TRANSPORTATION & REGIONAL GROWTH

a study of the relationship between transportation and regional growth

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Understanding Urban Travel Demand

Problems, Solutions, and the Role of Forecasting

Report #2 in the Series:

Transportation and Regional Growth Study

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This report is a general examination and critique of transportation policy making, focusing on the role of traffic and land use forecasting. There are four major components:

1. Current, historical, and projected travel behavior in the Twin Cities.
2. The standard travel forecasting model, and some of its shortcomings.
3. The potential application of integrated land use and transportation models.
4. Specific transportation problems and proposed policies in the Twin Cities.

The most important result is that the standard traffic forecasting model in its current form is not well suited for evaluating many of the policies of greatest current interest, in particular, those that seek to reduce the overall amount of travel through changes in land use or travel behavior. This model was developed to predict road capacity needs, taking the quantity of travel as more or less uninfluenced by policy.

However, currently available improvements, including integrated transportation and land use models, often add little value because they are not based on a well-established theoretical and empirical understanding of travel behavior. The most urgent need in forecasting is not for more complex models, but for a better understanding of the real world processes that the models are attempting to capture.

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Preface

The Transportation and Regional Growth Study is a research and educational effort designed to aid the Twin Cities region in understanding the relationship of transportation and land use. Many regions of the country are experiencing rapid commercial and residential development, often accompanied by population growth and growth in the total area of land developed. This has caused a range of concerns, including the direct costs of the infrastructure needed to support development and the social and environmental side effects of development patterns.

This study is an effort to better understand the linkages between land use, community development, and transportation in the Twin Cities metropolitan area. It is designed to investigate how transportation-related alternatives might be used in the Twin Cities region to accommodate growth and the demand for travel while holding down the costs of transportation and maximizing the benefits. The costs of transportation are construed broadly and include the costs of public sector infrastructure, environmental costs, and those costs paid directly by individuals and firms. Benefits are also broadly construed. They include the gains consumers accrue from travel, the contribution of transportation and development to the economic vitality of the state, and the amenities associated with stable neighborhoods and communities.

The University of Minnesota's Center for Transportation Studies is coordinating the Transportation and Regional Growth Study at the request of the Minnesota Department of Transportation and the Metropolitan Council. The project has two components. The first is a research component designed to identify transportation system management and investment alternatives consistent with the region's growth plans. It has six parts:

1. Twin Cities Regional Dynamics
2. Passenger and Freight Travel Demand Patterns
3. Full Transportation Costs and Cost Incidence
4. Transportation Financing Alternatives
5. Transportation and Urban Design
6. Institutional and Leadership Alternatives

The first three research areas are designed to gather facts about the transportation system and its relationship to land use in the Twin Cities metropolitan area. The other three research areas will use these facts to investigate alternatives in financing, design, and decision making that could have an impact on this relationship. Results of this research is and will be available in a series of reports published for the Transportation and Regional Growth Study.

The study's second component is a coordinated education and public involvement effort designed to promote opportunities to discuss the relationship between transportation and growth based on the research results. It is believed that this dialogue will help increase knowledge and raise the level of awareness about these issues among the study's many audiences, including decision makers who create policy, agency professionals who implement policy, stakeholder groups who try to influence policy, and members of the general public who experience the consequences of those policies.

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Executive Summary

This report is motivated by a generally increasing concern about problems related to local travel, especially auto travel. These problems have varying characteristics, which makes it difficult to find simple solutions. Congestion, for example, affects primarily drivers themselves, while air pollution impacts everyone regardless of how much they drive. Concern even extends to broader long-term effects of an auto-based system, such as the degradation of neighborhood environments.

This broad range of problems makes policy creation difficult because the solution to one problem can often worsen another. For example, while widening roads might reduce congestion, it might make air pollution worse by inducing additional travel. Another complication is that the needs of different groups, such as commuters and the residents of the neighborhoods they drive through, are often in conflict. And people can have differing notions of what it means to "solve" a problem – widening roads to reduce congestion, for example, versus improving transit so that people don't have to drive in the first place.

Still another significant difficulty is that it can be hard to know how people will respond to a given policy; that is, whether the policy will in fact have the desired effect. Many of the transportation solutions that have been proposed have little practical track record to use as a basis for predicting their effects. Furthermore, even if the effect of a policy can be predicted with some certainty, this does not prove that it is a good thing. People travel because they derive benefits from doing so; policies that aim at changing travel habits must consider how these benefits are affected.

Transportation experiments are costly and often hard to reverse once implemented. Simply trying ideas without a clear understanding of the factors that are likely to lead to success or failure is unlikely to produce desirable results, and may even lead to a backlash against "progressive" policies, and increased calls for highway expansion. This makes it critical to have good forecasts of the likely effects of different policies on travel behavior, and ideally, on other longer-term decisions such as land use. In addition, it is important to have methods for evaluating the relative desirability of different policies, given the predictions of their effects.

The purpose of this report is to examine what is known about travel behavior and forecasting in the Twin Cities, from the point of view that the ultimate objective of this knowledge is to assist in the formulation of transportation policy. The question is this: Are we likely, given the current state of knowledge and practice in travel behavior description and forecasting, to find the policies and investments that will have the greatest beneficial impact at the lowest cost? And if not, what are the shortcomings in knowledge or practice that prevent us from achieving this goal, and what can be done about them?

Looking at historical data highlights the difficulty of this problem. There are a large number of decisions that people make about their travel behavior, such as their destinations, the mode (car or bus, for example), the time of day they travel, organizing individual trips into chains, and so on. In addition, broader factors such as population, economic growth, and technological changes can impact travel decisions. This makes it difficult to trace specific cause-effect relationships between policies (such as highway construction) and the resulting changes in behavior.

The same complexity that makes it hard to understand what has happened in the past also makes it hard to predict the future. Forecasting models must make simplifying assumptions to be useable; however, the details that are assumed away as unimportant at one time may be precisely the ones of greatest interest at a later time. The traffic forecasting models in use today were developed in the 1950s and 60s to aid in planning the size and location of new highways needed to accommodate increasing auto travel. Because the policy objective was to accommodate travel behavior rather than to modify it, little research went into understanding the determinants of the total amount of travel, such as trip quantities, destinations, and home and work locations.

Now few new highways or major expansions are planned for the Twin Cities. The problems associated with auto travel seem clearer, and there is more interest in policies that aim at reducing or otherwise managing the quantity of auto travel. In fact, given that the size of the highway network is largely fixed, but the population is still growing, it seems inevitable that such policies will have to be utilized. Unfortunately, these are exactly the policies that are least suited to analysis given the existing state of knowledge and practice.

In fact, while forecasting models are very sophisticated in certain ways, they have little to say (because little is known) about the effects of many popular policy ideas, for example, high-density or transit-oriented development, and region-wide rail investment; that is, policies that aim at major long-term behavioral changes. This lack of understanding raises two dangers. On the one hand, good policies might appear ineffective, or might be poorly executed, because the models do not account for all the channels by which these policies might work. But on the other hand, policies that really would be ineffective might garner undeserved support because the models do not represent them well enough to convince people that they won't work.

The problem is that it is not at all obvious how to best improve the forecasting models. More accuracy seems desirable, but it's not clear that lack of accuracy is really the problem. More complaints seem to focus around the notion that the models do not consider a broad enough range of phenomena; that alternate modes are not well represented and that non-transportation impacts such as land use need to be considered.

Some forecasting models have been developed that attempt to integrate land use and transportation decisions into a common framework. Because land use is widely thought to have a significant impact on travel behavior, this idea has some appeal. Unfortunately, these models have not been shown to be more accurate or insightful than current heuristic methods of forecasting land use. To some extent this is because land use changes take place over a long time period, and so in many cases not enough time has elapsed to test the model predictions against actual outcomes. However, the problem is also in part more fundamental. Contrary to common belief, basic theoretical knowledge of how land use is determined and exactly how it interacts with transportation is not yet very well developed. Because of this, it is difficult to say with any certainty how transportation policies might impact land use, or vice versa; and thus it is hard to develop robust mathematical models of this relationship.

Inability to predict the full range of outcomes of different policies is a concern; however, possibly a more serious problem is the lack of tools for evaluating the relative desirability of various policy options. That is, the point of policy is not just to make things different, but to make them better. To know whether a policy will accomplish this, it is necessary first to have an idea of the desired characteristics of the transportation system, and second to have tools for measuring how well the policy does at achieving these characteristics.

Finding ways to measure accessibility seems to be the key to solving many of these problems in forecasting and evaluation. The transportation system exists to make it possible for people to access destinations; measuring accessibility would provide a way of knowing how well it accomplishes this objective. Using a unique, well-defined measure of system quality would make it possible to easily compare the benefits to be gained from different types of policies. This basic need is currently unmet because different policies are evaluated according to different criteria and objectives.

The transportation system is complex. There are many users, often with very different objectives, and generating different kinds of costs to the system. The value of the system to any one user depends on how other people are using it. Relationships that are true at one point in time may not hold true over a longer time span. Facts, *per se*, are ambiguous in the absence of other facts that can be used to place them in an appropriate context.

Thus transportation, like other kinds of complex systems, is hard for non-experts to understand. At the same time, it is not a self-contained system but is inextricably part of the broader economic and social life of the area. Thus it is appropriate for non-experts, such as legislators, to have the bottom-line say in at least the broad outlines of transportation policy. This creates a challenge.

Good policy is unlikely in the absence of good forecasts, and for many popular policies the state of knowledge is inadequate for predicting their effects with confidence. At the same time, accurate and detailed forecasts will not inevitably lead to good policy unless the results and implications of these forecasts can be presented in ways that can be appropriately interpreted by non-experts. To solve these problems will require the development of new knowledge and new tools.

Recommendations:

Policy makers need detailed but easily understandable and unambiguous information about the effects of various policies, in order to find the policy combination that will best achieve regional objectives. It would also be beneficial to have tools for evaluating the overall quality of the system from the points of view of the different groups of people using it.

There are three immediate practical steps that can be taken to move closer to this objective:

1. Research to acquire better understanding of the details of travel behavior and how they respond to different types of incentives; in particular, better understanding of the role of land use in determining trip quantities, mode choice, and destinations. Improving forecasting models by incorporating this understanding as it becomes available.
2. Making the output of forecasting models more useful and understandable to policy makers. Using the models to generate more detailed information on user behavior and how the system influences it. Relating forecasts to historical patterns and explaining similarities and differences. Using geographic information systems to show variations in behavior across the region, especially variations arising from land use or differences in access to the transportation system.
3. Tools for describing and measuring the overall quality of the system (accessibility), and how this quality varies for different places or groups of people. Using accessibility as a framework for evaluating and comparing different systems, modes, and combinations of policies. Developing ways of describing transportation and travel behavior that focus attention on the problem of improving the quality of the entire system rather than on solving individual problems.

1 Introduction

There is a growing sense among both policy makers and ordinary citizens that something needs to be done about transportation in the Twin Cities. However, there is considerable disagreement about what exactly the problem is. Some argue that almost all travel is done by car and thus that it is only logical to focus on alleviating traffic congestion. Others point out that not everyone can afford to drive and that cars create other problems such as air pollution, and thus argue that policy should focus on creating alternatives to the auto. Still others are concerned that our current transportation system is destroying neighborhoods or making it difficult for the poor to access jobs.

This variety of complaints, many of which seem to contradict each other, leaves decision makers in rather a quandary. A policy that solves one problem may very likely make another one worse. Furthermore, different groups suffer different problems, so that solving one problem at the expense of another will often mean benefiting one group of people at the expense of another. And it is sometimes not even obvious what it might mean to “solve” a problem. Is the solution to congestion widening roads so that people can drive faster, or is it providing better bus service so that they don’t have to drive in the first place?

Yet another complication is that the way people will respond to a given policy is somewhat unpredictable. Widening a road won’t reduce congestion if the extra capacity encourages more people to drive. Nor will improved bus service help if not enough people can be induced to use it. Travel behavior is complex, not only in terms of its motivations, but also in terms of how it manifests itself. Policies can be very expensive to implement, and once implemented tend to be long lasting. Thus it is important that decision-makers have good information about the likely effects of different policy options, and are able to use this information to draw appropriate conclusions.

The purpose of this report is to examine what is known about travel behavior and forecasting in the Twin Cities, from the point of view that the ultimate objective of this knowledge is to assist in the formulation of transportation policy. The question is this: Are we likely, given the current state of knowledge and practice in travel behavior description and forecasting, to find the policies and investments that will have the greatest beneficial impact at the lowest cost? And if not, what are the shortcomings in knowledge or practice that prevent us from achieving this goal, and what can be done about them?

The report exploits four different points of view in its effort to answer these questions. The first is an examination of historical travel behavior in the Twin Cities, and of the forecasts for future patterns. The second is a somewhat detailed description of the methods by which travel demand forecasts are created, and of the knowledge (and lack thereof) implicit in this process. The third perspective considers the link between travel behavior and land use, and of forecasting models that attempt to represent this link. The final angle is a more concrete discussion of specific policy issues, aimed at illustrating the range and complexity of questions that hinder efforts to find optimal policies.

The description of historical and predicted travel patterns serves two purposes. First, it provides factual background, which makes it possible to understand current and predicted problems as part of an ongoing process. Knowing how the system has changed over time, and how it is predicted to change in the future, also provides a basis for the discussions of forecasting models in subsequent chapters. A second purpose is to illustrate the complexity of the system, the ambiguity of the information that we have, and thus the difficulty of knowing what policies are likely to be effective.

The description of the standard travel demand forecasting model illustrates the current state of practice in understanding travel behavior for purposes of assisting decision making. This model was developed decades ago to answer certain types of questions, and as a result it is not always well suited to the types of questions that it is being used for now. Some of the more significant shortcomings are described, as well as some of the efforts currently being made to address them.

The discussion of the link between land use and travel behavior serves both a conceptual and a practical purpose. On the conceptual side, it highlights the fact that transportation is part of a broader urban system, and should not be considered in isolation, by discussing the important problem of how transportation interacts with land development. The practical purpose is to describe and evaluate the class of “integrated” transportation and land use forecasting models; specifically, to determine whether and how these models can improve upon the standard travel demand forecasting process.

Having evaluated what is possible and not possible given our current forecasting tools, the final step is to discuss the implications for policy making. Making good policy requires both detailed and broad understanding of costs and benefits: their magnitudes, timing, incidence, and how they are influenced by external conditions. It is necessary to predict the likely results (or range of results) of various policy options, and to relate these predicted results to regional objectives to evaluate which combination of policies will yield the most net benefit given the monetary cost. This is not a simple problem.

Given the importance and the difficulty of this problem, it is critical that we have good tools for generating relevant information, and good processes for ensuring that this information is interpreted and used appropriately. Thus while one theme of this report is to examine what kinds of tools and processes we have, another equally important issue addressed here is what kinds of tools and processes we need to have. In particular, this report argues that while much effort is going into improving the accuracy of travel forecasting models, accuracy has little value unless decision makers are able to understand the implications of the forecasts, and use them to make decisions that increase the overall quality of the system. Thus a major conclusion here is that more effort should go into developing ways to help decision makers understand what forecasts imply about policy, and in particular, to develop ways of measuring and describing the quality of the transportation system as perceived by its users so that alternative systems can be compared in intuitive ways.

The remainder of this introduction provides some context for understanding the general problem of urban transportation planning and policy. There are three parts to this. First is a short discussion of why travel matters; that is, the significance of the benefits and costs that it creates. Second is a description of the historical and legal context of planning: what its formal and informal objectives are.

The final section draws on the two earlier discussions to develop a statement about the contrast between the types of problems that we will be able to address given current trends in forecasting and policy, and the types of problems that we will *need* to be able to address. This assertion that our current approach is likely to leave many important questions unanswered serves as the underlying theme for the exploration and discussion in the remainder of the report.

The Importance of Travel

A good starting point for thinking about the importance of travel is the question: Why do we live where we do? There are obvious disadvantages to living in a big city. It is expensive, noisy, and congested, not to mention the threat of crime. But at the same time, big cities offer advantages that are not available in less populous areas. Access to a wide variety of unique shopping and recreational opportunities is one. An even more important consideration for many people is the availability of a variety of jobs, or of specialized work that doesn't exist at all in smaller cities.

People incur the expense and inconvenience of living in a large city because they want access to a variety of destinations or to a few specific ones. This significant reason for living in a city hinges, in turn, on the possibility of actually accessing those destinations; in other words, on being able to travel.

This is a critical point. People travel because they get benefits from it, or more precisely, because they get benefits from the things they do or buy at the end of the trip. Since people are under no legal obligation to travel, it must be the case that the benefits they gain from traveling, or from the lifestyle that it makes possible, must outweigh the costs they incur (although the costs to society as a whole might be larger). Otherwise the trip would not be made, or a way would be found to attain the same benefit with a less costly trip. This needs to be said because of the current popular emphasis on the costs or negative impacts of travel. The reason there is so much travel is because people are gaining something by doing it – travel is a benefit, not a burden.

Nonetheless, it is still not completely clear whether or in what ways we are becoming better off. The fact that the benefits of a trip exceed the costs to the traveler doesn't mean that there is as much net benefit as there used to be, or as much as is possible. It could be that each trip used to provide a large excess benefit, and now provides only a small one. Furthermore, because travel imposes costs on others besides the traveler, it is even less clear whether society as a whole is becoming better off because of the growth in auto use of the last several decades. Two classic and illustrative examples of these "external" costs are traffic congestion and air pollution.[1]

Congestion is an example of an externality whose negative effects are, for the most part, contained within the transportation system; that is, they are experienced by other drivers rather than by society in general. Each driver who experiences congestion also contributes to it (every car behind you at the ramp meter would get through five seconds sooner if you weren't there). Thus driving in congestion is doubly problematic: not only does it increase your cost of travel and reduce your net benefit, but it also increases the cost for everyone out there with you.

The primary impact of air pollution, by contrast, is outside the transportation system, so that unlike congestion, the amount one suffers is not closely related to the amount one contributes to the problem. Because of this, there is little incentive to incur substantial costs to avoid polluting unless there is a legal obligation to do so.

An important similarity between congestion and pollution is that they are both problems that arise from specific behaviors rather than from driving in general. Congestion is caused only by the cars involved in it, not by all the cars in the system, and pollution is to a surprising extent (perhaps as much as 50% of pollution caused by only 10% of cars) created by a small minority of vehicles. Thus, for both of these problems, policies aimed at simply reducing driving in general may not be particularly effective against them, or as effective as policies more targeted at the specific vehicles causing the problems.

Yet another type of cost associated with travel is the effects it can have on broader urban issues. Transportation does not exist in a vacuum; it influences other aspects of urban life.[2] An example of this that has received considerable attention (and is a central focus of the entire Transportation and Regional Growth study) is the effect of auto-based transportation systems on how land is developed.

This issue is becoming an increasingly important element of the nationwide debate about the future of our urban areas. The problem cuts two ways. The first question is the extent to which the transportation system has influenced the way

[1] Part 3 of the Transportation and Regional Growth study is estimating the full costs of travel in the Twin Cities, with special attention to these external costs.
[2] For example, Muller (1995) describes the "eras" of urban growth in terms of the prevailing transportation system.

land is developed in metropolitan areas. There is a widespread belief that accommodating the automobile has led to inefficient land use. This problem is particularly urgent because land use decisions tend to be relatively permanent.[3]

The other side of the problem is the possibility that inefficient land use has had the effect of making trips longer and less direct than they could be; thus that land use impacts the efficiency of the transportation system. This raises the intriguing prospect that an effective way to solve transportation problems might be to forget transportation and focus on land use. Indeed, there is a substantial variation across U.S. cities in the amount of auto travel per person,[4] and it is hard to imagine why such differences would arise unless differences in the land use and transportation systems of the cities are playing a role.

The problem of how to reduce the negative impacts of auto travel is one of the major questions motivating the Transportation and Regional Growth research. The desire to understand the interaction between land use and transportation is driven by a widespread sense that the movement towards an auto-based system has not been an unmitigated good. While few believe that the world would be a better place if there were no cars, there is a growing concern that the benefits of increased auto use are no longer so large as to justify continuing to ignore its many substantial costs.

Because the costs associated with auto travel are well covered by other research, this paper takes the approach of describing and understanding travel behavior from a more general viewpoint. In particular, there is a focus on the benefits to be gained from travel, and the need to consider the possibility that policies aimed at reducing costs might reduce benefits as well. Travel is complex, and benefits and costs arise as much from specific characteristics as from the total quantity of driving. Making good policy will require understanding and exploiting this complexity so as to reduce the negative impacts associated with travel while preserving as much as possible of its benefits.

Planning and Forecasting

The idea of urban planning arises out of the reasonable proposition that there are better and worse ways of organizing how the land in a city is developed and how people move around, and out of the fact that decisions about land use, once implemented, are hard to reverse. This permanence arises because of the huge expense involved in developing land. Some development activities, such as building roads, are costly to the government directly. However, even when no government investment is required, such as with a zoning code, decisions can be hard to change because families and businesses make expensive private investments based on them. Thus it is beneficial to have a clear sense of what the outcome of a particular policy is likely to be, before the decision is taken.

[3] Anas, Arnott, and Small (1998, page 1430) describe how the physical layout of American cities even today can be traced back to the transportation technology when they were originally developed.
[4] Highway Statistics, 1996, Table HM-72

Until the 1950s and 1960s planning was the exclusive province of professional planners, and the guiding principle was "architecture-writ-large."[5] This was the idea that designing a city is like designing a building; that is, that an expert or group of experts decides what the city should look like and what functions it should serve, and imposes this vision unilaterally. During these two decades, this concept of planning gradually gave way to the notion of "rational planning;"[6] that plans should be aimed at fulfilling politically determined regional objectives, and that the planning process should be aimed at finding the plans that best meet this goal.

Models for forecasting traffic flows were a central element of the new rational planning strategy, since one of the primary problems at the time was accommodating rapidly increasing auto use.[7] When planning had been architectural, aimed at simply creating a certain physical outcome chosen by the planner, prediction was trivial in the sense that the desired outcome was entirely in the designer's hands. However, with planning aimed at solving a broader range of problems, the characteristics of the physical environment became somewhat less critical than the issue of how people responded to that environment. Once plans came to include the behavior of the city's residents as well as physical structures, success became a matter not just of executing the plan, but of people responding to it in the desired ways. Predicting whether a plan would be successful then required models of behavior with respect to a given urban structure.

The importance of forecasting and using forecasts for planning has been affirmed by various federal legal requirements. The beginnings of these policies date back decades, while the policy issues that they address have evolved over the years with changing social objectives. New requirements imposed in recent years have further emphasized the role of planning and forecasting by requiring metropolitan areas to take steps to achieve air quality standards, often by the use of little-used (and hence not well understood) policies to reduce demand for single-occupant-vehicle travel.

Urban transportation planning as an institutionalized process began developing in the United States in the 1950s.[8] Prior to this, urban transportation policy consisted of attempts to deal with specific, immediate problems, and was largely the province of engineers. The advent of digital computers made it possible for the first time to attempt a more detailed modeling of the underlying process, with hopes of anticipating and avoiding problems rather then simply reacting after the fact.

During this time, post-war prosperity was making auto travel more affordable and increasing the desire for more spacious living conditions; and construction of the interstate highway system was beginning. People wanted, and could afford, newer and bigger houses in less crowded neighborhoods. The new urban freeways, by providing high-speed connections between far-flung points, facilitated this process of suburban expansion. Because there were still relatively

[5] Batty (1994), page 10
[6] Ibid., page 8
[7] Ibid., page 7
[8] Much of this material on the history of the transportation planning process is taken from Pas (1995).

few cars, the negative side effects of increased auto usage had not begun to appear.

In this environment, transportation policy was seen as an effective way of facilitating other social ends, such as better housing and less congested central cities. Thus the objective of policy was to accommodate this movement, by building highway capacity sufficient to cope with the expected future levels of usage. The basic problem of forecasting then was to determine where new highways would be needed, and how wide they needed to be. The fact that travel forecasting models originated in this environment, and were built around solving these kinds of problems, is a significant factor in understanding their applicability to modern issues.[9]

The first legal recognition of the importance of a long-range transportation planning process for cities came with the Federal Aid Highway Act of 1962.[10] There were two significant features of this act. First, by requiring that each urban area use a "continuing, comprehensive, and cooperative" (3C) planning process, it began the formalization and standardization of urban transportation planning. Second, by placing the onus of planning on "urban areas" rather than cities, it encouraged coherent planning for each metropolitan area rather than a mishmash of possibly contradictory plans by many individual municipalities.

The years following this act saw two important developments emerge. On the one hand the planning process was simplified by experience and by the publication of many technical manuals intended to help clarify problematic areas. On the other hand, the automobile and highway-construction focus of the planning process was increasingly challenged by developing awareness of the needs of the less advantaged, and of environmental problems caused by auto use. These problems were addressed by regulations issued in 1975, which were significant in that they required planners to consider specific non-automobile options when formulating plans. In addition, during these years the political nature of the planning process was recognized, and the process opened to citizen participation.

A third innovation, less significant at the time, but assuming increasing importance in recent years, was the beginning of attempts at more general urban modeling, specifically the interaction between the transportation system, travel behavior, and land use. These efforts did not achieve much success at the time, but have been quietly developing ever since, and recently have been seen by some as providing additional insight into the planning process, as the role of land use in urban life becomes more widely recognized.

The maturing of the urban freeway system in the 1970s and 1980s was accompanied by two gradual realizations on the part of policy makers and the public. First, the rapid increase in suburban development led to the realization that transportation investments could have longer-term side effects that could be significant and not necessarily desirable. Second, a boom in driving, created at least in part by the freeways themselves, brought back the congestion that the freeways had been intended to alleviate. The apparent futility of highway

[9] This idea is developed at considerably more length at the beginning of the chapter "Travel Demand Forecasting" in this report.
[10] Weiner (1997) discusses this issue at some length.

expansion as a solution to congestion has provoked major efforts to find other answers.

The beginning of the 1990s saw two additional developments of import to transportation policy. The first was the Clean Air Act Amendments (CAAA) of 1990, which require areas to take specific steps to meet air quality standards. The second was the Intermodal Surface Transportation Efficiency Act of 1991, which increased the emphasis placed on non-auto transportation modes.

The requirements of the CAAA pose a considerable challenge to the transportation forecasting and planning process.[11] Levels of various types of pollutants must be forecast well into the future with a high degree of precision. If forecasts are too high, the area may spend considerable money on pollution reduction efforts that turn out to be unnecessary. If forecasts are too low, the area may not pursue pollution reduction vigorously enough, placing it at risk of not meeting standards at some point in the future, and having to impose costly restrictions which might have been avoided with less costly preventive measures.

The need for accurate long-term forecasts is further complicated by the fact that emissions are not a simple function of miles or hours of travel. Running emissions are roughly proportional to miles traveled, but vary significantly with speed, and with time spent stopped at intersections or in congestion. Start-up emissions, obviously, occur in the first few minutes after the car is started, and vary depending on whether the car was cold or warm when started. Hot soak emissions occur when the car is turned off at the end of the trip. Good pollution forecasts require not just miles traveled, but the way those miles are covered, how often the car is turned on and off, and how much it cools down between starts (among other things).

There are a number of other important travel forecasting issues in addition to the requirements of the CAAA. These are nicely summed up in Harvey and Deakin:

> Clean Air Act transportation analysis requirements are pressing, but they are not the only (or perhaps even the most critical) forces for change in regional travel modeling. Other developments include the following:
>
> - Provisions of ISTEA permit much greater state and local discretion in allocating funds between transit and highways and among levels of the highway system. This will intensify the concern over how well models capture the long-run effects of distinctly different infrastructure alternatives …
> - Congress has broadened the scope of citizen suits under the Clean Air Act … There is reason to anticipate that shortcomings in meeting the analysis requirements of the Clean Air Act may result in legal actions …
> - Computer work station technology has brought travel demand analysis within reach of groups outside the traditional transportation planning community …competing models will present problems for MPOs

[11] Much of the discussion on the Clean Air Act Amendments is taken from Harvey and Deakin (1993).

unless it can be shown that "official" MPO models are equally or more current, comprehensive, and accurate.

- Increasingly, concerns are raised about whether project-level analyses are consistent with the analyses conducted at the regional level. … This has led to pressure for greater detail in regional networks…

All of these developments suggest that it would be prudent for MPOs to review their analysis capabilities and make improvements where warranted…[12]

These comments raise the idea that in the long term, legal requirements might be a less compelling force than citizen participation. That is, MPOs are being held responsible not only for meeting the letter of the law, but also for meeting its spirit. Forecasts and other analyses cannot just be "good enough;" they must be as good as is feasible, in order to be defensible against citizens who are not only deeply interested and perhaps hostile, but also possibly armed with their own models.[13]

Thus a basic purpose of this report is to examine in some detail how travel forecasting models work and evaluate their technical adequacy. A second level to this process is an examination of the less widely used class of "integrated" transportation and land use models, which attempt to improve on the traditional travel forecasting process by incorporating explicitly the interaction between transportation investment, land use, and travel behavior. Ultimately, however, the report looks beyond these technical questions to address more directly the question of how forecasting models can be best utilized in the policy making process.

What We Have and What We Need

The fundamental fact confronting policy makers is that the Twin Cities region is growing. The forecast is that we will add nearly 700,000 people between 1995 and 2020, an increase of almost 30%.[14] The problem facing planners and policy makers is how to accommodate all these people without destroying the features that make the area attractive in the first place, including the ability to travel easily to destinations around the region. That is, growth in general, and the additional traffic it generates in particular, can have many undesirable impacts on the quality of life in the region. However, the ability to travel to a variety of destinations is part of that quality of life, so it is important to not just take the simple approach that auto use must be reduced at all costs.

The Clean Air Act Amendments provide a general framework for planning and policy. They provide a set of "default" regional objectives through their requirements that certain air quality standards be met. They also offer some suggestions for basic policy tools to meet these objectives, including improved public transit, HOV lanes, walking and bike programs, and trip reduction

[12] Harvey and Deakin (1993), pages 2-5
[13] The 1998 transportation bill, TEA-21, continues basically the same types of requirements and incentives as ISTEA.
[14] Office of the Legislative Auditor (1998), page 55

ordinances.[15] While these laws are helpful in providing a legal basis for planning and policy, they also raise the possibility that a single-minded focus on air pollution could draw the attention of policy makers away from other important transportation issues.

Consider a simple thought experiment: what if there was no auto-based air pollution? Would we then no longer care about forecasting and transportation policy and planning? No, we would still care because there are other issues of real significance. Congestion jumps to mind, as does the effect of transportation on land use, neighborhoods, and even the economy more generally. Thus if these other issues would continue to be important in the absence of air pollution, it seems likely then that they are also of real significance now, and that the focus on air pollution in federal government policy is in some sense serving as a proxy. If so, it would be better to take a more general approach, for two reasons.

