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16. Abstract (Limit: 200 words)

The goal of this work is to calculate the full costs of transportation for autos, trucks, and buses in the Twin Cities region for the years 1998 and 2020. Our midrange estimate is that the costs were $27 billion in 1998, and the costs will grow to $42 billion in 2020 ($9,000 and $11,200 in per capita terms, respectively). These estimates include monetary and nonmonetary costs to individuals, firms, and units of government. Costs are divided into three main categories: governmental costs, internal costs, and external costs. Our midrange estimates were that 84 percent of full costs were internal, 9 percent were governmental, and 7 percent were external. Road construction and maintenance accounted for approximately 70 percent of governmental costs. Most time costs were nonmonetary and internal. The costs of travel time accounted for 40 percent of all costs and the costs of owning and operating vehicles also accounted for 40 percent. Approximately 98 percent of external costs were due to congestion, crashes, air pollution, and petroleum consumption. We project that most types of costs will increase at approximately the same rate as regional economic output between 1998 and 2020.

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The Full Cost of Transportation in the Twin Cities Region

Report #5 in the Series:
Transportation and Regional Growth Study

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The nature of this work, with its goal of assembling information on a wide range of current and future costs, has meant that we have had to rely on many people for help. We are sorry that we are not able to acknowledge everyone who has contributed to our understanding of the costs of transportation and that, for the most part, we can only acknowledge those people who have helped us on an ongoing basis.

Scott Peterson headed the Technical Advisory Panel that has overseen this work. Scott and the other members of the panel, Bruce Breise, Mark Filipi, Norman Foster, Sheffer Lang, David Levinson, Perry Plank, Steve Ruig, and Charles Sanft, have been very helpful. They have helped us from the beginning to determine how to structure this work. They have also helped improve our methods of calculating costs and provided sources for many types of data.

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The people mentioned above have helped to greatly improve this report. They are not, of course, responsible for any of the conclusions or errors contained in this report.

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 make 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 estimates the full costs of transportation in the Twin Cities region for 1998 and 2020. By the full costs we mean governmental, internal, and external costs (see Table 1). *Governmental costs* are those borne by any level of government. *Internal costs* are those borne directly by the person who causes them, and *external costs* are costs that are not borne by the person who causes them. We estimate these three types of costs for a 19-county area that contains the seven-county Twin Cities metropolitan area and the 12 adjoining counties.

Table 1: Three Types of Costs

Governmental	Costs borne by any level of government (roads, highways, highway patrol, …)
Internal	Costs borne by the person who causes them (depreciation, fuel, …)
External	Costs not borne by the person who causes them (noise, air pollution, congestion, …)

Calculating the costs of transportation requires knowing the amount of travel people engage in. On a typical day in the Twin Cities region in 1998, 9.1 million vehicle-trips and 12.6 million person-trips were made. Motor vehicles traveled over 71 million miles. Autos accounted for 94 percent of person-trips in motor vehicles, public transit for 2.5 percent, and school buses for 3.5 percent. We project that population and income will grow significantly in the next two decades, and this will lead to a significant increase in auto ownership and use (see Table 2). We expect the time people spend traveling will increase by 34 percent and, because of declining rates of auto occupancy and increasing suburbanization, we expect somewhat larger increases in vehicle-hours and vehicle-miles traveled.

The high volume of travel in the region reflects both the tremendous benefits people derive from transportation and the relatively low direct costs of transportation. People derive benefits from living, working, shopping, and recreating in a variety of locations. They also derive benefits from consuming a wide variety of goods, which the transportation system helps to produce and distribute. The benefits of transportation almost surely outweigh the costs, and we recognize that it is important not to focus narrowly on reducing either the amount of travel or the cost of travel. The goal of this work is to help identify policies that will allow the people of the region to hold down the costs of transportation and continue to receive the full benefits of transportation while accommodating growth.

Table 2: Travel Projections[1]			
	1998	2020	Change
Population	3,036,600	3,704,700	22.0%
Households	1,159,900	1,474,600	27.1%
Vehicles	2,685,000	3,514,000	30.9%
Daily Vehicle-Miles	71,000,000	100,500,000	41.6%
Daily Vehicle-Hours	2,620,000	3,650,000	39.3%

The Full Costs of Transportation

Though transportation costs may be low relative to benefits, they are significant and growing. We estimate that the full cost of transportation in this region was $27 billion in 1998, and that the cost will grow to almost $42 billion by 2020 (all figures are in 1998 dollars). These costs amount to $9000 per person in 1998 and $11,200 in 2020. Table 3 shows our cost estimates in more detail. It should be kept in mind that these are totals that reflect the costs of all motor vehicle travel in the region, including commercial vehicles and heavy trucks. These costs are much larger than direct expenditures on automobiles because

- They include time costs that do not show up in accounts of personal income or regional output ($10.6 billion in 1998 and $17.2 billion in 2020).
- They include the annualized costs of long-lived investments such as parking, garages, and private driveways ($2.3 billion in 1998 and $3.6 billion in 2020).
- They include the costs of air pollution ($900 million in 1998 and $1 billion in 2020).
- They include the costs of government services that indirectly support transportation ($490 million in 1998 and $850 million in 2020).

[1] Population and household projections are from the Metropolitan Council, Minnesota Planning, and Wisconsin State Demographer. The other projections are our own—see Section 3.3.

Table 3: The Full Costs of Transportation
(All figures are in millions of 1998 dollars.)

	Governmental Costs					
	1998			2020		
	Low	Mid	High	Low	Mid	High
Streets and Highways	1,340	1,535	1,735	1,820	2,195	2,570
Transit	245	260	270	355	415	470
Law Enforcement and Safety	225	315	405	370	565	760
Environmental Cleanup	60	105	155	90	165	245
Parking	205	270	340	295	415	540
Costs to Other Agencies	40	70	170	55	120	325
Total Governmental Costs	2,120	2,560	3,080	2,900	3,870	4,910
	Internal Costs					
	1998			2020		
	Low	Mid	High	Low	Mid	High
Fixed Vehicle	5,650	6,450	7,300	7,800	9,000	10,050
Variable Vehicle	2,200	2,650	3,150	3,050	4,350	6,100
Transit Fares & Travel Time	170	220	265	285	365	445
Non-Transit Travel Time	6,780	8,910	11,060	10,890	14,440	18,070
Other Personal Time	770	1,240	1,720	940	1,480	2,000
Crashes	1,115	1,365	1,810	1,640	2,005	2,635
Parking and Drives	1,100	2,040	3,925	1,700	3,165	6,075
Total Internal Costs	17,800	22,900	29,250	26,300	34,800	45,400
	External Costs					
	1998			2020		
	Low	Mid	High	Low	Mid	High
Congestion	165	330	525	565	1,145	1,860
Crashes	150	220	320	230	335	480
Air Pollution (Health)	260	725	4,035	260	800	5,040
Air Pollution (Other)	95	175	365	95	220	575
Global Warming	30	100	185	45	135	260
Petroleum Consumption	155	295	575	235	355	870
Noise, Fires, & Robberies	15	40	75	25	55	105
Total External Costs	870	1,890	6,040	1,450	3,050	9,190
Full Cost of Transportation	20,800	27,400	38,400	30,700	41,700	59,500

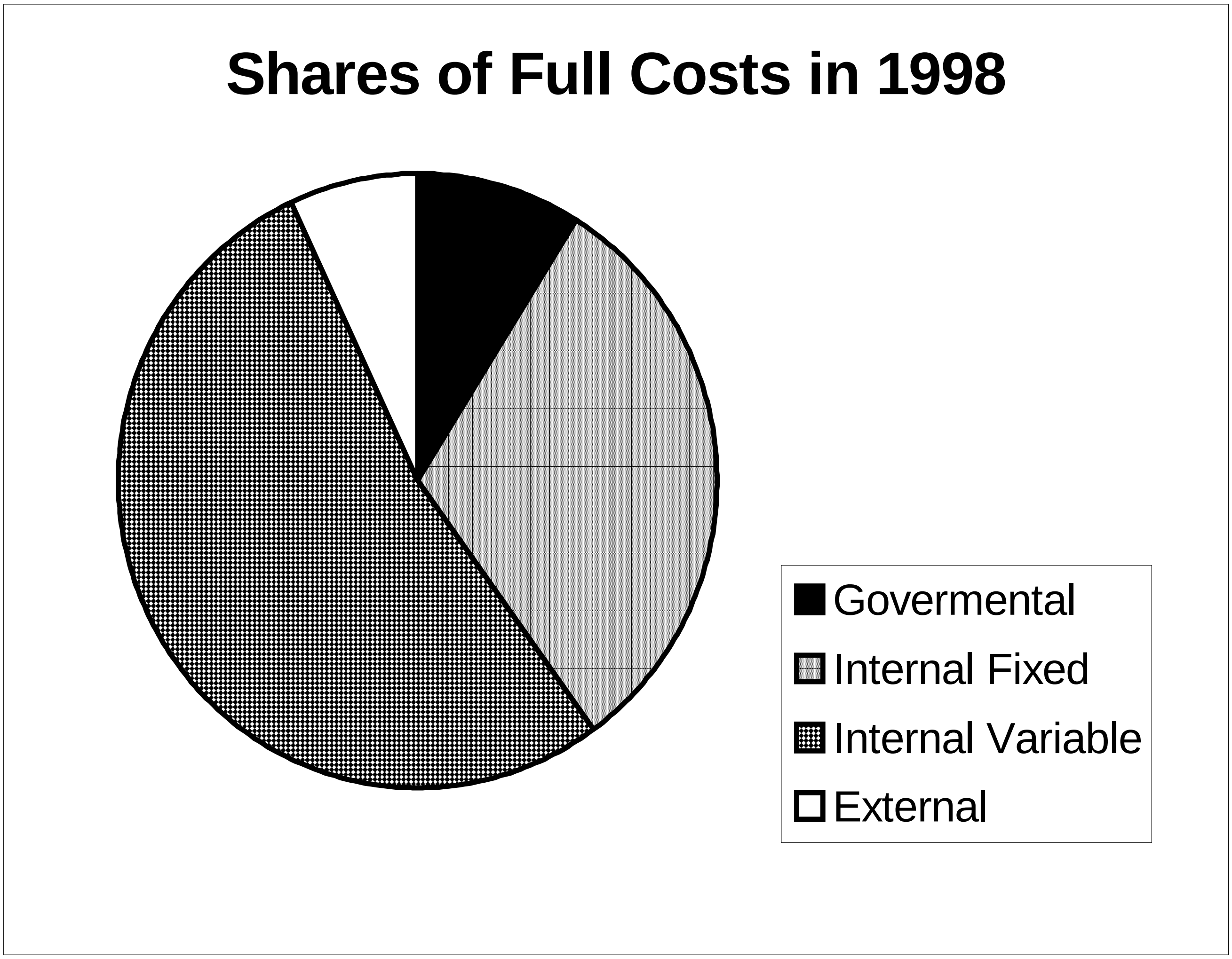

Figure 1: Our mid-range estimate of the full costs of transportation in the Twin Cities region for 1998 is $9,000 per person. Internal variable costs, of which travel time is the largest component, account for 53 percent of the full costs of transportation. Internal fixed costs account for 31 percent of full costs, governmental costs for nine percent, and external costs for six percent.

