**Title**

# Smart Parking Management Field Test: A Bay Area Rapid Transit (BART) District Parking Demonstration; Final Report



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# Overestimation Reduction in Forecasting Telecommuting as a TDM Policy

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## Abstract

Overestimated forecasts of the impact of new policy, which over-predict policy success, are a well-known problem. Studying the effects of forecasting methods on potential biases may help modelers, planners and policy makers better use the forecasting tools. This paper addresses overestimation of telecommuting as a travel demand management (TDM) policy. The research hypothesis underlying this study posits that overestimates are virtually inevitable in forecasting the effect of new policies that aim to change travel behavior, but these biases eventually decline over time. The sources of overestimated forecast are the prediction tools used, and the ways in which modelers use these tools. The sources of the reduction in overestimation are the changes made to the modeling tools results from knowledge and data gained over time.

## INTRODUCTION

Overestimated forecasts of new policy performance, which over-predict policy success, are a well-known problem in transportation planning. Although at their hart, these overpredictions of success are almost always a function of prediction of adoption rate, these failures vary in a number of context-specific ways. The most widely known and researched phenomenon of over-optimistic forecasting is related to the cost of and demand for new public transportation infrastructure, such as rail projects. Other less studied areas that experience overoptimistic forecasts are transportation technology adoption, in which errors are typically related to the time (as well as extent) of implementation, and Travel Demand Management (TDM) policies, in which errors are usually related to the effect of the policy on travel behavior. In this paper, I will focus on the less-studied field of TDM forecasting, and I will propose a new explanation for the causes of overestimation.

This paper examines overestimations in new policy forecasts, changes in forecasts over time, and the sources of these changes. The research hypothesis underlying this study posits that overestimated forecasts are almost inevitable in forecasting new policies that aim to change travel behavior, but that these biases eventually decline over time. The sources of forecast overestimation are the tools used to predict them and the ways in which modelers use these tools. The sources of the reduction in overestimation are the changes made to these tools over time. This research hypothesis will be presented as a conceptual model and applied then to the case of telecommuting. I will focus on demonstrating the reduction of overestimation over time and on the changes made in forecasting tools which cause this reduction. The proposed explanation is not meant to replace other possible explanations, but rather, to add to them.

## TDM MODELING AND FORECASTING

### Travel Demand Management Policy Forecasting

The term Travel Demand Management was coined in the 1970s and is used to describe a wide variety of policies that focus on changing travel behavior and reducing car use on the existing transportation network [1]. Forecasting the effect of a new TDM policy has a higher level of uncertainty than that in forecasting the influence of new roads or public transportation projects. The uncertainty in forecasting the performance of a new behavioral change policy is caused by the lack of experience that both the modelers and the possible users have with the policy, as well as by the unpredictability of users' behavioral responses to the new policy. In contrast to forecasting the effects of infrastructure, in forecasting TDM, the modeler's ability to learn and predict travel behavior based on previous cases or cases from different locations is very limited.

Currently, behavioral models that aim to predict revealed behavior are the primary tool used to create forecasts in the transportation and planning process. Models that predict user behavior patterns are used extensively to plan transportation systems, forecast the effects of specific policies, and select alternative policies. In many cases, models that predict user behavior patterns are required either by law or by custom for decisions that involve funding allocation. Furthermore, because the methods of modeling human behavior are, by nature, exposed to many sources of uncertainty that demand conscious decision-making and the use of assumptions that may be influenced by bias, forecasting models can range anywhere from a simple “back of the envelope” type of calculation to a complex, four-step regional travel demand model, depending on needs and capabilities.

Experience over the last three decades suggests that forecast of new policies aimed at changing travel behavior are usually overly optimistic. However, there is limited direct evidence of such overestimation bias, as most of the research in the field is focused on the performance of the policies rather than on the quality of the forecasts. The accuracy of travel demand forecasts is rarely the subject of rigorous study, nor is it usually considered a motivation for model improvement. The relatively small number of studies that do exist on biased forecasts focus on two major issues: mega-projects and public transportation (see for example:[1-6], while critiques of the accuracy of other TDM effect forecasts can only be found indirectly within the literature that tests the success of different policies (see for example, TDM evaluation:[7-9], since this type of research usually uses forecasts as indicators of success or expectations.

## Definitions: Error Bias and Over-Forecasting

The literature that focuses on the accuracy of forecasts and models, and the success of policy implementation, is often vague when using terms such as “error,” “bias,” “overestimations,” etc., since these words can have more than one meaning. “Bias,” for example, can be defined as a personal attitude, such as prejudicial judgment. However, statistically speaking, “bias” has a very different meaning: The *Merriam-Webster Dictionary* defines “bias” as an “inclination of temperament or outlook," a “personal and sometimes unreasoned judgment,” a “deviation of the expected value of a statistical estimate from the quantity it estimates” and a “systematic error introduced into sampling or testing by selecting or encouraging one outcome or answer over others.” However, these definitions are far too broad for this research, therefore I will use the following set of definitions:

- **Forecasts** are predictions of behavior of interest at some future point, and they are the product of models.
- **Models** are a set of calculations used to predict one variable by using others. Models may contain of sub-models that can be internal or external to the main model.
- **Error** is the difference between forecasted and actual performance.
- **Bias** is a systematic error that reflects a tendency
- **Personal bias** is a pre exist judgment or prejudice, which may or may not be relevant to the case.

