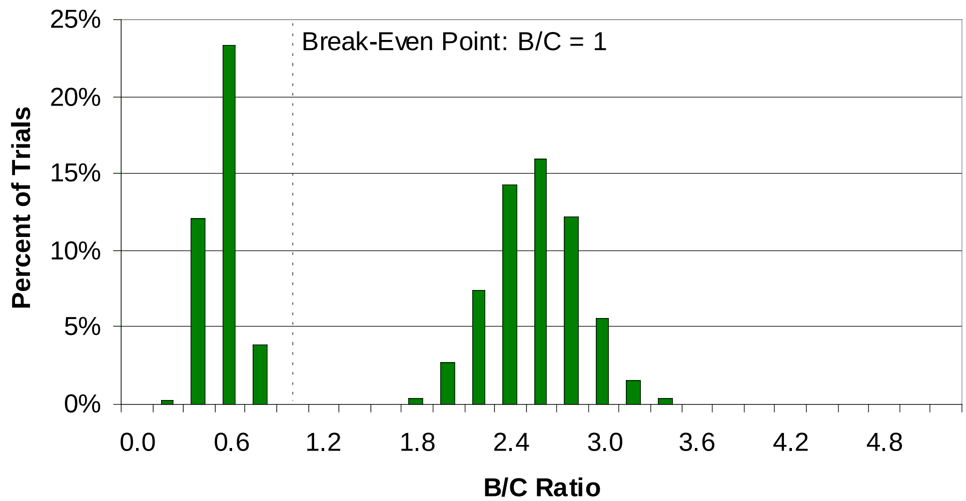

Figure 6. Telecommuter Stochastic Base Case B/C Ratio Histogram

From Figure 6, we can clearly see a bimodal distribution, with different populations of telecommuters on each side of the break-even point (where the B/C ratio equals one). Review of the simulation output and corresponding inputs reveal that the population of telecommuters to the left of the break-even point is entirely composed of cases where employees were required to bear the equipment cost burden. The highest B/C ratio observed by this population in this stochastic base case is 0.86. All of the other trials (where the employer bears the equipment cost burden) yield positive B/C ratios for the employee – between 1.55 and 3.46. From Figure 6, we can see that the expected B/C ratio for the population on the left is approximately 0.6 (indicating that costs are roughly twice those of benefits, on average), whereas the expected B/C ratio for the population on the right is approximately 2.5 (indicating that benefits are more than twice those of costs, on average). Moreover, because it is assumed that equipment costs paid by the telecommuter are non-transferable in the cases of telecommuter attrition, we find that the total equipment costs are much higher overall when borne by individual telecommuters.

A review of the outputs indicates that negative results can be compounded in situations where the commute distance is relatively short (thereby affecting benefits from fuel savings, insurance and maintenance savings and travel time savings). Some additional benefit can be obtained in the stochastic simulation process by the introduction of high individual travel time values. The highest observed B/C ratios exist when the employer bears the cost burden for equipment and software expenses, and the telecommuter benefits from both a high value of individual travel time and travel cost savings from a longer-than-average commute. Further review of the calculation sheet reveals that additional home energy costs are more than offset by the miscellaneous benefits that can be achieved from being at home (such as lower food and dry cleaning expenses). From the stochastic base case analysis, we can easily conclude that the single biggest factor affecting the employee’s decision to telecommute is that of equipment costs. If asked to pay for equipment and software costs, it is almost certain that a telecommuter will experience a B/C ratio less than one. Even when the commute distance is exceptionally long and/or the frequency is very high, the stochastic base case indicates that telecommuters buying their own equipment will probably not achieve a B/C ratio greater than one. On the other hand, it is quite conservative to attribute the full cost of the equipment to telecommuting, since a PC purchased by the telecommuter will normally be used for personal purposes, and may even have been purchased independently of telecommuting. Thus, the results shown here can be considered worst-case.

Because a bimodal distribution has developed, the observed mean from the stochastic base case histogram has little actual meaning. Nonetheless, the overall expected value for the telecommuter is calculated to be 1.66, which is above the break-even point but clearly much lower than the value of 2.24 obtained using our deterministic base case assumptions (as shown in Table 24). This expected value is obtained by averaging stochastic base case simulation benefit-to-cost ratios, and, in general, we see that the cost burden weighs heavily on the overall benefit-to-cost ratio. Furthermore, this comparison indicates that the stochastic base case introduces additional cost uncertainties that might otherwise not be assumed in the deterministic base case scenario.

The Employer

The stochastic base case histogram for the employer is shown in Figure 7 below, and we begin to see how the inclusion of some benefits can impact the employer's perspective. While we see a similar percentage of trials on either side of the break-even point, this histogram highlights the uncertainty in the employer perspective indicated by both very low and very high B/C ratios. Based on the results compiled by the stochastic base case, we calculate an overall expected B/C ratio of this histogram to be 1.92 – indicating that the large B/C ratios heavily skew the mean above the break even point. Clearly, this value represents a major improvement over the ratio of 0.52 obtained with our deterministic base case results (shown back in Table 24). This comparison indicates that the occasional introduction of uncertain benefits to the deterministic base case assumptions could greatly improve the economic evaluation of telecommuting to the employer. This also indicates that while the employer faces a lot of uncertainty supporting telecommuting the potential reward can be large.

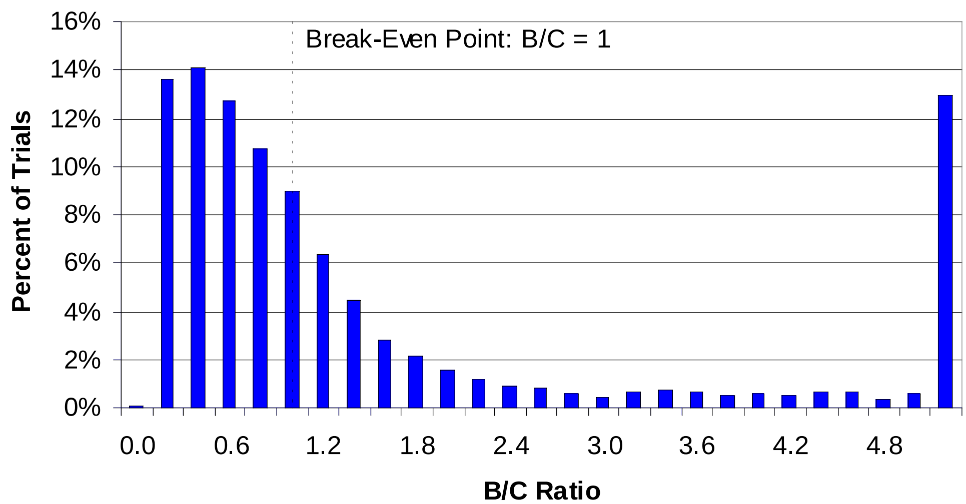

Figure 7. Employer Stochastic Base Case B/C Ratio Histogram

A review of our calculations indicates that these benefits, however, remain contingent on the assumptions of increased employee productivity and office space benefits. As was shown back in Chapter 4, it is possible for office space savings to provide a significant benefit. The long “tail” on the right side of the histogram comprises almost exclusively the 25% of trials in which office and parking space benefits are included. While this verifies that office and parking space benefits can produce significant results, the results indicate that the high office space valuations were amplified by high telecommuting frequencies that led to B/C ratios where the benefits were more than five times greater than the costs. This could indicate that our assumptions regarding space benefits were too generous. It may be that the office space "efficiency factor" should be lowered, or it may be that the office space rent values are allowed to be too high.