First, much of the interest in “alternative” (non-highway-construction) policies is predicated on the need to reduce air pollution. This raises the risk that interest in these policies, which may have much broader merit, will be undercut as technological innovation reduces the air pollution problem.[16] Second, if other issues are indeed important, they ought to be explicitly recognized as such. What we need to know to deal with these other issues is not necessarily the same as what we need to forecast pollution levels, and unquestioningly enacting a set of pre-defined policies to reduce pollution could very well make other problems worse. It is important to be clear that pollution, while important, is only one of many related issues, and that policy should consider the entire package.

Our current forecasting tools, and even to some extent our way of thinking about problems, arose out of a certain class of issues and policy alternatives in the 1950s and 1960s; namely the need to build roads to reduce urban congestion and accommodate increasing auto use. However, in the future those policies will not be available to the same extent (little major new road building is planned), and our notion of what problems are the province of transportation policy is considerably more extensive than it used to be.

Furthermore, being able to predict the existence and severity of problems is not the same thing as understanding how to solve them. Prediction can be (and is, for the most part) done by building a detailed model of the current system and calculating how a marginal change to that system will affect the outcome. Solving problems, on the other hand, can often require knowing not just how the system works, but why it works the way it does, so that the sources of problems can be attacked.

This was not so much of an issue in the past because the range of policies being considered was fairly limited, and only direct effects of policies were really considered. By contrast, now a variety of policies are being proposed, many of which represent more than marginal changes to the system. Also, the range of impacts that are considered relevant for evaluating a policy is much expanded. Longer-term, indirect impacts and even effects on non-transportation phenomena are now considered important. These considerations imply the need for

[15] Harvey and Deakin (1993, page 2-13) give a complete list.

[16] Several major car makers are investing in the development of fuel cell technology, and it is estimated that it may be commercially viable as soon as 2003 (*The Economist*, October 31, 1998, page 69).

forecasting models that are derived from a deep understanding of the system, rather than simply calculating the results of marginal changes to current conditions.

Many researchers have written about the importance of forecasting and its role in the urban transportation planning process. Sorting through the different statements that have been made leads the author to conclude that there are fundamentally three different levels of problems that need to be solved in order for good policy to be likely:

1. There is a need for forecasts that are technically sound. This means, first of all, that they are accurate. At a deeper level it means that they are based on a well-developed behavioral theory that is supported by a substantial body of empirical evidence.
2. Forecasts need to be useful. Besides accuracy, this implies two characteristics. First, they should provide the information that decision-makers need. Second, they should not only be objective, but should be generally recognized as such.
3. The forecasts need to be used appropriately within the policy process. This goes beyond forecasting to the need for a common framework for describing the costs and benefits associated with different kinds of policies. Obviously lawmakers have the last word; the cost-benefit analysis should describe the alternatives, not choose between them. But the lawmakers' task would be simplified if it were easy to compare the merits of different alternatives.

The objective of this report is to evaluate our current situation with regard to travel demand policy, and in particular with respect to the three issues just listed. This evaluation is accomplished by examining the problem from three broad points of view. First is a description of the history and projected future of Twin Cities travel patterns. This provides a factual basis for the discussion and illustrates the complexity of urban travel, the surprising volume of information that is potentially relevant to policy making, and the difficulty of understanding how all this information fits together.

The second perspective is an examination of existing forecasting technology. The idea here is that by understanding how forecasting is done and the results it produces, it will be possible to evaluate the extent to which forecasts meet, or can meet, the needs outlined above. This has two parts. First is a detailed discussion of standard travel demand forecasting technology. The second part is a study of the potential benefits offered by integrated transportation and land use models, and a determination of what, if any, additional value they could provide to the policy-making process.

The final point of view is a general discussion of the types of problems that we face in the Twin Cities, and of some policies that have been proposed for solving them. The purpose of this is not to offer solutions or to promote particular policies, but simply to use these problems and policies as concrete examples to illustrate the range and complexity of the facts and arguments that need to be considered in the decision making process.

Many questions whose answers are essential for good decision making are still the subject of speculation. This points to the need for research, and in particular for research into the specific objectives and constraints that influence people's decisions on how to use the transportation system. Without this knowledge it will be impossible to ever have any confidence in predictions of how people might respond to major system changes; nor will it be possible to answer the more significant question of whether changes are making people better or worse off.

2 Characteristics of Twin Cities Travel

The purpose of this chapter is essentially to provide the necessary background and context for the subsequent discussions of forecasting models and policy evaluation. The background consists of two broad parts. First is a discussion of the historical and present conditions of travel in the Twin Cities region. In addition to providing basic facts that are needed to understand how the system works, this discussion also introduces a number of the themes around which the rest of the report is built.

The second part of the background is a description and evaluation of the forecasts for the year 2020. The objective here is to illustrate how the system will change in the next couple of decades, and to describe the major forces driving these changes. The evaluation of the forecasts is not a detailed technical examination, but simply a discussion of whether the results seem plausible given our understanding of the major forces involved. A more significant element of the evaluation is an attempt to go beyond the simple question of accuracy, and to examine how these forecasts can fit into the broader policy making problem discussed at the end of the introduction.

Aggregate Trends

This section gives a few basic facts about the historical context of Twin Cities travel patterns at an aggregate level. The primary purpose is not so much to provide facts as to use these facts to introduce and illustrate a number of basic ideas and questions about travel demand.

Table 2.1: Aggregate Statistics (all numbers in millions)[17]

	1958	1970	1990	Change 58 - 70	Change 70 - 90
Population	1.4	1.9	2.3	36%	22%
Households		.57	.88		53%
Jobs	.59	.85	1.3	44%	52%
Autos	.54	.85	1.5	57%	79%
Person-Trips	3.4	5.1	8.9	51%	73%
Person-Miles	7.5	23.8	55.3	217%	132%

The most striking thing about this table is the huge percentage increase in person-miles traveled relative to the changes in other variables. This is indeed an interesting and important fact, and as such there is some value in postponing the discussion of it until the other numbers have been explored.

Leaving miles aside for the moment, the other remarkable fact in these numbers is the large increase in trips relative to the increase in population, especially in the 1970 to 1990 period. There are four keys to understanding this phenomenon: the increases in households, jobs, and automobiles, and demographic changes.

The increase in households from 1970 to 1990 far exceeded the increase in population. Part of this sizable decrease in average household size was due to increasing divorce rates, later marriages, and the resulting increase in single-person households. However, a significant fraction of the household size decrease also arose from the more prosaic source of declining birth rates. While the baby boom ended in the early 1960s, the majority of the children it produced were still at home in 1970. In the next decade, they all left home, formed their own households, and did not produce as many children as their parents had.

The increase in households is significant because trip rates have historically been more strongly correlated with the number of households than with the number of people. For example, two adults in separate households must each make all their own trips; while if they are in the same household, one can shop for both, or they can share trips to shopping and especially entertainment. Another factor is that children don't generate quite as many trips as adults, so that an increase in the number of children will not increase trip rates proportionally. For this reason especially, the number of households is usually thought to be a better predictor of trip rates than the number of people.

The second important factor in understanding the increase in trips is the increase in the number of jobs. This has a two-pronged effect. One is the obvious point that if you have a job, you have to go to it, thus generating two trips per day, approximately.[18] The second impact is that people with jobs have disposable

[17] Numbers taken from various pages of the 1970 and 1990 Travel Behavior Inventory (TBI) summary documents.
[18] Although there are significant exceptions: part-time or occasional workers, people who travel as part of their job, people who work at home, etc.

income and mobility, thus providing both the means and the reason for making additional trips for shopping, entertainment, or other activities. This increase in jobs resulted both from the increase in the adult population, and also the large growth in workforce participation among women that started in the 1960s.

Auto ownership affects trip rates through the obvious means of making travel easier. This variable, in fact, is the most closely related to the number of trips of any factor in this table. If a car is available, it will tend to be used.[19] However, the argument could also be made that auto ownership is not really a *cause* of trips, but is simply, like trips, a result of other factors. That is, cars are expensive, and people buy them because they have some reason for thinking that they need to. In other words, the desire to make trips precedes the purchase of the car. Nonetheless, it is not improbable that the availability of a car could induce people to make types of trips that were not anticipated when the car was purchased.

The final major factor influencing trip rates is demographic changes. The simple point here is that older people who grew up in a time before cars and travel were so central to life, have tended to make relatively few trips, even after cars became easily available. Between 1958 and 1990, many of these people were replaced in the population by people who grew up with cars, and who tend to make more trips. This is an interesting phenomenon in its own right, and is the subject of a subsequent section.[20]

Having established this background behind the increase in the number of trips over the period in question brings us back to the anomalous fact that total trip mileage increased by an amount that was far out of proportion to anything else. The obvious explanation for this dramatic increase is that the new freeway system opened the possibility of high-speed, long distance travel.

Prior to the opening of the freeways, a trip of ten miles would take twice as long, more or less, as a trip of five miles. Because all streets were "local," speeds were nowhere very high, and stop signs and traffic signals were ubiquitous, as they still are on local streets. Freeways changed all this. The fact of being able to drive two or three times as fast, and to go indefinitely without ever having to stop at an intersection, made it entirely feasible that long trips could actually be quicker and easier than short trips. Indeed, a comparison of trip lengths and times supports this view:

Table 2.2: Auto Trip Lengths and Times[21]

	1958	1970	1990	Change 58 - 70	Change 70 - 90
Miles/Trip	2.2	4.9	6.6	122%	33%
Minutes/Trip	20.0	16.9	15.5	-15%	-8%
Miles/Hour	6.6	17.4	25.5	164%	47%

[19] It is interesting that the number of person-trips per car is actually declining slightly, implying that while there are more cars, they are less intensively used. However, because occupancy rates are also falling, it is hard to tell what is happening to the number of *vehicle*-trips per car, which is a better measure of the likely trends in congestion.

[20] See "Demographics" in the following section "Dimensions of Travel Behavior."

[21] 1970 TBI, pages ix, 30, 34; and 1990 TBI, page 22. These are person-trips. The figure of 20 minutes per trip in 1958 is an estimate based on information about the distribution of trip times.

Somewhat surprisingly, despite the fact that trips got much longer, the time needed to complete the average trip actually declined during this time. The high travel speeds made possible by freeways not only made distant destinations relatively easier to access, but must in many cases have made them actually easier than the closer destinations to which people had previously traveled. This diversion of many trips onto the freeways (in 1970 25% of trips used the freeway system, which constituted only 2% of the highway mileage of the region)[22] also had an important secondary effect. This was to reduce to some extent the amount of traffic on other arterials and local streets, thus making it possible for traffic on those streets to move faster as well. An interesting way of thinking about the qualitative nature of this change is that in 1958 the average time needed to cover a mile in a motor vehicle was over nine minutes, which is about an average pace for marathon runners.

One point of view might argue that this increase in speeds and resulting increase in available destinations represented an enormous benefit to the urban population that is not sufficiently recognized today by those who complain that freeways don't really improve anything. That is, there is a possibility that this benefit happened so quickly and has been part of life for so long that many people have forgotten (or never knew) that travel was not always this easy, while the costs of this increased travel have been slower to develop and hence have higher current visibility.

Another perspective, however, is that freeways, rather than creating a general improvement, led to a huge improvement for long, freeway-based trips and to a much smaller improvement for shorter local trips (because trips diverted onto freeways reduced traffic on local streets). Furthermore, changing travel patterns might have helped to hasten the demise of local businesses. In other words, the higher speeds overall might not have given improved access to *more* destinations, but merely to different (and more distant) ones.

This is an important question: Do longer, faster trips reflect better access to destinations or do they just keep pace with the increasing distances between destinations? Higher speeds may to some extent require longer distances between things (driving fast needs more space than does driving slowly), and the possibility of high-speed travel seems to have led to some consolidation of destinations. The average distance from a house to the closest grocery store, for example, is undoubtedly more than it was 40 years ago. This could be a natural result of competition, since stores now have far better selections and lower prices than they did then. However, some consolidation could also reflect a situation in which local stores lose too much of their business to freeway-accessible places.

There are really two different questions here. One is the simple descriptive problem of the extent to which freeways have induced economic changes, versus simply facilitating changes that would have happened anyway. The other is whether these changes have ultimately made people better off. Higher speeds should be better, all other things equal, but it is not entirely clear whether freeways have really left other things equal.

[22] 1970 TBI, page ix. By 1995 freeways constituted about 3% of the lane-miles, and carried about 44% of the vehicle-miles of travel (*Highway Statistics*, 1996, Table HM-72).

While it hard to say how the increase in distance and speeds has affected overall well being, there is another interesting idea that emerges from this situation. This is the point that more miles being traveled doesn't mean that more time is spent traveling. Such "logical" conclusions don't always hold true in transportation, for two main reasons. The first reason (and the case here) is that something else might also have changed. Many different sources contribute to what seem like simple facts, so that, for example, when drawing conclusions about time from data about distance, one must bear in mind that speeds might have changed.

At the same time, one also cannot conclude from the fact that speeds have increased that travel time must have decreased. Interestingly, overall daily travel time shows a tendency to remain constant as speeds change.[23] In other words, people historically do not seem to have desired to spend less time in their cars (not to say that there aren't people who feel that way, only that people in general don't seem to). The possibility of traveling more quickly seems to have induced people to increase their range of destinations rather than spending more time at home. This makes sense given that a major reason for living in a city is the variety of destinations.

This brings up the other reason why logic based on a small set of facts doesn't always give the right answer when applied to transportation phenomena. This is the possibility that secondary effects generated by a change could ultimately cancel out the primary effects. For example, nationwide, work trip times are pretty stable around 22 minutes.[24] This has been true for many years and in a wide range of cities.

The reason is the same as why faster speeds do not lead to less total travel time. People have many choices at their disposal. If congestion makes the drive to work take longer, there are several possible responses. These include moving closer to work, finding a job closer to home, or saving time by shopping closer to home or by making stops for shopping as part of the work trip. The problem with congestion is not so much that it takes up all our free time as that it restricts the range of choices that we can make, losing part of the point of living in a big city in the first place.

Dimensions of Travel Behavior

The full complexity and difficulty of the transportation policy problem can only be fully appreciated by looking at some of the details of travel behavior. These details are significant to policy for three reasons.

The first reason is the accuracy of forecasting. Predicting the quantity of traffic and transit usage on every road in the area requires forecasts of the numbers of trips travelling between every possible origin and destination, the time those trips will be taken, and the mode that will be used, among other things. This in turn requires that the characteristics of individual trips be described at a considerable level of detail.

[23] Zahavi and Talvitie (1979), page 14
[24] Pisarski (1996), page 43

The second reason that the details of travel are significant is that they are key to understanding the likely effect and magnitude of policy initiatives. Knowing the impact that a policy will have on a given problem requires a sense of what kinds of trip characteristics will be affected, and how much.

It also requires knowing how much impact the particular characteristics that will be influenced will have on the problem under consideration, which is the third reason details are important. Problems arise not from travel in general, but from specific details of travel, and policy can be far more effective by focusing on the relevant details of a problem rather than by seeking to influence travel in general.

Trip Purpose

This is perhaps the most important single characteristic of a trip, in that it tends to influence many other relevant details. Trips undertaken for different reasons tend to have different characteristics. Work trips, for example, are longer than other trips, more likely to use transit (in some cases), more likely to go to the downtowns, and more likely to be taken during peak periods.

Other types of trips, such as shopping and recreation, differ from work trips in most characteristics. They tend to go to different destinations, are substantially less likely to use transit, and are more likely to be taken during off-peak hours, although a surprising number aren't. Not only do non-work trips manifest themselves in different ways in terms of their effect on the system, but their different characteristics also reflect different traveler objectives. In other words, policies such as improved express transit that makes work trips better might not have the same positive impact on other trip types.

A major complication in exploiting trip purposes as a way of improving the transportation system is chaining. That is, people don't always drive from home to a destination and then back again; instead, they make "tours," chaining different purposes into a sequence of shorter trips. This is especially prevalent as part of the trips to and from work.

Table 2.3: Daily Trips by Purpose (Counts in thousands)[25]

Trip Purpose:	1970	1990	% Change
To Work	829	1,111	34%
To Shopping	566	1,090	93%
To Home	2,009	2,942	46%
All Others	1,691	3,717	120%
Total	5,095	8,860	74%

Table 2.3 gives a rough idea of the significance of trip chaining. Every time a person leaves home to visit a destination, the resulting sequence of trips must end with a trip "to home." In 1970, trips to home were about 40% of all trips, and by 1990 only about 33%. Thus in 1990 people were visiting more destinations per

[25] 1970 TBI, page 26; 1990 TBI, page 17

tour than in 1970, and on average were visiting two destinations every time they left their home.

Chaining has a number of important effects on problems and on the policies that could be used to solve them. Chaining, for example, may reduce total driving but increase the amount during peak period. Total driving could be reduced because it is often shorter and quicker to complete several stops while you're out anyway, rather than going home and back out again each time. This could have some effect on reducing emissions, both because of the decrease in mileage and because of the possible reduction in cold starts.

At the same time, chaining different destinations into the work trip could have the effect of worsening peak period congestion. This could happen because the work trip would take longer and cover more miles, and also possibly because of the greater number of cars turning in and out of the main body of traffic on a road. Another issue is that transit is less likely to be a viable mode for someone who needs to make other stops on the way home. In this case, the effect could be that the entire work trip is made by auto, simply because some part of it has to be.

This raises an interesting policy conundrum. A policy such as a higher gas tax, aimed at reducing total driving, could actually worsen congestion by giving people an incentive to make more trips during rush hour, when they are out anyway. On the other hand, a policy aimed at reducing congestion, such as a road pricing scheme, could increase total driving (and thus possibly total pollution) by encouraging people to go straight home from work and then out again later. This paradox nicely illustrates the problem with simple solutions to transportation problems; namely, that the problems themselves are not simple.

Time of Day

No one will be surprised to hear that traffic is much heavier at some times of day than at others; indeed, if this were not so, it is not likely that transportation would be of much interest to the average person. There is, however, some insight to be gained from considering the details and consequences of this daily ebb and flow.

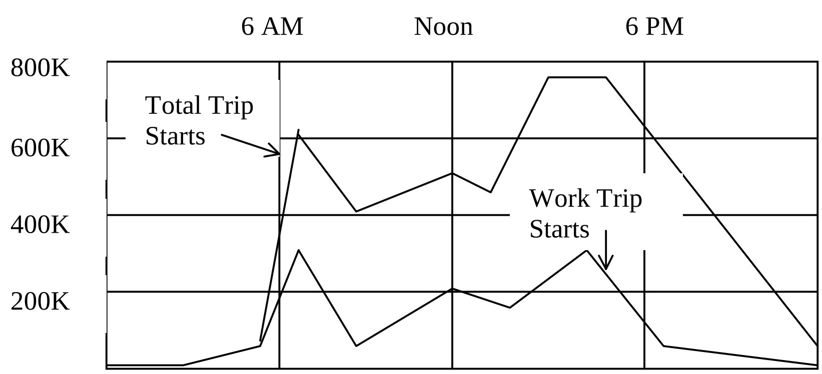

Figure 2.1: Trip Starts by Time of Day, 1990[26]

[26] 1990 TBI, page 38

Two points jump out from this diagram. First is the size and duration of the evening peak, which is higher than the highest point of the morning peak for a period of almost four hours, and reaches a level nearly 30% higher. The second interesting observation is that work-related travel constitutes a surprisingly small portion of the total trip starts during the evening peak period, and even to a lesser extent during the morning peak. (The "work trip starts" is counting both going to and coming home from work. The distance between the two lines is the quantity of non-work-related trip starts.) Some of this is probably trip chaining, but certainly not all of it. The level of "other" trips rises to a high level early in the day and remains at that level or higher until late in the evening. This fact is important for determining the potential effectiveness of schemes aimed at influencing peak-period travel. Because non-work trips have different characteristics, policy must recognize that the majority of peak-period travel is not work-related.

The size of the peak, besides its obvious contribution to congestion and accidents, also has a less recognized but equally important impact. This is that it is a major determinant of highway capacity needs. Roads ideally are built to accommodate something close to the peak volume of traffic that they might face, not the average. Freeways in particular could probably be smaller if traffic was more spread out over the day, but the size of other major arterials could be reduced as well. This would save money as well as land.

Unfortunately, it is hard to exploit this fact for policy purposes. People travel during peak periods because that is when it is convenient (congestion notwithstanding) or necessary, so to induce them to travel at other times would not only be difficult, but would probably not make them better off.[27] The savings in road construction and maintenance, and the reduction in land taken by roads, would be unlikely to be adequate compensation for the inconvenience of not being able to travel at the most desired times. This illustrates the point that policy must be judged not only on its effects and effectiveness, but also on whether it is actually improving people's lives.

In some cities this effect of trip time-shifting does seem to have occurred, although by people adjusting their trip times to avoid congestion rather than by legal requirement. In large congested cities the difference between the peak and off-peak periods is shrinking. Roads can fill to near capacity early in the morning and stay that way until late in the evening.

This process is beginning in the Twin Cities, as off-peak traffic is proportionally heavier than it used to be.[28] This is not because peak-period is lighter traffic, but because off-peak is heavier. Once the highway is full, it can't get fuller – it can just stay full longer.

[27] Although some of the peak period spike in travel is not because people *want* to travel then, but because they must, because they have fixed work hours. More flexible work hours could reduce the size of the peak while also making people better off, since they would be changing by choice rather than by coercion.
[28] 1990 TBI, page 36

Mode of Travel

The method used to make a trip is another factor that impacts a variety of different problems. Autos, for example, create air pollution while bicycles don't. Cars, on the other hand, have other advantages, most notably the vastly increased range and convenience of travel that they provide.

More than 90% of trips in the Twin Cities are made by automobile.[29] This is roughly the national average for large metropolitan areas. Transit is used for about 2.5% of all trips, but accounts for 5.2% of work trips,[30] and 25% of trips into the central business districts.[31] This is significant since work trips, and especially CBD trips, are the most likely to contribute to congestion. Walking and biking (mostly walking) are used for about 4% of work trips.[32] Typically these are short trips, 1/2 mile or less for walking, 2 miles or less for bike). People do still walk, but they tend to walk within large destinations that they reach initially by car (such as a mall), and this walking doesn't count as a trip.

Transit use in the Twin Cities has followed the same trend as elsewhere in the country:[33]

Table 2.4: Daily Transit Trips and Share[34]

	1949		1958	1970	1990
Transit trips	430K	(270K?)	252K	162K	225K
Auto trips	1.2M		3.0M	4.6M	8.3M
Transit share	26%	(16%?)	7.5%	3.2%	2.5%

As with other transportation facts, the impression one gets depends on the specific numbers being considered. The transit share of total travel has indeed declined precipitously, although even in 1949, just after the peak of transit use during World War II, at least three of every four trips were still made by car. On the other hand, the raw number of transit trips has not declined so dramatically (although holding even is really a loss given that the population has tripled). The decline in share has not come from a decline in transit, but rather from an increase in auto use.[35]

Carpooling is a trip by auto, but it is in some sense a "good" type of auto trip, in that it doesn't use additional highway capacity. Furthermore, despite the famously low rate of carpooling for work trips, the number of work trips made as

[29] 1990 TBI, page 9
[30] 1990 TBI, page 15
[31] 1990 TBI, page 47
[32] Commuting in America II, page 68
[33] School bus trips were not counted separately until 1970. The 1970 TBI, p. 138, breaks out the numbers separately for 1958, and the numbers in parentheses in the 1949 column here are estimates based on that breakdown. In 1958, 164,000 of a total of 416,000 bus trips were by school bus, leaving 252,000 by transit.
[34] 1970 TBI, page 20; 1990 TBI, page 9. Transit share is of all motorized trips, including school bus but not walking or bicycling.
[35] Interestingly, transit mode share into the central cities, at 25%, compares much better to 1949 (39%), and 1958 (26%), and is actually higher than 1970 (17%). 1990 TBI, page 47

auto passengers is still larger than the number made by public transit (7.0% versus 5.2%).[36]

Table 2.5: Auto Occupancy[37]

	1949	1958	1970	1990
Work	1.12	1.12	1.19	1.08
Shopping	1.67	1.79	1.48	1.31
All Trips	1.55	1.57	1.50	1.29

It is interesting to note that even in 1948, auto occupancy for work trips was only 1.12, barely higher than today, even though traffic was congested, cars were less common, and employment was much more concentrated in the downtowns. Occupancy rates have been higher in the past for other types of trips, but there are two reasons not to attach too much weight to this fact. First, non-work trips are less likely to take place during peak hours, thus higher occupancy for these trips would have less value in reducing congestion. Second, a simple count of people per car does not indicate if it is really ridesharing in the sense of people from different households traveling together. It could just be that when families go out now, there are three people in the car where there would have been six in 1958, thus pulling down the average.

Origins and Destinations

Where travel takes place is another important consideration in terms of making good policy. The widespread belief is that recent decades have seen the central cities empty out as people and business moved to the suburbs.

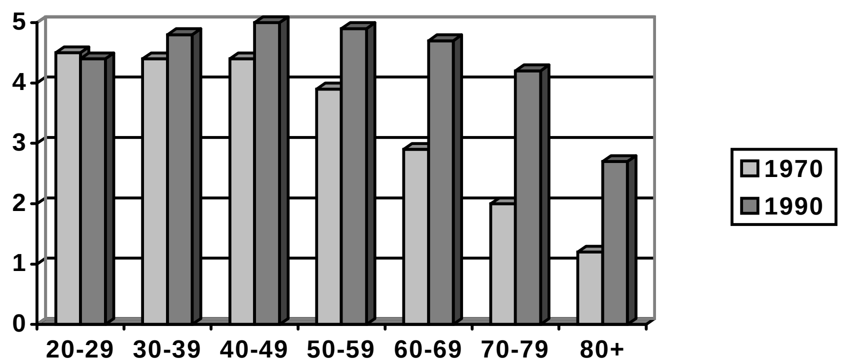

Figure 2.2: Location of Travel, % of Total

The obvious implications of this figure[38] are, however, not quite so obvious when one factors in the enormous increase in total trips over this time period. When

[36] 1990 TBI, page 17
[37] 1990 TBI, page 31
[38] 1970 TBI, pages 5-6, 1990 TBI, page 14

this information is represented as actual trips, rather than as fraction of the total, a very different picture emerges.

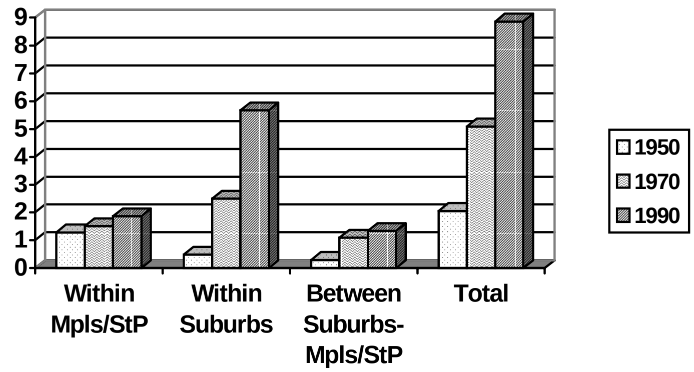

Figure 2.3: Location of Travel, Total Daily Trips (Millions)

In fact, travel in and to the central cities has continued to grow throughout this period. Their decrease in relative importance has been because of the considerably faster growth of travel in the suburbs. This is not hard to understand. The cities were essentially full to start with, and thus could not grow much more, or rapidly, unlike the suburbs, which were basically empty (and even now have considerable empty space). In general, any place, city or suburb, will grow more slowly as it approaches its available capacity. The growth of travel in “suburbs” in the above figure continues at a high rate because “the suburbs,” unlike the central cities, have no fixed boundaries, and thus don’t get full. In other words, while travel growth in inner ring suburbs might slow down as they approach capacity, high growth in emptier outer ring suburbs keeps the overall growth rate high.

The point here is that growth in travel tends to occur in places that are not already full, and thus a large increase in travel will not necessarily cause correspondingly large problems. On the other hand, even a small increase in a place that is already full to capacity could be a serious issue. In other words, the *amount* of growth or decline in travel is not in itself a good indicator of whether a problem is getting better or worse. The amount of change must be considered in conjunction with the amount of *capacity* for change that was available in a given spot.

The location of travel could be extended further to talk about specific roads or specific destinations. That is, traffic problems are often localized, sometimes to a specific area or neighborhood, sometimes to a road or set of roads. Policies that aim at solving these problems by reducing the amount of driving in general thus will most likely be ineffective. In addition, they will probably be unfair, in that they will punish drivers who are not contributing to the problem, while not imposing enough punishment on those that are.

Demographics

A final consideration in describing transportation patterns is who the traveler is, and how travel behavior depends on gender and generation. It is interesting that the large increase in auto trip rates between 1970 and 1990 was not a general phenomenon. Almost all of the overall increase was due to the larger number of car trips being taken by women, and by older men.[39]

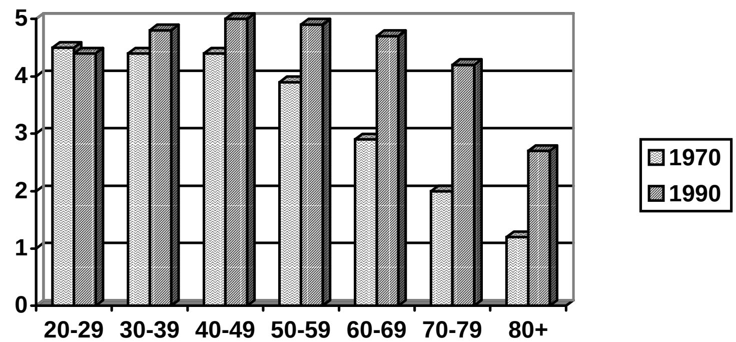

Figure 2.4: Trips per Day by Age, Males

However, this perspective doesn't tell the whole story. The 70-year-olds of 1990 are not the same people as the 70-year-olds of 1970. Looking at the behavior of male age-cohorts across time yields a different and even more striking result.