According to these definitions, overestimated forecasts are the combination of modeling error and bias.

## Background: Error Bias and Over-Forecasting

Uncertainty is inherent in forecasting travel behavior or any future human behavior [10-13]. Therefore, it requires numerous assumptions to create a forecast that is not just a projection of the future based on the past, but a demonstration of the real correlations between variables. Wachs [14] pointed out that a simple model may have a large specification error, but that trying to reduce this error by using a more complex model will increase measurement errors. In the political science arena, Dror [15] distinguishes between two types of uncertainty: quantitative uncertainty, in which the possible options are known but the probability of each option occurring is uncertain, and qualitative uncertainty, in which even the options are unknown. Forecasting the effect of a new policy in which the behavioral options are still unclear is, according to Dror, a qualitative uncertainty, while forecasting the effect of a more mature policy that has been modeled or even tested in the past will be less vulnerable to qualitative uncertainty and can better handle quantitative uncertainties.

Most of the literature that assesses model accuracy focuses on the sources of potential errors and the inaccuracy of models but do not distinguish between random errors or inaccuracies or biases. However, these studies do point to biases rather than randomness as being the main problem by showing that randomly scattered errors are not the problem. For many years, researchers have focused on the biases in estimating the cost of transportation projects, particularly public transportation projects. Pickrell [5] was the first to draw a statistical conclusion on the relationship between travel demand and cost forecasts by examining forecasted versus actual ridership and the cost of urban rail transit projects in the United States. Pickrell concluded that ridership forecasts were consistently overestimated. However, he did not identify the cause of these discrepancies. Instead, he suggested a set of methods to reduce forecasting error which included the improvement of forecasting methods and a more cautious adoption of external variables. Flyvbjerg, et al. [2] also performed a wide-scale multinational analysis focusing on the cost of public works projects. They concluded that, based on the error distributions, the forecasting overestimation could not be caused by a random error in technical incapabilities, and that therefore the errors were the outcome of a deliberate act.

## HYPOTHESES AND CONCEPTUAL MODEL

Two main explanations are usually given to rationalize the inaccuracy of forecasting models: (1) The models do not reflect reality because of deficiencies in knowledge and in data or computing capabilities and (2) modelers, whether deliberately or not, create biased forecasts that reflect their agendas [6]. This paper suggests an alternate explanation for overestimation based on a dynamic process that combines the two explanations in an evolutionary process of modeling, as articulated in these study hypotheses:

> **H1**. Forecasts of a new policy that aim to reduce vehicle use by changing travel behavior will focus on the policy potential (i.e. the benefits that could be achieved rather then the benefits that will be achieved), and thus will be optimistically biased at first.

> **H2.** Modeling improvements and data gained reduce overestimation: In the beginning, models are based on the policy potential. Later, more sophisticated models that are developed over time contribute to reducing the overestimation bias by incorporating possible drawbacks, secondary effects, and feedback loops. The transition from aggregate models to disaggregate models allows better forecasts of travel behavior that reflect possible sets of responses to the policy. The sets of possible responses both as a direct effect or indirect effect of the policy are the result of accumulating research data.

Comparing a forecast to an actual performance measure may be the best method for studying forecasting errors. However, in most cases data on actual performance are not available for one or more of the following reasons: the data were not collected, the data are not available to the public, or the policy was not implemented as planned and forecast. Therefore, because the actual performance measures are not available to illustrate our hypotheses, I use the trend only (i.e. the changes in forecasting over time) to illustrate the hypotheses.

Sources of overestimation are varied and are based on the type of model and the type of policy being modeled, the underlying motivation of the modeler, and the motivations of the institute or organization that requests the forecast. In this paper I focus on biases created by the forecasting methods and the way changes in the methods reduce bias. The methods I am focusing on include the modeling and forecasting tools, the type of data collected and the type of questions or possible effects that are being modeled. The models in use may have been affected by modelers' and institutional motivation but these effects do not contradict the effect created by the modeling and will be discussed in a later paper.

I hypothesize (H2) that in the initial forecast, the potential is calculated based on the behavior change (which is the policy goal) assuming that every individual who will theoretically gain from the new policy will actually adopt it. In forecasts based on this approach, the policy potential is modeled quantitatively while possible limitations, that will prevent adopting, are described qualitatively because of lack of data, or left out altogether because of lack of knowledge.