If we look only at the cases in which office and parking space savings were neglected, then we discover that the employer's outcome relies almost exclusively on the assumption of increased productivity. Simply put, without productivity (or significant space) benefits, the employer has no economic motivation for participating in a telecommuting project. This finding stresses the importance of research in this area – especially when the employer is expected to pay for the majority of expenses.

Additionally, we find that net employer benefits are possible when the equipment costs are shifted to the telecommuter. When the employer's costs are minimized, the telecommuter does not need to have much in additional productivity to yield positive results for an employer.

The Public Sector

From Figure 8, we see how rarely the public sector is expected to realize net economic benefits from telecommuting. Instead, we find that the monetary valuation of air quality benefits do not exceed losses in fuel tax revenue, and the public sector fails to break even. While these and other public sector benefits are still believed to exist (along with net reduction in peak hour commute travel demand in urban areas), it does not appear likely that the public sector can achieve substantial direct benefits.[50] More than anything, this report reinforces what has already been known throughout the transportation industry for some time now – that it is difficult for travel demand management (TDM) strategies to compete in the marketplace when their benefits are both difficult to quantify and not explicitly valued in the open market. This problem is explored further in the next chapter.

However, it is important to remember that there are still many public sector benefits that were not quantified, such as the employment of individuals who are underemployed or mobility-limited, as shown back in Table 1.

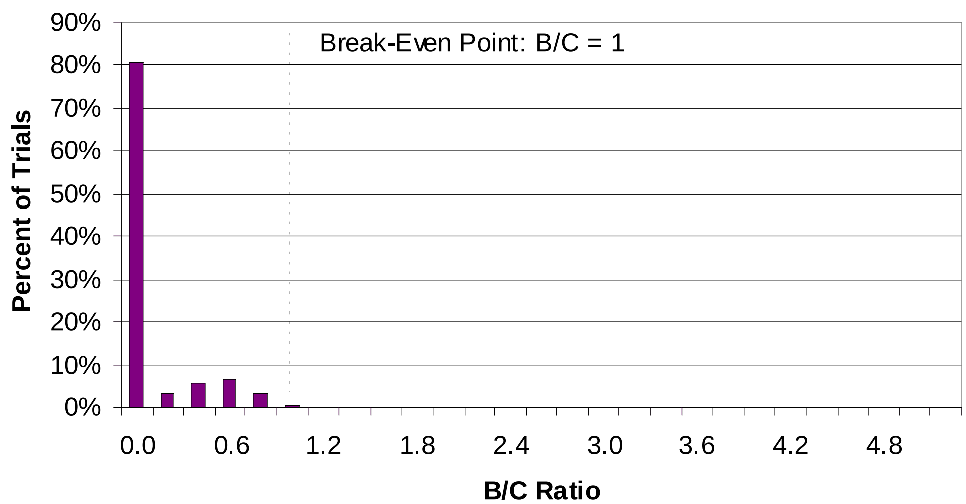

Figure 8. Public Sector Stochastic Base Case B/C Ratio Histogram

[50] A review of the modeling process reveals that it would be unrealistic to expect air quality benefits under the following conditions: 1) Telecommuting is not concentrated within a localized air basin (represented in the simulation model by the Monte Carlo "dummy" indicator variable, where air quality benefits are assumed to have no market value 80% of the time), 2) Low emissions estimates (due in part to the fact that we are only accounting for running emissions – which represent only a fraction of the total emissions produced), or 3) Low emission valuations (shown at the end of the previous chapter).

Summary of Results

A summary of results, shown in Table 25 below, indicates that different results are possible depending on the assumptions that are made and on the uncertainty that is permitted in the model. The deterministic base case results suggest that the telecommuter is the primary beneficiary of telecommuting, while the stochastic base case results suggest that the employer is often the recipient of the majority of the benefits. It could be that the "truth" lies somewhere in between. While it is possible that both telecommuter and employer can develop an arrangement where both parties yield positive economic outcomes, it is also conceivable that both parties could have bad experiences in a poorly planned telecommuting project. The ideal telecommuting program would resemble an economic "equilibrium" by making tradeoffs between employer and employee so as to maximize total benefits while minimizing total costs.

The results in Table 25 also seem to support the claim that it is possible for the net overall impact of telecommuting to be positive. The histogram for the overall situation is shown in Figure 9 below, and we calculate the expected value of the overall B/C ratio to be 1.55. The overall B/C ratio from the stochastic base case analysis (1.55) is much better than the deterministic base case value (0.69), shown in the last row of Table 25. This is because the stochastic base case procedure allows for greater benefits to be included in the model, even if only probabilistically. However, the expected B/C ratio of 1.55 is pulled to the right by the heavy tail of the distribution (representing cases in which private sector office space and parking benefits are realized). In fact, the overall B/C ratio is below the breakeven point for 63% of the trials.

Table 25. Comparison of Results for U.S. Telecommuters

Perspective	Deterministic		Stochastic	
	NPV	B/C Ratio	NPV	B/C Ratio
Telecommuter	$13.6 billion	2.24	-$3.31 billion	1.66
Employer	-$46.3 billion	0.52	$68.8 billion	1.92
Public Sector	-$1.29 billion	0.00	-$1.20 billion	0.09
Overall	-$34.0 billion	0.69	$64.3 billion	1.55

Note: Results for the entire U.S. telecommuting population, assuming no growth.[51]

Note: The last column group represents the expected value of B/C ratios and NPV for the observed stochastic base case histograms, respectively, obtained by taking the mean of all simulated B/C ratios and NPV calculations. Note that although the average B/C ratio is greater than one for telecommuters, their average NPV is negative. While for any single outcome the NPV will be negative if and only if B/C is less than one, the observed result can occur for the average when NPVs tend to be larger in magnitude for cases where B/C is less than one compared to cases where B/C is greater than one. For example, suppose there were two cases, with discounted benefits B_1 = 2.5, discounted costs C_1 = 1 , B_2 = 73.08, and C_2 = 81.2. Then the average B/C would be the average of B_1/C_1 and B_2/C_2, or (2.5 + 0.9)/2 = 1.7, and the average NPV would be the average of ($B_1 - C_1$) and ($B_2 - C_2$), or (1.5 - 8.12)/2 = -3.31.