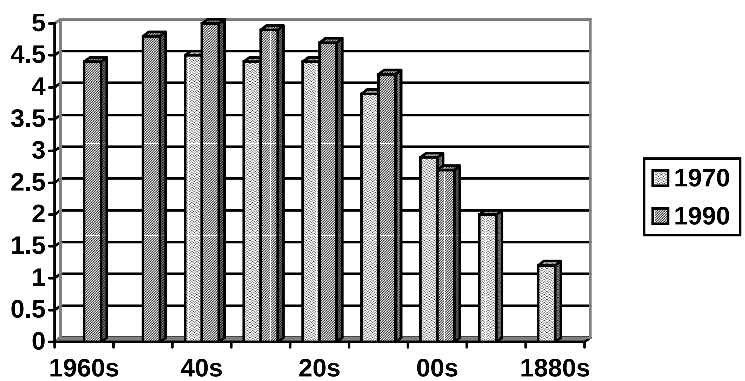

Figure 2.5: Trips per Day by Birth Decade, Males

Between 1970 and 1990, men of every age cohort tended to maintain roughly the same car trip rates as they grew older. In other words, the apparent increase in trip rates among older men was not in fact due to anyone making more trips, but

[39] 1990 TBI, page 18

was because middle-aged men in 1970 maintained their trip rates as they aged, while the low-trip-rate older men were replaced by high-trip young men.

The pattern for women is similar, with the sole exception that women in their twenties in 1970 increased their trip rates substantially. As this is the age cohort that would be expected to take the most advantage of the increasing work opportunities available to women after 1970, this is not surprising. What *is* a little surprising is that older women, like men, did not really change their trip rates. The large increase in trip making among women arose out of the same source as did that of men: that low-trip-rate older women were replaced by high-trip young women.

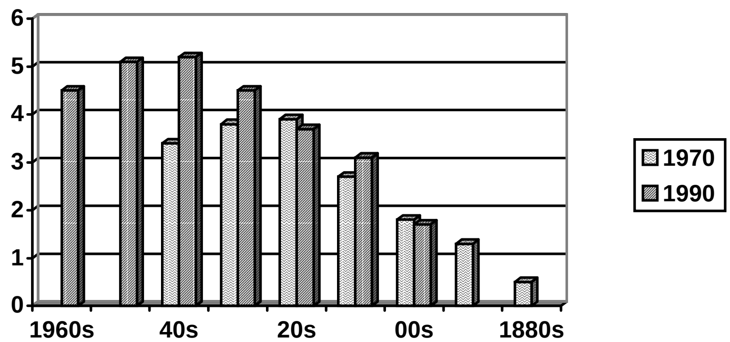

Figure 2.6: Trips per Day by Birth Decade, Females

These facts have somewhat grim implications for policies aimed at reducing the number of auto trips that people make. While people on average did make fewer trips in the past, this was not because everyone traveled less, but because a few specific individuals did. Since many of these individuals are no longer alive, this particular method of turning back the clock is no longer available to us. Furthermore, the one group (young women of 1970) who did change their behavior radically during this time did so in response to a lifting of social restrictions that no one wants to reinstate. Given these facts, achieving lower auto trip rates would require inducing people to behave in ways that they have never behaved before. This will be a challenging task.

The 2020 Forecasts

Having now established some background facts about the history of travel patterns in the Twin Cities, it is time to look at the forecasts of the future. In addition to providing a sense of the types of changes that can be expected in the next twenty years or so, this description of a set of actual forecasts provides a concrete example from which the subsequent evaluation and discussion of forecasting models more generally can be based.

The starting point in describing the forecasts is the demographic and economic inputs to the process, which are derived independently of the traffic forecasts.

Table 2.6: Forecasting Model Inputs[40]

	1995	2020	Change
Population	2.43M	3.12M	29%
Households	937K	1,275K	36%
Workers	1.40M	1.80M	29%

These forecasts display the expectation that the Twin Cities population in the year 2020 will be larger but otherwise similar to now. The number of households is predicted to increase only slightly faster than population, indicating that the average household size will remain roughly the same. Workers are predicted to grow at the same rate as population, which may be optimistic given the historically high levels of employment the region is currently enjoying, and the higher fraction of retirees expected in the future.

The next step is to show how these demographic inputs translate into predictions of traffic patterns.

Table 2.7: Aggregate Travel Forecasts

	1995	2020	Change
Total vehicle trips	6.74M	8.68M	29%
Average miles per trip	7.7	8.7	14%
Daily vehicle miles traveled	51.7 M	75.5 M	46%
Daily transit trips	223K	266K	20%

This table shows clearly the two sources of the sizable increase in daily vehicle miles traveled. A 29% increase in trips, multiplied by a 14% increase in average trip length, yields a 46% increase in total miles traveled (given some rounding). As the two key predictions of the entire forecasting process, these numbers deserve some discussion.

The fact that the total number of trips is expected to grow at the same rate as population implies that the number of trips per person will remain constant. It is not clear if this makes sense. On the one hand, older people traditionally make fewer trips; thus as the population ages, they should tend to pull the average down somewhat. However, as discussed earlier in this chapter, individuals seem to maintain roughly the same trip rates throughout their lives, with changes to the average occurring because men born before about 1920, and women born before about 1940, make fewer trips than people born after those dates, regardless of age. Thus as these older people are replaced by people born more recently, who tend to travel more, the average rises.

This process is largely played out among men, as even men in their sixties had relatively high trip rates in 1990. However, among women the process was not close to complete. Young women entering the ranks of drivers now have trip

[40] All forecasting tables taken from Office of the Legislative Auditor (1998), page 55.

rates of 4.5 or more per day, while the older age cohorts they are replacing all have trip rates below 4 per day, in some cases considerably lower. If the hypothesis that trip rates depend more on year of birth than on age is true, then there could still be a substantial increase in the average trip rate among women, as there are still a substantial number of women born before 1940 pulling the average down.

By contrast, a case could be made that the estimate of average trip lengths could be too high. The built-up area of the region will certainly continue to increase in size, and development density will likely continue to decline. Both of these factors will tend to lead to longer trip lengths. Offsetting this process is the fact of increasing traffic congestion. As discussed in the last section, the huge increase in trip lengths in the past seems to have been driven at least in part by the possibility of higher speeds. As roads fill up and traffic slows down, one possible result is that people might start to work and shop closer to home.

The growth in transit trips is positive, but not as large as the projected increase in population or in auto trips. This implies a slight decrease in transit share of total trips. This seems plausible. First, these projections are based on the assumption that the transit system will have the same routes and frequencies of service in 2020 that it has now. While this is improbable, no alternative definition is any more justifiable.[41] Thus using the current system to make projections could be thought of as placing a lower bound on transit share, assuming that the system will in fact be more extensive and convenient in the future than it is now.

Given this, there are two offsetting factors behind the change in transit share. First, increasing congestion in many parts of the region will create additional incentives to use transit, which will tend to increase the share in those areas. However, this will be offset by the fact that the bulk of the new people and jobs will probably be housed in outlying areas, and will thus have limited access to transit, pulling the average back down.

The final step in the projections is discussing what this increase in miles traveled means to the average person.

Table 2.8: Twin Cities Current Conditions and 2020 Projections

	1995	2020	Change
VMT per person per day	21.3	24.2	14%
AM-peak-period speed	39.8 mph	38.2 mph	-4%
AM-peak-period travel time	16.5 min.	19.2 min.	16%

These numbers give a general sense of how the average person might perceive traffic conditions in the year 2020. Because the total increase in vehicle miles traveled was caused largely by population increase, the difference to the average person is relatively small. Perhaps more surprising is that the large increase in total miles traveled leads to a surprisingly small decrease in peak-period speeds. This is partially because much of the population increase will be at the edges of

[41] While now it seems likely that the 2020 transit system will include some rail, this was not the case when these estimates were generated.

the metro area, along roads that currently have excess capacity, and partially because ramp metering gives some control over expressway speeds.[42] The increase in travel time is larger than the decrease in speed because, as discussed above, the average trip is predicted to be slightly longer.

It may appear from these numbers that conditions will not worsen significantly, and thus that there is little reason to worry much about transportation policy. There are, nonetheless, a number of reasons for concern. Perhaps most important is the point that these numbers represent averages. Even if the average doesn't look bad, some considerable number of people will inevitably be worse off than the average. And significantly, there are likely to be political issues involved in the distribution of those who are better off than average versus those who are worse off. That is, generally good conditions for new area residents who settle on the outskirts of the area could mask worsening prospects for current residents who will likely be in more congested, central parts of the city.[43]

Other reasons for concern arise because these summary numbers fail to capture some relevant aspects of the situation. For example, these speeds and times are for "normal" days, assuming no accidents or storms or other unusual delays. As traffic becomes heavier, the normal days may not get that much worse, but there may be fewer of them, and more "bad" days. Another problem is that people avoid congestion by traveling earlier or later, thus the "peak" period lasts longer. It may not be possible in the future to avoid rush hour traffic by avoiding rush hour. In other words, peak congestion may not get much worse, but the number of people who will have to suffer through it could increase as the length of the peak period grows.

Finally, it is interesting to note the geographical extent of expected congestion in the year 2020.[44] Currently, freeway congestion is a problem mostly just north of St. Paul and south and west of Minneapolis. By 2020, however, virtually every freeway inside and including the 494/694 circumferential, is expected to suffer peak-period congestion. Thus even those people and companies that wish to avoid congestion by the extreme step of relocating, will no longer have many options.

It is also worth noting that as the freeways become more crowded, shorter trips will increasingly be shunted onto "local" arterials and smaller roads. These roads will become more crowded, making it more difficult for area residents to complete errands and generally reducing the quality of life in many neighborhoods.

[42] Also, the time spent at the ramp meters themselves may be underestimated with current techniques. Thus the average speed may be overestimated to some extent.

[43] While it should be possible in principle to identify "winners" and "losers" in the forecasts, this would involve a considerable investment of time in working with the original forecast computer files. That such information is interesting, and not easily available, is an issue which needs to be addressed in efforts to improve the forecasts.

[44] Based on forecasting model output.

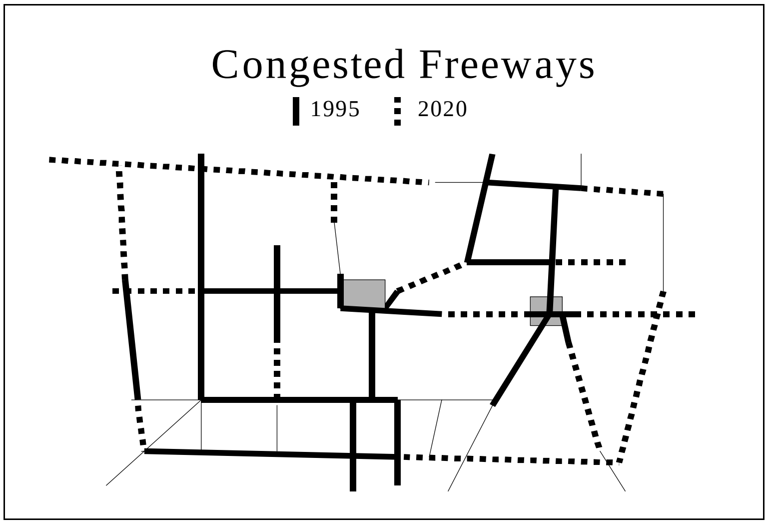

Figure 2.7: Freeway Congestion, 1995 and 2020

Given our current state of understanding of the determinants of travel demand, the Twin Cities 2020 forecasts seem generally plausible. While it is possible to argue that some specific predictions might be slightly too high or low, there are no numbers that seem at all indefensible. Other organizations have looked at both the forecasts[45] and the forecasting process[46] and have been largely complementary. Papers that discuss forecasting processes nationwide lead one to conclude that the models used here are among the most sophisticated and best thought-out of all U.S. cities.[47] The trends that the forecasts are predicting are similar to those predicted by forecasts elsewhere.[48] All these factors lead to the conclusion that, given the current state of the art, our forecasters and planners here have done as well as could have been desired. It appears that the forecasts are based on best practice in forecasting methodology.

This brings us to a bigger question: how good is "best practice?" That is, even if the forecasts seem plausible given the current state of knowledge and practice, there is still the possibility that the current state of knowledge and practice is in some ways inadequate.

Which brings us back to the purpose of the forecasts: to improve our ability to plan. From this perspective, the problem with the forecasts has to do not with accuracy but with usefulness. The forecasting models in use today, even though they seem to be fairly accurate, don't always provide as much information as would be optimal. As discussed at the end of the last chapter, forecast accuracy is a necessary but not sufficient condition for making good policy. Forecasts also need to provide the specific details needed to evaluate the pros and cons of different policies, such as the distribution of who is made better and worse off by system changes.

[45] Office of the Legislative Auditor (1998)
[46] Lyons (1993)
[47] For example, Harvey and Deakin (1993) raise many points of criticism regarding "standard" forecasting practice which have already been appropriately addressed in the Twin Cities forecasts.
[48] Kipp (1994)

In addition to providing appropriate detail, forecasts should also address as broad a range of transportation-related phenomena as possible. The most common model in use today does not address walking and bicycling as modes, for example, nor does it have a mechanism for representing the interaction between transportation and land use in a way that is useful for policy making.

A final shortcoming is that the forecasts merely describe the future system, without providing any means of evaluating its quality. An investment is not an improvement unless it makes the system better, not just different. Current forecasting technology indicates how the system performs under different alternatives, but still leaves it to the generally non-expert policy makers to determine how much better off people will be, and thus how much should be spent.

Much research is being done to fill in these gaps, but improvements are expensive, due to the need for data collection and modifications to computer code. Thus choices will have to be made about which model improvements should take priority in this region.

This is in a broad sense the practical purpose of this report – to provide some background and context for organizing the discussion of how resources allocated to forecasting model improvements should be used. The objective is not to recommend what should be done, but rather to clarify what is done now (and what is possible) and to discuss the value of current forecasting methods within the broader context of policy and planning. The ultimate question is this: what kinds of improvements to the forecasting process would be the most helpful in terms of improving our ability to make good plans and policies?

The next chapter begins the process of answering this question by describing in some detail the standard models and process for forecasting travel demand. This examination will help to clarify the current state of the art, and to evaluate whether shortcomings in existing travel forecasts are inherent in the process or in the underlying state of knowledge; or whether the existing process simply has not been adequately exploited to produce the most useful forecasts possible.

3 Travel Demand Forecasting

The introduction to this document identified a number of transportation-related problems that the Twin Cities region currently faces, or will face in the near future, and discussed the types of information and tools that will be needed to make good policy to deal with these problems. The next chapter described the complexity of travel, and evaluated the forecasts for the year 2020 in light of this complexity and of the need for tools for policy making. The forecasts, in their current form, do not seem to provide all the answers that good decision making could require. For example, there is a need for more detail on the distribution of costs and benefits, examination of a broader range of phenomena such as land use, and tools for evaluating the quality of the system rather than simply describing it.

The purpose of this chapter is to examine the standard traffic forecasting process and technology, in order to determine the reason for this apparent inadequacy. There are three possible explanations. First, it could be that the forecasting process and the tools used do not fully reflect all that is known about how travel patterns are determined. Second, the problem could be deeper, in that knowledge itself could be lacking in some important respects. Finally, another possibility is that the current forecasting technology is capable of producing better answers to policy questions, but is not yet being used to its full potential.

There is a standard travel forecasting process used throughout the world, with individual cities sometimes using slightly different methods, with more or less detail, on specific parts of the process. This chapter will examine this process in general, and in particular the way it is applied in the Twin Cities, to get a sense of the potential of the general model structure and the major areas of weakness.

While the purpose of this section is to describe how the standard travel-forecasting model works, there is value to spending a little time first providing some historical context. History is important because the forecasting process was originally developed to answer different kinds of questions than those it is being called on to answer today, and most of the shortcomings of the model can be directly traced to this source.

Travel forecasting as a formal process began in the 1950s;[49] an era when the interstate highway system was first being built and post-war prosperity was making better housing and auto travel more widely affordable. People wanted, and could afford, newer and bigger houses in less crowded neighborhoods. The new urban freeways, by providing high-speed connections between far-flung points, facilitated this process of suburban expansion. Because there were still relatively few cars, the negative side effects of increased auto usage had not begun to appear.

In this environment, transportation policy was often used as a way of facilitating other social ends, namely better housing and less congested central cities.[50] Thus a basic objective of policy was to accommodate this movement, by building highway capacity sufficient to cope with the expected future levels of usage. The basic problem of forecasting then was to determine where new highways would be needed, and how wide they needed to be.

The process that emerged became known as the four-step method. In keeping with the needs it was addressing, the creators of the model approach focused the bulk of its considerable sophistication on the problem of allocating an expected amount of traffic to specific roads. Because the expected quantity of travel could easily be accommodated by new and expanded highways, there was no particular reason to be concerned with the problem of why a particular quantity of travel arose in the first place. All that was needed was a reasonably good estimate of what that quantity would be.

Indeed, early researchers viewed traffic forecasting as a particle physics problem; the fact that the particles were human beings was felt by some to be basically irrelevant. Howe's 1962 model took this approach:

> Human beings may be considered to be electrons. Given the initial distribution of these unit negative charges, corresponding to centres of residence, and the distribution of centres of positive charge, representing places of employment, with magnitudes equaling the number of persons employed, the probability of movement between places of residence and places of employment can be predicted on the basis of electrostatic field theory.[51]

In other words, people will be "pulled" toward attractors: places of work, shopping, entertainment, and so on; with the level of attraction for a given person

[49] Weiner (1997) is a good general history of transportation planning and forecasting.
[50] Pas (1995), page 54
[51] Quoted in Pas (1990)

roughly proportional to some combination of the total attractiveness of the place and the difficulty of getting there. Given the total number of trips,[52] and the starting point of each trip (based on where people live), the total amount of traffic on every road can be predicted on this basis.

Considerable progress and refinements have been made to the model since that time; however, this is still more or less the gist of the approach.[53] And, perhaps surprisingly, it's not a bad approach. Travel behavior in the aggregate can in fact be fairly accurately predicted with this relatively simple view of human motivations. The reason it works is because, as modelers have long realized, it captures essential elements of logical human behavior. People balance the desirability of a destination with the cost of getting there in deciding how frequently to visit.

With this historical context in mind, a brief description of the four-step method will introduce the more detailed discussion that will occupy the remainder of the section. To describe it very roughly, the four-step method first predicts a total number of trips based on externally-generated predictions about the people and the economy of the region and on current patterns of behavior. Each trip is then assigned a specific origin and destination based on current travel patterns, expected locations of future homes and businesses, and expected characteristics of the road network. Characteristics of the road and transit networks, and of the locations of homes and businesses relative to the transit network, are then used to predict mode shares. Finally, each trip is allocated to a specific highway or transit route, based on the principle of minimizing the total time and money cost of each trip.

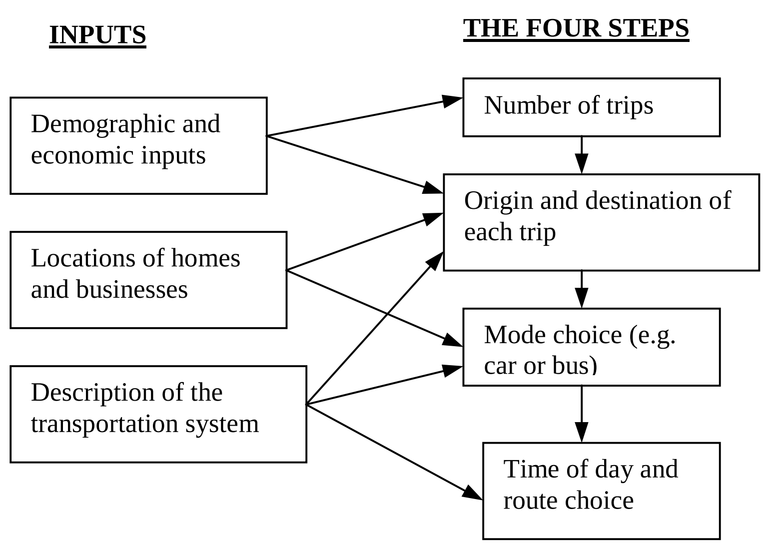

Figure 3.1: The Four-Step Method

[52] Trips are actually more the counterpart of electrons than are human beings.
[53] Even by 1962, researchers were starting to think of this process in terms of "gravity" rather than electrons. Now it is explained in terms of people maximizing travel utility given the relative costs of various destinations.

While this is an oversimplification of a very complex process, it is intended only to give an idea of the underlying conceptual basis for the method. The objective of the remainder of this chapter is to give some detail about each phase of the process, from the inputs to the four steps to the outputs. This is not intended to be a complete accounting of every possible angle,[54] but only to give a sense of what the model does, and perhaps more importantly, what it doesn't do. This will provide a basis for the evaluation of the model in the last part of the chapter.

Forecasting Inputs

While the description of the four steps of the model might seem intuitively more interesting, this section on inputs is possibly more important. There are two major reasons to take a detailed interest in the inputs to the model.

First, what comes out of the model is only as good as what goes into it. Even if the model were a perfect representation of the world, if it relied on inputs that couldn't be measured or predicted accurately then it couldn't give accurate results. This is in fact the case when the model is used for long-term forecasts – inputs such as population and number of jobs are difficult to predict accurately far into the future, yet they are major forces in determining future traffic levels.

Second, the inputs to the model inevitably limit what the model can be used to analyze. For example, if travel time is the main factor affecting bus ridership in the model,[55] then it is possible that transit policy could focus too much on reducing travel time. This could come at the expense of other initiatives that might have more impact in reality, but which don't have much impact in the model because they are not part of the input set.

The basic geographical frameworks by which the inputs are organized are Traffic Analysis Zones (TAZ) and the highway network. The Twin Cities region is divided into 1165 zones,[56] whose size depends on the nature of the road network and on population and employment density. Thus in downtown Minneapolis, a single block or group of blocks could be a zone, while in rural areas of the seven-county region, a zone might be an entire township. The highway network is the system of major roads that are normally used for long-distance travel. A zone typically occupies the area between major (network) roads.

The general idea of zones is that they are areas of business or residence that are sufficiently small that there is relatively little traffic inside them, compared to the amount on the highway network. Thus activity inside zones is generally ignored in the forecasting models. For example, we care how many total trips enter and leave a particular residential area, but we don't normally care about which specific house each trip is going to or coming from. In other words, what matters

[54] Many detailed descriptions of the four-step process have been written. A recent and well-done example is by Harvey and Deakin (1993), who devote an entire 118-page chapter to describing this process. Oppenheim (1995) is another thorough discussion.

[55] There are in fact a large number of factors affecting bus ridership that are included in the model. This is one of the most detailed and best-understood parts of the entire forecasting process. The hypothetical example offered here is just to illustrate the idea that omitted factors could lead to misguided policy.

[56] 1990 TBI, page 36

about a trip is where it gets on and off the main road network, or the transit network.

The inputs to the four-step method fall broadly into three categories: households, which determine trip origins, employment, which determines destinations, and the transportation system itself, which influences how people move between origins and destinations.

Households (Trip Origins)

Households are the generators of trips. Therefore understanding the methods used to predict the number of trips based on characteristics of households is crucial to understanding how the model works and how it could best be improved.

The very first important point is that trip quantity predictions are based on households rather than individuals. This is done because historically the number of trips that a given person makes depends on the kind of household of which that person is a member. A household of two people, even if they are both adults, will often not make as many trips as two individuals. This is simple enough – when people live together, they can share some trips, or one person can make a trip, such as grocery shopping, on behalf of the others. A source of increased trip-making in recent decades has been the ongoing decrease in household size – even if population weren't growing, the increase in the number of households would mean more trips.

The number of trips that a household will make can be fairly accurately predicted using a surprisingly small set of characteristics, namely the number of people, number of cars, and ages (within ranges) of the members of the household. The number of workers is also an important consideration, but in the Twin Cities forecasts workers are counted by zone rather than by household.

Household inputs
Number of people
Number of cars
Ages of members

The idea then is to count and/or predict the number of households in each TAZ with each possible combination of characteristics. For each zone, a matrix is created whose cells contain the number of households with the characteristics represented by the row and column in question. The reason the counts need to be done like this is that each type of household will generate a different number of trips than the other types.

Table 3.1: Household Counts by Type for a Zone

Zone number *n*, Number of households of each type:			
	0 children	1 child	Etc.
One adult, no cars	Number of households		
One adult, one car			
Two adults, one car			
And other combinations			

The predictions of household counts begin with forecasts by the state demographer of metro area population and households for the future year of interest. These forecasts are based on the age characteristics of the current population, trends in the birth rate, and domestic and foreign migration into the area. The total number of future households is then divided among the different parts of the metro area based on current population and growth trends. Discussions are then held with the municipalities of the region to establish general agreement that the forecasted growth in households and employment has been allocated appropriately.

The other important input about households is the types of trips they make. That is, there are different trip purposes, and the various types of households will produce different proportions between the trip types. For example, a household with two workers will obviously make more "work" trips than a household with no workers.

This information about how households travel takes the form of a series of "cross-classification tables," which are matrices whose cells contain counts for the different types of trip, organized by the three important household characteristics listed above: number of adults, children, and cars. These counts are based on current averages over the entire region; that is, they are not specific to zones.

Trip types

Home-based:
- Work
- Shopping
- School
- College
- Work-related
- Other

Non-home-based:
- Work-related
- Other

Table 3.2: Number of Trips by Household Type

Number of trips per household per day:			
	HB Work	HB Shopping	Etc.
One adult, no children, no car			
One adult, one child, one car		Number of	
Two adults, no children, one car		Trips per day	
And other possible combinations			

Future trip making by household type is assumed to be the same as current patterns. That is, while there have been huge increases in trip quantities, these have occurred more because of households changing types than because of given types changing their behavior. For example, if a two-person household gains a second worker (a common occurrence in recent years as many women entered the workforce), then that household moves into the category of two persons, two workers, which implies a larger number of trips. Likewise, buying a second car (another frequent event recently) moves a household into a new, higher trip quantity category. Changes in future trip quantities are assumed, as has been the case in the past, to result from different household types rather than from different behavior by the types.

The available information then is the forecasted number of households of each type by zone, and the current quantities of each type of trip by household type. These two inputs are then used in the trip generation step to calculate the number of trips of each type by zone.

Employment (Trip Destinations)

The great majority of trips that are made have at one or both ends a place of work. That is, when you make a trip, it is almost always either to the place where you work, or to a place where someone else works, such as a store or an office or a restaurant. Thus predicting where people work is the basis of forecasting trip destinations, as it is the source of both work-related trips (for the people who work in a zone) and most non-work trips (for those who are going there to shop, for example).

For each TAZ, there are two key measures of employment, total non-retail jobs and total retail jobs. The first of these can be used to tell how many trips will be made to a zone (and away from the zone later on) by people going to their own places of work. "Retail" jobs are counted separately for two reasons. The first is that some business establishments attract customers as well as their own workers, thus the number of trips attracted can be very different than the employee count. Second, shopping and other trips that are not to one's own work have different characteristics than work trips. For example, they are usually made at different times of day, and they tend to be shorter in general. Thus it is necessary not just to estimate the number of trips attracted by each zone, but to have at least this rough idea of why they are coming.

Employment inputs

Total non-retail jobs
Total retail jobs

Forecasts of future employment are generated by the Department of Economic Security using a well-accepted procedure based on national and local trends for different types of industries and occupations. As with households, the total jobs are allocated to the individual municipalities (and eventually to zones) based on current trends and on discussions with the local governments. Various methods, such as employer surveys and parking lot counts, are used to derive an estimate of how many "customer" trips are generated by each type of job. This average is calculated over the region as a whole.

Transportation System Inputs

The final major class of inputs is information relating to the transportation system itself. An obvious point about this is that it is the object we are trying to understand, and thus it needs to be defined at a level of detail that makes it possible to answer the questions of interest. A more subtle point about the system is that it influences the determination of trip patterns. The model step of linking origins and destinations depends on the ease or difficulty of traveling between two points, and this is a function of the characteristics of the transportation network.

The road system is represented as a stylized network, in which the TAZs are connected by "links," which in most cases represent actual highways but could stand for groups of minor roads or other features. The links are described by their lengths, capacities, and free-flow speeds. Some links, rather than being part of the main network, are used to represent access to the network from the interior of a zone. Since travel within zones is not of concern, these "dummy" links simply represent an average travel time to access the main network.

Highway inputs (by link)
Length
Capacity
Free-flow speed

The cost of parking is in some cases a significant part of the total cost of a trip, so parking costs are included in the system description for the two downtowns and the University of Minnesota. The costs are estimated as a function of the employment density in a zone, and future costs are predicted based on current parking costs by density, and on the predicted future density of employment in each zone.

In addition to a description of the road network, there is also information about bus routes, frequencies, and costs. The probability of a trip being made by bus is dependent on the distance between the origin and destination, the frequency of busses on a given route (the expected waiting time), the number of transfers necessary to make the trip, the travel time, and other factors. Detailed information about the bus system is needed to make these calculations.

Transit inputs (by route)
Roads used
Frequency
Travel time
Cost

Travel Surveys

Twin Cities travel forecasting uses two main sources of data. The primary source is the Travel Behavior Inventory, which includes a survey of household travel behavior and a number of related surveys intended to provide supplemental information. These data are complemented by the U.S. census, which gives considerable demographic information, and also asks supplemental questions about commuting behavior of a fairly large sample of the population.

Four types of survey are done as part of the Travel Behavior Inventory. The household survey gives our primary information about the travel habits of households. In 1990 this was a sample of about 10,000 households, which is a very large survey for a region the size of the Twin Cities. This takes the form of a travel diary, in which a household records every trip made by every household member. The information recorded about each trip includes the origin and destination, the start and finish times,

Twin Cities Travel Survey Types
Household travel
Transit on-board ridership
External station
Work place

the purpose of the trip, and the mode. Information about the household and about the individual traveler is also collected.

Although this survey is quite extensive, the dominance of the auto in the Twin Cities means that the survey inevitably produces far more information about auto travel than other modes. Transit on-board ridership surveys complement this information by providing considerably more detail about the behavior of the subset of the population that uses transit.

External station surveys collect data about travel passing through the metro area, and between the metro region and the "outside," by surveying people who enter and leave the area. Work place surveys give information about trip destinations by determining the number of trips attracted by establishments of various sizes and types.

The Four Step Method

The heart of the forecasting process is the four-step model. It is actually a sequence of models,[57] which together perform the feat of converting basic facts about the people and places of a region into a prediction of every trip[58] that will be made and the specific way it will be executed. Each model in this process uses certain raw inputs plus the results of any previous models, and advances the process one step forward.

Trip Generation
- number of trips beginning and ending in each zone

Trip Distribution
- matching specific origins and destinations

Mode Split
- drive alone, carpool, bus, etc.

Time of Day and Traffic Assignment
- peak period or not
- specific route of each trip

Figure 3.2: The Four Steps of Travel Forecasting

There are really somewhat more than four steps in the process, if one thinks of a step as being a single model solving a specific problem. The time of day of each trip is determined separately from the route choice, and the trip generation step is actually accomplished in two separate parts as well. Furthermore, the generation, distribution, and mode split must be calculated separately for each of the six trip types. But this is just semantics. The problem at hand is not to count steps, but to understand how the process converts raw inputs into information about transportation patterns.