The full costs of transportation are high, but some of the costs that cause the most concern, governmental costs and external costs, account for a relatively small share of total costs. Governmental costs, which are the costs paid by federal, state, and local governments to support transportation, account for only 9 percent of total costs. External costs, which are defined to be the costs not borne directly by the traveler imposing them, account for only 7 percent of total costs. We classify the remaining 84 percent of costs as internal. While governmental and external costs account for only 16 percent of the full costs of travel, they are large in absolute terms—$4.5 billion in 1998 and $6.9 billion in 2020.

Growth in Full Costs

Overall, the full cost of transportation is growing only slightly faster than the value of the region's total output. This means that, while the real costs of transportation are increasing significantly, the region will not have to devote a much larger share of its resources to transportation. We project that **governmental costs** will fall slightly as a share of the full costs, from just over 9.3 percent in 1998 to just under 9.3 percent in 2020. The modest relative decline is due primarily to our expectations of efficiency gains in constructing and maintaining roads. We expect most other governmental costs to rise with regional income.

We expect most **internal costs** to rise with regional income. The fixed costs of vehicles are expected to rise somewhat more slowly, however, because we feel that technological progress will help hold down the costs of new vehicles. The variable costs of operating motor vehicles are expected to rise faster than other internal costs because the cost of fuel seems likely to increase. The costs of transportation-related services such as parking, which have land as a major input, may also rise in relative terms, because land prices usually increase faster than regional output.

We expect that **external costs** will rise slightly as a share of the full costs, from 6.9 percent to 7.3 percent. This increase is largely due to the fact that we expect congestion costs to increase rapidly between 1998 and 2020. The costs of air pollution will probably not increase much, and could even decline, if current trends that show air quality improving continue. We predict significant increases in travel and population, but we predict that these trends will be mostly offset by progress in making vehicles cleaner.

We expect the costs of crashes to rise only moderately because of progress in making vehicles safer. External costs associated with petroleum consumption are closely tied to oil prices, and could therefore rise more quickly than most other costs.

Areas of Special Concern

The elements of full transportation costs that cause the greatest policy concerns are usually the governmental and external costs. While we do not find that these costs account for a particularly large share of the full costs of transportation, there are still many reasons for concern. One is that there are situations in which governmental and external costs do account for a large share of full costs of travel. Costs vary greatly depending on time of day, location, and vehicle type. For example, congestion costs are quite high at certain times and places. A crucial first step to improving the region's transportation system will be identifying situations in which travel is especially problematic.

Another reason for concern is that the absolute size of the full costs, and even the governmental and external portions of these costs, are quite large. In 1998 the average person in the region bore $7550 in internal costs, $840 in governmental costs, and $620 in external costs. There would be large social gains if these costs could be reduced by new technologies, or if travelers were given incentives to avoid activities that impose high governmental or external costs.

Some of the internal costs of transportation also create reasons for concern. For example, "free" parking raises both efficiency and equity concerns, and imposes costs that are nearly as large as all of the external costs of transportation. Another question is raised by the difference between the costs people perceive and the costs they actually pay. For example, people may not be fully aware of risks posed by crashes or of all of the costs of maintaining a car.

While the external costs of transportation account for only a modest share of the full cost of transportation, they account for a larger share of the marginal cost of transportation. This is because almost all of the external costs of transportation are variable, while some significant internal costs are fixed (especially the costs of vehicle ownership). Because decisions about how much to drive are based on marginal costs, external costs may be more problematic than they first appear.

Some types of costs are expected to grow rapidly. Congestion, already an issue that concerns many people, is the most striking example. While most costs are expected to grow by approximately 50 percent, congestion costs are expected to more than triple between 1998 and 2020.

It is also important to realize that some costs can only be estimated with significant uncertainty. Nonmonetary costs and external costs are generally harder to quantify than other types of costs. Estimating the costs of air pollution was particularly problematic. The estimate with which we feel most comfortable is that the 1998 costs of air pollution were $1 billion, but it is possible that air pollution imposed costs that were four or five times higher.

There are some types of costs that we were not able to quantify. These include the effects of transportation on land and water resources and especially effects on the region's flora and fauna.

Conclusions

Transportation imposes many costs on the region that are not usually recognized. These include the costs of time, the health effects of air pollution, pain and suffering due to crashes, and a variety of governmental services that support transportation. Many costs of transportation are nonmonetary, i.e., people do not purchase them with money. While these costs are generally more difficult to quantify than monetary costs, they are real costs, and they account for approximately 40 percent of the full costs of transportation.

The size of the internal costs of transportation suggests that households and firms derive tremendous benefits from travel because they willingly pay a tremendous amount for travel. It also suggests that in an efficient transportation system, one where each user paid for all of the costs he or she imposed, people would probably *not* engage in a great deal less travel than they do now. While increasing the net benefits from transportation may not necessitate a *large overall* decrease in travel, it would require reductions in certain types of travel, for example, travel on congested roads and travel by vehicles with faulty emissions control equipment.

It is important to recognize that the governmental costs of transportation extend beyond the construction and maintenance of streets and highways. While almost 60 percent of governmental costs are related to streets and highways, transportation also leads to significant government spending on transit, law enforcement, environmental protection, and parking.

The presence of fairly large external costs of travel, in absolute terms, suggests that there are ways to significantly reduce the total cost of transportation without greatly reducing the benefits people derive from transportation. Because the share of costs that are external is relatively small, policies to reduce them should be carefully tailored to remedy specific externalities. Policies that are not carefully tailored run the risk of reducing the very large benefits of transportation by more than they reduce the significantly smaller external costs of transportation.

Time costs are particularly important. They are large in absolute terms and account for a significant share of both internal and external costs. Excluding the time spent by commercial vehicle operators and people who are paid to support the transportation system, 33 percent of the full costs of transportation are time costs. In addition, the costs of traffic congestion are expected to grow much more rapidly than other costs. Unlike the situation with air pollution and crashes, there do not appear to be any technological solutions that will greatly reduce the costs of congestion.

The costs of air pollution are quite uncertain, and studies of these costs that apply new research would be valuable. Our mid-range estimate of the costs of air pollution in 1998 is approximately $1 billion, but our high-end estimate is over $4 billion. A large part of this uncertainty is due to uncertainty as to the effects of the particulate matter resulting from vehicle emissions and from road dust.

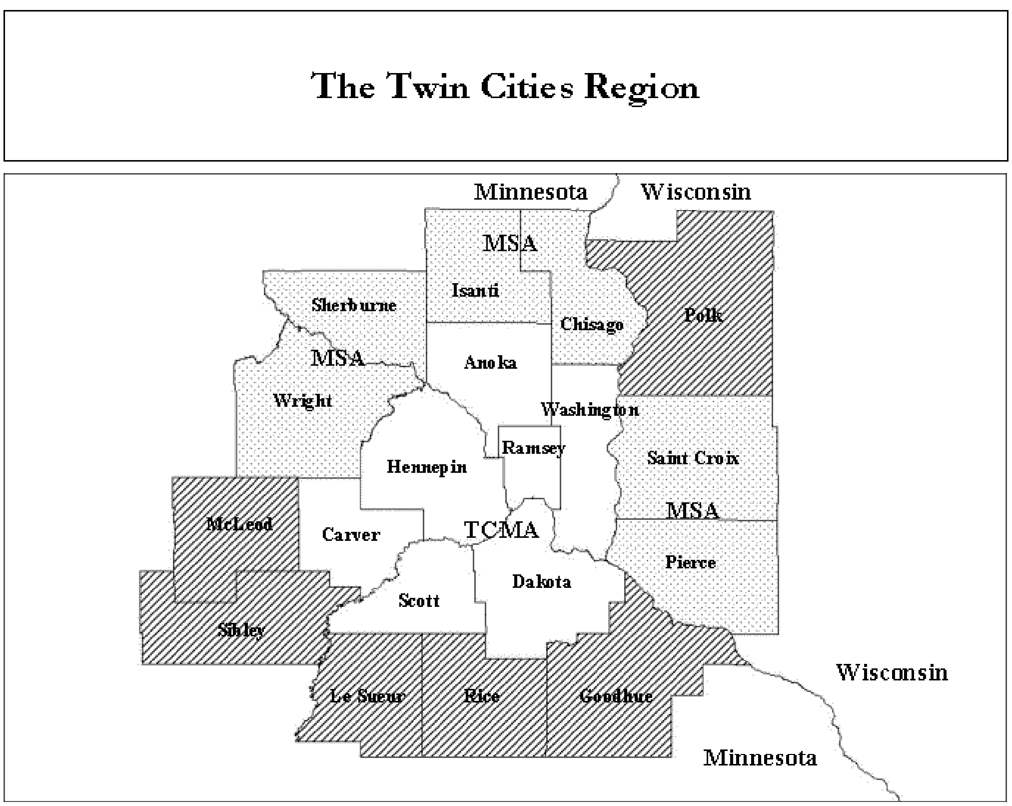

Figure 2: The Twin Cities region includes the seven-county Twin Cities Metropolitan Area (TCMA) and twelve adjoining counties.

1 Introduction

The purpose of this report is to calculate the full costs of transportation in the Twin Cities region. It represents the first step in our analysis of the costs of travel. A second report will determine cost incidence, i.e., who bears and imposes the costs of transportation in the region, and a third report will analyze the costs of alternative transportation systems.

This work is part of the Transportation and Regional Growth Study. The project has as its goal the identifying transportation policies that are consistent with desirable patterns of regional development. We hope this work contributes to this goal, helping to enable the people in the region to continue receiving the benefits of transportation while accommodating growth and holding down social costs. At this point in our study, we only identify policies for illustrative reasons. Further analysis of the costs of transportation, as well as the benefits of transportation and other aspects of regional growth, will be needed before we can identify and recommend promising policies.

1.1 Transportation in the Twin Cities Region

The transportation system for the Twin Cities region facilitates a great deal of travel. On a typical day in 1998, 84 percent of the region's three million residents made at least one vehicle-trip. They made 9.1 million vehicle-trips and 12.6 million person-trips. Autos accounted for 93.5 percent of vehicle trips, public transit accounted for 2.5 percent, and school buses for 3.5 percent. The average person who made at least one such trip during the day traveled 1.5 hours and 32 miles.[2]

This high volume of travel reflects both high demand and relatively low direct costs. High demand occurs because transportation produces significant benefits. People derive these benefits from living, working, shopping, and recreating in a variety of locations. They also derive benefits from consuming a wide variety of goods, which the transportation system helps to produce and distribute. The benefits of transportation almost surely outweigh the

[2] These numbers are based on Metropolitan Council (1994a). They were adjusted to apply to the 19-county Twin Cities region examined in this report. (Metropolitan Council (1994a) examines the seven-county Twin Cities Metropolitan Area (TCMA). Our 19-county region is defined in Section 2.3.)

costs, and we recognize that it is important not to focus narrowly on reducing either the amount of travel or the cost of travel.