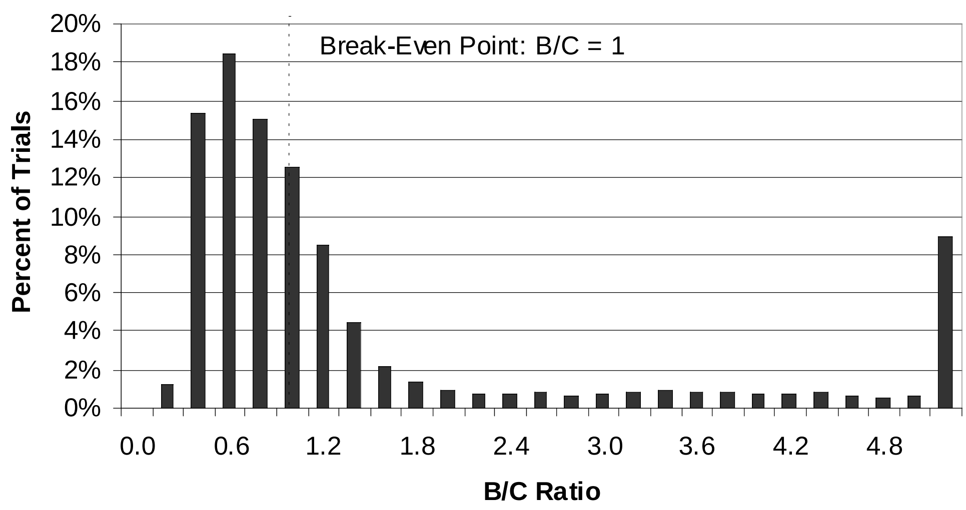

Figure 9. Overall Stochastic Base Case B/C Ratio Histogram

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[51] The deterministic B/C ratios are identical to those shown in Table 24 and are shown again here for comparative purposes.

6.0 SENSITIVITY ANALYSIS AND DISCUSSION

One advantage of the spreadsheet model is that sensitivity testing is relatively simple. By changing a value in one (or more) of the input cells, we can quickly and easily perform various analyses by noting the change from the deterministic and stochastic base cases. Unlike the deterministic base case where as little uncertainty is added to the model as possible, the sensitivity analysis allows for more of a "real world" representation where a wider range of outcomes is explored. Uncertainties with costs and benefits are introduced as in the stochastic base case, and the impact of assuming an "S-shaped" (macro-scale) telecommuting growth function can be tested. In this chapter, the following sensitivity analyses are performed:

- Adjustments to single input values (including Monte Carlo variables) to compare results with those of the deterministic base case results,
- Adjustments to single scenario assumptions to compare results with those of the stochastic base case results,
- Assumptions on net growth of telecommuting, and
- Other "break-even" sensitivity analyses.

Table 26. Summary of Sensitivity Analyses Performed

Assumption	Section 6.1	Section 6.2	Section 6.2	Section 6.3
Stochastic?	No	Yes	Yes	No
Growth	No Growth	No Growth	S-Shaped	No Growth
Monte Carlo Variables	Fixed Values	Allowed to Vary	Allowed to Vary	Fixed Values
Scenarios	Fixed	Fixed	Probabilistic	Fixed

6.1 Adjusting Single Input Values in the Deterministic Base Case

In this section, we present the change in results obtained after adjusting key input variables one-by-one. Many variables were tested, and the results are shown in Table 27 below. In the table, the first column represents the input variables that were increased by exactly 10% from their deterministic base case input values (shown in Table 15 and Table 16).[52] The remaining columns show the corresponding percent change in the B/C results – compared to those shown in Table 24. Please note that not all units are identical and that a 10% change in any input value can yield different results depending on the units involved.

Table 27. Sensitivity Analysis – Single Input 10% Increase

Input Variable (10% Increase)	**TCer B/C** (% Change)	**Empl. B/C** (% Change)	**Overall B/C** (% Change)
Commute Distance (mi)	3.4%	0.0%	1.0%
Employee Salary ($/yr)	0.0%	10.0%	6.7%
TC Frequency (days/wk)	0.0%	10.0%	8.8%
Productivity (%)	0.0%	10.0%	6.7%
Fuel Costs ($/gal)	1.6%	0.0%	0.5%
Fuel Economy (mpg)	-1.4%	0.0%	-0.4%
Equipment Costs ($/yr)	0.0%	-3.6%	-3.2%
Auto Insurance & Maint. ($/mi)	1.5%	0.0%	0.5%
Misc. Cost Savings ($/event)	4.0%	0.0%	1.3%
Add'l Energy Costs ($/event)	-9.1%	0.0%	-1.0%
Equip. Service/Maint. Cost ($/yr)	0.0%	-2.0%	-1.8%
Comm. Start-Up Cost ($)	0.0%	-0.3%	-0.3%
Comm. Service Cost ($/yr)	0.0%	-2.9%	-2.6%
Training Costs ($/TC-sup pair)	0.0%	-0.9%	-0.8%
Fuel Tax ($/gal)	0.0%	0.0%	-0.1%

Note: Because the deterministic base case B/C ratio for the public sector was calculated to be zero, any change cannot be defined. Therefore, the public sector perspective is omitted from this table; however, public sector results are included in the overall change presented in the final column.

[52] This sensitivity analysis was performed on the same base-case U.S. telecommuting population of 11,100,000, given no net growth.

From Table 27, we can see how changes in each input variable impact the result for each perspective. As we might expect, the telecommuter is most sensitive to increases in home energy costs – where a 10% increase from $2.40 to $2.64 per telecommute event results in more than a 9% decrease in the telecommuter B/C ratio. The telecommuter is also sensitive to changes in commute distance and miscellaneous cost savings. We see that a 10% increase in the one-way commute distance of 11.6 miles results in more than a 3% increase in the telecommuter B/C ratio, clearly indicating that the telecommuter obtains higher benefits for avoiding longer commutes (as we might expect).

Not surprisingly, we find that the employer is highly sensitive to changes in employee salary, increase in productivity, and telecommuting frequency. Most interesting is the fact that the results change in direct proportion to the changes in input. These results make sense because these inputs proportionately affect the calculation of productivity benefits, which remains the employer's primary benefit from telecommuting in the deterministic base case.

6.2 Adjusting Stochastic Base Case Assumptions and Incorporating Growth

Along with changing individual variables, we also explored changing whole scenarios that affect the initial stochastic analysis. In this section, we look at the change in results after making changes to both "dummy variable" and Monte Carlo variable parameters, as well as assumptions of an S-shaped growth curve. Rather than compare single B/C value outputs, we make visual comparisons of the simulation histograms by realizing the possible outcomes, and calculate the expected values (i.e., means). In this section, the analyses shown in Table 28 are performed with respect to the stochastic base case discussed in the previous chapter.

Table 28. Summary Scenario Assumptions for Sensitivity Analyses

Assumptions for Stochastic Base Case	**Assumptions for Additional Sensitivity Analyses**
• No growth	• "S-shaped" growth function
• Space: 25% probability that office space benefits are allowed	• Space: 100% probability that space benefits are allowed (no telecommuting growth)
• Air Quality: 20% probability that air quality benefits are allowed	• Air Quality: 100% probability that air quality benefits are allowed (no telecommuting growth)

Note: Even when we "allow" benefits to occur, it is possible that benefits will not be realized due to low valuations.