The first forecast starts an evolution process triggered by the motivation to improve on the original methodology. The first forecast initiates collection of a new set of data and knowledge and creation of new modeling and forecasting processes, based on the initial model, that introduce secondary effects and feedback loops. These new models have the potential to reduce the first model's overestimations, since in most cases these secondary effects and feedback loops reduce the main effect of the policy by demonstrating behaviors that allow the potential users to not change their current behavior. On this point, Salomon and Mokhtarian demonstrate behavioral types that are usually not modeled or taken into account when forecasting travel behavior [16, 17]. While the first generation of forecasts focus on the policy's potential, the next generations focus on performance in different scenarios and on limitations.

## Telecommuting Case Study

substituting commute trips by working from home using electronic communication was first suggested in the 1960s [18].Nilles et al., [19] market the policy as a way to reduce transportation energy consumption by substituting working from home for commuting trips.. Telecommuting refers to employees who can work from their conventional work place but choose to work from home or from a telecommuting center [20]. The original idea behind telecommuting was that the elimination of commuting trips would reduce total VMT and congestion, and thus save energy and improve air quality. As a result, this policy was adopted by transportation and environmental agencies in the United States and elsewhere. Other potential benefits were also considered in adopting policies of telecommuting (see for example: [21-23], though they will not be discussed in this paper.

Telecommuting was expected in many policy and popular arenas to provide significant transportation benefits during the 1980s and early 1990s [24]. However, reports that focused on the potential benefits of telecommuting were followed by skeptical, mostly scientific reports that focused on the potential constraints of the phenomenon of substituting telecommuting for commuting.

### Method

In this section I will focus on telecommuting forecasts that both directly and indirectly affect policy-maker and public expectations of telecommuting. These forecasts can be part of a decision making process, the basis for the creation of other models, or they can be the background for a public discussion that indirectly influenced the decision-maker's expectations of telecommuting.

The most generally relevant variables in forecasting telecommuting as a transportation-related policy are the Vehicle Miles Traveled (VMT) and the number of trips saved by telecommuting. These variables are directly derived from the number of telecommuters and the number of days they commute per week. However, the use of VMT reduction as a measure by which to compare forecasts from different studies raises the problem of any meta-analysis work in which one compares apples to oranges, in this case the VMT reduction of different places or different times, that the comparison will yield an incorrect conclusion. When evaluating the results of models spread over 30 years and aimed to answer different questions, one cannot completely avoid the problem. However, I can minimize the potential combination of oranges with apples by comparing forecasts of VMT reduction, a term with relatively high consensus on its definition, rather than other measure such as the numbers of telecommuters, the number of telecommuting days per week, or the number of telecommute-events, terms that do not have consistent definitions. Some forecasts are reported in energy savings rather than VMT reduction; these forecasts have been converted and included in the analysis. The forecasts In table 1 are for the year 2000 or some potential year in the future (in cases in which the potential of telecommuting was not attributed to a specific year) corresponds to telecommuting policy discussions in which the final number of telecommuters and the expected reduction are discussed in general terms rather than with respect to a specific year. Although some discrepancies remain, the analysis compares apples to apples as much as possible.

The second examination of the forecasts focuses on the tools used to create the forecasts. I use three different dimensions to create a typology categorizing the forecasting tools and the questions and assumptions made. First, I distinguish between one-step and two-step processes. The first step includes a theoretical representation of the policy and the second includes a theoretical representation of the expected changes. Salomon [25] classified TDM forecasts as derived from 10 different methodologies. Salomon's typology considers both qualitative and quantitative methods: (1) assuming the current number based on theoretical framework, (2) using empirical studies in which a theoretical framework is followed by data gathering, and (3) using a case study or a demonstration project to estimate current levels, build scenarios, or generate forecasts. The forecasting methods include: (1) using scenario building, (2) using projections to a maximum future point, (3) presenting the maximum potential under ideal conditions, (4) using "what if" assumptions. The second dimension of the present typology is based on Mokhtarian's (1998) work that synthesizes most of the empirical data available on telecommuting. For each model or forecast paper each question is answered by "ignored", "assumed" or "adopted". The forecasts are organized by date, from the oldest to the most recent. The third dimension of the typology is based on the amount of data required and the forecast limitations as described in the forecast paper.

## Forecasts

Table 1 shows different telecommuting forecasts for the year 2000 (or the nearest date) in the United States, made by scientists, government agencies, and consulting firms. The forecasts presented in Table 1 were selected because they show the effects of telecommuting on VMT reduction for the year 2000 or, in some cases, for later years. Other telecommuting forecasts were examined and rejected for this work as they relied on forecasts from previous work and not contribute to the methodological development or political discourse. Most of the local forecasts were also rejected as they relied on VMT reduction rates from one of the forecasts presented in this study.