[57] Hence the use of both the singular "model" and the plural "models" in referring to the process in this report.
[58] "Trip" throughout this report refers to trips between zones. Trips within zones are not part of the travel forecasting process.

Trip Generation

This first step encompasses the solution to two fundamentally different problems. The first is determining the total number of trips of various types that will be generated by the households living in each zone (trip production). The second is predicting the trips of various types that will be attracted by the business and other establishments located in each zone (trip attraction).

Household trip production simply brings together the two parts of the household input information. The predictions per zone of households of various types (e.g. one person, one job, one car) are multiplied by the regional average trip type (work, shopping, etc.) quantities expected of each type of household. Thus if the number of households of each type in a zone can be predicted, and the number of trips of various types that a household of a given type makes is known, then the total number of trips of each type generated by an entire zone can be calculated. This is a simple matrix multiplication problem.

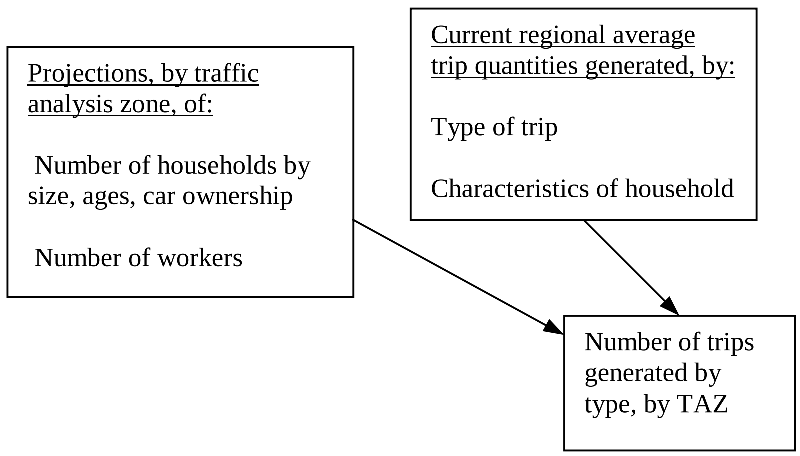

Figure 3.3: Predicting Trip Origin Quantities

The fact that a zone "generates" a certain number of trips does not mean that every trip originates in the zone. Each trip that comes out of a home has a corresponding return trip, not necessarily from the same place. Both of these trips are considered to be generated by the "home" zone, although the real beginning and end are straightened out in the trip distribution step. In addition, there are trips for which neither end is at the home. For example, if a person leaves work, stops at the grocery, picks the kids up from soccer practice, and then goes home, this is counted as three trips, two of which do not have the home as an end point. Such "trip chaining" is a topic of considerable interest among travel demand researchers, both because it is an increasingly important part of peak-period travel, and because there is not much understanding of how to predict it. Currently it is handled somewhat roughly through the use of the trip category "non-home-based." This problem is addressed in somewhat more detail later in this chapter, in the section called "Activity Analysis."

Table 3.3: Result of Trip Origin Substep

<table>
<tr><th colspan="4">Number of trips of each type produced by each TAZ</th></tr>
<tr><td></td><td>HB Work</td><td>HB Shopping</td><td>Etc.</td></tr>
<tr><td>Traffic Analysis Zone 1</td><td colspan="3" rowspan="3">Number of Trips per Day</td></tr>
<tr><td>Traffic Analysis Zone 2</td></tr>
<tr><td>Etc.</td></tr>
</table>

Trip destinations are estimated based on the total number of jobs and the number of retail jobs in each TAZ, and on the average number of trips generated by each type of job in the region as a whole. The two sides are multiplied to derive a total number of trips attracted by each zone. The result of this substep looks exactly like the result of the trip origin substep, except that it contains the number of trips of each type attracted by each zone, rather than the number produced.

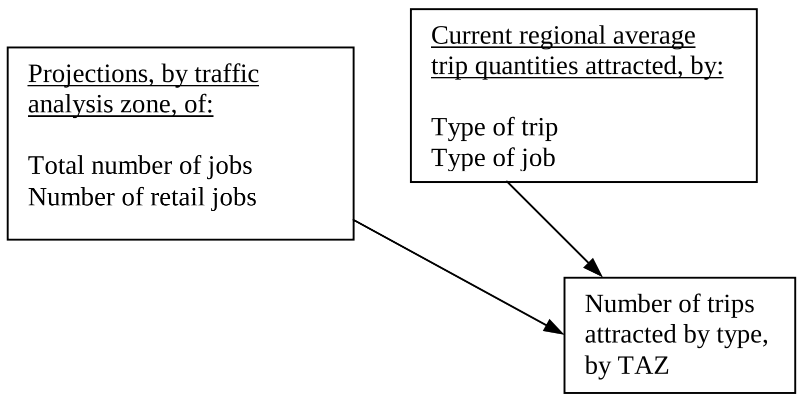

Figure 3.4: Predicting Trip Destination Quantities

In principle, the number of trips generated by households should equal the number of trips attracted by businesses and other destinations. That is, every trip that is created by a household has to go somewhere. In the Twin Cities an adjustment is done to achieve this equality. In modeling terms, this is necessary because in the next step specific origins and destinations are linked together, which cannot be done unless there is a trip being attracted for each trip that is being generated.

Trip Distribution

This step matches an origin and destination for each individual trip. That is, the trip generation step determined the number of trips beginning and ending in each zone, but did not match specific beginnings and endings.

To simplify the explanation of how this process works, consider a specific kind of trip, say home-based-shopping. We know from the trip production substep that the residents of a given zone will generate a certain number of this type of trip. We also know the number of trips of that type that will go to each of the zones in the region. The problem then is to allocate the trips beginning in each zone to all the available destinations.

There are two basic ideas involved in answering this question. First, any given shopping trip is more likely to go to zones that attract a large number of shopping trips than to zones that don't. But trips can't just be allocated based on the attractiveness of the destination zones. The reason is that while people like to go to zones with many shopping opportunities, they also like to save time. Thus while people are more likely to go to zones that attract a lot of shopping trips, they are also more likely to go to zones that are easy to get to. The purpose of the trip distribution step is to find an appropriate balance between these two sometimes conflicting objectives to determine where the trips from a given zone will go.

The procedure by which this calculation is done is known as the gravity model. The idea is that attractive zones have greater "gravity," and thus pull more trips toward them. However, as with real gravity, the degree of attraction decreases with distance. In travel terms, "distance" means total cost, which is basically travel time, plus parking charges in a very few cases. It would also include tolls or other costs of travel if there were any.

The procedure is specific to trip types. For example, trips to shopping will only be attracted to zones that have shopping in them. It also is specific to zones, since accessibility is a matter of distance. Rosedale Mall is more likely to attract people from Roseville than from Edina. Thus this is a complicated procedure. Each trip type from each zone must be allocated over all of the possible destination zones in the region, bearing in mind that each destination zone has a different level of attraction for each type of trip.

The actual method by which this is done is to allocate a given trip type from a given zone to the destination zones based on a measure of composite attractiveness.

$$T_{i,j}^{K} = T_{i}^{K} \frac{A_{j}^{k} f\left(c_{i,j}\right)}{\sum_{h} A_{h}^{k} f\left(c_{i,h}\right)},$$

where

$T_{i,j}^{k}$: number of trips of type k from zone i to zone j

T_{i}^{k} : total trips of type k from zone i

A_{h}^{K} : total trips of type k attracted to zone h

$c_{i,h}$: the basic cost of traveling from zone i to zone h

$f\left(\cdot\right)$: a function converting basic to perceived cost

The composite attractiveness of each destination zone is summed to give a total attraction for each trip type. The cost of traveling between zones considers both auto and transit time and money costs. The ratio of the attractiveness of each destination zone to the total attraction is multiplied by the total number of trips of the type in question to give the number of trips going to that zone. Since these ratios must sum to one, all the trips of a given type originating in each zone are allocated this way.

Table 3.4: Results of Trip Distribution Substep

Trips of type home-based shopping from (row) to (column)				
From: \\\\ To:	Zone 1	Zone 2	Zone 3	Etc.
Zone 1	XXXX			Number
Zone 2		XXXX		Of Trips
Zone 3	Number		XXXX	
Etc.	Of Trips			XXXX

Finally, some *ad hoc* adjustments are made to reflect the fact that certain origins generate travel to certain destinations out of proportion to distance or destination attractiveness. For example, certain suburban locations generate more trips to downtown Minneapolis than would be predicted by the normal factors, while locations very near downtown don't produce as many trips to downtown as the ease of the trip might suggest.

Mode Choice

This step determines the travel mode, for example bus or single occupancy vehicle (SOV). This is a complex process that attempts to account for the differing time, money, and convenience costs of the various ways of making a trip. Trips are divided between modes by a series of choices, using a mathematical formulation called "nested logit."

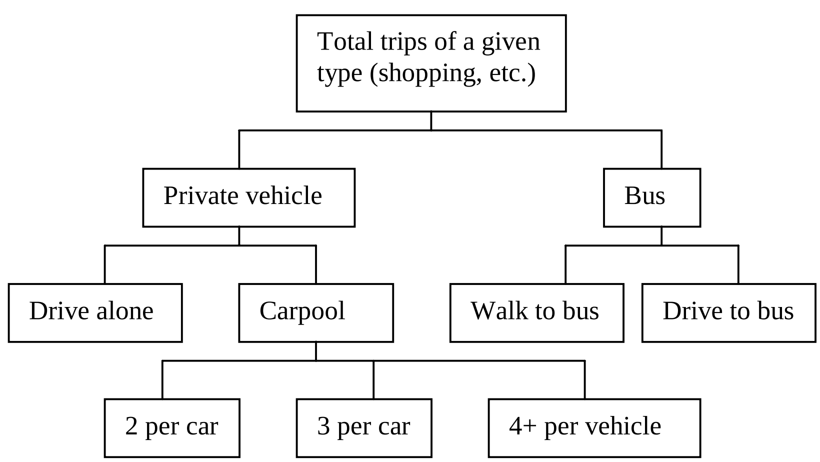

Figure 3.5: Mode Choice Process

First of all, the outcome of the process will depend on the type of trip and on the specific origin and destination. Given these considerations, the method first calculates the expected utility, or benefit, of each type of carpool, and each means of accessing the bus. The highest utility carpool type is then compared to the expected utility of driving alone. The winner of this comparison is then matched against the utility of the winning bus-access type. The outcome of this is then the mode that the trip in question is predicted to use.

The advantage of this type of process is that it can be much more precise than a more general method of choosing between all of the modes at the same time. The basic point is that different factors are important to different choices, and even when the factors are the same, their relative importance can differ. For example, the importance of travel time is much greater when choosing between walking to transit and driving to transit than it is when choosing between transit and private vehicle. This method of making a sequence of choices makes it possible to always use the right values for each factor, rather than some kind of overall average.

The number of people assigned to each choice at each step of the process is based on the type of trip (shopping, work, school, etc.), the origin and destination, and on a number of variables thought to influence the relative attractiveness of the various modes. The type of trip matters because people are far more likely to ride the bus for a work trip, when traffic is bad and bus service is frequent, than for other types of trip. Likewise, transit is unlikely to be chosen if there is no bus service to the trip destination.

The variables used, and their relative importance, depend on the specific choice being made. Variables that are important to auto-related choices include auto ownership, parking costs (in the downtowns and around the University of Minnesota), and highway travel times. Important factors for transit-related choices include ease of access (time to get to the bus stop, and waiting time), bus fares, whether a transfer must be made, and bus travel times.

The general form of the equations used to make these calculations is as follows.

$$P_{g,i} = \frac{e^{U_{g,i}(x_{g,i})}}{\sum_{g,m} e^{U_{g,m}(x_{g,m})}},$$

where

$P_{g,i}$: probability of a traveler from group g choosing mode i

$x_{g,m}$: attributes of mode m that describe its attractiveness to group g

$U_{g,m}(\cdot)$: utility function of mode m for travelers in group g

The utility function takes the general form:

$$U_{g,m}(x_{g,m}) = a_m + b_m L_m + c_{g,m} S_g + d_m T,$$

where

L_m, S_g, T are sets of variables describing respectively, the level of service of mode m, the socioeconomic characteristics of group g, and characteristics of the trip (such as CBD orientation),

b_m, $c_{g,m}$, d_m are vectors of coefficients describing the importance of the variables to which they are attached,

a_m is a constant specific to mode m that captures the overall effect of any missing variables (such as comfort and safety).

Despite the complexity of the mode choice process, a number of problems remain. Most significantly, bike and walk trips are not analyzed, and some important factors are unaccounted for. Harvey and Deakin make these points:

> While the treatment of auto and transit modes has tended toward greater complexity and sophistication, bicycling and walking modes continue to be omitted from the mode choice models of all but a few metropolitan areas. Such an omission is problematic, not only because these trips are an important component of personal mobility, but because cross-elasticities are quite high between walk trips and short bus and auto trips, depending on fares, parking charges, travel time, etc.…
>
> It also remains the case that a considerable number of variables found through research to be important to mode choice are commonly omitted from the models used in practice. In particular, research has shown that the comfort, convenience, and reliability of the various modes are critical variables in travelers' mode choices, and that the inclusion of measures or indicators of these variables improves model fit. Nevertheless, they are only occasionally incorporated into models used in practice, partly because data on these matters are not readily available and forecasts of future conditions would be hard to develop…[59]

This is the major place in the four-step method where there is a significant effort to base results on a theory of *why* people make certain decisions, rather than just projecting current behavior into the future. As such, despite its shortcomings, the methods used in the mode choice model are likely to be more widely used as other steps such as trip generation or time-of-day choices are backed up with a real understanding of people's behavior.

Time of Day and Traffic Assignment

Like the trip generation step, these are really two separate models, and in fact they need not even be linked. That is, the time-of-day step could be done at almost any point in the four-step process. It is included here because it is done at this stage in the Twin Cities modeling process.

[59] Harvey and Deakin (1993), pages 3-51

Each trip is assigned to a time of day, or more generally to peak and off-peak hours. This has become a more significant issue as highways become more congested. That is, some travelers may choose to avoid congestion by making the trip at a different time. Ultimately, the capacity of the road network limits the number of trips that can be made during peak periods.

When there is no congestion, typically traffic levels fluctuate in fairly predictable ways over the course of the day. Specifically, peak hours can be expected to carry a certain fraction of the total daily traffic. As congestion increases, relatively more trips are made during off-peak periods. That is, while the number of peak-period trips continues to grow, it does not grow as fast as the number of off-peak trips, and thus the fraction of trips occurring during the peak period declines.

The allocation of trips to each hour of the day is based on historical patterns, the expected growth in traffic levels, and experience on how temporal patterns have changed in other cities as congestion has increased. This is done by trip type, since different types take place at different times of day.

The final, computationally difficult step of trip assignment determines a specific series of roads or bus routes for each trip. This is an iterative process in which each interzonal trip is first assigned to the fastest route, based on free-flow speeds. Traffic levels on each road are then compared to capacity to calculate an average link speed based on a standard formula. If congestion exists, the speed of travel on some roads may be less than was assumed in the original assignment. This would make other roads relatively more attractive for some people. Some trips are then reassigned to these other roads, and traffic levels and speeds recalculated. This iterative process terminates when no trip can be made faster by a change of route.

Forecast Outputs

The output of the forecasting process is a map, or more strictly, a database representation of map elements. This map shows the origin and destination zones, the time of day, the purpose, and the mode of travel, the distance, and the total travel time of every trip. It provides estimates of transit ridership on the various routes, and estimates of auto occupancy rates. Finally, for each link, or small segment of a major highway, the model projects traffic volumes and speeds for various times of day.

The model is also run given current trip rates and patterns, and the forecasted traffic volumes are compared to actual counts at various places in the region. Adjustments are then made to the model in cases where the predicted counts deviate substantially from the actual. This calibration process ensures that forecasts of future traffic flows are derived from a model structure that correctly matches current conditions.

These “basic” data can then be used to derive other information of interest. This could include maps of congested highways, expected delays, total vehicle miles traveled, and vehicle hours traveled. A significant derived output is estimates of emissions. Information about trips can be used to determine the total emissions generated by the trip, based on distance, time, and so on.

Evaluation and Improvements

The standard four-step model has a number of advantages that all but guarantee its use for the foreseeable future. It is in fact the only model that is used in practical forecasting applications in the United States. While there has been some experimentation in Europe with other types of models, these different approaches (which are really more variations than competitors) have not significantly diminished the dominance of the four-step model there.[60]

This monopoly is based on a number of real advantages of the model. Most importantly, it has performed well historically in the applications for which it was intended, that is, predictions of traffic-flow adjustments to new or expanded highways. While mistakes have been made, the model has proven quite adaptable and easy to improve as understanding has advanced. The fact that the model is explicitly calibrated to match current conditions imposes considerable analytical and conceptual discipline on the modeler. The underlying processes that generate existing traffic patterns must be understood and defined in detail, which makes forecast results easier to explain.

The flexibility of the model is such that wholesale replacement with a new method seems unlikely. New insights can easily be added to the model as they are developed, and each addition makes the model a little better. While forecasting models in 20 or 30 years may bear little resemblance to those used today, this will almost certainly be the result of gradual, cumulative improvements to areas of weakness rather than revolutionary changes.

There is a final reason why the four-step model should be improved rather than discarded. Part of the purpose of modeling is to provide a degree of objectivity to the policy process – policy results are predicted using a prespecified, well understood method. While people can dispute whether this particular model structure is the right one, a case could still be made that it is better to have a single model whose weaknesses are generally recognized than to have a number of competing models whose methods and differences no one really understands.

The absence of a reasonable alternative to the four-step model should not be taken as evidence that it should simply be accepted as is. The method is not a monolith, unchangeable and identical from one place to the next. It is a set of tools for estimating different aspects of the urban transportation system, and a method for combining the information yielded by the various parts. While there is general agreement on what the pieces of the model are, the level of sophistication in the implementation of these pieces varies greatly among organizations in different cities, and has changed substantially since the model was first developed.

[60] The primary “competitor” is activity analysis, which changes how some of the steps are done by looking at why people make trips rather than simply basing trip quantities on current behavior. Jones (1990) has some discussion of applications of activity analysis in Europe.

Thus improvements to the model constitute not a radical departure from an established tradition, but rather are a natural, indeed traditional, part of the evolution that the model undergoes as times and needs change. The model was initially developed to answer a certain set of questions based on a given set of knowledge. As knowledge of urban transportation forces progressed, the model evolved to reflect this. Now the need for model improvement arises less from new knowledge than from new needs. As new highway construction largely ceases, it will be necessary to implement new types of policy to deal with future problems.

In recognition of this situation, a consortium of federal agencies[61] has initiated the Travel Model Improvement Program, which is "a major program to enhance current models and develop new procedures."[62] Thus developing better forecasting models is not just a local luxury, but has been widely recognized as a major issue of national scope. The Twin Cities region would benefit from close monitoring of the progress of this program, as its goals are very similar to our own:

> The objectives of the program are:
>
> - To increase the policy sensitivity of existing travel forecasting procedures and their ability to respond to emerging issues including environmental concerns, growth management, and changes in personal and household activity patterns, along with the traditional transportation issues;
> - To redesign the travel forecasting process to reflect today's traveler behavior, to respond to greater information needs placed on the forecasting process, and to take advantage of changes in data collection technology; and
> - To make travel forecasting model results more useful for decision-makers.

The following section outlines a number of significant practical improvements to the four-step model that are likely to be useable within the next few years. This is not a comprehensive list, but just a short description of some of the possibilities that are the most widely discussed and in some cases closest to implementation.

The final section then evaluates the four-step model, and the efforts being made to improve it, from the perspective being used in this report. That is, to go beyond accuracy and theoretical integrity, to ask in what senses the model is and is not useful in the policy making process, and what other types of improvements might make it more useful in the future.

Some Likely Future Improvements

A few classes of model improvements show up again and again in the literature. The following sections briefly describe a few of these. This is not intended to be

[61] Federal Highway Administration, Federal Transit Administration, and Office of the Secretary, U.S. Department of Transportation; U.S. Environmental Protection Agency; and U.S. Department of Energy
[62] Texas Transportation Institute (1998)

a comprehensive list or a "how-to" manual for model improvements. These short discussions are merely intended to give the general reader an idea of the scope and significance of some important possible changes.

Travel Surveys

While a number of different survey methods have been used to learn about travel behavior in the Twin Cities, there is increasing interest nationwide in two types of survey that have not been widely used here.

Stated preference surveys can be valuable in ascertaining people's opinions about options that do not currently exist, such as a rail system, or a road pricing scheme. The normal type of survey is based on the notion of "revealed preference," in which preferences are deduced from actual choices that people make. Obviously, if an option does not currently exist, it is impossible to observe actual choices about its use. Thus stated preference surveys are a way to learn about how people might react to these alternatives.

The problem with stated preference is that it is potentially unreliable. People like to think of themselves as doing the right thing;[63] thus "virtuous" options might appear to have more support than they would in reality. A second reliability problem is that people may simply be unable to say what they would do in a situation that they have never faced before. They must decide based on the option as it is described to them, but in real life there might be factors that were not described but which affect the person's decision. (And conversely, there might be information given that the person would not have in reality.) Research has been done into ways to overcome these problems,[64] and stated preference surveys have been widely used in evaluating new commercial products.

The second type of survey is the longitudinal or panel survey. The idea here is to survey the same households or people several times over a number of years. This would make it possible to determine how actual households are changing over time in response to changing conditions, as opposed to the current method of random sampling, which tells only how the region in the aggregate is changing.

To understand the difference, think back to the section on demographics in chapter two of this report. The initial view of trip rates by age indicated that older people made many more trips in 1990 than they did in 1970. However, in that case it was possible to compare the same group of people at two different times (30-year-olds in 1970 and 50-year-olds in 1990). This view showed that the increase in trip rates among older people happened because these age categories contained different people in each period. A specific group of people compared at two different times typically showed very little change in trip rates.

The same possibility exists in other areas. That is, we could be observing certain groups or areas exhibiting changes, and incorrectly concluding that people are behaving differently, when what is really happening is that the groups or areas contain different people. It is not certain that this is happening, but we have no

[63] For example, self-reported viewing of public television is higher than actual viewing as measured by TV set monitoring.
[64] Polak and Jones (1996) give a good overview of the pros and cons of stated preference surveys. Subsequent chapters of the book discuss current research in this area.

way of ruling out the possibility. Panel surveys would provide some assistance in this regard.

System Modeling

A number of suggested improvements aim at adding more detail or realism to the way the transportation system is modeled. Three examples are using Geographic Information Systems (GIS) to add more detail and precision to geographic data, increasing the model sensitivity to time of day, and modeling travel behavior as somewhat random rather than fixed.

Many travel demand researchers have recommended that forecasters should take advantage of advances in computer power and GIS software to increase the detail of travel networks and data.[65] The idea is that a GIS system be used to map geographic information as specific points rather than aggregating this information into predefined zones. This preserves more information and increases the flexibility of the data, since it can be subsequently aggregated into any zonal system desired. This could be helpful in situations where details of land use make a difference to the outcome, such as in predicting transit mode share. Currently such details are lost within the zonal aggregation.

GIS systems can also allow more detailed networks and better representation of results. There is, of course, an investment in setting up the more detailed network in the first place, but once it is done, it could give a much greater ability to analyze local situations and ideas for improvements. For example, there has been some difficulty with modeling the delays caused by ramp meters. Similarly, specific details of intersections can affect travel patterns on all the links leading into them.

The general principle of "dynamic assignment" is to represent the ebbs and flows of traffic more accurately by analyzing the progress of the system over very short time periods, say five to 15 minutes, and allowing trips to continue from one period to the next.[66] This can make it possible to gain a better understanding of smaller local bottlenecks, in which congestion can occur even though capacity may appear adequate when a longer time period is considered. Another advantage might be a better understanding of how people respond to congested conditions by changing the times of day that they make trips.

Using stochastic or random traffic patterns can further help in finding potential problems.[67] The idea here is that people begin their trips at random times, so that occasionally a lot of people will end up on a certain road at the same time, causing congestion. This could happen even if the capacity of the road is adequate in general, or would be adequate if people spread their trips out evenly over a time period. Thus there might in reality be more congestion than the model will predict based on average traffic levels.

[65] For example, three of the four model improvement proposals in Spear (1994) recommend the use of GIS systems as the basis for storing and analyzing travel data.

[66] Currently, longer time periods are considered, and all trips during a period are assumed to begin and end during that period.

[67] Again, three of four model improvement proposals in Spear (not the same three each time) recommend time-sensitive network loading and stochastic travel behavior. Cambridge Systematics (1994) also discusses time-sensitive loading, or dynamic assignment.

Equilibrium Calculation

Many sources have pointed out that the sequential nature of the four-step model can lead to errors.[68] Most significantly, the calculation of trip destinations is based on an assumed cost of travel (time), which in turn is based on free-flow highway speeds. These free-flow speeds may not be the same as the congestion-based speeds that result from the actual assignment of trips to the network. That is, the actual travel conditions predicted by the model do not feed back into predictions of destination and mode choice. (In fact, such a feedback loop is done in the Twin Cities forecasts, but is often not done in other cities.)[69] There is a growing call to set the entire system up as a "general equilibrium" problem, imposing consistency among the different parts of the model.

In practical terms, this potential inconsistency between the different steps of the model is likely to become more significant as congestion worsens. That is, if there is little congestion, the final speeds based on actual traffic conditions may not differ much from the free-flow speeds assumed in earlier steps. However, when there is congestion the difference could potentially become large enough to raise doubts as to the reliability of the model results.

The theory of how a general equilibrium model might work is well understood, and computer algorithms have been developed. It will likely not be long before the major forecasting computer programs incorporate this approach.

Activity Analysis

There is a significant group of travel demand researchers who feel that activity analysis is the future of forecasting technology.[70] The general idea is to take activities, rather than trips, as the basic unit of analysis. Looking at activities, or the purpose of trips, can give insights into the timing and "chaining" of trips that are not possible when the particular reason for the trip is not known.

The idea of trip chaining is that people may travel to a number of different destinations in the course of a single "chain" of trips. This is significant for several reasons. Most importantly, much trip chaining occurs during peak periods, as people visit other destinations on their way to and from work. Better understanding of this phenomenon could contribute to better management of peak period traffic.

Trip chaining also affects mode choice, in that people are likely to use the same mode throughout a chain of trips. This could affect the potential of mass transit – if people have to stop at three different places on the way home, they might prefer to just start out in a car and stay there. Thus even if transit is close to where people live and work, it may not be close to the other destinations that they need to visit. This leads to another point – that chaining can influence destinations. People might visit a destination as part of a chain that would be too

[68] For example, Oppenheim (1995) devotes an entire textbook on travel demand modeling to explaining and promoting an equilibrium-based approach. Miller (1998) also emphasizes this point.
[69] Another problem is that such feedback loops may not converge, or may not converge to the same answer each time.
[70] A good overview is Ettema (1997).

far out of their way to visit directly from home or work. Thus actual travel patterns may be more complex than is implied by simple gravity models.

There are two downsides to an activity-based approach to forecasting. First is that it requires much more data than a trip-based method. Second is that it is not clear that there is a deep enough understanding of how people convert activities into trips for this approach to provide practical benefits. Advocates of activity analysis will need to demonstrate that this approach can provide gains in accuracy and understanding that are large enough to justify the additional expense involved in implementing it.[71]

Strengths and Weaknesses of the Model

Most discussions of traffic forecasting and potential improvements to the model are motivated for the most part by the need for accurate predictions of air pollution levels. However, this is not a completely adequate perspective, as argued in the introduction to this report. First, there are other significant transportation-related problems which need to be considered. Second, accurately forecasting a problem is not the same thing as knowing how to solve it.

The objective of this section is to discuss the strengths and weaknesses of the current forecasting models and methods from this broader policy-based perspective. The particular goal is to evaluate how the models contribute to solutions of the three types of problem that are prerequisite to good policy, and to discuss how shortcomings might be addressed.

Any possible improvement to the forecasting process will cost money, and some improvements are likely to be of more value than others, given the issues of greatest interest in the region. Ultimately, decision-makers will need to determine the level of resources they are willing to devote to forecasting improvement, and the questions that are most important to them. At this point specific improvements can be prioritized, and studied and outlined in detail.

Model Accuracy

The first type of problem is the need for accurate, technically sound forecasts of future conditions under different policy scenarios. The current tools solve this problem – up to a point. As has been discussed, the tools were developed to answer a specific type of question, namely, the effect of road building on prespecified levels of travel. The models are generally considered by practitioners to be fairly reliable at solving this problem.[72] The difficulty now is that people want to ask different kinds of questions, and evaluate different kinds

[71] RDC, Inc. (1995) developed an activity-based modeling system for the Washington, D.C. area using mostly existing data.

[72] The author knows of only one published report comparing actual traffic levels to model predictions. This was done by Mn/DOT in 1981 to evaluate forecasts from 1965 (Page, et al., 1981). The forecasts are surprisingly accurate, given that the highway system turned out different than expected, but it is not clear from the report if this was because the forecasts correctly predicted everything, or if overestimates of some factors, like population, were offset by underestimates of others, like trip rates.

of policies. Like any tool, the forecasting models do not perform so well on functions for which they were not originally intended.

There are two basic kinds of problem. First, the models fail to consider some of the details that would be needed to understand the effects of certain policies, such as efforts to increase walking and bicycling, to shorten auto trips, or to increase land use density. Dealing with this is, on the surface, simply a matter of expanding the complexity of the models to account for a wider range of decisions and influences; and many of the improvements currently being researched are aimed at addressing these issues.

However, the second problem is more substantial. This is that many of the decisions and influences that determine policy outcomes are simply not very well understood. To a great extent this is because the questions that might provoke this understanding have not been asked until recently, because few people cared about the answers until now. This is a dangerous problem, not least because some people deny that it exists.[73]

This belief that the answers are known seems to be based on the fact that computer models incorporating certain phenomena have been built. However, building a model is a trivial computer programming problem, and does not by any means imply that the model is an accurate reflection of the reality that it is supposedly representing. Creating models that accurately reflect reality (as opposed to merely being "on the computer") is done by the much more mundane process of constructing theories and then testing them against actual (not simulated) data. The amount of this basic research that has been done is surprisingly small given the significance of the problem.