Growth: The Addition of the Macro-Scale Growth Assumption

When we use a growth function, we have more telecommuters participating in our analysis, and all of the results are essentially amplified. While this affects the resulting costs and benefits (and thus the net present value) that are calculated, it hardly affects the overall economic evaluation (or the decision to promote telecommuting). So while we find a substantial difference in the calculated net present values, our ratio of costs to benefits remain similar. Although the addition of the growth function represents a more realistic scenario, we find that it has little impact on the decision surrounding the economic evaluation of telecommuting (i.e., the B/C ratios). Because the evaluation's economic decision is not a really a function of the number of participating telecommuters, we can see that the TELESIMM program can be used for any size telecommuting population. Nonetheless, as pointed out in Chapter 4, the number of telecommuters remains an essential calculation, because all costs and benefits are compounded by the total number of telecommuters.

Table 29. Comparison of Stochastic Results with Different Growth Functions

Perspective	No Growth		S-Shaped Growth	
	NPV	B/C Ratio	NPV	B/C Ratio
Telecommuter	-$3.31 billion	1.66	-$5.38 billion	1.67
Employer	$68.8 billion	1.92	$108.0 billion	1.84
Public Sector	-$1.20 billion	0.09	-$1.95 billion	0.09
Overall	$64.3 billion	1.55	$101.0 billion	1.51

Note: The first column group results are for the entire U.S. telecommuting population (11.1 million), assuming no growth. The second column group results are for the entire U.S. telecommuting population and assume an "S-shaped" growth function with a maximum adoption rate of 20%. Application of the growth function results in an average of approximately 19.0 million telecommuters over the 10-year study period. See note on Table 25 for comment on negative average NPVs together with average B/C ratios greater than one.

Space: Allowing for Office and Parking Space Benefits in all Simulations

In the stochastic base case, we only allow employers to obtain space benefits in approximately 20% of simulated cases. This assumption was made because it may be that only a fraction of all telecommuting occurs in urban areas where a market value would exist for marginal office space savings. Further, office space savings can only be obtained when enough employees telecommute often enough and the employer explicitly reconfigures the use of existing office space. In this section, we allow employers to potentially achieve space benefits in all simulated cases (assuming no net growth in telecommuting) and compare results. (It should be noted that it remains possible for the *value* of the space savings to be randomly selected to be zero because it is assumed to be uniformly distributed between zero and a maximum annual value.)

By allowing employers to yield space benefits in 100% of simulated cases, we see that it has a sizable (and probably unrealistic) impact on the employer's overall B/C ratio. We find that the expected value of the B/C ratio shifts from 1.92 in the stochastic base case to more than 5.59 in this case, as shown in Figure 10 below. So while space benefits seem more likely in urban, central business district settings, it could be a worthwhile motivation for some employers.[53] This result implies that parking and office space benefits could have a measurable impact, even large enough to supplant the need for high increases in employee productivity.

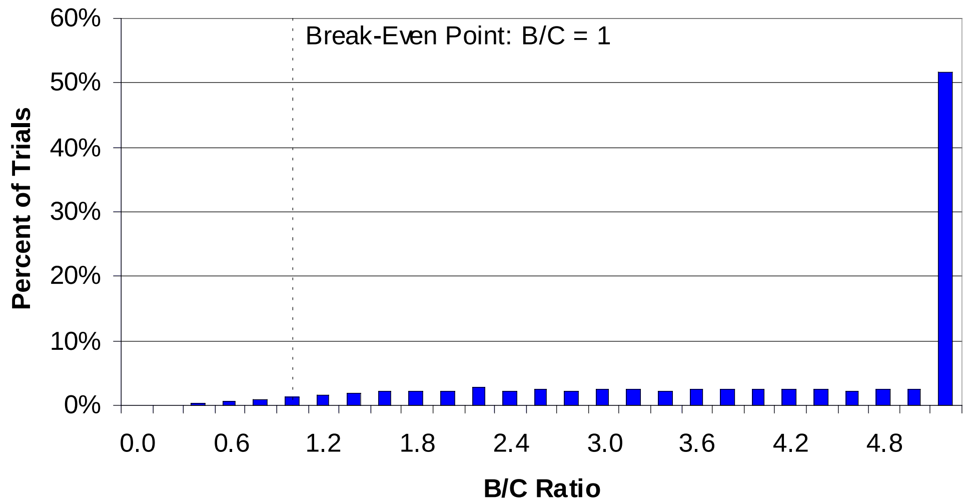

Figure 10. Employer B/C Ratio Histogram When Space Benefits Are Present in All Simulations

Air Quality: Allowing for Air Quality Benefits in all Simulations

In this section, we allow air quality impacts in 100% of simulated cases (again, assuming no net growth in telecommuting). We will use similar justification for this

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[53] Although it is more likely in urban areas, space benefits could certainly apply in suburban and even rural areas as long as rent is paid.

scenario as we did in the previous section by assuming the context to be that of an urban setting rather than a mixed/suburban setting. Specifically, this scenario represents the case for an area where air quality standards are "out of compliance" rather than an area meeting national ambient air quality standards. Even under this most favorable circumstance, Figure 11 indicates that there is little chance that the public sector benefits will exceed gas tax losses. It may be that our method for quantifying and valuing emission impacts is too conservative; on the other hand, it may actually be that gas tax losses more than counteract the market benefits of avoided air pollution. The histogram below corresponds to an average B/C ratio of 0.42, which is still well below the break-even point.

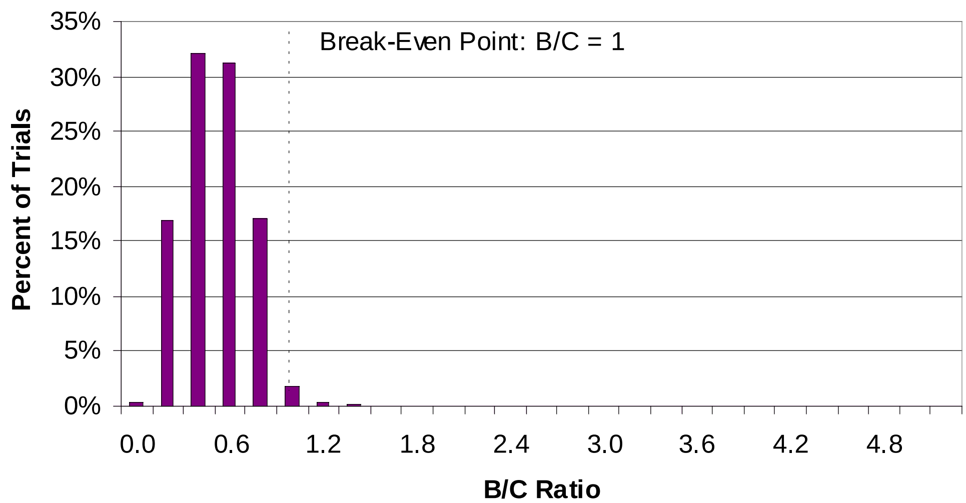

Figure 11. Public Sector B/C Ratio Histogram with Allowable Air Quality Benefits

6.3 Other "Break-Even" Sensitivity Analyses

While we have looked at a few possible scenarios in this chapter, we now try to identify certain threshold levels at which a telecommuting program "breaks even". In other words, these are the minimum telecommuting levels that must be met for the telecommuter or the employer to obtain positive economic outcomes from telecommuting, assuming all else remains constant (as given by the deterministic base case assumptions). Knowing these threshold values can simplify decision-making. In particular, we examine:

- the minimum level of productivity that the employer would need for benefits to equal equipment costs (for employees with different annual salaries and at different equipment costs), and
- the minimum parking space value that the employer would need for benefits to offset the necessary equipment burden – with and without assuming an increase in productivity by telecommuters.