**TABLE 1: List of Forecasts**

As shown in Table 1, these works focus on forecasts for the US, California, or a specific region in California. However, most of the telecommuting models developed in the last 30 years were not included in this table because they do not present VMT reduction forecasts, but rather, more limited forecasts of specific aspects of telecommuting.

Figure 1 demonstrates the changes in the forecast of VMT reduction from telecommuting, over the period of time from 1969 to 2002. Figure 1 also shows the percentage VMT reduction ranges given by each model. A significant change can be seen over the 34 year period. A simple linear regression fitted to the 13 points yielded an R square of 0.39. However, if the first forecasting point, estimated in 1969, is omitted, the R square is 0.62 for the forecasts published between the years of 1977 and 2002. I believe that the 1969 forecast which was based on data from the fifties, should be omitted from the regression analysis that is otherwise based on forecasts that use knowledge background from the seventies. I do use it in the methodological analysis as this report was cited in other early works and was part of the methodological evolution process.

There are two noticeable trends in Figure 1: (1) the reduction in the forecasted effect of telecommuting over time, and (2) the changes in the forecasting range, which starts small, becomes large and then becomes small again. In the next section I will present the modeling questions and methods that were used in these forecasts, and I will illustrate the correlation between these methods and the two above-mentioned trends.

**FIGURE 1: Telecommuting Forecast Change Over Time**

## Forecasting Tools and Methods

The first attempt to quantify the substitutability of telecommunications for vehicle travel which is relevant to this study was done in 1969 [18]. Though it can be argued that this work is too old to be appropriate for a discussion that focuses on forecasting for the year of 2000, relevant works from the 1970s that cite it substantiate its inclusion. In this study, the amount of VMT that can be substituted by reducing commute trips is calculated by multiplying the number of commute trips by a substitute coefficient per occupation. The share of commute trips or “earning a living” trips (which include commute and business trips) was adopted from an unpublished work from 1955. The range of potential trip substitution was set arbitrarily according to “extreme optimism” and “half than first assumed” alternatives. This very simple “back of the envelope” model was based on assumptions only rather than data on actual telecommuting abilities or preferences.

In his 1977 work that focused on telecommunication technologies and their effect on transportation/telecommunication interactions, Harkness chose a different way to address the level of uncertainty with respect to substitution. This work used scenarios and an analysis of the substitution effect of each scenario based on a "what if" system. Available numbers were adopted, including those from the 1969 NAE work. The results are described as "if-then" scenarios, and Harkness offers this disclaimer: "There are arguments why telework would affect these areas favorably and there are arguments to the contrary. Only hands-on experiment and trial are likely to provide the answered (p. x). Nevertheless, quantitative results are presented based on these assumptions. It is important to remember that the focus of this work was on identifying policy recommendations and not forecasting telecommuting. The 1977 work of Tyler et al. was similar to Harkness's in that it also adopted the 1969 reduction factors and used them to calculate potential energy saving. Obermann [26] used a similar approach by adopting the 1969 factors in order to identify the upper-bound limits, or maximum potential, of telecommuting and telecommunication substitution. Obermann's methodology and terminology of upper-bound was adopted in later forecasts, which often ignored his qualitative assessments about the forecasts as "Not so much forecast as a statement of potential" (p. 46).

These early works begin to express the need for research on telecommuting demand based on personal preference, and they also reveal a concern that actual substitution levels might prove lower than expected. Furthermore, the modelers identified a very small number of previous works that could be used in their models, as well as a few dozen papers that helped identify the potential substitution effects and limitations of telecommuting.

In contrast to the first four studies, which offered a foecast only of the 'potential' effect of telecommuting, works 5,7,8 acknowledge the uncertainty with respect to adoption by presenting three telecommuting adoption scenarios and their potential effects. Nilles in his JALA Associates report from 1983 addresses the lack of knowledge by adding a qualitative forecast to the report focused on "Barriers and incentives to more widespread use of telecommunications" p 62. In this section he argues that "Considerably less easy to quantify are the interrelationships between the inherent technological capabilities of telecommunications and the sociological settings in which they exist" p 62. This cautious method may lead to an adoption of the middle scenario as policy makers may perceive it as most probable to occur even if the modeler assumes an equal probability for all scenarios. The forecasting method used to build these scenarios is based on the assumption that the level of substitution will reach the upper bound. However, the adoption rate is different from one scenario to the next. That is, this approach still implies that every person who has the technical potential to telecommute will probably do so when conditions allow it. Accordingly, much of the policy and research work of these studies is focused on identifying the barriers to telecommuting adoption and on creating the conditions for telecommuting.

Since the emergence of telecommuting in the early 1970s, a large body of literature has accumulated on the pros and cons of working at home or in a local center, and the effects of these factors on the decision to telecommute. As expected, most of these studies suggested that the upper limit presented in previous works would not be reached.