Nevertheless, though transportation costs may be low relative to benefits, they are significant and growing. In 1991 in the U.S., $650 billion was spent directly on final goods and services that were used for transportation.[3] This does not include the costs of transportation used to produce other products (for example, the costs of shipping food to a grocery store). Transportation accounted for 10.5 percent of all spending for goods and services produced in the country. The total opportunity cost may be much higher than direct spending—perhaps as high as $3,000 billion.[4]

1.2 Concerns About the Costs of Transportation

Throughout this report, we use the word cost in a special way. To accountants and most other people, any expense is a cost. When we use cost, we mean opportunity cost. The *opportunity cost* of an activity is the value of the next best alternative that was forgone to undertake the activity. A good that is *provided* free is not necessarily costless. The “free” parking that is provided at shopping malls is not costless, because parking spaces use valuable land and because paving the spaces requires resources. Costs include money spent for transportation. They also include *nonmonetary costs*, which are the values of goods and services that are not paid for with money. Nonmonetary costs include most of the time costs of driving and pain and suffering from crashes for which victims are not compensated. For public policy purposes, it is important that nonmonetary costs be accounted for because these costs could make the difference when choosing between alternative transportation systems.

While the total costs of transportation are high, some types of costs cause special concern. For example, the $306 billion spent in the U.S. on vehicle purchases, maintenance, parts, gasoline, and oil in 1991 probably does not cause as much public concern as the costs of the air pollution caused by motor vehicles ($143 to $262 billion) or the costs of government spending

[3] Han and Fang (1996, page 97). All amounts used in this report have been converted to 1998 dollars.
[4] Delucchi et al. (1996) estimated the costs of motor-vehicile use in the U.S. in 1990 to be between $1,970 and $3,890 billion. Note that these costs include items that are not accounted for in GDP, including the costs of most types of environmental damage, most of the time costs of driving, and the costs of the pain and suffering caused by accidents.

on transportation ($127 billion).[5] The reason is that the costs of the first items are paid for directly by the people who use the items, and the purchases take place in reasonably competitive markets. Under these conditions, the economy is likely to allocate vehicles, parts, gasoline, and oil quite efficiently. There is no similar reason to believe that resources are allocated efficiently when vehicles produce air pollution (i.e., there is no reason to believe that vehicles produce the “right” amount of air pollution).

Governmental spending on transportation accounts for approximately 14 percent of total government spending.[6] Public decision-making processes are designed to solicit and respond to the concerns of a wide range of people but are seldom driven by the narrow efficiency concerns. This makes it likely that over- or under-investment will occur in certain types of public services. Government spending on transportation, which is primarily for streets and highways, has far-reaching consequences because it defines the networks on which most transportation takes place. Road networks and, to a smaller degree, transit networks influence when, where, and how people travel. In the long run, they also influence decisions about the size and placement of homes and businesses. These effects on development patterns underscore the need for coordinating transportation and growth planning

Air pollution and traffic congestion are examples of externalities. *An externality occurs when one person’s actions affect a second person without the second person’s agreement and outside of a market.* The presence of an externality is generally a sign that the economy is not operating efficiently, i.e., that the net benefits to society are not being maximized. This makes identifying externalities very important for public policy purposes. In addition to congestion and air pollution, externalities are also caused by noise and by crashes.

Also of special concern are costs that are borne by people who do not use the transportation system.[7] Governmental costs may be borne by non-users because of tax policy. Externalities such as noise, air, and water pollution also may impose costs on non-users. Such impacts may cause inefficiency and will often be seen as inequitable.

Concern about the costs of transportation is growing because many types of costs are increasing. In urban areas, for example, the time lost to congestion grew by 79 percent between 1982 and 1994.[8] In these areas, the cost of

[5] Han and Fang (1998, page 97) and Miller and Moffet (1993, page 66).
[6] Han and Fang (1996, pages 97 and 100).
[7] More generally, there is concern about costs borne by people who use the system a great deal on those who use the system little.
[8] Shrank and Lomax (1997).

increasing road capacity has also grown rapidly. There appear to be no painless ways to reduce many of the negative impacts of transportation. Identifying and implementing policies to mitigate these costs will require good information about the costs and benefits of system changes.

1.3 Increasing Net Social Benefits

One of the main goals of the Transportation and Regional Growth Study is to discover ways to increase the net benefits to society resulting from transportation. The net benefits of an activity are the benefits minus the opportunity cost of the activity. Achieving this goal means enabling the people in the region to receive the benefits of transportation while accommodating growth and holding down transportation costs. This part of the project will focus on the costs of transportation. The benefits of transportation are considered in Part II of the Transportation and Regional Growth Study: Passenger and Freight Travel Demand Patterns.

A transportation system is said to be *efficient* if it maximizes the net benefits to society. To say a system is efficient means it produces a given amount of travel as cheaply as possible. It also means the system produces the right amount travel and distributes the travel correctly, i.e., all people who value a trip more than the trip's costs travel, and all who value a trip less than its costs do not.

The equity of the transportation system is also important. Most people agree that the system should be equitable to the extent that users who produce the same costs should pay the same amount for using the system. Fortunately, efficiency also requires that users who impose the same costs are treated the same. There is less agreement on whether the transportation system should be used as a tool to reduce overall social inequity. In general, however, we would be concerned that using the transportation system to reduce social inequity would result in large efficiency losses compared to the losses that might result from more direct methods of reducing inequity. The equity of the region's transportation system will be examined in detail in the next phase of this research project, which will determine cost incidence.

To evaluate the equity of the transportation system, one needs to know the distribution of the total costs and benefits of travel. To evaluate the efficiency of the system, one usually focuses on the *marginal* costs and benefits. The marginal cost of travel is the additional cost caused by one extra unit of travel. The transportation system will not generally be efficient unless the marginal benefit of travel equals the marginal cost. If marginal costs exceed marginal benefits, less travel will increase net social benefit. If marginal benefits exceed marginal costs, more travel will increase net social benefit. Total costs are important because they summarize the state of the system, but marginal costs are also important because they tell us how to improve the system.

1.4 The Costs of Regional Transportation

We estimate that the full cost of travel in the region in 1998 was $27.4 billion, and project that this cost will grow to almost $41.7 billion in 2020. These costs represent $9,000 per person in 1998 and $11,250 per person in 2020. These numbers may seem high, but it should be remembered that many of these costs are nonmonetary. Time costs, most of which are nonmonetary, are particularly important and account for approximately 40 percent of the full cost of transportation. Governmental costs account for almost nine percent of the full costs and external costs for approximately seven percent. We classify the remaining 84 percent of costs as internal.

Overall, we expect that the full cost of transportation will grow at the same rate as the value of the region's total output. This means that, while the total cost of transportation will rise significantly, the region will *not* have to devote a larger share of its resources to transportation. We expect that governmental costs will fall slightly as a share of the full costs, from a little more than 9.3 percent in 1998 to a little less than 9.3 percent in 2020. The modest relative decline in governmental costs is due primarily to expected efficiency gains in constructing and maintaining roads. External costs are expected to rise slightly as a share of the full costs, from 6.9 to 7.3 percent. This increase is largely due to the fact that we expect congestion costs to increase rapidly between 1998 and 2020.

The types of costs that cause the greatest concern are usually governmental and external costs. While we do not find that these costs account for a particularly large share of the full costs of transportation, there are still many reasons for concern. One is that there are situations in which governmental and external costs account for a large share of full costs of travel. Costs vary greatly depending on time of day, location, and vehicle type. Congestion costs, for example, are quite high at some places and times. A crucial first step to improving the region's transportation system will be identifying the situations in which travel is especially problematic.

Another reason for concern is that the absolute size of the full costs, and even the governmental and external portions of these costs, is large. In 1998 the average person in the region bore $7550 in internal costs, $840 in governmental costs, and $620 in external costs. There would be large social gains if these costs could be reduced by technological progress or by providing travelers with incentives to avoid activities that impose high governmental or external costs.

Some of the internal costs of transportation create reasons for concern. For example, “free” parking raises both efficiency and equity concerns and imposes costs that are nearly as large as all of the external costs of transportation. Concerns are also raised by differences between the costs people perceive and the costs they actually pay. For example, people may be unaware of risks posed by crashes or of all of the costs of maintaining a car.

1.5 The Organization of This Report

The remainder of this report is divided into seven parts. Section 2 describes the accounting system we will use to determine the full costs of transportation. Section 3 describes the regional transportation system and its usage. This is done for the current system and projections are made for the year 2020. The governmental, internal, and external costs of transportation are calculated in Sections 4, 5, and 6, respectively. Section 7 summarizes the main findings of this report. Appendices to this report cover terminology, the transportation cost literature, some specific cost calculations, and a number of technical issues.

2 A Cost Accounting System for Transportation

This section of the report defines the accounting system that we will use to determine the full costs of transportation. In it we describe the types of costs that will be considered, how costs will be classified, and the level of detail of our analysis.

Defining the accounting system is done in three steps. In the first, we describe the goals of our accounting system. In the second, we define the general structure of the system and identify all major cost items. In the third step, we describe the level of detail that our accounting system will contain. More information on transportation cost accounting is contained in the appendices; Appendix A describes major cost items in more detail and Appendix B reviews the literature on the costs of transportation.

2.1 Accounting System Requirements

We chose our accounting system with important communications goals in mind. Our accounting system should

(i) provide a complete account of the full costs of transportation,
(ii) reflect a consensus on costs derived from the economic, environmental, and transportation literature, and
(iii) be easy to explain and justify to interested groups and individuals.

These goals are designed to help improve the dialogue in the region for groups that are trying to coordinate transportation and land use planning. Making the costs reflect a consensus, and making them easy to explain and justify will help the educational component of the project to communicate our results to interested individuals. Making the system account for all costs will aid in addressing the wide array of transportation-related concerns of people in the region.

2.1.1 What Do We Mean by the Full Cost of Transportation?

Our first research goal is to account for *all* costs of regional transportation. To this end, we have taken a broad view of costs. Our basic approach is summarized nicely by Lee (1997, p. 113):

Social costs include all costs to society, direct or indirect, monetized or in-kind, incurred by private individuals and firms or by collective entities up to and including the planet.

Four reasons are commonly given for ignoring certain types of costs:
(i) the costs are difficult to measure or are uncertain,
(ii) the costs are not monetary,
(iii) the costs are imposed outside the region, and
(iv) there are no policy instruments available to affect the costs.

While some costs are difficult to measure, we feel that providing the best information that is available on these costs is preferable to ignoring them. Consider, for example, the costs auto emissions may impose by causing lung cancer. There are difficulties in determining these costs. The distribution of auto pollutants is difficult to determine, as is the share of lung cancer attributable to these pollutants. In addition, there are problems assigning values to pain, suffering, and deaths attributable to lung cancer. Nevertheless, all studies of the full costs of transportation agree that the effects of air pollution impose real costs. We feel our approach should be to do our best to quantify costs and to explain the degree of uncertainty in our estimates.