Thus while the models could easily be altered to include information about such considerations as trip lengths, walking and bicycling, and land use issues, the mere fact of incorporating these factors into the model does not mean that they are being described correctly. In fact, including these factors in the absence of a solid understanding of the real-world phenomena that are being modeled can be worse than leaving them out entirely. Having them in the model could lead to policies that lead to good outcomes in the model, but which may not be so good in reality if reality and the model do not work the same way.

Usefulness of Forecasts

The second level of policy making is having forecasts that provide the information that decision makers need, and which are considered to be objective. In this respect the standard models don't do so well. Part of the problem is the issue just discussed, that many potentially important details are omitted from the models or are based on an inadequate theoretical and empirical base.

However, another aspect of this problem is not inherent in the models, but arises more from the way the forecasts are used and presented. The forecasts are a huge, complex database of map elements, describing various characteristics of the transportation network at different times of day. This database has no inherent "meaning;" using it to understand the system requires that the elements of the

[73] LUTRAQ volume 1, page 7: "The necessary basic research has been done. The challenge is to fund projects designed to demonstrate the practical value of these innovations…"

database be combined to create information that can be compared to some observable characteristic of the real world. For example, the elements of the database could be used to generate predicted levels of congestion on various highways, which could be compared to known current levels.

The problem is that with the exception of highway usage levels, the forecasts don't seem to be used in a regular way to generate a publicly available and understandable description of the 2020 transportation system; in the way that the TBI Summary, for example, describes the current system.[74] While the forecasts are under continual modification as discussions with local governments lead to new land use forecasts, there would still be value in publishing preliminary results. The possibility of publishing results on the Internet and updating them as new information becomes available reduces the danger that outdated forecasts will be used inappropriately.

Another consideration in the usefulness of the forecasts is whether they are objective, or more correctly, whether they are *perceived* to be objective. No matter how accurate the forecasts are, or how deep the knowledge on which they are based, if the public believes that the organization producing the forecasts has a vested interest in a certain outcome, they will have cause to resist policies that they oppose for whatever reason.

While this may be less of a problem with long-term, metro-wide forecasts, it is often a considerable issue with individual projects. Mn/DOT and local governments seem to face opposition to every proposed road or bridge improvement, and questions about the adequacy of traffic forecasts seem always to arise, with opponents asserting that traffic increases have been underestimated. And the reason, it seems, that this idea is defensible is the unfortunately suspicious fact that governments and agencies create or supervise the forecasts that justify their own projects.

The point is not that government can't be trusted, but simply that those people who for other reasons don't want changes to the highway system are being given free ammunition by this apparent conflict of interest. Making the models better and forecasts more accurate may have scientific value, but policy is ultimately political. And political acceptance is a matter of credibility as much as scientific soundness. A potentially simple and inexpensive way to address this problem would be to set up an independent organization that creates and audits forecasts, and does nothing else. If the political independence of this group could be clearly established, this could do more to increase the public acceptance of forecasts than spending millions of dollars improving the models.

There would be two other advantages to such a system. First, all planning and policy making groups would have a common forecasting baseline. This would avoid the problems noted by the Legislative Auditor, who complained that the forecasts created by Mn/DOT and the Met Council were not consistent with each other.[75] The second advantage has to do with an issue raised in the introduction. This is also a question of consistency; namely that regional and project-level forecasts need to be consistent with each other. If there were a single

[74] The Office of the Legislative Auditor (1998, page 54), complains that the forecasts were hard to obtain.
[75] Office of the Legislative Auditor (1998) pages 56-7

organization through which all forecasts had to be created or audited, this consistency could be assured.

Value to Policy Making

In addition to being accurate, providing the right information, and being believable, forecasts ideally ought also to make it possible for lawmakers to determine what policies would be most effective at solving problems, or more generally, at improving the quality of the system. This has two elements.

First, it is helpful to know not only what is going to happen, but to be able to know *why* it happens, that is, what factors have the biggest influence on a particular outcome and how they have their impact. This knowledge could help in designing policies that might mitigate negative impacts while promoting positive ones.

This goes back to the issue raised two sections ago, that models need to reflect how the system they are modeling actually works. All models necessarily simplify certain issues. The issues that are treated the most carefully should be those that are the most important. But priorities have changed over time, and there is the danger that models that unrealistically simplified certain issues that were not very important in 1965 will be used without modification to study those issues now.

This is more than an abstract danger. Several studies[76] have used the standard four-step model to demonstrate that denser, mixed-use development can reduce total travel. But this result arises from the very same properties of the model that are criticized in other contexts; namely the assumptions that the number of trips is fixed, and that people prefer to minimize travel time.

In the past, higher speeds have induced people to make longer trips rather than spend less time driving. But if shortening trips by increasing speeds has this effect, it is likely that shortening trips by making them physically shorter would too. However, in the forecasting models the number of trips is fixed, so shortening one trip will *by definition* reduce total travel time. This is an artifact of the model, not a fact about reality.[77] Yet these simulations have been cited as if they prove the virtues of high-density development.[78]

The second role that forecasts can play in policy is to provide a consistent set of criteria for comparing different policies. That is, in dealing with pollution or with any of the other problems that transportation can create, there are a number of possible solutions. Some are better than others, all are costly, and not all can be implemented. The question is how to choose between them.

This is an issue not with forecasts, but with how they are used. Currently forecasts for highway projects consist of certain numbers, while forecasts for transit projects involve different figures. This makes it possible to prioritize

[76] Parsons Brinckerhoff (1998, page 55) lists some of these.
[77] Higher density development may very well reduce travel. The point here is not about density, but is about the pitfalls of simulation as a way of understanding policy outcomes.
[78] Parsons Brinckerhoff (1998), for example, discusses empirical studies and simulations as equals, and does not apparently see any problem with this approach.

highway and transit projects within their own categories, but it does not help in the larger decision of how much money to provide to each category. That is, it could be that spending far more on transit and far less on highways (or vice versa) would be beneficial; however, the current evaluation methods do not provide any means for making this judgement.

4 Transportation and Land Use Forecasting

The standard travel demand forecasting model described in the previous chapter produced forecasts of travel using a number of inputs about regional characteristics given from outside the model. One of these inputs is land use, specifically the locations and densities of businesses and residences. The fact that this information comes from outside the model has long been a source of criticism because of the widespread belief that transportation investments and policy more generally exert a significant influence over how land is developed.

The recent surge of interest in this issue arises largely out of two concerns. First is the notion that the congestion-relieving impact of highway building might be oversold because forecasts of future travel might not sufficiently account for the increase in traffic resulting from the new development that extra highway capacity could generate[79]. Second is the idea that current metropolitan land use patterns seem objectionable in various ways, and that transportation policy might

[79] It is worth noting right away that traffic forecasts do *not* assume that highway building has *no* impact on development patterns. The issue is that the extent of this impact is currently determined essentially by heuristic methods rather than by an objective modeling process.

be a good way of influencing better land use given that more direct controls are difficult to implement in the United States.

The problem can be broken down into two related but different questions:

1. How does transportation affect land use? While much of the focus is on infrastructure such as highways and rail lines, less obvious factors such as bus schedules and automobile comfort and safety could also be significant influences on home and business location decisions, and on the style in which land is developed.
2. How does land use influence transportation? Recently there has been much discussion of the possibility of reducing auto travel by using gridded street patterns and higher-density, mixed-use development to reduce street distances between origins and destinations, as well as to encourage walking, biking, and transit.

The objective of this chapter is to discuss and evaluate the extent to which a more explicit and detailed consideration of the link between land use and transportation policy can help the region in making better forecasts and ultimately better policy. There are three levels to this question. At the highest level it is useful to know what, in principle, a consideration of land use can add to the policy making process. A second, more practical level is to ask what benefits can be gained given the current existing state of theoretical understanding of the problem. Finally, the most basic question is about the role that actual existing computer models of the problem can play.

This evaluation takes place, in order from basic to conceptual, in the last section of the chapter. It is preceded by, first, a discussion of the theory of how the interaction between transportation and land use takes place. This is important for understanding the complexity of the role that transportation plays in the broader urban system, and also because it is the theory on which the computer models are based. The middle section is a discussion of the history and the current state of computer-based modeling of this issue.

Basic Principles

The basic concept underlying both the theory and models of a transportation and land use interaction is accessibility. The idea is that, other things equal, the desirability of a particular location is determined by the ease with which one can move between it and other locations. Businesses want locations that are easy to get to from where people live. People want homes in places from which they can easily reach a variety of work and shopping destinations. The idea is that areas that have high accessibility will be attractive to many people or firms, hence the land will be more expensive and likely more densely developed.

In this view of the world, accommodation of population and employment growth is accomplished by allocating land to the uses for which it has the highest accessibility. Accessibility levels change over time, both because new development changes the locations of possible jobs and customers, and also because of changes in the transportation system. For example, a new or expanded highways has the effect of making it easier to get to places near it, making those places more accessible and hence more desirable than before[80]. By contrast, increasing congestion levels have the effect of making places near the congestion less accessible, and thus relatively less desirable than before.

The differing desirabilities of various locations are brought into an equilibrium though land prices and development densities. Desirable locations attract the interest of many potential users, and given that the supply of land at each location is fixed, their conflicting claims are resolved through the price of land at those locations being bid up. In turn, because the land is more expensive (and more profitable, potentially), it will be developed at higher densities than other less desirable locations.

While there is general recognition that other factors[81] matter in location decisions, this notion of changes and differences in accessibility levels is *the* link between transportation and land use, both in theory and in forecasting models. That is, both theory and models allow land use to be influenced by other factors; however, to the extent that transportation matters, it matters because of accessibility.

Accessibility

Accessibility can be understood by considering its two parts, mobility and density.[82]

Mobility is ease of movement: how quickly and conveniently one can get from point A to point B. In general, this will not be a single number, but will depend on a number of factors, such as the locations of A and B (trains move quite fast, but have limited coverage), the modal choices available (driving is faster than walking for most trips), the form of the network (how direct a route can be taken), and the level of congestion. In other words, improved mobility is not like cleaner air – a benefit to everyone. Rather, it is a local benefit, specific to a group of people, or a mode, or a particular set of places, or even a time of day. This local nature of mobility improvements is at the heart of the effect of accessibility on land use.

Density, in the context of accessibility, refers to the density of destinations. The idea here is that what really matters is how many places can be reached in a certain time, not how many miles can be traveled. Like mobility, density is local in nature. It is obviously specific to a physical location, but it also depends on the type of destination desired (business parks may have a huge number of job opportunities, but little in the way of a place to get lunch), and on the time of day.

Density is a physical count of destinations by distance; when combined with mobility, or how fast one can travel, it gives accessibility, or how many destinations can be reached in a given time (for a given mode, type of destination, time of day, etc.).

[80] At the same time, a new highway could also *reduce* the relative accessibility of places that are not near it.
[81] Such as, for example, the desire to live near people of one's own income level.
[82] This discussion is loosely based on Guiliano (1995, pages 307-309). Many other sources such as Southworth (1995) also discuss accessibility.

The two parts of accessibility play opposing roles in linking transportation and land use. Changes in transportation, either to the system itself or to peoples' behavior, imply changes in mobility, which given existing land use will tend to make some places relatively more accessible and others less so. Resulting changes in how land is used, on the other hand, influence density, which given the existing level of mobility, will also tend to change the relative accessibility of different places. As various places become more or less accessible as a result of changes in density, travel behavior and possibly even the infrastructure will change in response, and the cycle begins again.

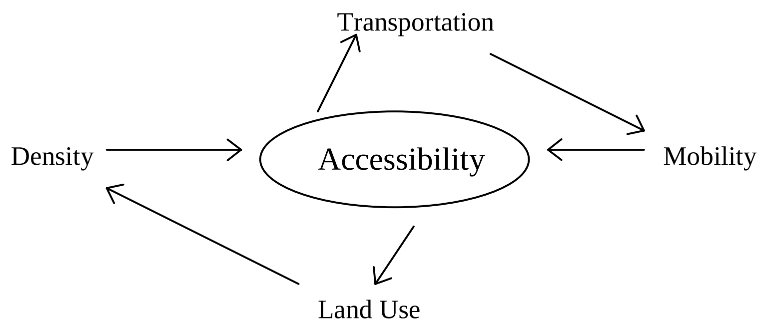

Figure 4.1: Accessibility, Transportation, and Land Use

As an example of how this process might work, consider a hypothetical new freeway between downtown Minneapolis and some remote undeveloped suburban area. The immediate effect is that it becomes easy to reach downtown from this area, increasing its accessibility for work trips for people who work downtown. Some of these people may move there. As the area becomes more populated (denser), its accessibility increases from the perspective of retail and other service establishments, who then move into the area. This change in retail density further improves accessibility (by improving a different aspect of it), which could then provoke further population increase. This process could in principle continue until the success of the area in attracting new business and residents leads to the traffic congestion that led people to leave their old homes in the first place. Thus at the end of the process accessibility could begin to decline, raising the possibility that other places could become more attractive in the future.

It is relatively straightforward to imagine what might happen to a given place when accessibility changes, but what happens to other places, or to the region as a whole? Consider a simple "region" consisting of three village sites, separated by ten minutes of walking and deep gorges. Sites A and B are connected by a bridge and house 1,000 people each. Site C is not connected and is thus unoccupied.

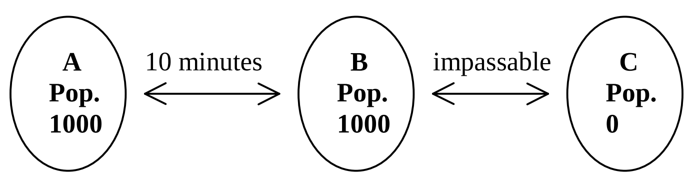

Figure 4.2: Accessibility Example, Initial Situation

Now suppose a bridge is built between B and C, making the trip between them ten minutes. The possibility of cheap land and solitude will attract some people to move to C. As this proceeds, the center of population, which was previously split between A and B, will move more toward B. In particular, people who produce goods for the entire population (rather than for local consumption) will want to locate at B, because it can be easily reached from anywhere. A will decline in relative importance.

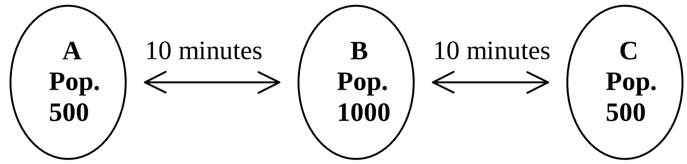

Figure 4.3: Accessibility Example, Final Situation

The final outcome could look something like the figure above, in which the symmetry of the “transportation system” leads to a symmetric distribution of population. The center village, B, becomes relatively more important than the two peripheral villages, because it alone is easily accessible to the entire population. The interesting outcome here is that village A, which had previously been of equal significance with B, has now declined into a second rank, leaving B alone at the top. The decline of A happened because the change in mobility between B and C led to a population shift. This change in density lowered the accessibility of A even though overall mobility had improved, because many destinations were further away than before, and none were closer.

This is an important point. Improving the transportation system in this case actually made accessibility worse for some people, because of the spreading of destinations. This sort of phenomenon may be at the heart of many complaints about “sprawl.” The point to note here is that other benefits may compensate for the loss of accessibility. Developing village C will increase the housing stock, leading to lower prices and more available capacity per person. Lower land prices overall should reduce rents, leading to lower prices for other products. Thus there is some (non-transportation) benefit offsetting the probably higher transportation costs (although it is not inevitable that the benefits overall are bigger than the costs for everyone). This makes an important point: that minimizing the costs of transportation, or even maximizing accessibility, should not be the sole objective of transportation policy. A better objective would be maximizing the overall quality of life, of which transportation costs and benefits are but one element.

Location Theory

The standard theory of urban housing location was developed in the 1960s.[83] Although the assumptions on which this theory is based are fairly unrealistic, the basic results and insights that come out of it can be applied to a broader range of

[83] Guiliano (1995, pages 310-312) summarizes this theory, which has a well-developed literature.

situations. Thus it is worthwhile to examine the very simple, if unrealistic, standard model, as it illustrates the principles without the complication.

The basic idea behind housing location theory is that people have two desires: a short commute to work, and a large lot. The way these two desires are balanced can be easily seen using the standard model, which makes use of four simplifying assumptions:

1. All employment is located in one place.
2. Each household has only one worker, and only work travel matters.
3. The only differences between houses are their lot size and distance from the employment center.
4. Transportation costs are constant and uniform in all directions.

It doesn't require fancy mathematics to imagine the result of such a situation. The desire for a short commute to work means that the locations close to the employment center will be the most desirable (remember that there are *no* other differences between houses, except size). Thus land prices will be bid up near the center, with prices declining as distance from the center increases (and thus commuting costs increase).

As land prices near the center are bid up, those people who care more about a big lot and less about a short commute will gravitate toward the cheaper land further from the center, where they can purchase a bigger lot for the same price. Those who care more about a short commute will pay the higher price for a smaller lot near the center. The different lot sizes resulting from this price differential imply that density is highest near the center and declines with distance from the center. This "gradient" of rent and density is the fundamental result of location theory.

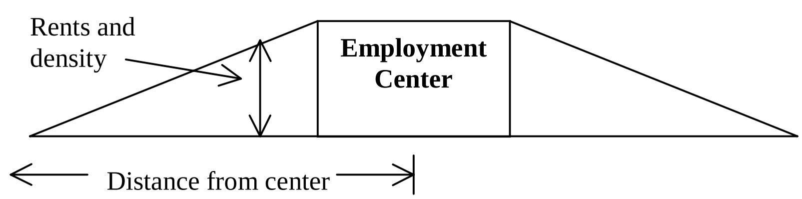

Figure 4.4: Density and Rent Gradients

Modern land use theory and models are considerably more realistic than this, in that they recognize that there are many different types of jobs, that these jobs are located in many different places, and that transportation costs depend on the available infrastructure and the level of congestion. Thus the most desirable locations are those which have good access to many different job locations. The models are still driven, however, by the idea that access to job opportunities is the key element in determining the relative desirability of different locations.

Business location theory has also developed beyond the simple assumption that all business is located in the center of the city. This theory is somewhat more complicated in that there are different types of business, with very different location objectives. Heavy manufacturing firms, for example, will favor locations with cheap land and good access to highways or railroads or shipping, to get their products to out-of-town customers. Retail firms, by contrast, need to be close to where people live. More generally, they will try to locate in places that are accessible to the largest number of local residents, or at least to an adequately large number to support their business. Other businesses might have other types of objectives that influence their location relative to the transportation system.

Forecasting Models

Since the 1960s, various efforts have been made to apply location theory to actual urban planning problems by incorporating the theory into computer-based models. Considerable optimism surrounded these early efforts; however this largely dissipated by the early 1970s due to a number of factors, not least of which was the models' apparent inability to actually predict anything. Important conceptual objections were also raised at this time.[84] Although some of these early problems were the inevitable product of the infancy of the enterprise, and have since been largely solved, other important limitations remain.

The purpose of this section is simply to describe, in broad outline and with a few details, how "integrated" models of transportation and land use work and how they could be (and have been) applied to policy problems.

It is worth stating explicitly two things that this section will *not* do. It is not a comprehensive or detailed technical discussion of different types of models. While there will be some technical detail to enable interested readers to understand more clearly how the models work, the ultimate objective is to evaluate the models' applicability to policy questions rather than their technical characteristics *per se*.

Neither is this an evaluation of the "best" forecasting model for use in the Twin Cities. To make such a judgement would require knowing in some detail the uses to which a model would be put, and that is a matter of public policy.[85] In any case, an important conclusion of this chapter is that large-scale computer modeling may not be the best approach for the types of questions we need to be able to answer.

Computerized land use forecasting models are based on location theory and accessibility. Essentially, what they do is replace the trip generation and distribution steps of the standard four-step travel demand forecasting model with an explicit (endogenous) derivation of land use patterns, and hence trip origins and destinations.

Specifically, the standard four-step travel forecasting model takes the locations of households and jobs as given by some outside authority. It then uses principles of accessibility to link specific origins and destinations. At the end of the process, when trips have been allocated to routes, some roads will be congested. A feedback loop can then be done, in which this congestion will change the relative

[84] The classic criticism was Lee (1973). The Winter 1994 issue of *Journal of the American Planning Association* revisits this issue.
[85] Oryani (1996) is an interesting example of such an evaluation.

accessibility of some destinations, changing the trip distribution pattern and restarting the forecasting process.

The land use models follow a similar logic, but take it one step further, in that congestion can affect not only the destinations of trips, but also where the households and jobs themselves are located. That is, there is a possibility that congestion could not only lead people to make different trips, but it could even induce them to move to a different part of town. The locations of new households and jobs are also influenced by the locations of existing households and jobs, so that this piece of information is determined inside the model rather than given from outside.

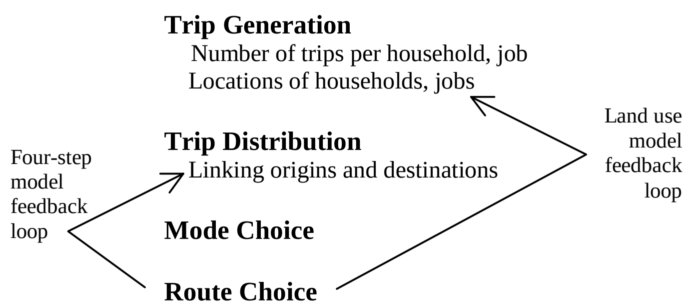

Figure 4.5: Four-Step and Land-Use Models Compared

It is worth emphasizing the point here that the land use models do not necessarily add new information to the forecasting process, but merely change how some of the information is calculated. Specifically, these models calculate the locations of households and jobs explicitly, based on location and accessibility theory, rather than taking them as given by an outside source. Furthermore, they “internalize” the link between transportation and land use by directly incorporating feedback from congestion levels to land use and location decisions. But it should be borne in mind that using these theories, and incorporating expected congestion into predicted land use, could in principle (and may in fact) be part of the external, judgement-based process currently in use here. In other words, the issue is not that the land use models create new information. The issue is that they might create this information in a more accurate or more objective way, and this is what needs to be evaluated.

Southworth (1995, page 16) identifies about 20 models of transportation and land use currently in use worldwide, with the major concentrations in the United States, Europe, and Japan. All the models use accessibility as the motivating force in location decisions. All are aimed at evaluating transportation system changes, and some also consider land use restrictions. However, there is considerable variation of purpose and technique within these general themes.

Model purposes fall into two classes, predictive and normative. Predictive models, which are the majority of existing applications, attempt to predict land use outcomes given a set of policies. Normative or evaluative models come at the problem from the opposite direction. Given a set of policy objectives, such as minimizing congestion or travel distances, they attempt to find the land use patterns that would best meet that objective.

Normative models are simpler than predictive models, since they are just finding the best solution to a problem, rather than attempting to describe how people might actually behave in a given situation. In other words, they don't predict how a region might actually evolve, but merely to describe the "best" way to achieve certain objectives. Of course the problem with these models is that we don't have a benevolent dictator who can control how people develop land, thus the problem they solve is somewhat unrealistic. More useful are the predictive models, which ask: Given those factors we can control, what is the likely outcome of a particular set of policies?

While the problem solved by normative models is not necessarily realistic, there is an important point that they highlight. That is the point raised throughout this report; that policy evaluation consists of both predicting the outcome and judging whether it is more desirable than some other outcome. While the normative models are not useful in that they do not help to know how to achieve particular outcomes, they do potentially provide a means of evaluating which of several alternative outcomes is "better." In particular, such models force the planner to answer the question: what are the objectives you want to achieve? This contrasts with predictive models, which predict the outcomes of specific policies, but which in most cases implicitly assume that the planner has some other means of evaluating which outcome is most desirable.

Many different mathematical techniques are used to predict land use and its relation to transportation. They differ in terms of their complexity, the theories they use, and the extent of empirical calibration, but none of them has emerged as dominant in terms of accuracy or insight.

The sheer variety of methods precludes a detailed or even superficial technical discussion of their similarities and differences. The purpose of this discussion is to evaluate the models with respect to the contributions they can make to the planning and policy process. In this sense, what are important are the features that the models share in common, given that differences in technique do not seem to imply differences in accuracy. There are good technical discussions available elsewhere.[86] For this reason, the focus here is on commercially available models rather than on providing a comprehensive technical description of the full range of models.[87]

Of the 20 or so models identified by Southworth, most are local or proprietary in nature and hence unavailable for general public use. Oryani (1996) identifies seven models as being commercially available, of which only three (at the time of that report) had an adequate base of users to allow evaluation.[88] These three are ITLUP, MEPLAN,[89] and METROSIM.

ITLUP (Integrated Transportation Land Use Program) is the product of Dr. S. H. Putman, and is currently the only land use model in widespread use in the U.S. It consists of two major components: DRAM (Disaggregate Residential Allocation

[86] Southworth is a good and easily available example.
[87] Oryani (1996) also discusses the experience of different agencies with actually using land use models, which is another dimension by which models can be described. However, he starts from the assumption that a model is necessary, and that the problem is finding the best means of implementation.
[88] Oryani (1996), page 125
[89] TRANUS is a derivative of MEPLAN that has recently been used in Oregon.

Model) and EMPAL (Employment Allocation). This model has been used by more than twenty public agencies.[90]

MEPLAN was developed in Britain by Dr. Marcial Echenique and has been used in Europe, Asia, and South America.[91] It does not seem to have been used by any American cities, although its offspring TRANUS has recently been used in Oregon. These models make more extensive use of economic theory in their methods for allocating land among competing uses, but this comes at the expense of considerably increased data requirements.

METROSIM, developed by Dr. Alex Anas, is a more recent product arising out of applications in Chicago (CATLAS) and New York (NYSIM).[92] Like MEPLAN, it is based on economic theory, with prices serving as the mechanism by which resources are allocated and markets cleared.

These models all use different mathematical and theoretical methods, but they all solve basically the same problem using more or less the same information. They all start with externally generated estimates of regional population and employment, and with a description of current land use (and with other inputs in some models), and solve the following set of problems (not necessarily in this order):

1. Predict the location of future housing, based on the current location of firms (jobs and shopping opportunities), and the cost of travel to the different possible firm locations.
2. Predict the location of future firms, based on the predicted location of future housing (potential workers and customers), and the cost of travel from those housing locations.
3. Match population to jobs, to determine commuting patterns, and as an input to predictions of total travel.
4. Calculate total travel on each road and the resulting congestion levels; use this as an input to steps 1-3.

This broad description can be better grasped by a more detailed examination of the workings of a specific model. Again, the objective is to focus on the common core rather than on the differences between models. ITLUP is the simplest of these three models, both in terms of the number of variables considered and the mechanism used to allocate housing and commercial space to locations. It also has the advantage of being by far the most widely used of these models. Thus it is the logical choice for a more detailed description.[93]

Residential location in the ITLUP model is broken down by household "type," in recognition of the fact that similar households tend to group together. Types in this model are typically income quartiles or quintiles, although factors such as race could also be considered. The model predicts the number of each type of

[90] Ibid., page 127
[91] Ibid., page 131
[92] Ibid., page 132
[93] It might be worth investing the extra effort to describe one of the more complex models if it were more accurate than ITLUP or had some other advantage. This, however, does not seem to be the case.

household (and by extension, total population) in each zone based on essentially three factors.

First is the location of jobs. Jobs, like households, are broken into a number of categories, and a given household type is more likely to hold some types of jobs than others. Second is the cost of accessing those jobs, based on the transportation infrastructure and congestion levels. This is the basic idea of accessibility discussed earlier in this chapter. The final factor is the "attractiveness" of a given zone to households of a particular type.[94]

$$N_i^n = \sum_j \left(\left(\sum_k a^{k,n} E_j^k \right) \frac{W_i^n f^n(c_{i,j})}{\sum_i W_i^n f^n(c_{i,j})} \right),$$

where

N_i^n is the number of type n residents in zone i,

E_j^k is the amount of sector k employment in zone j,

W_i^n is a measure of the attractiveness of zone i to type n people,

$a^{k,n}$ is a regionwide coefficient of the probability of sector k employment by type n households,

$f^n(c_{i,j})$ is a cost of travel function for type n people moving between zones i and j.

The "attractiveness" of zone *i* to type *n* people is based on measurements of the amount of different types of land in a zone, and also on the extent to which it is currently occupied by people of other types.[95]

$$W_i^n = V_i^{\gamma^n} (1 + x_i)^{\nu^n} R_i^{\delta^n} \prod_{n'} \left(1 + \frac{N_i^{n'}}{\sum_n N_i^n} \right)^{\beta_{n'}^n},$$

where

V_i is the amount of vacant developable land in zone i,

x_i is the fraction of developable land in zone i that is already developed,

R_i is the area of residential land in zone i,

n' is the set of all household types excluding type n,

$\gamma^n, \nu^n, \delta^n, \beta_{n'}^n$ are parameters to be estimated.

A similar process determines employment location. Jobs, like households are broken down by type. Types could be based on some kind of industry classification, or on a very simple breakdown like manufacturing, retail, and other. As households are assumed to choose locations based on access to jobs,

[94] Putman (1983), page 177
[95] Ibid., page 180

companies are assumed to locate based on ease of access of households that might provide workers or customers. And like households, there is an attractiveness factor that influences the location of jobs independent of accessibility.[96]

$$E_{j,t}^{k} = \lambda \sum_{i} P_{i,t-1} \frac{W_{j,t-1}^{k} f\left(c_{i,j,t}\right)}{\sum_{j} W_{j,t-1}^{k} f\left(c_{i,j,t}\right)} + (1-\lambda) E_{j,t-1}^{k},$$

where

$E_{j,t}^{k}$ is the employment in sector k in zone j at time t,

$P_{i,t-1}$ is the population in zone i at time t-1,

$W_{j,t-1}^{k}$ is the attractiveness of zone j for sector k,

$f\left(c_{i,j,t}\right)$ is the cost of travel function defined above.

The attractiveness function, as with households, is based on the amount of land in the zone, and on the types of jobs that are already there.

$$W_{j,t-1}^{k} = \left(\sum_{k} E_{j,t-1}^{k} \right)^{\alpha^{k}} L_{j}^{\chi^{k}},$$

where

L_j is the total land area of zone j,

α^k, χ^k are parameters to be estimated.

The model begins with current household and firm locations, and current travel times between zones, and allocates expected future locations based on the above formulae. These locations are then used to generate new estimates of congestion levels and travel times (using the standard traffic forecasting model or something similar), which then go back into the model as inputs to a second iteration. This process is repeated until the predicted locations and travel times are consistent with each other.

The Southern California Association of Governments (1994) has used ITLUP to forecast the land use consequences of some proposed highway improvements in the eastern Los Angeles region. The model showed, as might be expected, that the eastern parts of the region, which became more accessible as a result of the improvements, gained employment relative to the downtown Los Angeles area. In two of these eastern subregions, the total number of jobs was predicted to be about 10% higher with the highway improvements than without them, although in all the other regions the difference in employment levels was 2% or less. Changes in households were also small, in most cases 1% or less. The authors of the study note that it is not clear if these changes are even statistically significant (and the model itself apparently does not resolve this question).