Minimum Productivity Levels Necessary for the Employer to "Break Even"

Because increased productivity is one of the primary economic motivations for supporting a telecommuting program, we decided to explore its relationship to the telecommuter's income. Because equipment costs are the major expense, we also did some experimentation with this value. Looking at different employee salaries and equipment costs (assuming the employer pays), we determine the required level of productivity that telecommuting must achieve for the employer to break even. Because the value of productivity is a function of employee salary, we would expect the required levels of productivity to decrease as employee salaries increase, in order to reach the same benefit value.

Using our deterministic base case assumptions, we first found the minimum level of productivity that an employer requires to break even, ignoring all other employer benefits (i.e., parking or office space benefits). We found that the employer only needs to achieve an increase in productivity of almost 15% or higher on telecommuting days to break even given our base-case assumptions of $1,800 equipment costs and $35,000 annual salary. Moreover, when we are reminded that for the purposes of this study "productivity" is defined as all of the combined impacts noted in Table 1 (i.e., increased quality or quantity of work, increased time spent working, decreased sick leave, decreased employee turnover, and increased employee retention), it is not difficult to imagine that a 15% increase in productivity is attainable.

Because productivity is a function of the employee's compensated value, additional analysis looked at the telecommuter's salary and the required level of productivity required for the employer to break even. In other words, sensitivity analysis was performed to explore how higher salaried employees have lower minimum productivity requirements for the employer to "break even."

In Figure 12, we can see how productivity levels drop as income levels increase. Additionally, the figure shows the increase in required productivity necessary to break even if equipment costs range from $1,000 to $3,000 per telecommuter over the life of the equipment (approximately five years). From Figure 12, we see that employers can maximize their economic benefit by encouraging their most "valuable" employees to be the most productive through telecommuting.

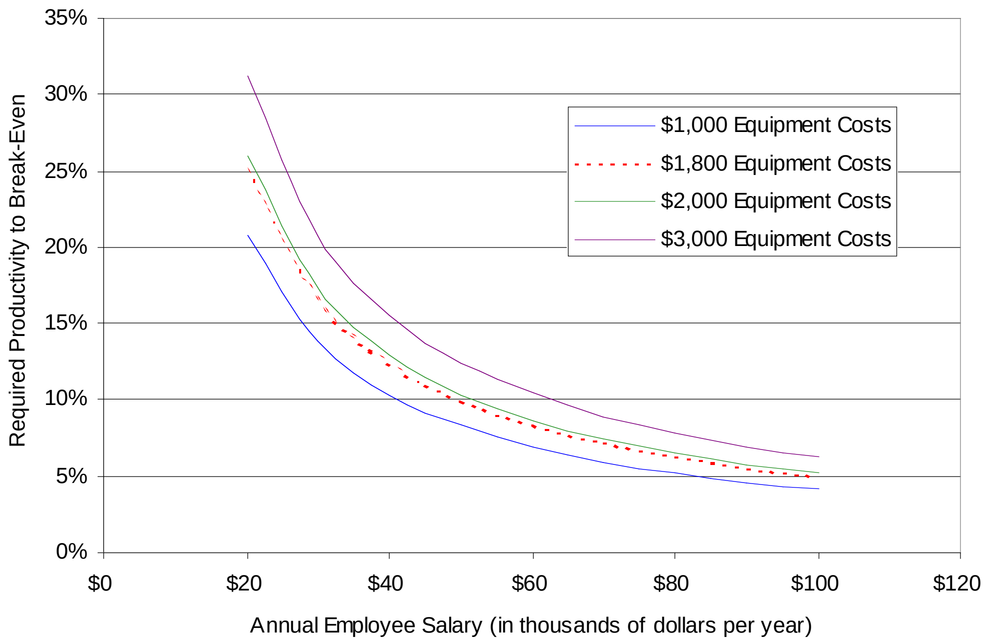

Figure 12. Productivity Required by Employers to "Break Even" Given Equipment Costs and Employee Salaries

So if employers are confident that their employees will be at or above 15% more productive on their telecommute days (given deterministic base case assumptions of $1,800 equipment cost and $35,000 annual salary), then this report indicates that telecommuting is a worthwhile endeavor – ignoring any space savings. Still, until research can empirically establish that telecommuting leads to increased productivity, there will continue to be doubt among some business decision-makers. By the same token, additional research investigating potential space savings, in a few major metropolitan areas for example, would be welcomed by telecommuting managers and employers.

Minimum Parking Space Values Necessary for the Employer to "Break Even"

Because office space benefits remain uncertain, we test the situation with parking space benefits and without office space benefits. The goal is to calculate the parking space benefits that would yield a "break even" outcome for the employer. If we modify our deterministic base case assumption such that the employer obtains parking space benefits but not office space benefits, we find that if the employer saves more than approximately $13.40 per telecommuter per day, on average, then the employer will break even without any office space benefits. While we are still assuming a 7.5% increase in productivity by each telecommuter, the deterministic base case also assumes that the employer will pay for the equipment. In other words, the employer could afford to supply all of its telecommuting employees with equipment if it were not required to provide parking at a cost of $13.40 (or more) per employee per day. If we neglect productivity altogether and assume that all employer benefits come from parking, the minimum parking space value skyrockets to $28.00 per telecommuter per day, indicating that some productivity increase should still be expected for the employer to achieve net benefits.

7.0 CONCLUSIONS

After running stochastic base case results and sensitivity analyses, we are able to reach certain conclusions about telecommuting and its economic impacts. In this chapter, we summarize major findings before acknowledging the limitations of this report and making recommendations toward areas of future research.

7.1 Major Findings and Recommendations

Along with many methodological contributions, this report has produced several notable findings. Formulas and various input values (with references) and missing inputs were identified, as summarized in Table 30. These are useful contributions because they begin to identify specific areas where research has been done and where future research is needed.

Table 30. Identified Key and Missing Inputs

Perspective	Inputs	Brief Explanation
General	• Forgone commute distance and other travel	• Some TC-specific empirical data, but generalizability uncertain
	• Telecommuting frequency	• Little empirical data; needs to be modeled as a function of time
	• Telecommuting attrition	• Little empirical data; needs to be modeled as a function of time
	• Percent events eliminating drive-alone commute trips	• Little empirical data
Telecommuter	• Home energy usage	• Little TC-specific empirical data
	• Travel time value	• Little TC-specific empirical data
	• Equipment costs and how shared	• Little TC-specific empirical data
Employer	• Equipment costs and how shared	• Little TC-specific empirical data
	• Productivity increase	• Difficult to quantify
	• Parking space value	• Uncertain when to assign parking space benefits
	• Quantifying office space benefits	• Location specific and little TC-specific empirical data
Public Sector	• Quantifying pollutants	• Conservative estimates
	• Valuing pollutants	• Location specific and little empirical data
	• Quantifying construction benefits	• Difficult to justify for telecommuting

While many costs and benefits remain uncertain, in this report we were able to identify the situations in which telecommuting is most (and least) attractive to the telecommuter and the employer. The conditions that favor and discourage telecommuting for each perspective are summarized below in Table 31.