Likewise, nonmonetary costs are sometimes ignored. Some people feel nonmonetary costs they are not "real" costs. With a few exceptions, however, there is general agreement in the economics and transportation literature that nonmonetary costs should be accounted for. One problem in accounting for nonmonetary costs is that they can be difficult to measure accurately. This seems to be the reason that the Puget Sound Regional Council included them in their study only "with considerable reluctance" (Puget Sound Regional Council (1996), p. 14). Fortunately, significant progress has been made recently in quantifying many types of nonmonetary costs.[9]

Another reason given for ignoring some costs of travel is that they are imposed on people outside of the region under consideration. This is the position taken in the Puget Sound Regional Council's report. Costs imposed outside our region are, however, real costs. They seem especially important at this time, because there is a great deal of evidence showing that locally emitted pollutants contribute to worldwide externalities such as global warming and ozone depletion. The Twin Cities region's contribution to the costs of global warming *in the Twin Cities region* is relatively small. Nevertheless, we feel that our own costs are not the only ones we should consider. For the purposes of identification, however, we will divide costs

[9] See, for example, Greene et al. (1996).

into those internal and external *to the region*. We realize that it makes no sense for the region to attempt to solve problems such as global warming or ozone depletion on its own, but it is useful for us to be aware of them. This awareness should inform us as we participate in statewide, national, or international solutions to extra-regional problems.

We also recognize that there may be no policy instruments that can be used to eliminate inefficiencies associated with some types of costs. For example, pricing an externality may impose high transactions costs or it may simply be politically infeasible. Identifying and developing policy solutions, however, is a problem separate from accounting for costs and is outside the scope of this report. Our intention is to account for all of the costs of transportation and to hope that knowing these costs will help those in the region who are developing policies that might affect these costs.

2.1.2 Policy Questions

A long-term goal of the Transportation and Regional Growth Study is to identify policies that will increase the net benefits the region derives from transportation. The focus is especially on ways to improve and coordinate transportation and land use.

While identifying such policies is the ultimate goal of the project, we do not wish our accounting system to be tailored to address only a few policy questions. Instead, we want our accounting system to be useful in answering a wide range of policy questions. We take this approach because of three primary considerations.

(i) Our accounting should aid dialogue on a wide range of policies by including all of the cost items that we feel we might be able to quantify.
(ii) Our cost estimates should help us to identify potentially beneficial policies.
(iii) Practical limitations greatly restrict the range of questions that can be answered directly from summary cost data.

The first consideration is driven partially by the educational and public involvement component of this study. Traditionally, studies of transportation costs have included only a few types of external costs—often only crashes, congestion, noise, and air pollution. We do not feel, however, that we should limit our work to studying these costs. We have tried to identify and discuss all of the costs that we feel might influence transportation policy; where possible, we have also quantified these costs.

The second consideration recognizes that there should be feedback between the policies analyzed and the accounting system. A useful accounting system cannot be designed in the complete absence of policy considerations, but a good accounting system can help identify policies that deserve more intensive study. Identifying activities that generate high marginal external costs may help one to find promising policies. For example, good ways to mitigate air pollution will most likely depend on how the damage cost of air pollution varies with vehicle type, location, and time of day. Policies that increase net benefits to society will likely be policies that are narrowly tailored to address specific problems. Such policies may be difficult to identify in the absence of good data on costs.

The third consideration is that it is difficult to usefully sum up many types of cost data. There is only a narrow range of policy questions that can be adequately analyzed with summary data. For example, congestion varies with road segment and time of day. Summarizing congestion cost for urban peak traffic hours and urban off-peak hours might be very misleading. It is much better to evaluate the congestion effects of a new transit policy by examining the effected road segments, than by examining aggregate data. We feel our approach should be to produce detailed data sets that can then be used to analyze policies. Because of this, one product of this work will be data files on transportation costs.

2.1.3 Level of Detail Required for Addressing Policy Questions

The overall goal of this research is to aid in answering policy questions. Appendix C.2 discusses three such questions. The examples illustrate that costs depend on many factors. Consider one of the approximately nine million vehicle-trips made in the Twin Cities region on an average weekday in 1998.[10] The cost of the trip will depend on where the trip was made, the location of the *origin and destination* of the trip, and of the *route* used. Did the trip go downtown? Was the trip made on a freeway or on local roads? The cost will also depend on how the trip was made, on the *mode* and *type of vehicle* used. Was the trip made in a bus, on a bike, in a single-occupancy vehicle? How big was the vehicle and how much fuel did it use? Costs may depend on when the trip was made, the *time of day*. Were roads congested when the trip was made? Was air quality poor? Finally, costs may depend on who makes the trip or on their *demographic characteristics*. Does the person place a high value on travel time or on the risks of crashes?

All of the factors above turn out to be important when analyzing the policy examples. Ideally, we would be able to quantify the cost of each potential trip in the study region. Naturally this is not possible. A common solution to this problem is to place trips with similar costs in the same category. For

[10] We define a trip to be one-way travel between two locations in which a person spends at least ten minutes.

example, all peak-period auto trips in an urban area might be placed in the same category.[11] While this classification is useful for evaluating some types of policies, it will not provide enough information to evaluate others. Congestion and crash costs may depend greatly on the specific road used, its direction, free-flow speed, and whether it is divided. The main limitation of an area-wide classification scheme is that it ignores the way travel costs vary across routes. Fortunately, we can use our classification system to include data on individual road segments. The way this is done is described in Section 2.3.

Average and Marginal Costs

Before we describe our accounting system in more detail, we need to distinguish between two special types of costs. The distinction is between average and marginal costs. The *average cost* of travel is the total cost of travel divided by the total amount of travel. Once we know the total cost of transportation, we could, for example, calculate the average cost of travel per person, per vehicle, or per mile. These average costs are useful for summing up the state of the system. They can answer questions such as, "How much time does it usually take to make a trip?" or "How much damage does air pollution cause the people in one section of the metropolitan area?" Average costs are usually easier to calculate than marginal costs because they can be calculated directly from total costs.

The *marginal cost* of travel is the increase in total costs that would occur if there were one additional unit of travel. Calculating the marginal cost of travel can be difficult because it requires that we know how costs change with travel. Knowing the marginal cost of travel is important when comparing alternative policies. Suppose, for example, that a transit system reduced auto traffic on a congested section of freeway by 200 vehicles. The average time cost of a trip on that section of road could be $1 while the marginal time cost is $3. This means the average driver spends time worth $1 traversing that section of road. Drivers not only experience congestion; they also create it. If the marginal cost of one vehicle trip were $3, then an additional driver would experience $1 in time cost and cause an additional time cost of $2 for all other drivers. The benefit in time savings from a 200-vehicle reduction in traffic equals $600. This is much higher than the $200 savings that we might have hypothesized if we knew only the average cost of travel.

Marginal costs are useful for evaluating and improving the efficiency of the transportation system. A system is efficient if it maximizes the net benefits to

[11] Studies that use this approach include Litman (1994), Apogee (1994), and Miller and Moffet (1993). See Appendix B for more on these studies.

society (total benefits minus total costs). A transportation system will not generally be efficient unless the marginal benefit of travel equals the marginal cost. If marginal costs exceed marginal benefits, less travel will increase net social benefit, and if marginal benefits exceed marginal costs, more travel will increase net social benefit. Marginal cost information, therefore, can help us identify areas where policies to change traffic volumes would be valuable.

We feel we need to account for both marginal and average costs. The distinction between them is so fundamental that we will develop two related sets of accounting data. This report focuses on total and average costs. The portion of this research that deals with cost incidence will focus much more on marginal costs.

2.2 Accounting System Structure

Our proposed framework closely follows Delucchi et al. (1996).[12] Delucchi's study quantified the full costs of motor vehicle use in the United States in 1990. His study was comprehensive. It was composed of twenty reports that examined many cost items in great detail. Because many of the costs of transportation are related to motor vehicle use, especially the external and governmental costs that are usually of the greatest concern to policymakers, we found Delucchi's research invaluable and use the same basic accounting framework that he did, with some modifications described below.

The basic accounting framework is shown in Table 2.1, and the accounting system is shown in more detail in Table 2.2. The most important difference between our framework and Delucchi's is that we include all public spending, government provided goods and services, in one group. Delucchi divides government provided goods and services between those which are priced, but priced inefficiently, and those which are unpriced. He admits this division is somewhat arbitrary (Delucchi 1997, page 46), and we agree. While the distinction he makes is useful for some purposes, we do not think it justifies the potential confusion it creates.[13] Also, we prefer to keep policy questions concerning how the government should price goods and services outside the scope of this report. Some of these questions will be addressed in other phases of the Transportation and Regional Growth Study, however.

Government-provided goods and services make up one category. The other two major categories are internal costs, which are absorbed directly by a user,

[12] See Part 1 of Appendix B for more details on Delucchi's study.

[13] Another complication arises because the government regulates some privately purchased goods. Examples include seat belts and catalytic converters. We ignore this complication, but it should be noted that these privately purchased goods may be consumed in inefficient quantities.

and external costs, which are absorbed by someone other than the user. This gives us three major categories:

- Governmental costs: public spending by any level of government (road construction and maintenance, highway patrol, …)
- Internal costs: costs borne by the person who causes them (vehicle purchases, fuel, …)
- External costs: costs not borne by the person who causes them (air pollution, congestion, …)

We suggest these divisions for the same reasons Delucchi does. Governmental costs are analyzed separately because many factors affect the way the government spends money. In some cases efficiency is a primary consideration; while in others equity is most important. Sometimes narrower concerns such as energy use or safety are important. The division between internal and external costs makes it easier to identify goods that may be allocated inefficiently or inequitably. When externalities are present, there is a good reason to suspect that goods are being allocated inefficiently. In addition, externalities often impose costs on outsiders. In such cases it is likely that costs are not being allocated equitably, either. For example, motorists may impose air pollution costs on non-motorists, or suburban residents may impose noise costs on residents of the central city.

Internal and external costs are divided further into monetary and nonmonetary costs (governmental costs are all monetary). *Monetary costs are the costs of goods and services that are bought and sold.* Examples include vehicles and fuel. Monetary costs can be relatively easy to determine by observing market transactions.[14] *Nonmonetary costs are the costs of goods and services that are not bought and sold in markets.* Examples include pain and suffering from crashes and travel time for which drivers are not compensated. Nonmonetary costs are usually more difficult to quantify than monetary costs because we cannot observe the prices of nonmonetary goods and services.

We also make one additional distinction. It is between bundled goods and non-bundled goods. *Bundled goods are goods that are used to facilitate travel but are usually purchased with other goods.* For example, garages or parking spaces are purchased with houses. Determining the value of bundled goods can be problematic because we do not observe them purchased separately in the market. Sometimes we have to infer their values. Note that bundling goods does not create an externality because the effects of bundling are transmitted

[14] In not all cases, however, is price a good indicator of cost. Prices may differ from costs because of factors such as hidden taxes, excessive profits by firms, or production externalities

through the market.[15] The division between bundled and unbundled goods is made only for internal, monetary goods.

It should be noted that one categorical distinction we do *not* make in our accounting system is between those costs incurred by users of the transportation system and those incurred by non-users. Congestion costs, for example, are external costs that are imposed only on people who are using the transportation system, while external noise costs are imposed primarily on people who are not using the system. Determining which costs users and non-users bear will be done in our study of cost incidence.

A list of the cost items in each of the six broad cost categories is shown in Table 2.1. These costs are described in more detail in Table 2.2 (and in Appendix A.3). This list covers all major costs of transportation. Appendix C.4 provides a justification for the completeness of Table 2.2.

We recognize that many events will have costs that are covered in more than one category. Suppose, for example, a person falls asleep and drives into a light pole. The crash may require the services of the highway patrol (category 1) and auto-body work (category 2). The crash may involve pain and suffering (category 4) and it may delay other motorists (categories 5 and 6, depending on whether the people being delayed are being compensated for the delays).