[96] Ibid., page 165

The model also shows that while the improvements would generate some additional trips, the average trip length would decrease (because the additional job growth in the eastern subregions would reduce commutes on average). Furthermore, the analysis shows that the highway improvements in conjunction with shorter trip lengths would reduce congestion, increase travel speeds, and reduce vehicle hours traveled and pollution levels.

The State of Understanding and Modeling

There is a widespread and growing belief that the incorporation of land use models into the travel forecasting process is essential to keeping up to date with "modern" practice. This belief was perhaps started, or at least given a strong boost, by the LUTRAQ study in Oregon in the early 1990s. One part of this study surveyed land use forecasting practices in other metropolitan areas, using a tone and expository method that left no doubt that the routine use of computerized land use models was the ideal method to which all regions should attain.[97]

This belief in the necessity of computerized land use forecasting models seems now to be deeply ingrained.[98] Indeed, while many reports have been written about these models, it is surprising how seldom the authors of these papers bother to explain exactly what the models contribute to the forecasting process.[99] This unquestioning acceptance is surprising in light of the fact that many in the academic community who spend their lives studying these questions are critical, or at best indifferent to these models.[100]

Criticisms of the models point to a variety of different issues. It is perhaps helpful to organize these complaints into three broad categories, corresponding to the levels of policy making discussed elsewhere in this report. The most basic level of criticism refers to the models themselves: whether they are sufficiently accurate and whether they appropriately represent how land use decisions are actually made.

A second level of criticism looks beyond the models themselves to ask whether the state of understanding of the urban system is really sufficient to justify trying to create computer models. That is, as with travel forecasting, the models cannot accurately represent land use decisions until we actually understand how these decisions are made. There is concern that the models are based on a theory of urban development which has not stood up well to empirical testing.

[97] LUTRAQ, volume 1, pages 40-43

[98] More than half of the twenty largest MPOs are using some kind of land use model, and the trend is clearly in this direction.

[99] For example, Oryani (1996) correctly notes that there is feedback between transportation investment, land use patterns, and congestion levels. He then concludes that "this *requires* the use of congested travel times…as an input to a land use model" (italics mine). He does not consider the possibility that there might be other ways to approach the problem.

[100] Lee (1994) writes the most comprehensive criticism. Other writers are more optimistic, but none could be called enthusiastic. See for example, Guiliano (1995, page 320), and Southworth (1995, page 11).

The highest level of criticism looks beyond models and science to ask the question raised a couple of paragraphs ago; namely, what exactly these models can contribute to the policy making process, and whether this contribution is useful.

Technical Issues and Accuracy of Models

If the primary users of computerized land use models were academics using them for theoretical purposes, it would be reasonable that there might be little interest in verifying the models' ability to accurately predict real urban development outcomes. However, the primary users are metropolitan planning organizations, who are using the models for very practical purposes, and for making planning decisions involving real resources. Given this, it seems remarkable that there is so little interest in the question of how well the models do at predicting actual land use outcomes.[101]

Wegener (1994), in a detailed survey of current land use modeling practice, complains that there are "few validation exercises" by which the performance of the models can be judged.[102] Webster (1988), which is the most comprehensive comparison of the various models available at that time, is primarily concerned with comparing the models' results to each other, rather than to actual outcomes. Southworth (1995) gives a few validation results from different models, in which values of R^2 on the order of 0.7 to 0.95 are reported.[103] Putman (1983) achieves similar results for a sample of U.S. and foreign cities.[104]

However, the statistical measure R^2 is not a particularly useful way of evaluating a land use forecasting model. This is a measure of how much of the variation from the mean value of a variable is explained by the model. If the variable is, for example, the value or growth rate of zonal population or employment, then R^2 measures how well the model predicts which zones will be big and which small, or which will grow fast or slowly. But neither of these is that hard to predict. Zones that are big now will likely remain so, and zones that have stopped growing will not likely return to rapid growth in the future.

In other words, simply predicting that the future will be the same as the present could yield fairly high values of R^2, as could a simple projection of current trends. Complex, expensive land use models need not just to predict future land use, but to predict it substantially better than simpler methods. In particular, they need to predict better than planner judgement. It is not clear whether this is the case, as the author was able to find only one example of such a comparison.

This one exception is Putman,[105] who compares actual land use outcomes for two cities to the employment location predictions of EMPAL (the employment location model of ITLUP), and to a simple trend projection. He finds that trend is

[101] Oryani (1996), for example, in the course of a 25 page report aimed specifically at recommending a land use model for actual use, does not even raise the question of how accurate any of the models are.
[102] Wegener (1994), page 25
[103] The common statistical measure R^2 is defined and discussed in the next paragraph.
[104] Putman (1983), page 225. A problem is that all these validation tests seem to be for very short-term predictions, which are not in general what the models are being used for in actual applications.
[105] Ibid., pages 168-9

a good predictor on its own, with EMPAL just slightly better. This was apparently only a short-term, five-year prediction (although it is not clear if the model would do better or worse over a longer period). Unfortunately, no similar analysis is done for DRAM, the ITLUP residential location model.

In any event, we can already make fairly good guesses as to which zones will be bigger than average or grow faster. What we really need to know is how big and how fast different zones will grow. A measure such as percentage deviation of predicted growth from the actual value would be more useful and give a better sense of how well the model is predicting.

Putman makes the point that even if a trend projection predicts just as well as a model, the model still has the advantage that it can be used for policy analysis, since it represents the actual variables driving the trend.[106] This is true in principle, but it raises another significant issue. This is that the values of the calibrated parameters may not be constant over time. The idea here is that the parameter values represent the constant baseline used to predict how people would respond to changes in other variables. If the parameter values themselves do not remain fixed over time, then there is no longer any basis for predicting how other values might change.

The reason for believing that the values may not remain constant over time is that they are not very similar across different cities. Putman gives calibration results for a number of U.S. cities.[107] These results are striking in that not only are the estimated parameters not at all similar across cities, but they don't even exhibit similar *patterns*. That is, parameters that are extremely important in one city may not matter at all in another. In other words, the estimated parameter values seem to be very sensitive to specific local conditions, and thus there is some question whether these specific conditions might not be rendered obsolete by population or economic growth, or demographic changes.

Behavioral parameters (such as those in the models) are supposed to represent fundamental elements of human nature, and as such should not vary much, if at all, from one place to another. The fact that they do means that there is something else going on that hasn't been accounted for, and that the models are not yet correctly specified.

A final criticism of the technical aspects of the models, and a possible explanation for unsatisfying parameter calibrations just referred to, is that the models use a narrow and arbitrary notion of accessibility. That is, the whole notion of a link between transportation and land use lies in the idea of accessibility. Yet rather than determining from a detailed study of data what accessibility is and how it influences decisions, the models simply construct an arbitrary definition, and assert the role that accessibility plays.

Furthermore, the definition used is simple, not reflecting the complexity of either travel behavior or of how access to different types of destinations might influence it. Accessibility might have very different characteristics and influences depending on whether the destination is a grocery store, a regional mall, or an

[106] Although he also finds (page 170) that spatial interaction (transportation and accessibility – in other words, the policies of interest) plays only a small (but statistically significant) role in explaining employment location.
[107] Ibid., pages 217-221

office building. Using simple measures of employment and population density seems likely to miss the very details that are at the heart of the current debate about land use design and transportation behavior.

Theory and Evidence

A common criticism of the early land use models was that they did not have a solid theoretical grounding. That is, in some ways they were just mimicking observed outcomes, with no real understanding of the underlying forces driving them. A detailed model of the interactions of a system, void of any theoretical underpinnings, can be a useful tool for evaluating immediate outcomes resulting from a marginal change to the system. This is, for example, the use of input/output analysis in economics.

However, evaluating immediate outcomes of marginal changes is, in general, not what people want to use the land use models to do. Thus it is important that the models be based on a theory that is grounded in basic human behavior and motivations, and that has been verified by testing against actual data. This makes it possible to predict how the relationship between different variables might evolve over time as the system changes.

Thus a second level of evaluating the land use models is to step back from the models themselves and think about the validity of the general theory of land use and transportation on which they are based; that is, the "location theory" discussed earlier in this chapter. If this theory is in fact well supported, this would be an argument, if not for using the models, at least for investing in improving them.

Standard location theory starts from the assumption that people want to minimize commute time. The basic practical result of this assumption is that changes to the transportation system, by changing some commute times and not others, will tend to change the relative attractiveness of different parcels of land. Unfortunately, reality is not as simple as this.

The effort to identify cause and effect in transportation and land use is hindered by two major complications. First is the dynamic nature of the urban system. Both land use and transportation changes take years to develop, and any effects they cause can also take years. Furthermore, people make long-term decisions such as these based on their *expectations* of future conditions. Thus the fact that, for example, a new highway was followed by development doesn't necessarily imply any cause-effect relationship: it could be that the highway was built because planners correctly anticipated where future development would take place.

A second complicating problem is that both transportation and land use are so intimately related to so many other important aspects of urban life. The last 100 years have seen vast increases in both transportation and urban land use, but they have also seen vast increases in personal income, life expectancy, technology, education, specialization of labor, and many other factors that would be expected to influence both transportation and land use needs.

Guiliano argues that not only is the connection between transportation and land use hard to discern and detach from other factors, but that the connection is becoming yet weaker over time. She discusses four other reasons why the connection is not as strong as it once was, and as it is often believed to be:[108]

1. Most land use changes result from population increases and economic growth, which makes it possible, and in many cases necessary, for both businesses and households to purchase more land and bigger buildings and houses. While a new highway may influence *where* new development takes place, it is not in general the *cause* of that new development.

2. The relative magnitude of transportation changes must be considered. That is, the first ten miles of freeway represented a large change from existing conditions. By contrast, ten miles added to a 200-mile system does not alter the regional network much (although it could represent a large change to its immediate vicinity).

3. The geographical scale of improvements is becoming more limited. That is, most improvements will have major land use impacts only within a fairly limited geographical range. As metro regions grow, the fraction of the region that is affected by a particular transportation improvement declines.

4. Finally, structures are durable. Even if transportation changes were able to influence how land is developed from now on, they can't do anything about all the buildings that are already there, and which will be there for decades more.[109]

This all raises the question of whether the connection between transportation and land use is really strong enough to have much significance to policy making. However, even a weak connection could still be important in certain specific ways. In this case it is even more important that we have a good, empirically validated theory of how transportation and land use interact, so that we can know more clearly how to exploit what may be a few significant connections between the two.

Unfortunately, empirical studies have not been particularly kind to standard location theory. Obviously the notion of a monocentric city is outdated, and the models themselves don't make that much use of this idea anymore. The models do, however, make considerable use of the idea that people wish to minimize commuting costs. And this concept is no more supported by the data than is the monocentric city.

The disconnect between theoretical predictions and empirical reality is so large and persistent that it has been given a name: excess commuting.[110] A number of studies have compared predicted commute lengths (based on the assumptions of

[108] Guiliano (1995), page 306

[109] While this fact may imply that it is fruitless to hope for land use changes from transportation improvements, it could also be a case for arguing in favor of stricter land use controls. If the results of current decisions will affect our lives for decades, this could be seen as implying that we should perhaps be putting more thought into these decisions.

[110] It is interesting that the name "excess commuting" seems to imply that the problem lies in people's behavior, rather than in the theory.

the standard location model) to actual commute lengths; the actual lengths are always twice as long or more.[111]

A popular explanation for this phenomenon is spatial imbalance or mismatch; that is, that urban areas often contain large areas that are primarily residential and others that are primarily commercial, thus leading inevitably to a long commute between the two. However, even when expected commute lengths are calculated based on the actual (not predicted) locations of housing and businesses, the actual commutes are twice as long.

The problem may simply be that commuting is not that important to people; that is, that the standard location model derives decisions on the basis of something that actual people don't consider that carefully. Certainly it is plausible that people would prefer to commute less rather than more; the problem is that commuting may be such a small overall cost that it is always superceded by something more significant. The standard model assumes that all work is the same and that housing is differentiated only by size and commute length. In the real world, however, these ignored factors may be more important than those that the model assumes to be significant.

Here is a simple illustration. In the Twin Cities, the difference between a very short commute and a very long one is only about 30 minutes, or an hour a day. This is a little over 200 hours a year, which at an average value of time of ten dollars an hour, is only $2,000. Thus even if nothing else is considered, a more distant job could easily pay enough extra to compensate for the additional commute, as could the cost savings from a more distant house.

There is a final, more theoretical reason that may explain why the standard location model does not perform as well as expected. This is that the theory is implicitly based on the idea of a kind of competitive resource-type market, which does not seem to reflect very well the way land is actually developed.

The idea of a competitive resource market is that the quantity of resources are fixed, and that people bid on quantity and price, based on what they want to do with the land, until the entire market is in equilibrium, at which point everyone takes possession of their purchases. The urban land development "market," on the other hand, deviates from this norm in three important ways.

1. Decisions about how land is developed and how it is subsequently used are often made by different people. In this sense, land development is more like a production economy than a resource market; in which some groups "produce" developed land and other groups subsequently, and based on different objectives, decide how to "consume" it.
2. A single organization (the developer) decides what to do with a parcel of land, given what can be negotiated with local government officials. The style is what is most profitable (or familiar) to that developer and local government at that time, and need not resemble what would have emerged from competitive bargaining among *all* the region's residents and businesses (including potential future businesses and residents).

[111] Guiliano (1995), page 315

3. Once a parcel of land is developed, it is very costly to change it. Thus, both development and location decisions at a point in time do not stand alone, but are conditioned on the fact that there is an existing stock of buildings which may or may not be optimal for the land they are occupying.

This is all rather theoretical; however, there is an important practical point. If we wish to understand and even exploit the link between transportation policy and land use decisions, we need tools for understanding this link that reflect the critical elements of how land is actually developed, and the role that transportation plays in the process. Models that do not correctly represent the process place us in danger of creating policies that attempt to influence the wrong things, and which fail to influence the factors that really matter.

The Planning Process and the Role of Models

The previous two sections have indicated first that existing land use models don't seem to work as well as could be hoped, and second that the underlying theory does not seem completely adequate. This indicates that for land use forecasting to be viable in the future, some basic research and model improvement will need to take place. The objective of this section is to offer some direction to these improvements by discussing the role that land use forecasts might play in the policy making process.

Using computerized land use models could offer three potential advantages over planner judgement: more accurate and detailed forecasts, better understanding of the land development process, and a greater level of objectivity, that is, freedom from actual or perceived biases or beliefs of human forecasters.

At this point in time no one seems to be claiming that the land use models are significantly more accurate and detailed than planner judgement. (Although to some extent this is because few people have even asked the question.) This issue has already been discussed two sections earlier in this report.

Another possible advantage of computerized models is that they can potentially provide tools for understanding how certain outcomes might arise. That is, with mathematical formulae, it is possible to trace exactly what factors played what roles in a given outcome. This is not quite as straightforward when forecasts are generated by planner judgement.

The problem is that a computer model is just a formal mathematical and logical representation of how someone thinks the world works. All the model does is calculate the mathematical implications of that point of view. In other words, any understanding that the model can provide comes from the scientific process that developed the theory, not from the fact of incorporating the theory into a computer program. And as discussed in the last section, a flawed theory is not improved by being computerized.

The final advantage that the models could offer to the planning process is a greater degree of objectivity. Indeed, the desire to appear to be taking land use seriously in planning seems to be the implicit force behind most of the current interest in these models. While concern about the impact of transportation on land use is certainly laudable, the question remains whether using these land use models is the best way to express this concern.

As discussed before, models replace planner judgement about land use with an explicit model based on access. Beyond that, they are basically just the regular four-step traffic forecasting model. Nonetheless, this could represent a real improvement if planners do not currently consider that transportation investments might lead to land use changes. It seems unlikely, however, that this would be the case. And if planners are already considering the impact of transportation on land use, then the models can improve the process only by being more accurate. However, as already discussed, they probably are not.

Another possible advantage of bypassing planner judgement might be objectivity. That is, planners might consider transportation impacts, but might do so with certain preconceived biases, or with the desire to justify a certain outcome. If this were the case, an emotionless mathematical model could truly improve the process.[112] On the other hand, so could an independent forecasting organization, as described in the travel demand forecasting chapter.

Lee, as part of his famous criticism of land use models, raises the question of what the model results will be used to do.[113] He makes a useful distinction between tactical and strategic planning, and notes that the two have very different information requirements (by way of claiming that current models don't meet either set of needs).

To think about large-scale, long-term (strategic) changes, high levels of detail are often not necessary. In fact, it could be that no detail at all is necessary. For this type of planning, it is often enough just to know, in a general sense, what kinds of things happen under certain conditions, and less important to know exactly where or when or how much. This could also be a simpler problem to solve, in that the "average" effect of a certain policy might be considerably easier to predict than specifically which places will and won't be affected.

However, to think about small-scale, short-term (tactical) policies, a great deal of detail is needed. It is necessary to know all the things that might matter, under what conditions they play a role, and how they exert their influence. This will be a difficult problem, but it would be a valuable problem to solve, as it seems to lie at the heart of many transportation project debates currently underway.

Ultimately, deriving value from using land use models as part of our regional planning process will only be possible if three things happen. First, the models need to be improved. Second, the theory underlying the models needs to be better developed so that its predictions correspond more closely to actual behavior. Finally, we in the region need to understand clearly what we want the models to contribute to the larger policy and planning process. While having models that can predict the land use impacts of policies could be useful in some sense; these models cannot answer the deeper question of what land use impacts we *want*, and why we might prefer one type of land use to another.

[112] Although human judgment is still needed to program and calibrate the "emotionless" model.
[113] Lee (1994), page 37

5 Problems and Policies

This chapter brings together the ideas and implications of the previous three. These earlier chapters took the need to make policy as a starting point to develop a more abstract, generic discussion of the important issues related to travel demand and what we know about it. These chapters established the point of view that urban life in general is the appropriate context within which to analyze and discuss transportation problems and policy: the transportation system does not exist in a vacuum. The purpose of this chapter then is to come back to the starting point; to look at a specific set of problems and policy options as a way of exploring the types of questions we need to be able to answer.

This exploration is carried out along three different directions. First is a discussion of the implications of our knowledge of travel demand on some issues of general importance for policy making. These themes are especially significant because they play a role in most or all of the specific problems and policies that are considered subsequently. Thus their general importance can be more easily apprehended and appreciated if they are discussed outside of the context of a specific problem or policy.

The second direction of exploration focuses on problems. The idea here is to work through a representative (but not comprehensive) sample of problems that are often cited as being transportation-related, and frame them within the broader context of urban life, rather than viewing them in isolation, as is often done. The perspective taken is that transportation (and its role in the urban system) is complex, and that understanding problems requires correspondingly complex thought and argument. The goal is not to propose solutions, but simply to examine the implications of this point of view in terms of the pros and cons of different possible solutions, and of the additional knowledge that we will need to make good decisions about these problems.

The third and final direction is to some extent the opposite of the second; that is, to look at specific policies and think about what kinds of impacts they might have on the broad context of urban life. Again, the perspective taken is that of complexity; considering the likely impact of policies on the various dimensions of travel and their interrelationships. Again, the point is not to recommend one policy or another, but simply to examine carefully which policies might be effective at solving which kinds of problems, and to determine some of the important questions that we can't yet answer given our current state of knowledge.

The purpose, then, is not to influence the outcome of the transportation policy debate, but merely to influence its focus and methods. Problems and policy ideas are unfortunately too often discussed from an excessively narrow, simplistic, and often partisan point of view. This has two undesirable effects. First, problems and ideas for solving them are made to appear either better or worse than they really are. This can lead people to choose sides prematurely, based on incomplete or incorrect information. Second, it makes problems and solutions look simpler than they are, by failing to recognize the broader context within which seemingly narrow policy decisions take effect. This can have the effect of polarizing the debate and can lead to important considerations being omitted.

Ultimately, these issues are complex. Attempts to influence the system will probably at best impact some specific aspect of it; yet at the same time could generate unanticipated side effects both within and outside of the transportation system. Taking the point of view that transportation problems can be easily solved with simple, one-dimensional policies is not a useful approach. A complex system requires a complex, fact-based understanding.

General Issues

There are three broad issues that are important to a broad range of specific problems and policies. So that their general significance can be best appreciated, they are treated here, outside of the context of any specific problem or solution.

The first issue is the contrast between description and evaluation. These are complementary but quite different parts of understanding the transportation system. Description, or prediction when it is applied to the future, is concerned only with what the characteristics of the system are, or will be. Evaluation takes up the other side of the problem, that is, whether and in what sense the described characteristics represent something good, or an improvement over some alternative set of conditions. The idea of accessibility can provide an intuitive means of connecting these two sides of the forecasting problem, since it can be both a way of measuring the quality of the system and a tool for predicting how people will respond to it.

Considering the importance of evaluation leads naturally to the second general issue, which is the method by which evaluation is done. Cost-benefit analysis is the standard evaluative tool in policy analysis, but different modes are evaluated based on different costs and benefits, making it difficult to compare them. Also, the incidence of costs and benefits can be important, and current methods often don't address this issue. Again, accessibility can provide a means of improving on some of the problems with cost-benefit analysis as it is currently practiced, by providing a common method of describing the benefits and incidence of transportation improvements.

The final issue of general importance is induced demand. The idea of induced demand is that transportation improvements, by making it easier to drive, can generate additional traffic; thus negating at least some of the benefits that they were intended to create. While this problem is cited most often in the context of highway improvements, it could reasonably be considered relevant to almost any transportation improvement at all.

Prediction, Evaluation, and Accessibility

Using forecasts to make good policy requires that two different but related problems be solved. First it is necessary to be able to predict what will happen under various policy scenarios. This is fundamentally a technical problem: understanding how the transportation system works and how it will respond to various kinds of incentives or constraints. The second problem is to use these predictions to evaluate the relative merits of different policies. This is a more judgmental process; its outcome will depend on the priorities of the person doing the evaluation.

These are basically different things: a policy can do everything it was expected to do, and yet fail to make anything better. Conversely, the effects of a policy could fall far short of expectations yet still provide significant benefits.

The link between these two problems lies in the concept of objectives, or what people want to be able to do with the transportation system (and with their lives more generally). Understanding what individuals want from the system can obviously simplify the evaluation problem; policy makers would not have to rely on their own personal preferences or hunches about what the broader public might want. The "performance" of the system could in principle be measured, from the point of view of the people using it. Currently it is necessary to use indirect measures, such as transit ridership or levels of congestion, which may be only weakly linked to how well the system is serving its users.

Using objectives to improve prediction is a less obvious application. The idea here is that it might be possible to improve predictions of behavior by using well-developed concepts from economic theory. Economists view behavior as resulting from people trying to achieve certain objectives subject to constraints of various kinds. The classic example is household spending: households have a budget constraint, within which they attempt to maximize the utility that they receive from the various goods, such as housing and food, that they can purchase.

The way this idea could be used to improve travel predictions is by treating travel in the same way as any other good; that is, as one of the many possible ways that people can spend a basically fixed budget of money and time. The difficulty in using this approach is that it is not clear what people's travel objectives are.

One way of approaching this problem would be from the point of view of accessibility as a measure of objectives. An argument could be made that the reason people incur the extra cost and stress of living in a city is because they want access to destinations that are only available in cities. They could be motivated by either the sheer variety of possible destinations, or by a small number of specialized destinations, such as a particular job, or set of suppliers to a business.

Not only do people want to be able to access destinations, they want that access to have certain characteristics. An obvious piece of evidence supporting this assertion is the sizable amounts of money that people spend in order to have certain features in their cars. Furthermore, the characteristics of travel that are highly valued could depend on the purpose of the trip, or the situation of the person making it. The consistent timing offered by a bus using a dedicated lane might be of great value to a person going to work, while a parent taking a bunch of kids home from soccer practice could be more concerned with space, convenience, and a flexible route.

In other words, people are not just concerned with how long it takes to get somewhere. While this point is generally recognized, there is not yet much detailed knowledge of exactly what characteristics people value in what circumstances, and how much they value them. As a result, forecasting models end up relying on travel time as a proxy for all these other factors. The problems with using time as a measure of everything are that time savings might be overvalued, while the importance of other types of features might be underestimated.

Given the apparent difficulty of measuring accessibility, it is worth discussing the potential advantages of doing so. One advantage is better prediction, not so much in the sense of more accuracy as in the sense of more flexibility. Our current forecasting models are organized around travel time as the main motivator of travel decisions; given this, they are obviously much better at predicting the outcomes of policies that will improve travel times than policies that change other aspects of the system. To some extent this built-in bias could tend to perpetuate the policy status quo: innovative policies might not be given due consideration simply because there is no way to predict what their effects might be. If we had a general understanding of what people want from the transportation system, it would be simpler to judge what travel characteristics a particular policy innovation might generate, and from this to predict how people would likely respond.

The other major advantage of understanding accessibility is that it provides a natural way to evaluate the relative merits of different policies and the performance of the system more generally. Current discussion tends to focus around specific improvements such as reduced congestion, better transit, or walkable neighborhoods. But these are all just different ways of improving access to destinations, either by making it faster or by improving some other quality of the trip. If all these different types of improvements could be described using a common framework such as accessibility, it would be considerably easier to compare the benefits of the many ways of spending a limited transportation budget.

Many statements made about transportation policy are speculation – we don't have the detailed understanding of how the system works to know for sure what will happen in most cases. Furthermore, even if we could predict the outcomes of policies with complete objectivity and accuracy, we still don't have an objective way of turning predictions into costs and benefits. Understanding and measuring accessibility seems like the best hope we have of addressing these problems.

Working out a good definition of what accessibility means will not be a simple task. It will be necessary to determine not only the potentially large set of transportation system characteristics that people value, and how much they value them, but also to clarify how those valuations depend on the specific situation. While this problem is intimidating, the potential benefits of solving it serve as a strong motivation.

Cost-Benefit Analysis

Throughout the past, and especially in the last few years, there has been a strong emphasis on producing accurate forecasts. But while forecasting can certainly be improved, there is another significant and largely unrecognized gap in our ability to make good policy. This is our lack of good evaluative tools; that is, some objective way of interpreting what the forecasts imply about how policy should be approached.

The primary point, as described earlier in this report, is that in understanding travel demand, the details matter. The problems we face and the merits of different policy ideas hinge on specific details about regional travel. Without some kind of standard method of presenting forecasts and discussing their implications, we run the risk that expensive and irreversible policy decisions will be made on the basis of information that is irrelevant, misleadingly represented, or taken out of the appropriate context.

Prediction in itself has no particular value. Its value arises because it can be used to make decisions about future actions. But this is not a simple or obvious process. And while lawmakers as elected officials rightly hold the bottom line on evaluation and decision making, their ability to perform this function is degraded by two significant handicaps. First, they are generally not experts in transportation and are aware in only a limited and often selective sense of its complexity both in itself and with regard to the rest of the urban system. Second, they are not experts in the forecasting models and thus do not know how the numbers were derived, and thus to what extent the conclusions of the model can be taken at face value.

For example, studies have been done in which traffic forecasting models have been used to show that mixed-use development leads to fewer and shorter trips, and thus to less total driving.[114] But this result is an artifact of the model structure, not a fact about the world. The standard traffic forecasting model takes the basic number of trips as fixed. Also, trip destinations, while flexibly

[114] See, for example, Middlesex, Somerset, Mercer Regional Planning Board (1990).

determined, are based on the relative attractiveness of the various destinations, which is fixed. Thus in the model, by definition, eliminating or shortening a particular trip will not lead to changes in the number or destinations of other trips. We do not, however, know if this is true in reality; and there is in fact evidence to the contrary, as discussed in the chapter describing Twin Cities travel patterns.

Most likely there is no single solution to transportation problems. Some types of trips might be best improved through better transit service, while others might benefit more from reduced congestion. Even what it means for a trip to be "improved" is probably different from one trip to another. To make better transportation policy, we will need to focus on specific people or places or types of trips and think about what kinds of changes could reduce problems while maintaining the same level of benefit.

Given the complexity of the problem, it seems likely that many different kinds of policies may play a role in our transportation future, with each policy aimed at solving a particular class of problems. There may even be more focus on using different policies to complement each other rather than viewing individual projects in isolation, as is often done now. This raises again the problem from the last section, that there is a need for a standard way of representing and evaluating the results of different types of policies.

A standardized method of cost-benefit analysis would make it possible to compare the relative merits of different kinds of policies, by providing a common framework for discussing what the merits are and who benefits from them. This could help to put innovative policies on a more equal footing with traditional approaches to problems, by providing a meaningful way of comparing the two. In addition, it would make it possible to evaluate combinations of policies, which might currently be evaluated by completely different criteria.

Using policy-specific, indirect evaluation criteria such as time savings or transit ridership, as is done now, opens the possibility of two types of mistakes. First, it is not inconceivable that an idea could be proposed that performed well when measured by the current criteria, but which actually worsened accessibility, either immediately or in the long run. (Some would argue that highway improvements are like this.) Second, an idea which would genuinely improve accessibility might be rejected because it does not perform well against the indirect criteria. For example, widening a congested road might not relieve congestion if new trips are made, but it still improves accessibility since more people are able to travel than before.

Cost-benefit analysis should ideally be done in the broadest way possible: all effects, direct and indirect, transportation and other, should be considered. (To some extent this would be inevitable if all modes were to be evaluated using the same criteria.) The costs and benefits of a project or policy not need be measured in terms of dollars, and in fact may not even be quantifiable. However, they should at least be describable, ideally in comparison to some alternative situation involving a similar amount of expenditure.

In addition to considering the impact of a policy on accessibility and on the level of negative externalities generated by the transportation system, it is also important to consider the broader effects of transportation on society and the economy. Transportation improvements and externality reductions need to be achieved in ways that don't negatively impact the broader economy and society which the transportation system is ultimately intended to serve.

[In this context, it's worth noting that job creation should not be counted as a benefit of transportation spending. Anything at all that is done with the money will have basically the same job creation effects. The relevant question is whether the project will give taxpayers more utility than other possible projects, and more than they would get from spending the money themselves. Furthermore, in a full employment economy such as we have now, big government transportation projects could actually harm the economy by drawing skilled workers away from the private sector, or by postponing maintenance of the existing system.]

Finally, since the point of cost-benefit analysis is to provide an objective way of comparing policies, it is important that it is, in fact, objective. This is not simply a matter of using good analysis tools, but also requires that political considerations do not play a role. (There is a place for politics, but it is in debating the numbers, not in producing them.) An unfortunate characteristic of the current system is that forecasts are produced or supervised by agencies or organizations that have a stake, either financial or political, in the outcome.