Table 31. Evaluation of Economic Conditions Favorable to Telecommuting

	Telecommuter Perspective	Employer Perspective
Favorable Conditions	• Employer bears equipment cost • Above average commute distances • High telecommuter frequency • Vehicle with below-average fuel economy	• Telecommuter bears equipment cost • High telecommuter frequency • Low telecommuter attrition • High productivity • Parking and office space benefits
Unfavorable Conditions	• Telecommuter bears equipment cost • Low commute distance • Low telecommuting frequency • Non-auto mode choice	• Employer bears equipment cost • Low productivity • No parking or office space benefits • Low telecommuting frequency • High telecommuting attrition

By making conservative assumptions about current conditions in our deterministic base case, we find that telecommuting yields average B/C ratios less than one for all perspectives except the telecommuter, indicating that telecommuting may often not be an economically justifiable alternative to traditional commuting behavior. This is consistent with observed practice, which finds that telecommuting is growing more slowly than many observers expected, and may not be adopted in many cases where it is technically feasible and apparently advantageous for the employee.

The stochastic base case, however, allowed for the introduction of more uncertainty with costs and benefits and thus closer-to-real-world representation. These results indicated that the telecommuter's overall B/C ratio could be lower than the deterministic base case suggested, while the employer's and public sector's overall B/C ratios could be higher. The introduction of parking and office space benefits allows favorable B/C ratios for employers to be more easily obtained.

Based on the deterministic and stochastic base case scenarios, we were able to reach a series of conclusions. For the employee (the telecommuter), telecommuting is most favorable when the forgone commute is long, travel time is highly valued, and, most importantly, the employer bears the burden of the equipment costs. Moreover, benefits are unlikely to exceed costs if the telecommuter is asked to bear the full equipment cost burden. For the employer, telecommuting is most favorable when productivity is realized among the highest paid employees and when parking and office space savings are realized.

For the public sector, it is difficult to justify localized benefits but we maintain that there is an overall rationale for promoting telecommuting as a way of mitigating traffic on the entire transportation network. While public sector assistance at the local or regional level would certainly yield some public benefits, these benefits remain difficult to quantify and monetize, because they get dispersed throughout the transportation system. It is more likely that segments of the public sector could lose fuel tax revenues due to telecommuting when the benefits are dispersed over a wide area. In this situation, the success of telecommuting would rely entirely on both the employer and the employee impetus to achieve adequate perceived benefits. (In general, if the public sector does receive some noticeable net benefit from telecommuting, its role would be to support either the employer or the employee to encourage telecommuting, as indicated by Table 32.)

Table 32. Public Sector's Role in Telecommuting (Assuming Net Public Sector Benefit)

		Telecommuter B/C Ratio	
		Value Less than One	Value Greater than One
Employer B/C Ratio	Value Less than One	Public Sector Assistance to Improve Both Parties' B/C Ratios	Public Sector Assistance to Improve Employer B/C Ratio
	Value Greater than One	Public Sector Assistance to Improve Telecommuter B/C Ratio	Do Nothing

Additional sensitivity analyses in this report indicate that productivity benefits need to exceed 15% on telecommuting days for telecommuters with annual salaries of approximately $35,000, in order for the employer to break even. As the employee salary increases, the amount of productivity needed to "break even" decreases. Additionally, employers can obtain net positive results if they save $13.40 or more per telecommute event, e.g. on parking costs.

One of the general observations from this research is simply the fact that even when we combine all of the empirical evidence surrounding the costs and benefits of telecommuting, we find that it may not make "economic sense" to telecommute. Depending on the underlying assumptions, it is possible for all participants to experience negative economic impacts from telecommuting. While telecommuting continues to grow and continues to be touted by transportation planners, a great deal of uncertainty remains present in this model. It remains possible that costs are overstated and benefits are understated in this model and that unquantifiable benefits play a much larger role in the decision to telecommute than can be expressed in a cost-benefit analysis. At the same time, it is important to highlight the fact that TELESIMM allows other users to modify or extend this research and to make additional modifications to the model.

7.2 Study Limitations

While this report contributes to the current state of knowledge regarding the "economic attractiveness" of telecommuting in certain situations, this study has certain caveats and limitations. One limitation is the fact that the results are not based on any original empirical data. Instead, they are based on calculations and simulations that utilize as much existing empirical data as possible. Because new empirical data were not collected, assumptions were often used to simulate different scenarios. Certainly, most of the assumptions in this report are debatable at some level. Ideally, we would want to compare the results obtained here with results from empirical cost-benefit evaluations.

One of the inherent assumptions in this report is that transportation-related benefits to the telecommuter stem from forgone single-occupant automobile travel and are a function of auto commute distance (i.e., avoided fuel costs, travel time savings, avoided insurance and maintenance costs). This report does not attempt to look at the economic evaluations of other modes. As a result, we see that commuters with long commutes in single occupancy vehicles having poor fuel economy would experience the largest benefits.

Another limitation of this model was the limited number of distributions that were used to perform the random number generation. Aside from normal and uniform distributions, the “random number generation tool” in Excel did not allow for many other options[54]. Because of our choice of distributions, some variables were artificially bounded by low variances to avoid obtaining unrealistic values, such as negative distances. This makes it difficult to model some situations that may be of interest, such as exceptionally long commutes and commutes with high levels of variability. For count variables (such as average telecommuting frequency), it would be appropriate for future revisions of this model to experiment with distributions such as the Poisson or negative binomial, which would avoid the generation of negative values.

In general, this model does not take into account long-term changes in travel behavior or evolution in land uses. In particular, transportation planners are concerned with changes in land use as a result of telecommuting. It has been noted that the effect of telecommuting on land use is uncertain and could lead to longer commutes by telecommuters. This report does not take into account changes in travel demand or the related latent demand or urban sprawl.

Additionally, this study does not assume any technological breakthroughs that could reduce costs. To the extent that the cost of the necessary computer hardware and software decreases, the cost of telecommuting could decrease accordingly. On the other hand, it is likely that the cost of a “standard” computer will remain roughly constant, but that that computer will be increasingly powerful as the technology improves.

7.3 Future Research

Specified areas of future research can be found throughout this report. We

[54] The random number generation tool allowed for uniform, normal, Bernoulli, binomial, Poisson, patterned, and discrete distributions.

believe that future research should be devoted to revising inputs and reducing the need for assumptions and theoretical scenarios. Greater research should focus on the issues being addressed by telecommuters and their managers. Present gaps in the literature have been summarized in Table 33. Additional attention should be devoted to making model improvements, and potential TELESIMM improvements have been noted in Table 34.