In work 9, Handy and Mokhtarian [27] tried to assimilate some of this work in their forecasting model based on scenario building for California. They avoided the problem of having a wide range of forecasts by choosing only one telecommuting adoption scenario to estimate a transportation reduction scenario. Works 10 and 11, which show low VMT reductions for the year 2000, are very similar to works 5, 6, and 7, and are based on the same assumptions. The main difference between later and earlier works is a different adoption curve that brings telecommuting to its maximum later than previously predicted. Work 12 presents a new approach of using all the available data in a forecasting process that ends with one number rather than with a range. Unlike the scenario method, with this approach each assumption has to be reasoned and backed by disaggregate behavioral research. This work is based on previous behavioral research that focuses not only on the ability to telecommute but also on the attitudes towards and limitations to doing so. The work of Choo et al.[28] work represents a new attempt to address the question of how many telecommuters there are by using aggregate time series data. This work does create forecasts based on current findings, but the methods can be used as the base-case for future forecasting.

Table 2 demonstrates the change in modeling over time. The first 6 forecasts are based on one-step forecasts of the maximum potential. Forecasts 7 to 12 are based on two-step analysis where at first the potential was estimated and then the actual performance was forecast based on disaggregate data. The policy constraints are ignored at first and then gradually analyzed qualitatively and then quantitatively, which increase the minimum required data. The shift in method and especially the adoption of a synthetic approach was made possible by the research accumulated in the 1980s and 1990s, as illustrated in Figure 2, which shows the number of "telecommuting" citations per year. The data accumulated was based mostly on behavioral research and pilot studies as wide scale adoption of telecommuting was still slow. We can also notice that the forecasts of the actual predicted performance of telecommuting are based on disaggregate modeling, with the exception of work 13, while the maximum potential forecasts are mostly based on aggregate data.

**TABLE 2: Model Type and limitation Analysis**

**FIGURE 2: "Telecommuting" Citations per Year (**Based on *Google Scholar*™ 06/12/2007)

Acquiring new data and knowledge allowed modelers not only to reduce the number of open questions that were answered qualitatively but also to raise new questions that in most cases suggested lower levles of VMT reduction than previously expected. Figure 3 demonstrates a set of questions based on Mokhtarian's (1996) work that synthesizes most of the empirical data available on telecommuting. Mokhtarian categorized the model variables by questions where each question is based on the data collected in the previous step. Each step creates the population of potential users for the next step and the potential reduction of VMT by these users.

**FIGURE 3: Modeling Questions**

Table 3 present the questions related to the total VMT saved by telecommuting based on Mokhtarian (1996). For each model or forecast paper, its handling of each question is categorized by: (M) A maximum potential number was adopted, (+) the question was modeled quantitatively, (I) the question was ignored, (?) the question was raised and answered qualitatively. The pattern revealed in this table is a change from maximum potential models where many of the potential effects are ignored, to a wider discussion and then modeling of these effects. The accumulation of data and knowledge on the basic questions at the bottom of the pyramid appear to raise the new questions alongside answering the questions quantitatively.

**TABLE 3: questions and answers**

## The Role of the Modeler's Core Belief

The role of deliberate biases in forecasting stemming from modelers' and planners' agendas is not part of this work, as this type of bias should be revealed and corrected by planners who hold a contrary agenda. However, planners' attitudes, norms, and beliefs may affect and bias the result of forecasting efforts - not as a deliberate abuse of the process, but more as a result of the effects of these norms and beliefs on the questions asked, the assumptions made and the method used. Hypothetically, each modeler can be classified into one of three groups based on her norms and beliefs associated with telecommuting as TDM. The first group includes the optimists, who believe that telecommuting can be an important or at least valid TDM policy. The second group includes the skeptics, who believe that telecommuting will not perform as an important TDM policy. The second group's core beliefs can be anchored with skepticism toward the first group's forecasts or towards the policy in general. The third group includes modelers who have no core belief about the specific subject. The hypothetical classification was tested by using in-depth interviews with nine of the modelers who verified the existence of the first two belief types but not the third one.

Assuming that the "optimists" will take the role of presenting the policy potential by using the early, aggregate, and low data requiring, models, I was looking for the "skeptics" to present counter forecasts that were lower than the optimistic maximum potential forecasts. These counter forecasts presented in early years, were the data and knowledge to present quantitative forecasts other then the 'potential', was not yet available. Rather than quantitative forecasts, early skepticism was presented qualitatively. There are several thoughtful early examples of such qualitative 'skepticism' . For example, in his dissertation, Harkness [29] chose not to focus on telework and shop-at-home scenarios since they are less possible to occur. In an unpublished work cited by Jones [30], Mitchell (1970) argued about telecommunication substitution that "urban transportation must look elsewhere for solutions to its congestion problems". Albertson [31] came to a similar conclusion, stating that telecommunications is not likely to substitute for travel. None of these examples presents any supporting quantitative models.