This is not to say that organizations are fudging the forecasts for their own gain. The problem is that the current system raises the possibility, or the appearance, that such things could occur.[115] Proposed highway improvements are routinely opposed by groups who believe that the forecasts overestimate the benefits and underestimate the costs. And the fact that the sponsor of the project is also the sponsor of the forecasts gives this belief some apparent credibility.

The response around the country to this problem seems to be a push for better forecasting models, in particular land use forecasting. In fact, given the dubious scientific and practical value of the available land use forecasting models, it could be argued that the main reason for their current popularity is the desire on the part of government agencies to appear more objective in their approach to land use.

But a much simpler alternative would be to have an independent organization create or audit the forecasts. Better models might make the process more objective; but they will not make it *appear* more objective, as long as forecasters have a stake in the outcome. An auditing group, set up somehow so as to be free of political pressure (and chosen so that different points of view are represented) could go far toward creating the appearance, as well as the fact, of objectivity. And this, in turn, could help the whole process of policy discussion and public debate flow more smoothly. While this might not be a perfect solution, it would be worth thinking carefully through the pros and cons of such a system.

[115] Wachs (1995, pages 274-5), discusses the phenomenon of forecasts being modified under political pressure, to get the results needed to qualify for federal funding.

The Question of Induced Demand

The problem of induced demand has arisen most dramatically in the context of highway improvements in highly congested areas. Highway improvements are promoted as a way of reducing congestion and saving driver time; however, when the new highway is opened, it is immediately as clogged with traffic as the old one, apparently because its presence "induced" new or longer trips.

Traffic on a new or expanded highway can be broken down into the following categories:[116]

- Existing traffic
- Natural-growth traffic – arising from demographic and socioeconomic changes
- Diverted traffic – from other roads
- Transferred traffic – from other modes
- Shifted traffic – trips going to different destinations because the new road has made them easier to reach
- Induced traffic – trips which would not have been made at all in the absence of the new road
- Development traffic – generated by land use changes
- Time-shift traffic – off-peak trips shifting to the preferred peak time

Thus there are many reasons why a new or expanded road might fill up sooner than expected. All of them arise from the same basic source of travel becoming less "costly," but only one of them is strictly speaking "new" trips. The anecdotal evidence that road expansion has often failed to relieve congestion has led to the popular belief that "you can't build your way out of congestion." While the truth of this assertion may seem obvious given the experience of the last few decades, it is unfortunately not as true as it is catchy. As with many other popular ideas about transportation, its simplicity is both its appeal and its downfall.

First, from a theoretical standpoint, driving is no different from any other activity or product – there is a finite limit to how much people want to consume. While there have been cases of highways seeming to generate new traffic, this is what would happen with any product in which the supply was not as large as peoples' desired consumption. If everyone wants to eat three oranges a day but only two are available, then increasing the supply to three will generate "new" demand for oranges. But increasing the supply further, to four oranges per day will not generate new demand, because demand is saturated at three. Likewise, if peoples' ability to travel is constrained by a lack of highway capacity, then increasing capacity will facilitate the additional (or changed) travel that people wanted to do anyway. But once they are traveling as much as they want to, new capacity will not continue to induce additional travel.

From a historical standpoint, the huge increase in traffic of the last 30 or 40 years was, as discussed in the section on Twin Cities travel patterns, due largely to two

[116] Southworth (1995), page 4

non-recurring events. One was the replacement of people who grew up in the pre-auto era, and who didn't make many trips by auto, with people who grew up with cars. This shift was especially pronounced among women, who had the additional boost of entering the workforce in large numbers. Now that this shift has taken place, it appears to be played out. People born in the 1950s and 1960s don't make any more trips than their parents.

The other non-recurring event was the original construction of the freeway system, which led to substantial increases in trip lengths in miles (although not in time). It is understandable that the change from a system based on local streets, with average speeds of six or seven miles per hour, to a system based on limited access highways, with speeds of fifty miles per hour, would lead to considerable changes in habit. However, freeways are now ubiquitous, and thus any further expansion would increase speeds for only a small fraction of regional trips, and would thus probably not lead to much overall change in trip lengths.

Empirically, the simple point is that the U.S. cities that rank as having the lowest levels of congestion are also for the most part the cities with the most miles of roadway per person,[117] and the cities with the least road per person also have in general the worst congestion.[118] There are plenty of small cities and towns that have no meaningful congestion at all. Thus in a purely technical sense, it would seem that you *can* build your way out of congestion.

The one sense in which congestion may be inevitable, is locally. If a particular area is congested because of a high concentration of destinations, such as might occur around a regional shopping mall, then increasing road capacity in that area, while it would likely have little effect on trip quantities overall, could have a big effect on the number of trips coming *to that area*. Lots of traffic, while bad for drivers, is good for businesses, because it increases their exposure to potential customers. Hence, in the absence of controls on land use, the increase in local traffic would tend to attract even more businesses to the area, thus attracting even more new trips. Thus even if the new road capacity was adequate for the trips generated by the existing businesses, it would again be inadequate once new businesses locate there and generate more new trips. (This is an example of the "land use changes" in the above list.) And further increasing road capacity could simply start the cycle over.

This is a good example of the importance of the connection between transportation and land use, and the ultimate futility of trying to create transportation policy in the absence of consideration of and cooperation with other types of urban policy. It could be the case that we could easily build enough roads to accommodate all the traffic we will ever have (indeed, we may already have done so), but that we can never reduce congestion because too much of that traffic is concentrated on a small subset of all the available road capacity.

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[117] The Texas Transportation Institute creates congestion ratings for major U.S. cities. (http://mobility.tamu.edu/) The federal government publication *Highway Statistics* gives information on road mileage in cities.

[118] Los Angeles, for example, contrary to common belief, has the highest population density of any major metropolitan region, and the fewest miles of road per person. While the Los Angeles region does occupy a large area, and does have many miles of roads, it also has more than 12 million people; so the amount of land and road *per person* is not as large as in smaller cities.

There are two more important points relating to induced demand. The first is that even if a new highway does not reduce congestion, it is still improving accessibility, because more people are able to make trips, or they are able to make existing trips in a more preferred manner, by using a different route or mode, or travelling at a preferred time of day. Thus there are still important benefits even if there are not travel time improvements.

The second important point is the antithesis of the first; namely that even if a new or expanded highway does inevitably create benefits, it is still not at all clear that this alternative creates the *most* benefits while generating the fewest costs. In other words, the fact that highway expansion can be a good thing doesn't prove that it is the best thing. This is the challenge of future transportation policy – to understand the nature of the benefits that our auto- and freeway-based system has created, and to determine if there are other ways of achieving those benefits that are not so costly and damaging to the social and natural environments.

Understanding the Problems

The objective of this section is to work through a number of representative area problems or issues, to show the number and complexity of details and unanswered questions that need to go into answering them, and to consider the implications of viewing these problems as part of the broader transportation and urban system rather than addressing each one in isolation.

Transportation-related problems are not as simple as they are sometimes made out to be. It is hard to find an effective and implementable solution to a given issue. This is particularly true given that problems arise from different and sometimes conflicting sources – a solution to one problem is unlikely to have much impact on others, and when it does this impact is perhaps as likely to be negative as positive. Thus it is important to consider the interrelationship between problems rather than viewing each in isolation.

Land use-transportation connection

This is an issue that has generated considerable interest in the Twin Cities, and it is one of the basic themes of the Transportation and Regional Growth research project. The gist of the problem is this:

> The traditional four-step modeling process is sequential and ignores the effects of transportation access on land use, and, therefore, trip generation. … legislation such as the 1990 Clean Air Act Amendments requires that such factors be considered.[119]

The driving force in pursuing this idea is the notion that congestion occurs because too many people are using the same road at the same time, and that this phenomenon is at least partially due to the number of destinations that are accessed via a given road. Thus it may be possible to help with a transportation problem through the non-transportation policy of encouraging new development

[119] Cambridge Systematics (1994), pages 2-9

to take place in areas that are not already congested. Alternately, dense development may not be a bad thing if it is possible to access it by some means other than private automobile. Thus another option is to encourage development in areas that are well served by mass transit, or in which modes such as walking or bicycling are viable.

The basic principle here is that travel behavior and the problems it can create are conditional on longer-term choices; in particular where to live and work and how many cars to own. If it is possible to influence these long-term decisions in a relatively unobtrusive way, it may be that expensive direct interventions in the transportation system can be avoided. At the very least, we would like to avoid encouraging long-term choices that will ultimately make the situation worse, as many people claim that low-density suburban development has done.

There are two fundamentally different questions involved here. The first is whether and in what sense land use matters to transportation outcomes. Obviously more destinations in an area means more traffic, but what is the effect of broader land use changes? For example, if development everywhere in the region were slightly denser, would that make for shorter trips and more use of mass transit? Or would it just make congestion worse because there would be less road capacity? Would mixing residential and commercial land induce people to shop more in their own neighborhood? How dense does development need to be before mass transit becomes a really viable option for a large number of people?

These questions are at the heart of many policy proposals, and although proponents of aggressive land use policies talk confidently of the benefits of their ideas, their confidence seems to be based more on faith than on strong empirical evidence. The disquieting fact remains that there is not a great deal of compelling evidence one way or the other on these issues. Not only can we not predict what will happen, but we have no good means of evaluating whether any such changes would be desirable. For example, if people were to walk and use transit more in densely populated areas because those modes were more effective, that would be a good thing. If, on the other hand, they used those modes not because they wanted to but because the high density made driving miserable and parking impossible, that would not be such an unambiguously good thing.

The second question comes at the problem from the opposite direction: How do transportation patterns, and the transportation network, affect how land is developed? The possible irony here is that improvements to the network, by making travel easier, might attract so much new development that the system ends up functioning worse in the long run. Understanding how transportation affects land use might help in designing improvements in such a way that they don't become self-defeating, or at least to avoid investments whose benefits might be so short-lived as to not justify their expense.

Unfortunately, as discussed at length in the chapter on transportation and land use forecasting, surprisingly little is really known about the influence of transportation infrastructure and policy on land use and development. While development frequently follows infrastructure, it doesn't always; nor does development always wait for infrastructure. In general, it seems to be the case that roads (or rail lines) won't make people locate where they wouldn't otherwise want to; neither will the absence of adequate road capacity prevent people from developing otherwise desirable locations. People can still move there, knowing that once they are there, it will be hard for policy makers to resist their calls for better highway service. Transportation most likely influences the speed of the development process more than its location.

In summary, land use changes could in principle be a good way to solve or at least delay certain kinds of transportation problems, especially congestion. The two problems with this approach are first, that we don't really have any idea of how different land uses would actually influence overall travel behavior; and second, that even if we did know, it would be difficult to evaluate if this would represent a gain or a loss to society. And until we can answer those questions confidently and objectively, it will be impossible to convince people that they have something to gain from submitting to new rules about land use.

Congestion

This is the "classic" urban transportation problem. While everyone has experienced it and it seems obvious enough why it happens, it is still worth thinking a bit about it. Congestion is, at its most basic, a matter of too many cars trying to pass through the same stretch of road at the same time. There are basically three ways of dealing with it, and there is insight to be gained by thinking about the implications of each, as there is a certain amount of public mythology surrounding this issue, not all of it factually or logically correct.

The first, traditional way of reducing congestion is by increasing the capacity of the road. This is simple arithmetic: twice as many cars can get through if there is twice as much space. In some cases even increased capacity is not strictly necessary; turn lanes can remove problematic stopped cars from the traffic lane, increasing the potential throughput.

There are three major implications of this approach. First, increased throughput on one stretch of road might simply lead to a new bottleneck further down; as higher levels of traffic reach areas that may have only been equipped for the lower levels allowed by congestion elsewhere. Second, it could be a somewhat self-defeating strategy because removing this barrier to driving might encourage more people to use the road, thus creating congestion even at the higher capacity (although this would still be creating benefits). Third, increased traffic throughput might be good for drivers, but might not be good for the people who live in the neighborhood, for whom that street could become a formidable nuisance or barrier to foot travel.

Strategy two is higher speeds, often by grade separation and limited access (freeways). Some people believe that freeways are a failed experiment, using vast amounts of valuable urban land while ultimately falling victim to the very congestion that they were made to circumvent. However, this perception is not entirely accurate. There was congestion before freeways, and there is again, but there is also about eight times as many vehicle miles of travel, accommodated by a surprisingly small increase in the amount of road space. Freeways constitute only about 3% of the lane miles of road in the Twin Cities, but even with congestion they carry 44% of the total vehicle miles.[120] Freeways do take a lot of land, but they also provide a lot of transportation, even when congested.

The problems with increasing speeds are the same as those with increased capacity, except even more so. In particular, the higher speeds seem to encourage, or at least to facilitate longer trips, and more trips by freeway rather than local streets. While removing traffic from local streets could be seen as a good thing, lengthening trips tends to nullify at least some of the effective increase in road capacity that the higher speeds created in the first place. This is the paradox of freeways, and the sense in which they are seen as self-defeating. Again, however, it is important to remember that reducing congestion is a means to the greater end of improving accessibility, and that while freeways may not ultimately reduce congestion, they do clearly give people access to a range of destinations that would not be possible if local streets were the only option.

The final idea for reducing congestion comes at the problem from the other way, that is, by decreasing the demand for road capacity rather than by increasing the supply. There are two major approaches to this idea: using other modes than driving, and bringing destinations closer together through higher density or different development styles.

The main question with using other modes to reduce congestion is how much potential really exists. Walking and biking are mostly infeasible for all but very short trips,[121] and it's not clear that short trips are really the problem in terms of creating congestion. If transit were successful at reducing congestion, this would just serve as an incentive for transit riders to switch back to driving. Furthermore, the right of way devoted to providing access for these other modes could have been used for additional road capacity, and it could be that simply increasing road capacity might have a bigger impact on congestion. Finally, as alternate modes become more heavily used, they can begin to contribute to congestion in their own right.

However, this again points out the idea that reducing congestion is not an end in itself. While encouraging alternate modes may in fact do very little to reduce congestion, the point must be made again that the objective is not to reduce congestion *per se*, but to improve accessibility. If some people choose to make use of alternate modes, we can assume that they prefer them to driving, and thus are achieving, if not greater, at least more enjoyable access to destinations. If this can be accomplished without making driving conditions significantly worse (which should not be taken for granted), then it would appear to be an idea worth considering, especially since this way of improving accessibility seems to avoid the undesirable side effects of highway improvement.

The other demand-reduction idea has to do with reducing trip lengths through higher density. This was discussed in the land use section preceding this one.

The upshot of all this is that it is inappropriate to view congestion reduction as a transportation objective in its own right. First of all, some amount of congestion is good. If there is no congestion at all, then probably too much money and too much land is devoted to roads. However, while not many would argue that severe

[120] Highway Statistics, 1996, Table HM-72
[121] Most walking trips are less than ½ mile, most bike trips less than 2 miles.

congestion is a good thing, the fact that it is a problem does not mean that solving it is the best approach. As has been argued throughout this report, the ultimate measure of the quality of the transportation system is accessibility. While reducing congestion is a way of increasing accessibility, it is not the only way, nor is it necessarily the best way in any given situation.

Externalities

While accessibility may be the best way to measure the quality of the transportation system, increasing accessibility is not the only valid objective of transportation policy. The problem with transportation is that one person's actions cause almost inevitable impacts on the lives of others. In an auto-based system, these impacts come in the form of air pollution, noise, and aesthetic degradation of neighborhoods, among other things.[122] Thus transportation policy must strike a balance between accessibility and the resulting degradation to the social and physical environment associated with it.

There are three main approaches to reducing externalities. First, to limit the amount of externalities generated through reductions in driving. Second, to reduce the generation of externalities through technological means. Third, to limit the impact of externalities after they have been created.

The first approach may be reducing externalities at the expense of reducing accessibility. It's not clear that there is any net gain from this, although possibly people who live near highways might be better off at the expense of people who use them. But a more serious problem with reducing externalities in this way is that travel behavior and its effects are complex and multi-dimensional, as discussed throughout this report. Thus, in general, externalities are not that closely linked to the amount of driving *per se*. They may be linked to specific types of driving, or particular travel patterns, but this is a different thing from the quantity of driving in general.

Pollution, for example, is much more a function of the quality of the pollution control equipment on a car than of the number of miles the car is driven. A new car could be driven dozens of miles and produce less pollution than an old car with faulty emissions equipment would produce in one mile. Also, it matters where the pollution is generated: in a densely populated area versus out in the country where no one will ever be exposed.

The technological approach to reducing externalities has been quite effective. The reason we can still live in our cities given the levels of traffic today is because of the enormous reductions in pollution levels that have been achieved by technological means in the last 40 years. Of course, this doesn't do anything about or barriers or aesthetics, but that just confirms the point from the introduction that pollution is not, or should not be, the only issue of interest when considering non-auto options. There could still be reasons to want to reduce or

[122] Other types of systems have their own externalities. For all the problems associated with cars, at the beginning they were seen as far superior to their main competitor, horses, which had their own even more obnoxious emissions.

modify auto use, even if air pollution were well controlled by purely technological means.

The third approach doesn't try to reduce the amount of externalities, but merely to mitigate their impacts. An example is noise barriers along freeways, which don't affect the amount of noise cars make, but can often prevent it from being such a nuisance to nearby residents. Neighborhood-level externalities, such as heavy or fast traffic, or barriers to walking can be contained to a point through traffic calming and by aesthetically pleasing street design. Some people also take this approach on their own by choosing to live in houses that are well separated from major roadways. This points out a largely unrecognized problem with high density development – that while there may be fewer externalities generated, more people are in close proximity to their sources. People might drive more in suburbs, and generate more total pollution, but it has a chance to thin out and dissipate before many people are exposed to it.

Problems with Freight Movement

Several issues have been raised with regard to the problems faced by firms attempting to ship freight around congested metropolitan areas. First, firms whose business it is to deliver things are rendered considerably less productive by congestion. Here the issue is simple travel time – if congestion means that each UPS driver, for example, can make only half as many deliveries per hour as before, then UPS will need to invest in twice as many trucks and drivers in order to maintain the same delivery rate. These extra costs will ultimately have to be recouped by higher rates, creating additional indirect costs to urban residents. While deliveries may not be a large part of most family budgets, the same problem applies to a lesser extent to any company that sends or receives shipping, such as grocery stores, for example.

Another type of congestion-related shipping problem is that firms that need deliveries at precise times can be hurt by the uncertainty associated with irregular congestion levels. In this case the problem is not the extra travel time itself so much as the uncertainty. Just-in-time manufacturing, for example, is a significant innovation made possible by computers. The idea is that only those parts or components that will be used in the next few hours are kept on hand; there is no space for "inventory." A computer tracking the manufacturing process orders new supplies as they are needed, and the suppliers deliver them "just in time" as the old supply runs out. This approach can lead to considerable savings in building and inventory handling costs.

The gamble with this approach is that the entire assembly line can be brought down if a single parts delivery fails to arrive on time, which becomes much more likely as congestion becomes severe and unpredictable. While line shutdowns can be averted in principle by ordering new shipments well before the old ones run out, this loses much of the advantage of the concept, since the point is to minimize the space needed for inventory storage.

Trucks could try to organize their schedules around avoiding rush hour traffic, by getting to a destination early and loading or unloading during the heavy traffic hours. This approach, while it could work, might not in general be optimal. That is, both truckers and shippers might benefit from not having these constraints on their loading times. For example, having many trucks loading at once could lead to the need for excess dock capacity, as well as excess workers who might not have enough to do the rest of the day.

On the other hand, express shipping services, which need to make early morning deliveries and late afternoon pickups, obviously can't avoid a certain conflict with rush hour. Increases in the number of people working at home may be leading to increases in the number of small trucks moving about the metro region, as the number of places from which pickups and deliveries must be made increases.

In general this is a hard problem to say anything about, because unlike people traveling for personal reasons, truck travel is business-oriented and data about it is usually proprietary. Firms don't want to give out the private information that would be necessary for someone else to calculate and understand the costs that congestion imposes. Furthermore, as with other travel-related problems, the best solution probably depends on the details of the case, and again these details may be of competitive interest.

Poverty and Accessibility

There are a number of questions about the impact of the existing auto-oriented transportation system on the urban poor. This illustrates the notion that transportation decisions can have broader effects on society at large. One theory, for example, is that autos do provide a higher level of accessibility than other modes. As a result, those people who could afford to have moved to almost exclusive auto use in the last few decades. The problem is that those people who can't drive or are too poor to afford a car might be left worse off than before. This could happen because land use, which was previously organized around walking and transit, which were accessible to all, becomes oriented to auto use instead.

There are several classes of questions that arise from this basic idea. One is equity, that is, whether the existing system accentuates the disadvantages already faced by poor people, by reducing their relative level of access to jobs and other destinations, or by making it necessary to invest a considerable sum in a car.[123] Some 68% of poor (income under $15,000) households own cars,[124] indicating that a car is indeed a nearly necessary investment, even for those who can little afford it.

This points to another set of questions, which revolve around the fate of that minority that can't afford a car, or who can't drive for some other reason. There are important questions about who these people are, why they don't drive, and what their transportation needs are. The answers to these questions should make it possible to formulate policies that best improve the accessibility level of this group. Simply assuming that they need better transit because that is what they

[123] An interesting and little recognized counterpoint to this argument is that cars may have actually reduced inherent disadvantages faced by other groups. Many people, for example, have difficulty walking. However, the possibility of driving a car places them on much the same accessibility level as everyone else.
[124] Pucher (1998), page 17

currently use is faulty logic. It could be that they use transit because that is the only option that is available or affordable.

Still another idea is that low-skill jobs have moved to the suburbs, leaving poor (autoless) people stranded in the central city unable to access them. This is a complicated question. First of all, as many have pointed out, this is a problem of restrictive suburban housing policies as much as it is of transportation. Low-skill jobs moving to the suburbs would not necessarily be a problem if low-skill workers could follow them there (they might even benefit from lower housing costs further from the central city). Second, it's not clear that different transportation could really alleviate this problem. Even if every building in the region were accessible by transit, the time needed to travel from the central city to the edge would be prohibitive (even people who drive don't generally travel long distances). It could be that central city residents would benefit more from incentives to firms to locate in the city, rather than from improved suburban transit. Here, as with other transportation-related questions, a clear understanding of the costs and benefits associated with different solutions is critical to finding the best policy.

Some Policy Ideas

The previous section used the facts and insights developed throughout this report to develop a discussion of what we know and don't know about some of the major transportation-related problems facing the Twin Cities area. This section takes the same approach to a discussion of what can be said about some of the major policy options that have been proposed.

There are two broad points of view. First is the question of the likely impacts and benefits of the various policies, given the complexity of the transportation system and how the different parts interact. Second is an evaluation of the degree of confidence that we can have in these policies, given the current state of knowledge and modeling. As in the last section, there is an emphasis on the system as a whole, rather than an effort to analyze specific ideas in isolation from each other.

As the last section did not attempt to propose solutions to the problems that were discussed, this section does not attempt to evaluate the various possible policies, although there might be suggestions about the types of problems that a given policy might be good at solving. Given the complexity of the transportation system and its role in urban life, it seems not unlikely that many different types of policy could play a positive role in dealing with specific issues. (By the same token, no one policy is likely to solve all problems.)

There are two broad classes of policy discussed here: ideas for reducing single-occupant auto use by promoting alternate modes, and policies that attempt to influence auto use directly.

Changing Travel Modes

As single-occupant vehicles are thought to be at the root of most transportation-related problems, the question of how to induce people to use other modes, such as carpool and bus, is of considerable interest. The question of alternative modes has two distinct elements. First is the question of efficiency, that is, the extent to which these modes might be expected to make the transportation system in general work better. Efficiency improvements could result, for example, from reduced congestion or pollution.

However, there may be good reasons to support alternative modes that go beyond efficiency. These reasons could be broadly classified as "equity." An important example of this is the idea that there are many people that are "transit-dependent;" that either cannot afford or cannot drive a car. The provision of transit to these groups is based on a fundamentally different motive than, say, express commuter busses to the suburbs, and needs to be studied and evaluated as a different type of problem.

A broader argument for alternative modes encompasses both of these issues. This is the idea that people should be able to choose their preferred mode of travel. This is an efficiency question since being forced to use a less-preferred mode implies that utility is lower (or costs higher) than it could be. It is also an equity issue, in that the system is set up for the benefit of people that like to drive cars, while people with other preferences are left to adjust on their own.

The fundamental problem is that travel takes up space, and thus an argument could be made that it is more efficient to focus on one mode, rather than attempting to provide several parallel systems.[125] Another problem is that competing systems will tend to interfere with each other. (Consider an intersection such as Hennepin-Lake where walkers, bikers, in-line skaters, skateboarders, busses, and cars are all trying to cross the same streets.) However, another point of view could be that different modes are good at serving different kinds of trips, and that a system that incorporates the strengths of various modes and allows people to move easily between them could be both efficient and equitable.

Bus and Rail

Mass transit is currently used to provide two main services: increasing roadway person-carrying capacity during peak hours, and providing a minimal level of accessibility to those people who don't have access to a car. It is not clear to what degree these two objectives overlap, or whether the same system is optimal for both of them.

The main strengths of mass transit are its efficient use of right-of-way and rolling stock. Its main weakness is that it can lead to an inefficient use of traveler time. Transit proponents tend to focus on the first of these in claiming that it is more "efficient" than autos. However, most people seem to intuitively understand that human time is a scarce resource just like iron or oil, and as such also deserving of

[125] It is not even just a matter of providing right-of-way for all the modes. The types of land use that make walking a viable mode are inherently bad for an auto-based system (and vice versa).

conservation. Indeed, the dominance of the automobile could be taken as a sign that time is a resource that people value highly.

The high value that people place on time relative to other resources doesn't mean that mass transit has no role, but it does mean that we need to determine what niches it can fill well. If the objective is efficiency, we need to consider how to increase the efficiency with which we use *all* resources, including time. If the objective is equity, the question is whether the needs of non-auto users are best met by a mass transit system or by something else. And where needs are best met by mass transit, the question is exactly what system characteristics are optimal given the needs that the system is serving.

What mass transit does well, in terms of utilizing resources efficiently, is hauling many people at once, with short headways[126] and infrequent stops. Rush hour express busses mostly have these characteristics. It is probably not coincidental that these are the only busses that attract a significant number of non-transit dependent people. (Although it is also said that these busses have the highest per-passenger subsidy.)

What mass transit doesn't do well is haul small numbers of people with long headways and frequent stops. The time spent waiting for the bus is a wasted resource, as is all the time that every bus passenger spends waiting for other passengers to get on and off. Not only is such service not very attractive to the rider, it also fails to capture the other advantages of transit. A 50-foot bus with two passengers takes up *more* space on the road and produces *more* pollution than would be used by hauling the two people in cars. Indeed, the claim has been made that because most bus time is in this low-efficiency mode, that bus service actually provides little environmental advantage over the course of the entire day, compared to all the passengers simply using cars, especially given the likelihood of carpooling.[127]

A final disadvantage is that such off-peak, low-occupancy service is not profitable for the transit agency. It is offered for three reasons. First, the drivers are being paid anyway. Second, this is service to the transit-dependent. Third, some peak-period passengers would be lost if the off-peak service were not available for the return trip.

Despite the current popularity of the Light Rail Transit (LRT) option, it is not clear that this technology really solves any of these problems faced by bus transit. LRT could certainly be an efficient way to move people during peak hours, but busses already do this pretty well. The environmental disadvantages of running nearly empty busses during off-peak hours could be lessened somewhat since LRT produces less pollution, but so would using vans (or cleaner busses) during off-peak hours.

In any case, it has been claimed that the environmental benefits of LRT are overrated. While the electrical operation saves energy and emissions during operation, an enormous amount of energy is used, and pollution generated, during the construction of the tracks. It has been estimated that it could take nearly 50 years for the energy savings of LRT to compensate for the additional

[126] The headway is the time between busses.
[127] Fielding (1995), page 297

energy used in construction.[128] It seems likely that something similar might be true for pollution.

LRT might run slightly faster than busses, but this is because it has dedicated right-of-way, not because it is a train. It can be more comfortable than busses, but the author's own research indicates strongly that people value ride quality very little compared to time savings, especially waiting time.[129] In other words, spending the money increasing bus service frequency throughout the system, rather than building tracks on one line, is likely to have a much bigger impact on overall transit usage.

LRT may, like other policies, play a useful role in the future transportation system of the Twin Cities. The problem, in the opinion of the author, is that no convincing vision has yet been offered as to what this role might be, and why a limited rail system rather than a greatly expanded bus service is the best way to serve this role. In other words, it is not enough to say that people prefer rail to bus. Rail is far more expensive, so it obviously must provide some benefits.[130] The relevant question is not whether these benefits exist, but whether they are larger than would be obtained by spending the same amount of money improving bus or other public transportation service.

Personal Rapid Transit

Personal Rapid Transit (PRT) is an inconspicuous elevated guideway on which small, one or two person vehicles would travel under computer guidance. This idea has been around for 30 years or so, but recently there is increased confidence that the technology is sufficiently mature to make such a system viable. PRT systems have mostly been envisioned as internal circulators in high-density, congested areas, such as downtowns, universities, or congested suburban areas, although they could also serve denser residential areas.

While PRT shares characteristics with both autos and mass transit, it has its own niche, and is not really a competitor to either. Rather, it could complement mass transit by providing the kind of quick, customized local service that is inherently impossible for a multi-occupant vehicle; and it could complement cars by providing a better way to move around within congested areas.

The advantage of PRT is that it shares important characteristics with cars; namely that there is no waiting for a vehicle, and the trip can go directly from start to finish. At the same time, it eliminates a major disadvantage of cars: the need for a place to park them. Because PRT could provide easy access from remote parking areas (or transit stops), much parking could be eliminated from prime commercial and office areas. This in turn could lead to the areas being developed more densely, which could then make walking, biking, and transit modes more viable within the area, further reducing auto traffic.

[128] Ibid.
[129] Barnes (1995), page 51
[130] The Hiawatha LRT cost estimate is pushing $500 million. To use the same right-of-way as a dedicated bus lane would cost $40 million. While many believe that LRT is faster, the speed advantage comes from dedicated right-of-way, not from being on tracks. A bus on dedicated right-of-way would move just as fast.