We also recognize that sometimes it would be useful to organize costs based on the event that causes them. For example, all of the costs associated with emissions of carbon monoxide might be placed in one category. These would include the (i) governmental costs of monitoring and research, (ii) the internal costs associated with using special fuels and certain types of pollution control equipment, and (iii) the external costs to the people whose health is affected by the emissions. This information would be helpful for determining whether current policies are minimizing the net social costs of carbon monoxide emissions.

Our accounting system does not organize costs in this way for two main reasons. The first is that it would greatly complicate our work. We would need to try to trace costs to root causes, and we would still want to divide costs into governmental, internal, and external. The second reason is that, sometimes we can solve problems without knowing all of the costs resulting from one cause. For example, economic theory tells us that in certain circumstances we can establish the right level of congestion by merely pricing

[15] Non-drivers pay more for goods at a store that provides free parking, other things equal, than they would pay if the parking were not provided. This may or may not result in inefficiency, but it is not an externality because the effect is transmitted through the prices of the goods sold in the store.

road use based on the external costs of congestion *only*. In these cases, an efficient outcome would not require that we know the governmental or internal costs associated with congestion.

The goal of this study is a detailed elaboration, for the Twin Cities region, of the full costs of transportation enumerated in Table 2.2. This elaboration is contained in the remainder of this report. We estimate the full costs, on an annualized basis, for two years: 1998 and 2020. Later research will examine other aspects of the costs of transportation, including how costs are distributed among individuals and across the transportation network.

2.3 Level of Accounting System Detail

The amount of detail an accounting system contains is important because it determines what the system can do. A system that calculates the cost of noise at a county level will not be very helpful to someone trying to evaluate the benefits of noise barriers in one neighborhood. A system that calculates the average cost of congestion throughout the day will not help determine the benefits of shifting traffic from peak periods to off-peak periods.

This section of the report describes the amount of detail our accounting system will contain. We will not include all of this detail in this report. Many types of cost data will be developed in future reports on incidence, which will explain how costs are distributed among individuals and across the transportation system. The purpose of this section is to explain the detail that we will need in this and future work, so that we can collect data and develop methods of allocating costs to meet these needs.

Table 2.1: The Structure of the Accounting System			
Category Description			**Example**
1. Governmental Costs: the costs of government services and infrastructure provided for regional transportation.			Road construction and maintenance
2, 3, & 4. Internal costs: the costs of regional transportation that are borne entirely by the individual who causes them, not including fees or taxes used for government-provided goods and services.	**2 & 3. Internal, monetary costs:** the internal costs of goods and services purchased in the market.	**2. Unbundled goods and services:** goods and services that are purchased solely for transportation.	Vehicle depreciation
		3. Bundled goods and services: goods and services that are purchased for transportation but are purchased with non-transportation goods or services.	Garages and driveways
	4. Internal, nonmonetary costs: the internal costs of goods and services not purchased in the market.		Travel time not caused by congestion
5 & 6. External costs: those costs that are not born by the person who causes them.	**5. External, monetary costs:** the external costs of goods and services purchased in the market.		Health care costs from auto emissions
	6. External, nonmonetary costs: the external costs of goods and services not purchased in the market.		Value of time lost due to congestion

Table 2.1: We divide costs into three main categories—governmental, internal, and external.

Table 2.2: Major Governmental Cost Items

1. Public spending—government services and infrastructure provided for regional transportation
   - 1.1. Federal, state and local roads
     - 1.1.1. Construction
     - 1.1.2. Maintenance
     - 1.1.3. Value of land and overhead costs
   - 1.2. Subsidies to publicly provided parking (excluding on-road parking)
   - 1.3. Law enforcement and safety
     - 1.3.1. Parking enforcement
     - 1.3.2. Traffic enforcement and response to crashes or fires (this includes costs to the judiciary and the penal system)
     - 1.3.3. Police protection for vehicles and passengers (including subsidies for vehicle registration and tracking)
   - 1.4. Traffic safety (except for law enforcement costs)
     - 1.4.1. Subsidies to drivers' education courses (except those mandated by the penal system)
     - 1.4.2. Costs of licensing drivers
     - 1.4.3. Costs of monitoring and regulating traffic safety (except those incurred by Mn/DOT)
   - 1.5. Subsidies to transit (state, federal, and local)
     - 1.5.1. Infrastructure
     - 1.5.2. Operating expenses and overhead
   - 1.6. Transportation-related costs of environmental regulation, protection, and clean up
     - 1.6.1. Emissions monitoring costs
     - 1.6.2. Costs of abating or cleaning up transportation-related pollution of the air, land, and water (except emissions monitoring costs)
     - 1.6.3. Publicly funded research and development
   - 1.7. Energy security costs
     - 1.7.1. Military protection of oil supplies
     - 1.7.2. Strategic Petroleum Reserve
     - 1.7.3. Publicly funded research and development to reduce energy use
   - 1.8. Costs of services provided for transportation by governmental agencies not specified above

Table 2.2: A list of major cost items. See Appendix A.3 for more details on these items.

Table 2.2: Major Internal Cost Items

2. Internal costs of monetary, non-bundled goods and services
   - 2.1. Fixed costs of private vehicle operation (to individuals and businesses)
     - 2.1.1. Depreciation (including damage that does not occur while driving)
     - 2.1.2. Overhead costs to businesses
     - 2.1.3. Insurance overhead to individuals
     - 2.1.4. Anti-theft costs (the costs of security devices and legal services)
     - 2.1.5. Fees paid for drivers' education and licensing
   - 2.2. Variable costs of private vehicle operation (to individuals and businesses)
     - 2.2.1. Vehicle repair, maintenance, and parts (excluding that caused by crashes, fires, or crimes)
     - 2.2.2. Fuel, oil, etc. (except that used due to travel delay)
     - 2.2.3. Costs associated with crashes and paid for by the responsible party
       - 2.2.3.1. Hospital care
       - 2.2.3.2. Lost work / wages
       - 2.2.3.3. Damage to vehicles
     - 2.2.4. Parking fees
     - 2.2.5. Time costs of travel while at work (excluding congestion delays)
     - 2.2.6. Costs of fires paid for by the responsible party
   - 2.3. Fares for transit and taxis

3. Internal costs of monetary, bundled goods and services
   - 3.1. Home garages and driveways
   - 3.2. Parking lots, driveways, and roads which are provided free by businesses
     - 3.2.1. Services provided for employees
     - 3.2.2. Services provided for non-employees

4. Internal costs of nonmonetary goods and services
   - 4.1. Personal pain and suffering from crashes and fires caused by the driver
   - 4.2. Personal time costs (the value of (uncompensated) time while not at work)
     - 4.2.1. Travel time (excluding congestion delays)
     - 4.2.2. Personal time spent maintaining vehicles
     - 4.2.3. Time costs of driver education classes

Table 2.2 continued. See Appendix A.2 for more details on these items.

Table 2.2: Major External Cost Items

5. External costs of monetary goods and services
   - 5.1. Congestion costs
     - 5.1.1. Costs of (compensated) travel delays incurred while at work
     - 5.1.2. Costs of oil and fuel used because of traffic delays
   - 5.2. Crash costs for which the driver is not responsible or compensated
   - 5.3. Pollution costs
     - 5.3.1. Health costs
     - 5.3.2. Damage to output (crops, forests, etc.)
     - 5.3.3. Monetary costs of global warming
   - 5.4. Petroleum consumption costs
     - 5.4.1. Losses to the U.S. of not using market power when buying oil
     - 5.4.2. Expected losses to GDP due to fluctuations in oil prices
   - 5.5. Monetary costs of robberies†
   - 5.6. Costs of fires due to transportation

6. External costs of nonmonetary goods and services
   - 6.1. Costs of uncompensated delays due to congestion
   - 6.2. Crash costs resulting from pain and suffering for which the driver is not responsible and is not compensated
   - 6.3. Pollution costs
     - 6.3.1. Pain and suffering caused by air pollution
     - 6.3.2. Pain and suffering caused by land and water pollution
     - 6.3.3. Lost visibility
     - 6.3.4. Noise pollution and vibrations
     - 6.3.5. Losses of wildlife and recreational areas due to pollution
     - 6.3.6. Losses of wildlife and recreational areas due to global warming
   - 6.4. Other effects on land or neighborhoods
     - 6.4.1. Barrier effects (costs associated with the avoidance of traffic and lost pedestrian accessibility)
     - 6.4.2. Losses of recreational areas not due to pollution
     - 6.4.3. Losses of plants and animals not due to pollution
   - 6.5. Nonmonetary costs of robberies†
   - 6.6. Costs associated with transportation-related fires

Table 2.2 continued. See Appendix A.3 for more details on these items.

† Note that these are external costs imposed on drivers, not imposed by drivers.

2.3.1 Geographical Detail

We wish to account for the costs of all passenger and freight transportation that takes place within the Twin Cities region. We define the region as a 19-county area that includes the seven-county Twin Cities Metropolitan Area (TCMA) and 12 adjoining counties. This 19-county region also includes the 13-county Metropolitan Statistical Area (MSA).[16] The U.S. Office of Management and Budget (OMB) defines the Metropolitan Statistical Areas. They include outlying counties based on commuting to central cities, percent of population living in urban areas, and population density. We add six outlying counties to the MSA to make our study area. These counties were added because of the many concerns about development outside the urban core areas, and because we feel commuting patterns are particularly important.[17] Significant types of costs are associated with commuting, especially the costs of congestion, road expansions, and air pollution. The percentage of people commuting to the TCMA falls to approximately 20 percent in the ring of counties outside our study area. An additional consideration is that most of the 12 counties outside the TCMA have similar populations, i.e., the increase in population when going from 13 to 19 counties is almost as large as the increase when going from 7 to 13 counties. Finally, it seems sensible to have data on all of the counties that are adjacent to the TCMA.

We have data on approximately 20,000 one-way segments of road in the TCMA. To the extent possible, we will try to assign variable costs directly to sections of roads.[18] In the 12 counties outside the TCMA, we do not have data on individual road segments, so we will assign most costs at an aggregate county level. Fortunately, the external costs that concern us most are concentrated in the TCMA.

It is not possible to assign all costs to individual links. There are three levels of association that costs can have with a particular link.

1. Some costs vary depending on usage of individual links. Almost all variable costs of driving fall into this category. Time and fuel costs are

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[16] The TCMA includes the Minnesota counties of Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington. The Twin Cities' MSA contains the additional Minnesota counties of Chisago, Isanti, Sherburne, and Wright and the Wisconsin counties of Pierce and St. Croix. To these we add the Minnesota counties of Goodhue, LeSueur, McLeod, Rice, and Sibley and the Wisconsin county of Polk.

[17] This area was identified by Adams and Wyly (1993). The region corresponds to the zone in which, on an average weekday in 1990, 40 percent of commuters or more travel to the seven-county Twin Cities Metropolitan Area (TCMA).

[18] This will be done in our study of cost incidence.

examples. So are air pollution costs and some road maintenance costs (those caused by vehicles and not by other factors such as the weather). A few variable costs such as parking, however, cannot be tied directly to links. We call the ones that can be *variable link costs*.