The effect of the core beliefs on the methods and type of questions used by the two core belief groups over the years is presented in Table 4. Modelers who hold an optimistic core belief will start with presenting the policy potential using aggregate data. Subsequently "optimists" are more likely to use disaggregate data and pilot studies, which still emphasizing the policy potential. The "skeptics", who started with qualitative analysis of the potential limitations, will also move to disaggregate models, often focusing on one aspect of the policy effect and on its limitations.

**TABLE 4:** The Role of the Core Belief

## Conclusions

Did the accumulation of knowledge, data, and experience lead to the decline in the forecasted effect of telecommuting? Or was it an external change such as fuel cost or changes in the technology and information work sector? On one hand, most of the forecasting models presented in this work did not include travel cost in the quantitative part of the forecast. On the other hand, a latent assumption about travel cost may be reflected in the downward trend of the forecasts. The answer is probably both. However, a different question needs to be asked: Could modelers have come out with better, probably lower, forecasts at an earlier stage? In other words, could the evolution of forecasting models have been speeded up, to produce more realistic forecasts more quickly?

The case of telecommuting establishes a correlation between the model used and an overestimation in the policy forecasts. The use of models of the “maximum potential” that are based on aggregate methods as a result of a lack of better knowledge is the main cause for this overestimation. The reduction of overestimation over time can be attributed in part to both knowledge gained and method changes. The first generation of forecasts includes a quantitative aggregate evaluation of the policy potential and a qualitative evaluation of barriers and limitations that will prevent telecommuting from achieving its full potential. The first generation models of telecommuting as a TDM policy were inherently biased toward overoptimism in that any quantitative estimation that can be produced in this stage will be biased. Only later forecasts can suggest more quantitative disaggregate evaluations of the limitations based on behavioral studies, which reduce the final estimates of policy success.

Thus, it appears that in early stages a quantitative evaluation will almost inevitably be optimistically biased in that any lower estimation can be presented only qualitatively. The work of both optimistic and skeptical modelers on the policy led to a feedback effect that improved the quantitative models and reduced the expectation from the policy.

If forecasts of a new TDM policy, telecommuting in this case, are inherently biased, what are the possible lessons for modeling and policy? First, data and knowledge gathering reduced the bias even before any wide scale implementation of the policy. Research work that was based on surveys and limited pilot studies answered most of the questions about the limits. This phenomenon may suggest that more investment in research may reduce the time needed to get to a less biased forecast. Second, we can see that qualitative forecasts may be less biased in early stages of the policy modeling and that policy makers should attend to these qualitative forecasts. Third, it may be important not only to identify the limitations and barriers but also to quantitatively explore their potential effects, the same way the “what if” scenarios demonstrate the policy potential. Fourth, overoptimistic forecasts can be the outcome of lack of data and knowledge. Skeptic modelers have an important role in improving the models and creating a fertile dialog with the optimist forecasts.

This work can and needs to be developed in three different directions. First, the framework presented in this paper needs to be tested on a different, preferably newer, policy in order to assess its generalizability. Second, I suggest inquiring into the motivations of the modelers and institutes in order to assess the indirect and direct effects they had on the forecasts’ tools and outcomes. Third, I will suggest a focus on the policy implications of this study mainly by studying the way these forecasts were used over time.

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## LIST OF TABLES AND FIGURES

**TABLE 1: List of Forecasts**

| | Title | Year | Principal Authors | Performing Organization | Sponsoring Organization |
|---|---|---|---|---|---|
| 1 | Telecommunications for enhanced metropolitan function and form : report to the director of Telecommunications Management | 1969 | | National Academy of Engineering | National Academy of Engineering |
| 2 | Technology Assessment of Telecommunications/Transportation Interactions | 1977 | Harkness, Richard | Stanford Research Institute | National Science foundation |
| 3 | The Contribution of Telecommunications to the Conservation of Energy Resources | 1977 | Tyler M; Elton M and Cook A | University College London | U.S. Department of Commerce |
| 4 | The impact of telecommunication on transportation demand through the year 2000 | 1978 | Obermann R | The MITRE Corporation | National Transportation Policy Study Commission |
| 5 | Telecommunications and Energy: The Energy Conservation Implications for California of Telecommunications Substitutes for Transportation | 1983 | Nilles J | JALA Associates | California Energy Commission |
| 6 | Air Quality Management Plan: Transportation Land Use & Energy Conservation Measures | 1988 | | | South Coast Air Quality Management District. |
| 7 | Traffic Reduction by Telecommuting: A Status Review and Selected Bibliography | 1988 | Nilles J | Forecasts based on JALA Associates 1986 | |
| 8 | Can Telecommunications Help Solve American's Transportation Problems? | 1991 | Boghani A; Kimble E and Spencer E | Arthur D. Little, Inc. | A Multiclient Study |
| 9 | Base Case Estimates and Forecasts of Telecommuting in California | 1993 | Handy S and Mokhtarian P | University of California Davis | California Energy Commission |
| 10 | Transportation Implications of Telecommuting | 1993 | Hopkins J | Department of Transportation | Department of Transportation |
| 11 | Energy, Emissions, and Social Consequences of Telecommuting | 1994 | | Multi Sources | Department of Energy |
| 12 | A Synthetic Approach to Estimating the Impact of Telecommuting on Travel | 1998 | Mokhtarian P | University of California Davis | |
| 13 | Does telecommuting reduce vehicle-miles traveled? An aggregate time series analysis for the U.S. | 2000 | Choo S; Mokhtarian P and Salomon I | University of California Davis | California Energy Commission |