The major problems with PRT at this time seem to be uncertainties about the technology and about cost. That such a system *can* work seems clear, whether it *will* work, given the uncertainties involved in actual operation, is less so. And while a PRT system could be relatively inexpensive to build, the cost-effectiveness may need to be more clearly demonstrated. Part of the problem seems to be that PRT is often subjected to design restrictions and evaluative criteria that are more appropriate for a mass transit system.[131] A serious and unbiased effort to evaluate the potential costs and benefits of PRT on its own terms could resolve many of these questions.[132]

Carpooling

This idea is appealing in its simplicity – two people per car instead of one could cut traffic by half. Unfortunately, it falls victim to the same problems as mass transit. The reason people buy cars in the first place, rather than using transit, is at least partially to eliminate the inconvenience of building their schedule around someone else's. This preference also serves to make carpooling unpopular (and potentially inefficient, given that time is a resource with real value).

Even if people didn't mind inconvenience, there are other barriers to carpooling. First, there are so many different origins and destinations and possible times of travel that the odds are relatively low that two people will have all the necessary factors in common. Second, since many people might feel uncomfortable or unsafe being in a car with a stranger, the need for the ride sharers to know each other is another possible restriction. Finally, many people value the flexibility to arrive at and leave work when they want or use the work trip as a way of running other errands.

Because many people find carpooling difficult to organize or justify, designated carpool lanes often carry fewer people than unrestricted lanes, missing the point of increasing highway carrying capacity. As a result, many non-carpooling drivers have become opposed to carpool lanes. Even some environmentalists are now skeptical,[133] because the environmental benefits seem to be minimal given induced travel. The extra space created by ridesharing encourages other people to shift their trips into the peak period, or to make additional trips, or use a car instead of another mode.

Although a small fraction of people carpool, there are so many trips by auto that it is still a fairly large share, especially of work trips.[134] And although it may not reduce congestion, it could still increase mobility, since more people may be able to travel at their preferred time, or using their preferred route or mode.

Walking and Biking

These are the ultimate environmental modes, as they consume no fuel, produce no pollution or noise, and require very little space. The down side is that they can

[131] Burke (1979)
[132] Anderson (1997) is a good introduction to PRT concepts and technology.
[133] *New York Times*, October 21, 1997
[134] As discussed earlier in this report (page 23), the share of work trips made as a carpool passenger is 7.0%, compared with a share of 5.2% for transit.

require considerable expenditures of energy, time, and possibly discomfort on the part of the individual doing them, especially during inclement weather or when carrying things. Thus for most people these modes are only viable for short trips during good weather, although they are often preferred to the auto in these situations.

Within some of the most congested areas of the city, such as the downtowns and the University campuses, walking and bicycling can (and do) make a considerable contribution to expanding the capacity of the system. Non-motorized modes have not been formally studied much in the Twin Cities because they don't play a very significant role in the overall system. However, advocates might claim that this is because little has been invested in making them significant.

Many cities in northern Europe have made considerable investments in bicycle facilities, and some of these cities have bicycle mode shares of 20% and more (compared to less than 1% here).[135] But it could also be argued that the physical or cultural characteristics of these cities might be a more important factor than bicycle facilities in determining this mode split.

Like other mode choices, biking and walking can be efficient ways of completing certain kinds of trips. And as with other modes, there is a need to understand better exactly what this niche is and how best to exploit it. Better understanding of this issue has the potential to lead to inexpensive but significant improvements to our transportation system.

Telecommuting

While this is not a travel mode as such, it can be viewed as a way of completing the purpose of a trip by some mode other than auto. The idea is that people could work (or shop) at home or at an office close to their home, while maintaining contact with their employers through various telecommunications links. The particular attraction of this idea is that it is eliminating or shortening a work trip, which tends to be the longest and most congested trip of the day. This would provide benefits to other travelers as well as to the telecommuter. If 25% of all workers were to telecommute one day a week, the resulting 5% reduction in auto use would be equivalent to the savings implied by the mode share of the mass transit system.

There are significant barriers to widespread adoption of telecommuting, the most obvious of which is that many jobs, such as retail and manufacturing, require the physical presence of a person. And while many office workers could in theory telecommute, many companies and even workers themselves have good reasons for not wanting to do it. But in terms of the transportation system, there are two major questions about the efficacy of this "mode" choice.

First is that people may use the time that they save by not driving to work to increase their travel to other destinations. This need not be a problem, if these trips were mostly local and/or during off-peak times. A more significant concern is that many peak-period trips are not apparently work-related. Any reduction in work travel caused by telecommuting could be offset by increased non-work

[135] Pucher (1997)

travel, as people who had previously made their trips before or after peak period take advantage of the lower congestion levels.

A second, longer term impact of the telecommuting option could be that people who rarely come to the office could take advantage of this freedom to move far outside of the metro area, making one or two long trips per week rather than five shorter trips. While one point of view could see this as the ultimate in sprawl, it could also be interpreted as a good thing. Houses are being abandoned in small towns and rural areas even as others are being built on the edge of the metro area. Telecommuters using existing housing in far away areas could help to preserve small-town economies, while reducing the need for new suburban housing. The additional miles implied by the long commute would take place mostly in uncongested, unpopulated areas where the negative impacts would be reduced.

Other Approaches

Other ideas for dealing with the region's transportation-related problems start from the premise that most people appear to prefer driving to other modes, or are making trips for which other modes are not feasible. The gist of these ideas is to deal with driving directly, either by making it easier, thus reducing congestion, or by making it more costly and hence reducing the total amount of driving that is done.

The idea behind the first approach is that people want to drive, and thus that policy should simply focus on removing any obstacles to their doing so. While this could help with congestion, at least in the short term, it does nothing to deal with the broader non-congestion side effects of auto usage.

The second approach is focused more directly on reducing the externalities associated with auto use. While less driving could also have the effect of reducing congestion, it is questionable whether this would lead to any net gain. While accessibility would improve because of the increased speeds, these gains could be offset by the loss of accessibility due to people making shorter trips, or forgoing trips entirely.

Road Construction and Expansion

This topic has been well discussed. Both the advantages and the disadvantages of a transportation policy built around increasing highway capacity are available for everyone to see; although there is still some room for dispute regarding which effects really have to do with road construction, versus auto use more generally or even other reasons such as population and economic growth.

In any case, the era of road construction seems to be drawing to a close. As cities become larger and traffic heavier, the monetary cost and the environmental and generally disruptive effects of construction become more significant. Furthermore, the benefits of new roads seem less significant than they once did, now that we are more aware of the longer-term consequences. Very little expansion is planned for the Twin Cities highway system in the foreseeable future.

As discussed earlier in the section on induced demand, it is not entirely impossible that road expansion, especially if combined with appropriate land use controls, could significantly and permanently reduce congestion. The problem with road construction as a long-term policy tool is not that it can't eliminate congestion, but that even if it does it may not make things better. As has been emphasized throughout this report, there are many problems and issues associated with transportation, of which congestion is an element of one issue, namely accessibility. And while road expansion may yield accessibility improvements, it is not clear that the same level of improvement cannot be achieved at the same expense by other, less problematic means.

At the same time, highways, like other alternatives, have a role to play. To claim that some transportation functions might be better served by means other than the automobile is not to claim that cars can be replaced. There are some types of trips for which it is hard to imagine any alternative being even remotely competitive with cars. The key is not to think about eliminating cars and highways, but to think about how to use them to their best advantage, in conjunction with other alternatives.

Intelligent Transportation Systems

These are a class of ideas aimed at using technology to make auto use more efficient. They could be described in two broad categories. The first idea is to give drivers better information with which to avoid problem areas or to achieve other benefits. The second is to make the system operate more smoothly by various forms of computer driving control aimed at reducing the scope for problems caused by driver error or inattentiveness or timidity.

The general focus is on making more efficient use of the transportation resources we already have. This is an attractive notion, and many of the specific proposals could also have great benefits, particularly in accident reduction. However, as an overall transportation strategy, these ideas are subject to many of the same objections as highway construction. One is the question of cost, that is, that few people will want to put several hundred dollars worth of equipment in their car to avoid a few hours per year of congestion. The other important issue is again the point that while this might reduce congestion, it's not improving any other auto-related problems, and to the extent that it helps to reroute traffic off of congested freeways and onto local streets, it could even make these other problems worse.

Gas Tax

Increases in the gas tax are a favorite policy of many who want to reduce auto use. However, this is not in general a particularly effective way of dealing with auto-related problems. The reason, quite simply, is that the amount of gas an individual uses is almost completely unrelated to the degree to which that person is causing problems. Congestion, for example, has to do with driving on certain roads at certain times of day. Pollution has to do largely with the quality of the emissions control equipment. And neither of these is influenced that much by the amount of gas a person uses, which depends more on the size of the engine and the total amount of driving.

Large increases in gas prices in 1973 and 1979 did not lead to reduced driving so much as to more fuel-efficient vehicles. If fuel conservation is taken as an objective in its own right, then a gas tax could be an effective tool. (Although given the low price of gas, it might be that only a very high tax would have much impact.) However, the technology now exists to attack other auto-related problems more directly. If the objective is to reduce congestion or pollution, taxes or fees should be applied directly to the vehicles contributing to those problems, in proportion to their contributions.

Road Pricing

The obvious way to target congestion-related penalties to the people causing the problem is some form of road pricing. Driving uses more resources during peak periods, both because of the additional highway capacity that must be provided, and because of the delays imposed on other travelers. However, drivers currently pay for highway use based only on the amount of gas used, which does not cover these extra costs.

Many economists feel that the only effective way to reduce peak period congestion would be to have a system in which drivers pay a surcharge for driving on congested roadways during these times of day. (Money raised by this surcharge could be used to lower the general gas tax, leaving the overall cost of driving the same.) Under this system, some drivers would shift to less congested roads to avoid the toll, while others might make their trip at a different time of day, or eliminate the trip entirely by riding the bus or carpooling. This is thought to be a better solution than simply encouraging other modes, because the higher cost of peak-period travel means that people who quit driving would not simply be replaced by new drivers.

This is an important point. Reducing congestion lowers the cost of peak-period travel (by lowering the time cost), in the absence of other charges. Because of this, other solutions, such as improved transit, will tend to simply attract additional auto trips taking advantage of the lower cost. A congestion pricing system, on the other hand, while lowering the *time* cost of peak-period travel, would increase the *monetary* cost. Thus the faster speeds will not attract new trips, since the total cost will be the same or higher than before.

The possible effects of such a system have been studied in some detail,[136] but mostly within the context of route choice; that is, the extent to which drivers would shift to uncongested and untolled alternate routes. Another major effect could come from drivers shifting their trips to different times of day, since many peak-period trips are not commuters. This possibility has not been explored in much depth because there is currently insufficient understanding of the travel time decision.

Like other policies, road pricing has disadvantages. One of these is the flip side of its strength; namely that who seek alternate routes are reducing congestion on the freeways, but increasing the amount of traffic on local streets. While these streets may, strictly speaking, have the capacity to absorb this extra traffic, it is

[136] Anderson and Mohring (1996) analyze the impact of road pricing in the Twin Cities. Many other studies have done similar analyses for other areas.

not clear how the externality costs to local residents and businesses compare to the value of the time savings for freeway drivers.

Another curious problem is that road pricing could create perverse incentives for transportation policy. If congestion pricing replaces all or part of the gas tax, then congestion becomes a revenue source as well as a problem. That is, it is not clear whether policy makers would have appropriate incentives to try to solve congestion problems, given that these problems are their funding source.

Road pricing has clear advantages. It is more efficient than the current gas tax, since it targets congestion directly. It is also more equitable, since drivers are charged based on the costs they actually impose on the system. While some poor people could be made worse off if for some reason they are unable to avoid tolls, the great majority of the poor would benefit, since they would pay less gas tax and could in most cases avoid tolled roads during rush hour. In any case, it would be simple to set up a reimbursement scheme for people who truly can't afford tolls, but at the same time can't avoid them.

An interesting point that most people don't realize is that the current system of peak-period ramp meters is already in effect a congestion pricing system, albeit one which charges time tolls rather than monetary. That is, people already have to "pay" more to use freeways during peak periods, since they have to wait longer to enter the freeway. A system with monetary pricing would eliminate this wasted time. Those who were willing to pay could simply use the freeways without delay, while those who don't want to pay could use alternate routes or modes, which in many cases would not take more total time than the current system with ramp meters does.

At the same time, the possible negative effects of road pricing need to be given serious consideration. The political unpopularity of the idea could simply be the result of poor understanding on the part of the public. On the other hand, it could reflect real objections that have not been adequately addressed. Efforts to be more thorough about *all* the possible impacts of road pricing could help in building a greater level of public acceptance.

6 Conclusions

It can be comforting to imagine the 1950s as a simpler time, when everyone wanted a car and a home in the suburbs; when transportation policy could be one-dimensional because highway improvements were unanimously supported. In such a world there were no tradeoffs between investments, no competing groups offering contradictory ideas. In this world, solving one problem did not worsen others.

Unfortunately, such a world probably never really existed, and certainly doesn’t exist now. In our world, economic and personal activities are specialized. People have different goals, and they want different things from the transportation system. The external costs of transportation are increasingly recognized, and affect people differently. The benefits of highway improvements seem less impressive than they once did, because better roads just seem to generate more traffic, leaving us with little reduction in congestion, but higher external costs.

Major alternative policy ideas such as rail investment, road pricing, and land use changes will not automatically be successful; indeed, if they do not work as hoped they could even make things worse than they are now. For these policies to work will require that we be able to predict how people will respond to them, and understand what factors are important in generating this response. Furthermore, we need to be able to go beyond basic prediction of results to evaluation of which alternatives yield the greatest net benefit to society. That is, we need to do more than problem solving, such as relieving congestion or increasing transit use. We need to view transportation as part of urban life more generally, and evaluate the ways in which different transportation policies make life as a whole better or worse.

An examination of historical travel behavior in the Twin Cities illustrates the difficulty of the problem. Travel behavior is complex: it includes decisions about what destinations to visit, what time of day to travel, the mode to use, how to chain trips together, and other factors. In the longer term, travel behavior can be influenced by indirect factors such as the locations of ones home and work, and the number of cars a household has available. Thus even with accurate data, it can still be difficult to draw sound conclusions about the quality of the system and its effect on urban life more generally, or even about more basic questions of cause and effect, such as the impact a given highway had on regional development.

The same complexity that makes it hard to understand the past also makes it hard to predict the future. Forecasting models must make simplifying assumptions to be useable; however, the details that are assumed away as unimportant at one time may be precisely the ones of greatest interest at a later time. The standard forecasting tools do have weaknesses. They were developed in the 1950s and 60s to provide answers to certain types of questions, considering certain information. Specifically, they were intended to provide predictions of traffic levels and transit usage, given predictions of trip quantities and origin and destination locations.

No one really disputes that there are problems with this approach. The questions that this method is best at answering (where should roads be built, and how big do they need to be) are becoming irrelevant in an era when road construction is extremely expensive and politically unpopular. At the same time, the questions we want to answer now (e.g., will denser land use reduce or shorten auto trips) are hard to answer with a model that assumes that trip quantities and destinations are largely unaffected by transportation policy.

The problem is that it is not at all obvious how to best improve the forecasting models. More accuracy seems desirable, but it’s not clear that lack of accuracy is really the problem. More complaints seem to focus around the notion that the models do not consider a broad enough range of phenomena; that alternate modes are not well represented and that non-transportation impacts such as land use need to be considered.

The use of forecasting models that omit important parts of the system raises two contradictory dangers. On the one hand, some policies might incorrectly appear ineffective because the forecasting models do not take into account some of the channels by which these policies might work. But on the other hand, policies that really would be ineffective might gather undeserved support because the formal models do not represent them well enough to show why they won’t work.

There is a class of forecasting models that aims to deal with part of this problem by integrating land use and transportation decisions into a common framework. No one really seems to dispute that land use could be important; yet at the same time a strong case can be made that existing models do not accurately capture the role of land use in transportation and urban development. Thus it is not unlikely that policies that have a major impact in the model could be ineffective in reality, and vice versa, because the models and reality do not work the same way.

The problem with land use models seems to be that the theory on which they are based, while it is well-developed in general, may be inadequate for the detailed uses to which these models put it. That is, while land use theory seems plausible in a general way, many specific predictions, such as average commute lengths, are not at all supported by empirical evidence. And unfortunately the land use models draw heavily on these less well supported details. As a result, it is not clear that these models really predict land use any better than the more heuristic, expert-based methods currently in use. More generally, it is not apparent that the models can tell us anything about the interaction of land use and transportation that we don't already know.

This points us to the big question about transportation policy and forecasting, namely, what do we need to know? Forecasting models are simply tools, forged from the raw material of knowledge. Given the raw material, the tools can be made in almost any form, to accomplish almost any function. From this perspective, it is misleading to blame inadequate forecasting models for our uncertainty in policy making. The models answer the questions we ask of them. We must consider the possibility that we are confused not because the models are giving bad answers, but rather because we are not asking the right questions.

Consider, for example, the chapter in this report on the characteristics of travel in the Twin Cities. The historical facts related in this chapter and the broader data on which they are based are not in dispute. They constitute in this sense perfect information: accurate, detailed, and not subject to any possible bias, both in their depiction of transportation behavior and of land use. In other words, they have exactly the qualities that we want from the results of our forecasting models. However, as that chapter made clear, there is still considerable room for confusion and contention in using this information to draw conclusions about the quality of the system, or even about simpler questions of cause and effect.

The transportation system is complex. There are many users, often with very different objectives, and generating different kinds of costs to the system. The value of the system to any one user depends on how other people are using it. Relationships that are true at one point in time may not hold true over a longer time span. Facts, *per se*, are ambiguous in the absence of other facts that can be used to place them in an appropriate context.

Thus transportation, like other kinds of complex systems, is hard for non-experts to understand. At the same time, it is not a self-contained system but is inextricably part of the broader economic and social life of the area. Thus it is appropriate for non-experts, such as legislators, to have the bottom line say in at least the broad outlines of transportation policy.

This obviously creates a paradox. It also creates a challenge. More accurate and detailed forecasts will not inevitably lead to better policy unless we can find some way to present the results and implications of these forecasts in ways that can be appropriately interpreted by non-experts. That is, we need some way to reduce all the relevant facts into a few intuitive parameters that describe the system rather than particular modes, and that have some inherent and understandable meaning from which policy makers can draw correct conclusions.

One possible approach would be to find ways to describe the system in terms of user satisfaction, rather than usage measurements; in the same way that we describe wine by how it tastes, not by its chemical composition. The goal of policy is to make the system better for the people using it. It would be valuable to have descriptive tools that make it possible to tell whether we are actually accomplishing this.

However, there is a difficult problem with this approach, namely, defining what is meant by “better.” This depends on what people want. This will vary from one person to another, and likely even from one time to another for a given person. Understanding this will probably be far more difficult than predicting congestion or air pollution levels. Yet if we don’t know what people want, how can we know what will make them better off? We could just keep using traditional measures, or we could go by what interest group has the most effective lobbying force. But neither of these seems very likely to produce satisfactory results.

In particular, we need a way of describing the quality of the transportation system that does not refer to particular modes of travel. Simply knowing how much each mode is used does not give us any way of knowing if shifts from one mode to another would create benefits or losses. Currently we have detailed tools for ranking proposals of the same type, but we cannot compare a highway proposal to a transit or bike proposal to find which would yield the greatest benefit. Yet the need to compare radically different ideas, considering benefits and costs outside of the transportation system, is most likely the future of transportation policy.[137]

The need for good travel demand forecasting is driven by the need for good transportation policy. It makes little sense to talk about “improving” the models unless the purpose of the improvement has been defined. That is, we need to determine exactly how we want the models to be improved, and this in turn depends on what we want to do with them. The most valuable improvements may not even involve forecasting, as the more pressing needs may be for better presentation and interpretation.

Transportation policy makers are faced with many different problems, many possible solutions, and the need to consider transportation in the context of broader urban issues such as land use. In dealing with this extraordinarily difficult challenge, they are handicapped by the fact that they are non-experts in a field that is often hard even for experts to understand. While they need to have good forecasts to have a chance of producing good policy, forecasts alone are not nearly enough. The purpose of the transportation system is to make life better for the people who use it. To accomplish this will require not only forecasts, but methods of presentation that make the forecasts understandable to non-experts, and tools that can measure how well people like the system, rather than simply describing what it looks like.

Recommendations:

Policy makers need detailed but easily understandable and unambiguous information about the effects of various policies, in order to find the policy combination that will best achieve regional objectives. It would also be beneficial to have tools for evaluating the overall quality of the system from the points of view of the different groups of people using it.

[137] In the author’s own neighborhood, for example, debate over the future of Ayd Mill Road has polarized around the options of connecting it to the freeways on either end, or turning it into a park.

There are three immediate practical steps that can be taken to move closer to this objective:

1. Research to acquire better understanding of the details of travel behavior and how they respond to different types of incentives. In particular, better understanding of the role of land use in determining trip quantities, mode choice, and destinations. Improving forecasting models by incorporating this understanding as it becomes available.
2. Making the output of forecasting models more useful and understandable to policy makers. Using the models to generate more detailed information on user behavior and how the system influences it. Relating forecasts to historical patterns and explaining similarities and differences. Using geographic information systems to show variations in behavior across the region, especially variations arising from land use or differences in access to the transportation system.
3. Tools for describing and measuring the overall quality of the system and how this quality varies for different places or groups of people. Using the concept of accessibility as a framework for evaluating and comparing different systems, modes, and combinations of policies. Developing ways of describing transportation and travel behavior that focus attention on the objective of improving the quality of the entire system rather than on solving individual problems.

Bibliography

Anas, Alex, *Modeling in Urban and Regional Economics*, New York: Harwood Academic Publishers, 1987.

Anas, Alex, Richard Arnott, and Kenneth Small, "Urban Spatial Structure," *Journal of Economic Literature*, September 1998.

Anderson, David and Herbert Mohring, *Congestion Costs and Congestion Pricing for the Twin Cities*, Minnesota Department of Transportation, August 1996.

Anderson, J. Edward, "Essentials of Personal Rapid Transit," *Infrastructure*, Vol. 2, No.3, 1997.

Barnes, Gary, "The Values of Waiting Time and a Seat on the Bus: Some Evidence from Singapore," unpublished Ph.D. thesis, University of Minnesota, 1995.

Batty, Michael, "A Chronicle of Scientific Planning: The Anglo-American Modeling Experience," *Journal of the American Planning Association*, Winter 1994.

Ben-Akiva, Moshe and Steven R. Lerman, *Discrete Choice Analysis: Theory and Application to Travel Demand*, Cambridge: MIT Press, 1985.

Burke, Catherine G., *Innovation and Public Policy: The Case of Personal Rapid Transit*, Lexington, Mass.: Lexington Books, 1979.

Cambridge Systematics, Inc., *Time-of-Day Modeling Procedures*, http://www.bts.gov/tmip/papers/triptabl/Time-Day/toc.html, February 1997.

Cambridge Systematics, Inc., and Barton Aschman Associates, *Short-term Travel Model Improvements*, http://www.bts.gov/NTL/DOCS/445.html, October 1994.

Cambridge Systematics, Inc., and others, *Making the Land Use Transportation Air Quality Connection (LUTRAQ)*, 1000 Friends of Oregon, eight volumes, 1991-1997.

Cambridge Systematics, Inc., et al., *Twin Cities Commuting Area: Transportation System Performance Audit*, January 1998.

Eash, Ronald, *Incorporating Urban Design Variables in Metropolitan Planning Organizations' Travel Demand Models*, http://www.bts.gov/other/tmip/papers/tmip/udes/eash.html, 1997.

Ettema, Dick, and Harry Timmermans, eds., *Activity-Based Approaches to Travel Analysis*, Oxford: Pergamon Press, 1997.

Fielding, Gordon J., "Transit in American Cities," chapter 12 of *The Geography of Urban Transportation*, ed. Susan Hanson, 1995.

Guiliano, Genevieve, "Land Use Impacts of Transportation Investments: Highway and Transit," chapter 13 of *The Geography of Urban Transportation*, ed. Susan Hanson, 1995.

Hanson, Susan, ed., *The Geography of Urban Transportation*, 2nd edition, New York: The Guilford Press, 1995.

Harris, Britton, "The Real Issues Concerning Lee's 'Requiem,'" *Journal of the American Planning Association*, Winter 1994.

Harvey, Greig and Elizabeth Deakin, et al., *A Manual of Regional Transportation Modeling Practice for Air Quality Analysis*, National Association of Regional Councils, http://www.bts.gov/tmip/papers/airqual/mrtm/toc.html, July 1993.

Highway Statistics, http://www.fhwa.dot.gov/ohim/1996/index.html.

Howe, R.T., "A Theoretical Model of Work-Trip Patterns," *Highway Research Board Bulletin* 253, 1962.

Jones, Peter, ed., *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, Aldershot, England: Avebury, 1990.

Kipp, Barbara, et al., *Impacts of Highway Facility Improvements on Travel and Regional Development – Wisconsin TransLinks 21*, http://www.bts.gov/smart/cat/ihfi.html, January 1994.

Klosterman, Richard E., "An Introduction to the Literature on Large-Scale Urban Models," *Journal of the American Planning Association*, Winter 1994.

Klosterman, Richard E., “Large-Scale Urban Models: Retrospect and Prospect,” *Journal of the American Planning Association*, Winter 1994.

Lee, Douglass B., “Requiem for Large-Scale Models,” *Journal of the American Institute of Planners*, Summer 1973.

Lee, Douglass B., “Retrospective on Large-Scale Urban Models,” *Journal of the American Planning Association*, Winter 1994.

LUTRAQ: see Cambridge Systematics, Inc.

Lyons, William, et al., *Review of the Transportation Planning Process in the Twin City Metro Area*, http://www.bts.gov/NTL/DOCS/twincity.html, November 1993.

Metropolitan Council of the Twin Cities, *A Summary Report of Travel in the Twin Cities Metropolitan Area*, April 1974.

Metropolitan Council of the Twin Cities, *1990 Travel Behavior Inventory Summary Report*, June 1994.

Metropolitan Council of the Twin Cities, *Transportation Policy Plan*, December 1996.

Middlesex-Somerset-Mercer Regional Planning Board, *Mixed-Use Development: Traffic and Other Impacts*, 1990.

Miller, Harvey, *Towards Consistent Travel Demand Estimation in Transportation Planning*, http://www.bts.gov/tmip/papers/feedback/miller/toc.html, June 1998.

Muller, Peter O., “Transportation and Urban Form: Stages in the Spatial Evolution of the American Metropolis,” chapter 2 of *The Geography of Urban Transportation*, ed. Susan Hanson, 1995.

Munson, Michael, *Twin Cities Metropolitan Area Regional Blueprint Forecast Methodology*, April 1998.

Office of the Legislative Auditor, State of Minnesota, *Transit Services: A Program Evaluation Report*, Report 98-03, http://www.auditor.leg.state.mn.us/98-03.htm, February 1998.

Oppenheim, Norbert, *Urban Travel Demand Modeling: From Individual Choices to General Equilibrium*, New York: John Wiley & Sons, 1995.

Oryani, Kazem, and Britton Harris, *Review of Land Use Models and Recommended Model for DVRPC*, http://www.bts.gov/tmip/papers/landuse/compendium/toc.htm, September 1996.

Page, Jim, Mark Levenson, and Bill Stewart, *Twin Cities Forecasting Accuracy Study*, Minnesota Department of Transportation, July 1981.

Parsons Brinckerhoff Quade & Douglas, Inc., *The Full Social Costs of Alternative Land Use Patterns: Theory, Data, Methods and Recommendations*, for U.S. Department of Transportation, June 1998.

Pas, Eric, “Is Travel Demand Analysis and Modelling in the Doldrums?” chapter 1 of *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, ed. Peter Jones, 1990.

Pas, Eric I., “The Urban Transportation Planning Process,” chapter 3 of *The Geography of Urban Transportation*, ed. Susan Hanson, 1995.

Pisarski, Alan E., *Commuting In America II*, Eno Transportation Foundation, Inc., 1996.

Polak and Jones, chapter 8 of *Understanding Travel Behaviour in an Era of Change*, eds. Peter Stopher and Martin Lee-Gosselin, 1996.

Pucher, John, “Bicycling Boom in Germany: A Revival Engineered by Public Policy,” *Transportation Quarterly*, Fall 1997.

Pucher, John, Tim Evans, and Jeff Wenger, “Socioeconomics of Urban Travel,” *Transportation Quarterly*, Summer 1998.

Putman, S.H., *Integrated Urban Models*, London: Pion Limited, 1983.

RDC, Inc., *Activity-Based Modeling System for Travel Demand Forecasting*, http://www.bts.gov/tmip/papers/activity/amos/toc.html, September 1995.

Smith, LaRon, et al., *TRANSIMS: Project Summary and Status*, http://www.bts.gov/NTL/DOCS/466.html, May 1995.

Southern California Association of Governments, *Technical Documentation and Findings: Conformity Analysis for the Fiscal Year 1993-1999*, http://www.bts.gov/tmip/papers/airqual/tdf/toc.htm, June 1994.

Southworth, Frank, *A Technical Review of Urban Land Use – Transportation Models as Tools for Evaluating Vehicle Travel Reduction Strategies*, http://www.bts.gov/smart/cat/ornl.html, and http://www.bts.gov/tmip/papers/landuse/compendium/toc.htm, July 1995.

Spear, Bruce D., *New Approaches to Travel Forecasting Models: A Synthesis of Four Research Proposals*, http://www.bts.gov/NTL/DOCS/444.html, January 1994.

SRF, Inc., *Model Design Specifications for the Twin Cities Region*, February 1992.

Stopher, Peter and Martin Lee-Gosselin, eds., *Understanding Travel Behaviour in an Era of Change*, Oxford: Pergamon Press, 1996.

Texas Transportation Institute, *Travel Model Improvement Program*, http://www.bts.gov/ntl/DOCS/467.html.

Travel Behavior Inventory (TBI): see Metropolitan Council.

U.S. Department of Transportation, *Highway Statistics*, http://www.bts.gov/ntda/fhwa/, 1996.

Wachs, Martin, "The Political Context of Transportation Policy," chapter 11 of Hanson, ed., *The Geography of Urban Transportation*, 1995.

Webster, F.V., P.H. Bly, and N.J. Paulley, eds., *Urban Land-use and Transport Interaction: Policies and Models*, Report of the International Study Group on Land-use/Transport Interaction (ISGLUTI), Brookfield, Vt.: Gower Publishing Co., 1990.

Wegener, Michael, "Operational Urban Models: State of the Art," *Journal of the American Planning Association*, Winter 1994.

Weiner, Edward, *Urban Transportation Planning in the United States: An Historical Overview, Fifth Edition*, http://www.bts.gov/tmip/papers/history/utp/toc.htm, September 1997.

Zahavi, Yacov and Antti Talvitie, "Regularities in Travel Time and Money Expenditures," *Transportation Research Record 750*, 1979.