2. Some costs are tied to links without being dependent on the amount the link is used. Examples include the cost of constructing a link or some of the costs caused by a link acting as a barrier. We call these *fixed link costs*.
3. Some costs are not tied to links at all. Examples include some transit subsidies, the costs of garages, and the costs of licensing drivers.[19] This is a catchall category that could be broken up many ways. Some costs may depend on the entire transportation system—overhead costs for the Department of Transportation. Others depend on the number and location of trips—emissions from cold starts. Still others will depend on the number of drivers or the number of vehicles. We call these *non-link costs*.

When determining the marginal cost of a trip, generally the only things that matter are variable costs associated with the links used and a few costs directly associated with the trip such as parking and emissions from cold starts. When determining the effects of altering the road network, both variable and fixed link costs matter. When analyzing the effects of major policy changes, all types of costs may be affected.

[19] Less driving may lead people to build fewer garages in the long run, but changing routes, i.e., using different links, doesn't seem likely to affect the number of garages built.

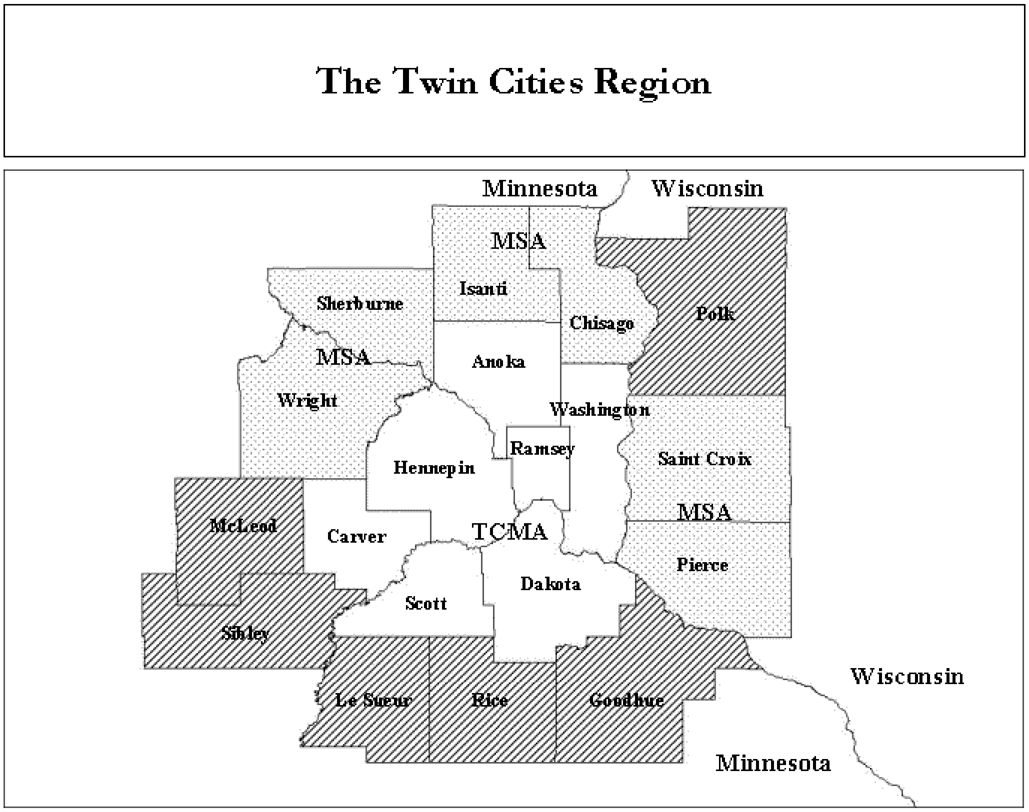

Figure 2.1: The Twin Cities Region.

The region contains 19 counties. It includes the 13-county Metropolitan Statistical Area (MSA) and six additional outlying counties. The seven-county Twin Cities Metropolitan Area (TCMA) is in the MSA.[20]

Table 2.3 shows how the cost items in Table 2.2 can be classified depending on whether they are variable link costs, fixed link costs, or non-link costs. Consider governmental costs first. The largest costs in this category are road construction and maintenance. Most of these costs are fixed link costs. Some maintenance costs, however, are variable link costs. A few other types of

[20] The Metropolitan Council is the Metropolitan Planning Organization for the TCMA. The U.S. Office of Management and Budget defined the MSA. Adams and Wyly (1993) identified the 19-county area as the region in which at least 40 percent of workers commuted to the TCMA on an average weekday.

governmental costs can be assigned as fixed or variable link costs. Most of these costs, however, cannot be assigned to any individual segment of road.

Now consider internal costs. Many of the cost items in category 2.1 are non-link costs that depend primarily on the number of vehicles in use. Many of the costs in category 2.2 are variable link costs. These include travel time, fuel use, and crash costs. The bundled goods, garages and driveways, are non-link costs. These costs are essentially fixed given that autos are the mode choice.

Many external costs are variable link costs. Examples include congestion, pollution, and crash costs. Some crimes and fires are non-link costs. This is because some of the costs of crimes and fires depend on how and where a vehicle is stored, and some depend on how much a vehicle is driven.

2.3.2 Mode, Time, and Demographics

As discussed in Section 2.1.3, other factors affect the cost of travel in addition to the road segment on which the trip is made. These include the travel mode, when the travel takes place, and even who makes the trip. Of course, who makes the trip is also important for determining cost incidence.

We include the costs of autos, trucks, and buses. We also include the potential costs of light rail and commuter rail for the year 2020, because it appears likely that at least one light rail line will be operating by then. We do not include a heavy (commuter) rail mode because regional plans for constructing commuter rail lines are at a much earlier stage than the plans for light rail. These modes enable us to account for most of the costs of moving passengers and shipping freight within the region. Our cost estimates also include the costs imposed by autos and trucks that travel through the region, but do not stop here.

We ignore travel via air and water because they are not used a great deal for transportation *within* the area. We also do not include walking and bicycling modes because we do not feel that assembling cost data on these modes will be very helpful to policymakers. This because (i) these modes impose such small governmental and external costs and (ii) the internal costs of using these modes vary so much from person to person and from trip to trip. The small external and governmental costs imposed means that these modes are almost always good options for reducing social costs *provided people choose to use them*. Whether or not people will choose to use them will depend on individual circumstances.

Table 2.3: Accounting for Major Governmental Cost Items			
Cost Item	**Cost Type**		
	Variable Link	**Fixed Link**	**Non-Link**
1. Public spending			
1.1. Federal, state, and local roads			
1.1.1. Construction		X	
1.1.2. Maintenance	X		X
1.1.3. Land and overhead[ℑ]		X	X
1.2. Subsidies for public parking			X[T]
1.3. Law enforcement and safety			
1.3.1. Parking enforcement			X
1.3.2. Traffic enforcement	X		X
1.3.3. Police protection			X
1.4. Traffic safety			X
1.5. Subsidies to transit			
1.5.1. Infrastructure			X
1.5.2. Operating and overhead	X		X
1.6. Environmental regulation or protection			
1.6.1. Emissions monitoring costs			X
1.6.2. Costs of abatement or cleanup	X	X	X
1.6.3. Publicly funded R&D			X
1.7. Energy security costs[*]	X		
1.8. Costs to other governmental agencies not covered above	X	X	X

Table 2.3: Accounting methods used to track major cost items.

[ℑ] Some of land costs depend on the entire road network, not just on the individual link.
[T] These costs are primarily associated with the origin and destination of a trip.
[*] These are associated with individual links through fuel use.

Table 2.3: Accounting for Major Internal Cost Items			
Cost Item	Cost Type		
	Variable Link	Fixed Link	Non-Link
2. Internal costs for monetary, non-bundled goods			
2.1. Fixed costs of private vehicle operation			
2.1.1. Depreciation			X[V]
2.1.2. Overhead costs to businesses			X[V]
2.1.3. Insurance overhead to individuals			X[V]
2.1.4. Anti-theft costs			X[V]
2.1.5. Driver education and licensing			X
2.2. Variable costs of vehicle operation			
2.2.1. Vehicle repair, maintenance, etc.	X		
2.2.2. Fuel, oil, etc.	X		
2.2.3. Crashes	X		
2.2.4. Parking fees			X[T]
2.2.5. Time costs of travel at work	X		
2.2.6. Costs of fires	X		X[T]
2.3. Fares for transit and taxis			X[T]
3. Internal costs for monetary, bundled goods			
3.1. Home garages and driveways			X[V]
3.2. Free parking lots, driveways, and roads			X
4. Internal nonmonetary costs			
4.1. Pain & suffering from crashes or crashes	X		X
4.2. Personal time costs			
4.2.1. Travel time (except congestion)	X		
4.2.2. Time spent maintaining vehicles	X		X[V]
4.2.3. Time costs of driver education			X

Table 2.3 continued.

[V] These costs are primarily associated with vehicle ownership.
[T] These costs are primarily associated with the origin and destination of a trip.

Table 2.3: Accounting for Major External Cost Items			
Cost Item	Cost Type		
	Variable Link	Fixed Link	Fixed System
5. External costs for monetary goods			
5.1. Congestion	X		
5.2. Crashes	X		
5.3. Pollution*	X		X[T]
5.4. Petroleum consumption	X		
5.5. Robberies net of gains to criminals			X[V]
5.6. Fires due to transportation	X		X[V]
6. External costs for nonmonetary goods			
6.1. Uncompensated congestion delays	X		
6.2. Crash costs caused by pain and suffering	X		
6.3. Pollution			
6.3.1. Pain & suffering from air pollution	X		X[T]
6.3.2. Pain & suffering from land or water pollution	X		X
6.3.3. Lost visibility	X		X[T]
6.3.4. Noise and vibrations	X		
6.3.5. Losses of wildlife or recreation due to pollution	X		X
6.3.6. Losses of wildlife or recreation due to global warming	X		X
6.4. Other effects on land or neighborhoods			
6.4.1. Barrier effects[ℑ]	X	X	
6.4.2. Losses of recreational areas		X	
6.4.3. Losses of plants and animals		X	
6.5. Costs associated with crimes			X[V]
6.6. Costs associated with fires	X		X[V]

Table 2.3 continued.

* The trip costs are those caused by the extra emissions that occur when vehicles are started.
T These costs are primarily associated with the origin and destination of a trip.
V These costs are primarily associated with vehicle ownership.
ℑ Some barrier effects may be partly due to traffic levels, and some due to road width.

For our study of cost incidence, we will also break some modes into additional categories according to vehicle class. These distinctions are important because of differences in fuel consumption, emissions, and crash costs. The auto mode will be divided into heavy autos (including pickup trucks, vans, and full-size cars), midsize cars, and small cars. Each vehicle class is then broken down into two categories depending on occupancy—single occupancy vehicles and high occupancy vehicles. The freight truck mode is divided into two classes: light and full-size trucks.

Another consideration that is especially important for our study of cost incidence is when travel takes place. In particular, both congestion and air pollution levels vary throughout the day. We will divide travel into six time periods: two one-hour periods for weekday mornings (from 6:30 – 7:30 and from 6:00 – 6:30 and 7:30 – 8:00), three one-hour periods for weekday afternoons (from 3:40 – 4:40, from 4:40 – 5:40, and from 3:00 – 3:40 and 5:40 – 6:00), and one period for all other times.