**TABLE 2: Model Type and limitation Analysis**

| Study # | Model type | Two Steps Analysis | Disaggregate Method | Policy Limitation Analysis | Minimum Data Requirement |
|---|---|---|---|---|---|
| **1** | “Back of the Envelop” | - | - | None | Low |
| **2** | “What If” | - | - | None | Low |
| **3** | “Maximum Potential” | - | - | Qualitative | Low |
| **4** | “Upper-Bound ” | - | - | Qualitative | Low |
| **5** | Technology Adoption Scenarios , Maximum Potential Analysis | | -+ | Qualitative | Medium |
| **6** | “What if” | - | -+ | Qualitative | Medium |
| **7** | Technology Adoption Scenarios , Maximum Potential Analysis | + | + | Qualitative and quantitative | Medium |
| **8** | Technology Adoption Scenarios , Maximum Potential Analysis | + | + | Qualitative | Medium |
| **9** | Synthetic Approach, Scenarios | + | + | Qualitative and quantitative | High |
| **10** | Technology Adoption Scenarios | + | + | Qualitative and quantitative | Medium |
| **11** | Technology Adoption Scenarios | + | + | Qualitative and quantitative | Medium |
| **12** | Synthetic Approach, Scenarios | + | + | Quantitative | High |
| **13** | An Aggregate Time Series Analysis | Not Relevant | - | None | High |

**TABLE 3: Questions and Answers**

| Study # | Year | Who Can? | Who Wants To? | Who Will? | How Often? | How Long? | How Far? | Out Of How Much? | What About Increases In Travel? | What About Relocation? | What About Latent/ Induced Demand? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1969 | + | I | I | M | M | M | I | I | I | I |
| 2 | 1977 | + | ? | ? | M | M | M | I | ? | ? | I |
| 3 | 1977 | + | I | ? | M | M | M | I | I | ? | I |
| 4 | 1978 | + | I | I | M | M | M | I | ? | ? | ? |
| 5 | 1983 | + | ? | ? | M | M | M | ? | I | ? | I |
| 6 | 1988 | + | ? | ? | + | + | + | I | I | I | I |
| 7 | 1988 | + | + | + | +M | +M | +M | +M | I | I | I |
| 8 | 1991 | + | I | + | M | M | M | + | I | I | I |
| 9 | 1993 | + | + | + | + | + | + | + | + | ? | ? |
| 10 | 1993 | + | + | + | + | + | + | + | I | ? | I |
| 11 | 1994 | + | I | + | + | + | + | + | ? | ? | I |
| 12 | 1998 | + | + | + | + | + | + | + | + | + | + |

M Maximum potential number was adopted
I The question was ignored
? The question was raised and answered qualitatively
\+ The question was modeled quantitatively

**TABLE 4:** The Role of the Core Belief

| | | Timeline | |
|---|---|---|---|
| | | **New Policy** | **Over Time** |
| **Core Belief** | **Optimistic** | Quantitative<br>Aggregate<br>“Potential” | Quantitative<br>Disaggregate pilot studies<br>“Potential” |
| | **Skeptical** | Qualitative<br>“Limitations” | Partial analysis<br>Disaggregate<br>“Limitations” |