Table 33. Noted Gaps in Telecommuting Cost-Benefit Research Literature

Input	Explanation
• Telecommuting Frequency	• Telecommuting frequency is a critical input and is worthy of additional research to verify
• Non-Commute Travel	• The average number of trips made during the telecommute day, the corresponding mode choice, and average trip length are necessary components to understanding the impact of telecommuting on travel.
• Modeling Telecommuting Attrition	• A model which represents attrition *over time* is needed for the cost-benefit model
• Telecommuting Productivity	• Productivity remains a vital input in the costs and benefits for the employer and should be researched further

Table 34. Potential TELESIMM Improvements

Improvement	Explanation
• Increased Customizability	• Refinement is conceivable throughout each step in the model, by allowing the user the ability to customize inputs for each year.
• Improved Distribution and Model Parameters	• Expand beyond normal and uniform distributional assumptions and allow for a desired level of variability (or empirical standard deviations) without unreasonable values (e.g. negative commute distances).
• The Inclusion of Other Modes of Transportation	• Add modes other than drive-alone auto, especially transit modes, where travel time and travel cost savings could be notable.
• "True" Micro-Scale Analysis	• Another model improvement would be the development of a true micro-scale analysis where a population of telecommuters is simulated by modeling each individual separately then adding together the collective costs and benefits.

Finally, and above all, from the transportation planning perspective, the eventual goal of this area of telecommuting research should be to encourage comparisons of competing transportation demand measures. Ideally, as transportation planners and engineers, we hope to identify the transportation demand management tactics that work together to provide the biggest benefits and travel demand impacts at the lowest cost. Simply put, telecommuting is not the sole or necessarily the most important solution to increasing demand for travel, but it remains a critical piece of the transportation management puzzle.

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APPENDIX A. TELESIMM MONTE CARLO INPUT SHEET

Instructions: These are Monte Carlo variable inputs. You are allowed to change the cells in **blue** for deterministic calculations, or change the cells in **green** for stochastic calculations. The cells in **green** are used as parameters to randomly select a value in **blue** before it is used in a calculation. The cells in **purple** represent our recommended deterministic base case assumptions, but these cells do not affect the calculations.

MONTE CARLO ASSUMPTIONS										
Variable	**Distribution**	**Minimum**	**Maximum**	**Mean**	**Std. Dev.**	**P-Value**	**Selected Value**	**Interpretation**	**Base Case**	**Reference**
Discount (Interest) Rate (%)	Uniform	3.0%	12.0%	N/A	N/A	N/A	8.0%		8.0%	-
One-Way Commute Distance (mi)	Normal	N/A	N/A	11.6	4.0	N/A	11.6		11.6	1995 NPTS
Annual Salary ($/yr)	Normal	N/A	N/A	$35,000	$6,000	N/A	$35,000		$35,000	-
Value of Travel Time ($/hr)	Uniform	$0.00	$6.30	N/A	N/A	N/A	$0.00		$0.00	WA DOT (1995)
TC Attrition (%)	Uniform	50%	70%	N/A	N/A	N/A	50%		50%	-
TC Frequency (days/wk)	Normal	N/A	N/A	1.2	0.3	N/A	1.2		1.2	Handy and Mokhtarian (1995)
Net Productivity Increase (%)	Uniform	0.0%	15.0%	N/A	N/A	N/A	7.5%		7.5%	-
Space (Park/Office) Dummy	Bernoulli	0	1	N/A	N/A	0.25	0	Abundant Space: Neglect Parking/Office Space Benefits	0	-
Parking Space Value ($/day)	Uniform	$3.50	$9.50	N/A	N/A	N/A	$3.50		$3.50	Washington COG (1991)
Office Space Value ($/yr)	Uniform	$0.00	$780.00	N/A	N/A	N/A	$0		$0	-
Scale (AQ) Dummy	Bernoulli	0	1	N/A	N/A	0.20	0	Macro Scale: Neglect AQ Benefits	0	-
Emission Costs - ROG $/ton	Uniform	$0	$8,945	N/A	N/A	N/A	$0		$0	Wang and Santini (1994)
Emission Costs - CO $/ton	Uniform	$0	$4	N/A	N/A	N/A	$0		$0	Wang and Santini (1994)
Emission Costs - NO_X $/ton	Uniform	$272	$18,746	N/A	N/A	N/A	$272		$272	Wang and Santini (1994)
Emission Costs - PM $/ton	Uniform	$713	$7,378	N/A	N/A	N/A	$713		$713	Wang and Santini (1994)
Emission Costs - CO_2 $/ton	Uniform	$0	$0	N/A	N/A	N/A	$0		$0	-
Emission Costs - SO_X $/ton	Uniform	$362	$9,611	N/A	N/A	N/A	$362		$362	Wang and Santini (1994)
Equipment Burden Dummy	Bernoulli	0	1	N/A	N/A	0.40	0	Employer Pays for Equipment	0	-

Number of Monte Carlo Simulations	**2,500**

APPENDIX B. TELESIMM CALCULATION WORKSHEET

(FOR U.S. TELECOMMUTING POPULATION AND MACRO-SCALE "S-SHAPED" GROWTH FUNCTION)

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total Population	264,000,000	266,349,600	268,699,200	271,048,800	273,398,400	275,748,000	278,097,600	280,447,200	282,796,800	285,146,400
Total Workforce	133,900,000	135,372,900	136,845,800	138,318,700	139,791,600	141,264,500	142,737,400	144,210,300	145,683,200	147,156,100
TC Adoption by Workforce	8.65%	9.75%	10.86%	11.94%	12.98%	13.96%	14.85%	15.65%	16.36%	16.97%
Total Telecommuters	11,583,978	13,201,230	14,859,180	16,520,987	18,150,977	19,717,855	21,197,005	22,571,615	23,832,649	24,977,923
Existing Telecommuters	0	11,583,978	13,201,230	14,859,180	16,520,987	18,150,977	19,717,855	21,197,005	22,571,615	23,832,649
Net New Telecommuters	11,583,978	1,617,252	1,657,950	1,661,807	1,629,990	1,566,878	1,479,150	1,374,610	1,261,034	1,145,274
Replacement Telecommuters	2,316,796	2,640,246	2,971,836	3,304,197	3,630,195	3,943,571	4,239,401	4,514,323	4,766,530	4,995,585
Total Telecommute Events	656,116,514	747,717,667	841,623,955	935,748,704	1,028,071,337	1,116,819,307	1,200,598,363	1,278,456,274	1,349,881,239	1,414,749,559
TELECOMMUTER										
COSTS										
Energy Costs	1,574,679,634	1,794,522,401	2,019,897,492	2,245,796,890	2,467,371,209	2,680,366,337	2,881,436,071	3,068,295,058	3,239,714,974	3,395,398,942
Equipment/Software Costs	0	0	0	0	0	0	0	0	0	0
Disc. TCer Costs	**1,574,679,634**	**1,661,594,816**	**1,731,736,533**	**1,782,785,978**	**1,813,591,496**	**1,824,212,291**	**1,815,793,494**	**1,790,320,696**	**1,750,317,195**	**1,698,544,814**
BENEFITS										
Misc. Benefits	1,410,650,505	1,607,592,984	1,809,491,503	2,011,859,714	2,210,353,375	2,401,161,510	2,581,286,480	2,748,680,989	2,902,244,664	3,041,711,552
Avoided Travel (Fuel) Costs	548,349,914	624,905,653	703,387,910	782,052,746	859,211,463	933,382,651	1,003,401,066	1,068,470,879	1,128,164,352	1,182,378,104
Auto Ins. & Maint. Savings	518,594,493	590,996,044	665,219,574	739,615,776	812,587,585	882,733,980	948,952,946	1,010,491,839	1,066,946,131	1,118,218,051
Travel Time Savings	0	0	0	0	0	0	0	0	0	0
Disc. TCer Benefits	**2,477,594,912**	**2,614,346,927**	**2,724,707,637**	**2,805,028,638**	**2,853,497,923**	**2,870,208,640**	**2,856,962,538**	**2,816,883,735**	**2,753,942,379**	**2,672,483,912**
Disc. TCer Value	**902,915,279**	**952,752,111**	**992,971,104**	**1,022,242,660**	**1,039,906,427**	**1,045,996,350**	**1,041,169,044**	**1,026,563,039**	**1,003,625,184**	**973,939,099**