Demographic characteristics are important for calculating costs and determining cost incidence. Income is one of the most important demographic factors for determining costs because it is generally agreed to affect the value people place on travel time.[21] It is also sometimes of interest when evaluating the equity of a policy. The Metropolitan Council's travel survey contains data on eight household income categories.

The other demographic characteristic we use is location. It is of importance primarily in studies of cost incidence. The Metropolitan Council data divides people who live within the TCMA into 1200 traffic analysis zones. We will keep data at this level of detail within the TCMA. Traffic analysis zones can be aggregated into minor civil divisions (cities and townships) or counties. There are 197 minor civil divisions in the TCMA. Outside the TCMA we will keep data at a county level.

One question that will be explored in more detail in our study of cost incidence is whether costs are incurred in our study region or outside of it. In some cases policymakers will wish to consider the costs we impose on people outside the region, while in others they will not. To address incidence questions of this type we will add one special locational category—outside of the study area.

Table 2.4 summarizes the level of detail that will eventually be contained in our accounting system. Data requirements are greatest for variable link costs. There are six time periods. For each period, there are 20,000 links and for each link there are 14 mode types. For each of these categories, we will store

[21] See Hensher (1997) for a discussion of the relationship between travel time value and income.

data on all of the variable link costs listed in Table 2.3. Fixed link costs require less data because they do not vary with mode type. Non-link costs generally will require even less data. Demographic data will be kept on the household population for five income categories in each of 1213 locations, with most detail inside the TCMA.

2.4 Summary

The accounting system developed in this section has been designed to meet both communications goals and research goals of the Transportation and Regional Growth Study. Our system identifies a wide range of costs of regional transportation. The scope of this system complicates the accounting process, but dealing with these complications will make the research more valuable to policymakers and others analyzing the Twin Cities region's transportation system and growth plans. We also feel we need to calculate both marginal and average costs. Average costs are useful when evaluating the state of the transportation system and its effects on different individuals. Marginal costs are useful for assessing the efficiency of the system, and for analyzing the costs and benefits of alternative transportation policies.

We divide the full costs of transportation into three main categories: governmental, internal, and external. Internal costs are those that are borne by the person who causes them and external costs are not borne by the person who causes them. These categories are then further divided so that our accounting framework has six main categories:

1. Governmental costs (the costs of public services and infrastructure)
2. Internal costs of monetary unbundled goods and services
3. Internal costs of monetary bundled goods and services
4. Internal costs of nonmonetary goods and services
5. External costs of monetary goods and services
6. External costs of nonmonetary goods and services

We have found a great deal of agreement in the transportation and economics literature about the types of costs that result from transportation. There is less agreement in the literature on how to classify costs and especially whether costs are internal or external.[22] Some studies use a broad definition of external costs that includes all goods that are not fully priced. We use the standard economic definition of an externality, which is

[22] Appendix C discusses some general methodological problems in cost accounting. Appendix C.3 discusses the specific problem of classifying costs as internal or external.

somewhat narrow, but we also make note of internal costs that may be problematic. Our classification of cost items is shown in Table 2.2.[23]

Table 2.4 Accounting System Details	
Time	6 periods
Road Segment	20,000 links
Mode	
Auto	3 classes
Truck	2 classes
Bus	1 class
Other	Light rail and commuter rail
Demographics	
Income	8 categories
Location	1200 zones, 12 counties, and “Outside Study Area”

Table 2.4: The level of detail for our accounting system.

Our accounting system will be set up with enough detail to determine the costs of travel on most major road segments. Our system will also contain data on six time periods and 15 modes. Demographic data will be kept on the household population for five income categories in each of 1213 locations. This report will not develop all costs in this level of detail. Much of the “allocation” of costs across individuals, time periods, and parts of the transportation network will be done in future reports on cost incidence. The remainder of this report will focus on determining the full costs of transportation in the Twin Cities region.

[23] Appendix A.3 describes the cost items in Table 2.2 in more detail and discusses some of the accounting problems various items present.

3 Regional Transportation in 1998 and 2020

In this section we describe the regional transportation system for the years 1998 and 2020. The section is divided into three parts. The first two parts focus on current (1998) transportation. Section 3.1 describes the public infrastructure devoted to transportation. Section 3.2 explains how we predict the use of the transportation system—who will travel and when, where, and how much they will travel. Section 3.3 contains our projections for 2020. It includes our assumptions about demographic and economic trends and our predictions about the 2020 transportation network.

Identifying the public infrastructure used for transportation is a large but relatively straightforward task. The Metropolitan Council and Mn/DOT have most of the necessary data. The Metropolitan Council maintains data describing current and year 2020 networks. These networks represent all major roads in the TCMA. The Metropolitan Council also has data on the region's transit (bus) network and a description of the planned transit network for the year 2020. Mn/DOT has a database that contains detailed information on most of the roads in the state. This database is used to identify local roads that are not included in the Metropolitan Council's network and to predict the cost to the public sector of transportation infrastructure.

Travel behavior is determined in three steps. First, the public infrastructure that is devoted to transportation is identified. Second, the location and some of the demographic characteristics of individuals and firms are identified. Third, models of travel behavior are used to predict how individuals and firms will use the transportation system.

Gathering demographic information is a large task. Two important sources of data are the 1990 Travel Behavior Inventory (TBI) and the 1990 Census (and updates of the Census). The TBI was created from a one-percent sample of households in the TCMA. The TBI and the Census contain information on factors such as vehicle ownership and commuting behavior. The Metropolitan Council also has made demographic predictions for the year 2020. We use long-term trends to predict attributes such as the mix of vehicles, fuel consumption, and vehicle emissions.

The focus of this report is not on travel demand modeling, but we do need to know how people use the transportation system. The standard model of travel behavior is called the four-step process. The model takes as given the transportation infrastructure and demographic information on where people and firms are located. The Metropolitan Council has used the four-step process to estimate the use of the transportation system currently and to predict travel in the year 2020. We use its results as the basis for our estimates of system usage.

3.1 Public Infrastructure

Identifying the public infrastructure used for transportation is an important first step in determining who will travel and when, where, and how much they will travel. Table 2.2 lists over 20 government cost items, but in this section we are only interested in the infrastructure that has the most direct effect on travel. These are the road and transit networks. We do not include public infrastructure provided for transport via air or water or for rail freight shipments because it is seldom used for transportation within the region.[24]

Defining the road network that we will analyze is important. Road construction and maintenance costs are significant in themselves. In addition, the network directly affects the amount and location of travel. Traffic tends to be more concentrated on large limited-access roads, while locations that are relatively inaccessible are likely to attract less traffic.

We rely on the Metropolitan Council's road and transit networks to quantify the effects of the transportation network on travel behavior. The Council's road network includes all sections of roadway that carry an average of over 1,000 daily trips. The network represents these 12,000 lane-miles of roads with approximately 20,000 one-way links.[25] Ten types of links are identified: metered or unmetered freeway, metered or unmetered ramp, high occupancy vehicle (HOV) freeway, HOV ramp, divided or undivided arterial, collector, and centroid connector. Associated with each link is a traffic-delay function. Each such function defines a relationship between traffic volume and travel time. This enables the modeling of travel during congested time periods. Table 3.1 describes some of the road network information maintained by the Metropolitan Council.

The Metropolitan Council's road networks are designed to provide enough data to accurately model travel behavior, but they are not intended to identify

[24] We also ignore any indirect effects this infrastructure might have on intra-regional transportation. For example, public infrastructure devoted to rail or water transport may affect the quantity of freight shipped on roads.

[25] Each link represents a one-way, homogeneous section of road of a certain type.

all roads.[26] For information on other, primarily local, roads we use the *Transportation Information System*, a database maintained by the Minnesota Department of Transportation. This database contains information on nearly all of the roads in Minnesota. Some of the information most useful to us is

- the width and surface type of each roadway,
- funding sources (federal, state, or local) for construction and maintenance, and
- the location and date of motor vehicle crashes.

All of this data can be broken down by county and by other road characteristics. Table 3.2 contains information on the roads in the sixteen Minnesota counties in our study area.

The Metropolitan Council also has developed models of their transit networks for travel demand modeling. As with their road networks, the Council's transit networks contain a great deal of information but are not designed to identify all transit infrastructure.

[26] An additional problem is that the Council's networks only contain roads within the TCMA. We will analyze travel outside the TCMA at the county level. This does not present a major problem for our analyses because there is relatively little congestion in the outlying counties.

Table 3.1: The Metropolitan Council's Road Networks	
Data Element	**Notes**
Origin or Destination	Coordinates are given to define the location of each origin and destination node.
Assignment Group	The links are divide into ten categories: Metered Freeway — Undivided Arterial Unmetered Freeway — Collector Metered Ramp — HOV Lane Unmetered Ramp — Centroid Connector Divided Arterial — HOV Ramp
Location	Link locations are divided into eight types: Rural — Saint Paul Developing — Minneapolis CBD Developed — Saint Paul CBD Minneapolis — Outlying Business District
Lanes	The number of lanes the link contains.
Length	The length of the link in hundredths of miles.
Mode	Links are classified according to whether all autos can use them, or whether their use is restricted to high occupancy vehicles.
Free Flow Travel Time	The time it takes to traverse the link in hundredths of minutes when there is no congestion.
Capacity	A measure of the number of vehicles that can traverse the link in one hour without causing significant congestion.

Table 3.1: The Metropolitan Council's 1990 and 2020 networks each contain more than 20,000 links describing over 12,000 lane-miles of road.

Table 3.2: The Roads by Funding Source and Surface Type[27]

	Category	Lane-Miles	Center-Line Miles
Route System	Interstate Trunk	1,532	312
	U.S. Trunk	1,503	440
	Minnesota Trunk	3,081	1,260
	County State Aid	9,705	4,470
	Municipal State Aide	4,279	1,886
	County	3,807	1,891
	Township	29,821	14,886
Surface Type	Brick or Block	44	21
	Bituminous Concrete	3,488	1,173
	Bituminous	29,504	14,105
	Concrete	2,336	671
	Dirt or Gravel	16,361	8,181
	Unknown or Uncoded	1,995	992

Table 3.2: The TIS contains data on the road network for each of the 16 Minnesota counties in our study area. We break the data into eight funding categories and six surface types.

[27] The table shows the roads in the sixteen Minnesota counties in our study region. The data is for 1998.

3.2 The Use of the Transportation System

The use of this region's transportation system influences most major costs of transportation. The system affects traffic conditions and travel time; vehicle emissions and air pollution; noise; rates at which roads deteriorate; fuel and oil consumption; vehicle depreciation; and crash costs. The goal of travel demand models is to predict travel behavior—who will travel, how much they will travel, and when and where they will travel. We rely on the standard model of travel behavior, known as the four-step model. This part of the report contains a brief description of the model and an explanation of how the model is used in the Twin Cities region.[28]

3.2.1 The Four-Step Model

The four-step model is the standard tool used to predict travel behavior in urban areas. The model is used to "predict" the *current* use of the transportation system for two reasons. Empirically, the models produce estimates that would be costly to obtain from direct observation. Examples include traffic flows on relatively minor roads such as arterials and collectors. The models are also needed to make actual predictions for various policy scenarios. These predictions are evaluated by comparing them to the baseline "predictions" provided by a status quo scenario.