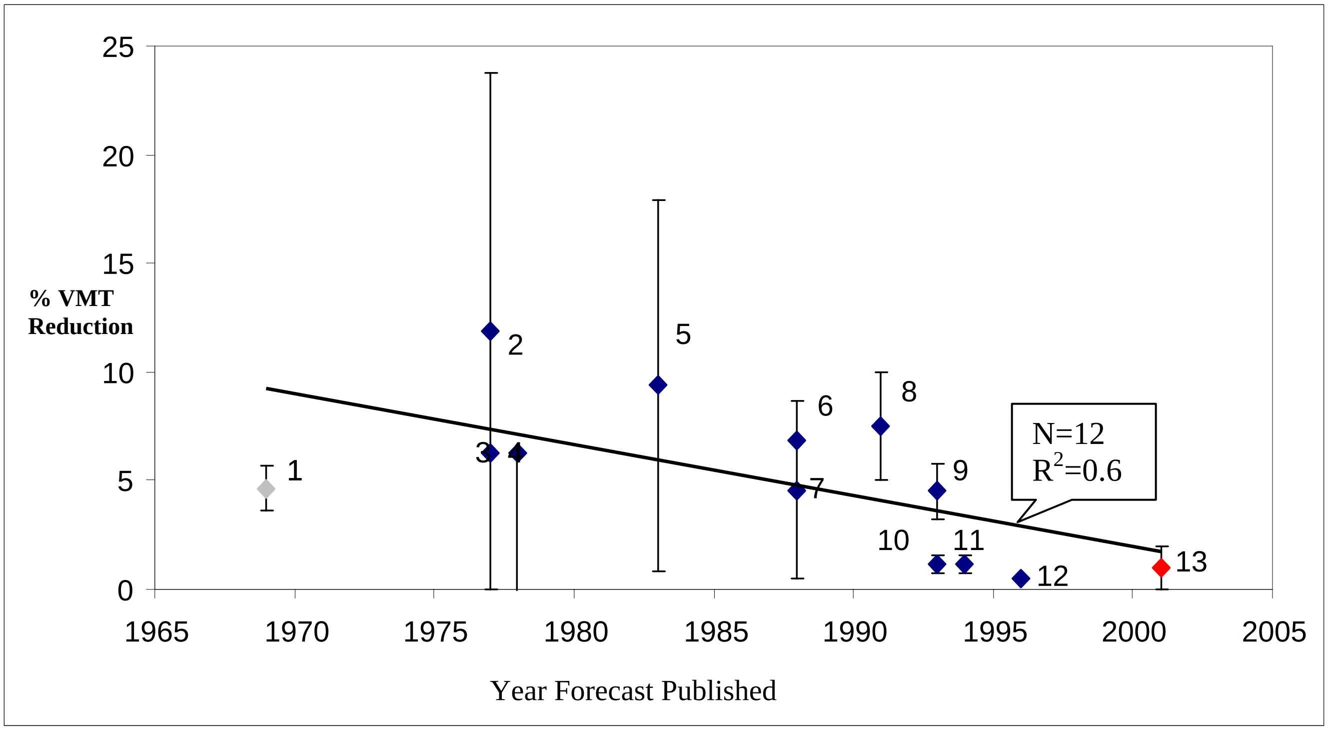


**FIGURE 1: Telecommuting Forecast Change Over Time**

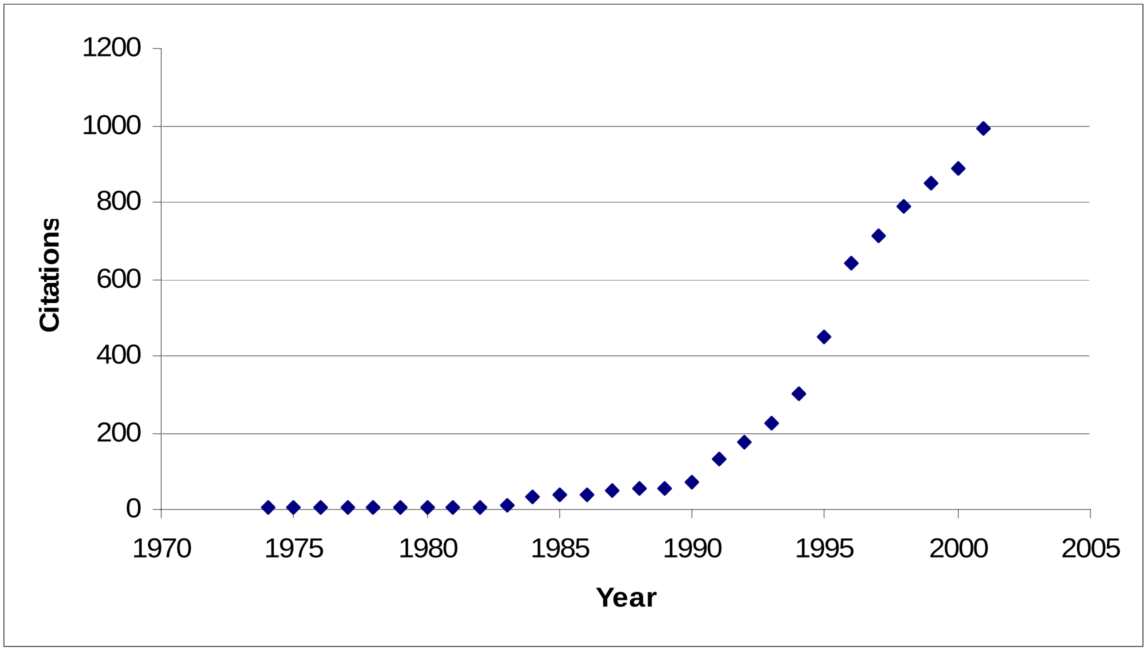


**FIGURE 2: "Telecommuting" Citations per Year (**Based on *Google Scholar*™ 06/12/2007)


**FIGURE 3: Modeling Questions**