EMPLOYER										
COSTS										
Equipment/Software Costs	5,222,307,707	5,951,399,871	6,698,839,573	7,448,018,094	8,182,852,823	8,889,235,299	9,556,068,096	10,175,772,000	10,744,273,389	11,260,587,667
Training Costs	4,170,232,200	1,277,249,400	1,388,935,800	1,489,801,200	1,578,055,500	1,653,134,700	1,715,565,300	1,766,679,900	1,808,269,200	1,842,257,700
Telecommunications Costs	5,560,309,480	5,178,192,600	5,812,283,400	6,444,155,720	7,060,370,220	7,649,472,700	8,202,776,900	8,714,674,700	9,182,510,040	9,606,138,180
Equip. Service/Maint. Costs	2,895,994,500	3,300,307,500	3,714,795,000	4,130,246,750	4,537,744,250	4,929,463,750	5,299,251,250	5,642,903,750	5,958,162,250	6,244,480,750
Disc. Employer Costs	**17,848,843,887**	**14,543,656,825**	**15,101,897,954**	**15,489,430,730**	**15,699,519,380**	**15,735,972,663**	**15,611,609,053**	**15,345,815,104**	**14,961,782,311**	**14,483,940,609**
BENEFITS										
Productivity Benefits	9,800,045,388	11,168,240,580	12,570,866,280	13,976,755,002	15,355,726,542	16,681,305,330	17,932,666,230	19,095,586,290	20,162,421,054	21,131,322,858
Parking Space Savings	0	0	0	0	0	0	0	0	0	0
Office Space Savings	0	0	0	0	0	0	0	0	0	0
Disc. Employer Benefits	**9,800,045,388**	**10,340,963,500**	**10,777,491,667**	**11,095,198,745**	**11,286,917,420**	**11,353,016,112**	**11,300,621,587**	**11,142,091,192**	**10,893,128,732**	**10,570,922,434**
Disc. Employer Value	**-8,048,798,499**	**-4,202,693,325**	**-4,324,406,287**	**-4,394,231,985**	**-4,412,601,960**	**-4,382,956,550**	**-4,310,987,465**	**-4,203,723,912**	**-4,068,653,579**	**-3,913,018,175**
PUBLIC SECTOR										
COSTS										
Incentive/Marketing Costs	0	0	0	0	0	0	0	0	0	0
Lost Fuel Tax Revenue	182,783,305	208,301,884	234,462,637	260,684,249	286,403,821	311,127,550	334,467,022	356,156,960	376,054,784	394,126,035
Disc. Costs	**182,783,305**	**192,872,115**	**201,013,920**	**206,939,561**	**210,515,358**	**211,748,183**	**210,770,958**	**207,814,165**	**203,170,699**	**197,161,142**
BENEFITS										
Avoided Air Pollution Value	0	0	0	0	0	0	0	0	0	0
Disc. Benefits	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Disc. PS Value	**-182,783,305**	**-192,872,115**	**-201,013,920**	**-206,939,561**	**-210,515,358**	**-211,748,183**	**-210,770,958**	**-207,814,165**	**-203,170,699**	**-197,161,142**

APPENDIX C. TELESIMM USER INSTRUCTIONS

Instructions on how to use TELESIMM (the telecommuting economic simulation model):

1. Open the file "TELESIMM.xls" in Microsoft Excel 97®. (You will be prompted with a message that alerts you that the spreadsheet that you are opening contains macros. You must select "Enable Macros" for the Monte Carlo Simulation program to work.)
2. Load the Data Analysis Tools:

   Tools ⇒ Data Analysis… ⇒ (Cancel)[55]
3. Select either the "micro" or "macro" scale telecommuting growth model, located in cell D5 on the "Growth" worksheet and change any parameters, if necessary.
4. Change any input parameters on the "Inputs" worksheet, if necessary.
5. Change any Monte Carlo parameters on the "MC Assumpts" worksheet, if necessary.
6. Run the "Random" macro (shortcut: CTRL + SHIFT + R).
7. Go to the "Simulation" worksheet to see the compiled results.
8. View the corresponding histograms (frequency or percent) for the telecommuter, employer, public sector, or overall.

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[55] Troubleshooting: If this option is not available, you must load the VBA Add-In Tools ⇒ Add-Ins… ⇒ Analysis ToolPak - VBA. (For additional detail, see Microsoft Excel Help topic: "Use add-in programs of Microsoft Excel.")

Overview

The TELESIMM Excel file contains nine worksheets:

1. *Growth*: The user selects and modifies the telecommuter growth function.
2. *Inputs*: The user modifies any of the input values.
3. *MC Assumptions*: The user modifies the Monte Carlo input parameters.
4. *Calcs*: Contains the cost/benefit calculation spreadsheet.
5. *Simulation*: Contains the randomly generated inputs and their associated output.
6. *Results*: Contains the results from the current *Calc* sheet.
7. *Charts*: Contains charts of cost and benefits.
8. *Hist Data*: Contains the histogram data.
9. *Histograms*: Contains the completed histograms.

APPENDIX D. TELESIMM USER MODIFICATIONS

TELESIMM was designed to allow the user to customize and adjust the model to fit his or her personal specifications so that telecommuting can be analyzed for a particular region, company, or individual. As a result, the spreadsheet can be modified in any way – with two exceptions: for the Monte Carlo simulation procedure to work properly, the cells in either the “MCAssumpts” or the “Results” worksheet *cannot* be moved; nor can the worksheets be renamed. The macro (named “Random”) requires that the Monte Carlo variables and the results be in specific cells on their respective worksheets. Inputs can be added to the “Inputs” worksheet and the “Calcs” sheet can be modified in any way provided that the results still appear on the “Results” sheet.