The four-step model has been in use for a long time, at least for a model that must be run on a computer, and the model's predictions have been tested in a variety of situations. The model is usually fairly accurate at an aggregate level but significantly less so at the level of an individual road segment. While modifications and improvements are possible, and the model has a variety of shortcomings, no consensus has emerged on an alternative approach. In practice, travel behavior modeling has been improving primarily by refining individual parts of the four-step process. At least in the short run, it appears that the four-step model, along with its refinements and extensions, will remain the standard travel demand model.[29] A short description of each of the four steps follows.

[28] Barnes (1999a) contains a more complete description of travel demand modeling in this region.
[29] One shortcoming of the four-step process receiving particular attention, is that land use, the locations of households and firms, is exogenous to the model. Models that make land use endogenous have been developed but have not been widely used. Barnes (1999a) discusses a variety of problems that have hampered the adoption of these models. The problems include (i) lack of consensus on how to model the transportation/land use connection, (ii) large data requirements, and (iii) difficulty validating the models.

Before the four-step model can be used, the region to be studied must be divided into sections called traffic analysis zones (TAZs).[30] The model requires that the land use for each TAZ be specified. The most important information is the number of households, the total amount of commercial space, and the amount of retail space contained in each TAZ. Supplementary information might include household incomes and vehicle ownership rates.

Once the land use information is specified, the four-step model can be run. The steps are:

1. Trip generation (determining how many trips will be made out of each TAZ and how many trips will be made into each TAZ),
2. Trip distribution (matching the origins to the destinations of trips made in step 1),
3. Mode choice (determining which mode travelers will use to complete the trips identified in step 2), and
4. Trip assignment (determining which routes travelers will use to make their trips and the traffic conditions on these routes).

The steps can be performed repeatedly to find an equilibrium, i.e., to find travel patterns so that the output from any one step is consistent with the output from the other steps.

Trip Generation: The first step is trip generation. This step predicts the number of trips that will be made by the households and firms in each zone. Trips of various types are estimated including trips for work, shopping, and recreation. The model can also account for demographic and economic information such as household income, ages of household members, and costs of travel. This step also estimates the number of trips that will be made to and from the businesses in each zone. The models can account for different types of businesses; for example, retail businesses usually generate more trips than other commercial enterprises. Finally, the trip generation model also predicts the times at which trips will be taken.

Trip Distribution: The second step is trip distribution. This step links the origins and destinations of the trips that were generated in the previous step. The trips leaving the households or businesses in one zone are matched (or "balanced") with the trips arriving at households and businesses in other zones. Trips are distributed across destinations based on the attractiveness of various locations. Given an origin zone and a type of trip, the attractiveness of a destination zone is usually assumed to be directly proportional to the total number of trips of the specified type arriving in the destination zone

[30] The number of these zones is usually fairly large because only travel between zones is carefully modeled. The Metropolitan Council models the Twin Cities Metropolitan Area with 1200 TAZs.

and inversely proportional to the cost of travel to the zone. The balancing process makes sure that, for each zone, the number of trips that terminate in the zone equals the number of trips that arrive in the zone.

Mode Choice: The third step is mode choice. The previous steps have told us who is travelling and where they are travelling. This step tells us how they will travel. Usually the choice is between auto and transit, but there may be other options as well. The model may include choices between car-pooling and driving alone, between various forms of transit, or between walking and bicycling. The models are usually set up so that the probability that a person uses one mode is a function of personal characteristics and travel costs.

Trip Assignment: The fourth step is trip assignment. Thus far, the models have predicted the origin and destination of each trip and the mode by which the trip is made. In this step, trips are assigned to the routes or paths along which they will travel. The trip assignment step usually focuses on auto travel because (i) auto travelers have so many routes to choose from, and (ii) autos cause most of the congestion on the road network. Generally, the transportation system is described in great detail and travelers are assumed to make their trips along least-cost paths. Costs usually include travel time and may also include mileage, toll, and parking costs. Travelers' route choices are usually interdependent. Any one individual's route choice depends on the choices of others because of the congestion they cause. In equilibrium, each traveler chooses a route that minimizes the traveler's own costs, taking the choices of all other travelers as given.

The four steps are sometimes repeated until the output from all steps is consistent. For example, travel costs are determined in step four. These costs should agree with the inter-zonal travel costs used in steps 1 and 2. Usually the data from all steps can be brought into agreement after the steps are repeated a few times. It should be noted that the resulting travel patterns will be an equilibrium (sometimes called a users' equilibrium)[31] but they will not, except in very special circumstances, be optimal. The resulting travel patterns will *not* generally maximize the net benefits to travelers.

After an equilibrium is found, a variety of information can be obtained. The basic output is the amount of travel on each part of the transportation system. These traffic flows can then be used to predict congestion levels, fuel consumption, and emissions. Information can also be obtained on trips. Examples include the total number of trips made between each pair of zones

[31] Technically the equilibrium is a Nash equilibrium, which means that each user is choosing an action that is *personally* optimal, taking the actions of all other users as given.

and the cost of different types of trips. It is also possible to determine the characteristics of travelers using various parts of the transportation network.

3.2.2 Travel in the Twin Cities Region

Our predictions of system usage rely almost entirely on the Metropolitan Council's application of the four-step model. Overall, we feel that their predictions provide a baseline and will help make our work easy to compare to other studies. Their predictions match fairly well with observations.[32] This reflects the accuracy of the TBI survey, the detailed nature of the Council's networks, and the Council's experience in working with travel behavior models. We feel it would be very difficult, even ignoring the data requirements of the Council's models, to improve upon their estimates.

Before using their travel demand models, the Metropolitan Council had to develop representations of the region and its transportation system. They (i) divided the region into 1200 traffic analysis zones (TAZs) based on land use and (ii) created detailed models of the region's road and transit networks. The road network was designed to include all sections of road used for significant amounts of travel between TAZs.

The Council's travel demand models use an abbreviated version of the four-step process—one that relies most heavily on steps 3 and 4. Much of the output that would have been produced in the first two steps was obtained from the 1990 Travel Behavior Inventory (TBI). The TBI was produced by the Council from a one-percent survey of the region's households. Respondents kept a diary of daily travel. Information on respondents' trips included when they occurred, origins and destinations, purposes, and modes of travel. The survey also gathered demographic data. This included the number of persons in the household, household income, and the number of vehicles available to the members of the household. Table 3.3 identifies some of the information that was gathered by the TBI.

Estimates of total region-wide travel were made by assuming that the behavior of sample households was representative of all households. Because the survey was so large, the TBI generally produced good estimates. A few adjustments were made in cases where, based on the 1990 Census, survey respondents did not seem representative of the region's population. One problem was that two-worker households seemed to have been less likely to respond to the survey than single-worker households were. In addition,

[32] The models are better at predicting aggregate levels of region-wide travel than at predicting the travel on any one road, however. The average absolute value of the error for freeway volumes in 1990 was 15 percent. See page 17 of Metropolitan Council (1994b).

certain types of trips seem to have been underreported. After these adjustments were made, the TBI was used to estimate trip volumes between pairs of TAZs. Because the TBI data was available, the trip generation and trip distribution models were *not* used.

The Council used a mode choice model (step three of the four-step process) to estimate travel on the region's bus transit system.[33] The model was run using detailed representations of the region's road and transit networks, data on parking costs, and demographic information such as income and vehicle availability. The model was also calibrated to reflect the actual number of travelers using transit in the region. Transit is important for some types of trips and especially for commuting trips to the Minneapolis and Saint Paul Central Business Districts. Overall, however, only 2.5 percent of vehicle trips in 1990 were made on public transit. The Council used a traffic assignment model (step four of the four-step process) to predict the auto drivers' route choices. The adjusted TBI data was used to produce the vehicle-trip tables that were the input for this model. The assignment model was run assuming that each traveler attempted to minimize the cost of his or her trip, taking the other drivers' route choices as given. Travel time was used as a proxy for cost. This is a standard assumption, which is made because many of the variable costs of travel change in ways that are approximately proportional to travel time. Standard travel-delay functions were used to model congestion. Finally, predictions of traffic volumes were checked to insure that they were close to observed traffic volumes on major roads.[34]

3.3 Projections for the Year 2020

In this section we attempt to characterize year 2020 transportation in a general way, not to provide a detailed description. The reason is that we do not require most of these details for our cost calculations. Our goals are to (i) clearly describe the transportation system that we will analyze in the rest of this report and (ii) provide perspective on some of the changes that we expect will occur in the region.

Predicting the size of economic and demographic variables in the future cannot be done with complete accuracy. Our projections for economic variables are generally based on underlying demographic projections. For the most part, we use long-term trends to predict year 2020 attributes and ignore

[33] The model also predicts auto usage, but these estimates were obtained directly from the TBI. Because the share of transit trips was small, the TBI alone could not provide accurate estimates of where and when these trips took place. In addition, the mode choice models established a baseline for policy evaluation.
[34] For more information on the validation of the model, see Metropolitan Council (1994b).

the potential for short-term fluctuations. We attempt to quantify uncertainty in our forecasts by constructing a range of cost estimates.

Table 3.3: The 1990 Travel Behavior Inventory

Data File	Key Data
Household (sample size: 9,746)	Location of household Number of persons in household Number of licensed drivers in household Number of vehicles available
Persons (sample size: 24,511)	Age Gender Main employer Work location (if applicable)
Trip (sample size: 98,535)	Purpose Mode Vehicle occupancy (if applicable) Origin and destination TAZs Trip start and end times

Table 3.3: The 1990 Travel Behavior Inventory provides input for the Metropolitan Council's travel behavior models.

3.3.1 Demographics

Demography drives much economic activity, and travel behavior is no different. Population size and characteristics influence many of our predictions of transportation costs. The number and location of households in the region affect the number and location of trips. The size of the labor force affects the number of commuting trips made. Income affects mode choice.

The 1990 Census contains detailed information on all of these demographic characteristics. Some of this data is shown in Table 3.4 and a map of the Twin Cities region is shown in Figure 2.1. Note that there are significant differences between the seven-county Twin Cities Metropolitan Area (TCMA) and the other 12 counties in our study area. The outlying counties have approximately one-tenth the density of the TCMA are significantly more rural and have lower median household incomes. Updated information on some of the data contained in the 1990 Census is available. In addition, special tabulations of 1990 census data are available in the Census Transportation Planning Package (CTPP). The tabulations are organized in ways that are useful for transportation planners. For example, the CTPP contains information on place of work that is arranged by traffic analysis zone and not just by census tract.

The Bureau of the Census provides updates of major demographic variables for the counties in the region. The most detailed forecasts for the area are contained in the Metropolitan Council's *Regional Blueprint* and its supporting documentation. Less detailed forecasts of the number of households and population are available from the Minnesota State Demographer's Office and the Wisconsin Demographic Services Center.

Table 3.5 contains our baseline predictions for population and households. We do not incorporate the uncertainty inherent in these projections into our analysis. This greatly simplifies our work and aids in establishing a baseline for comparing our study to other research. Fortunately, this simplifying assumption does not create as many problems as might be expected because many types of travel and their associated costs rise in almost direct proportion with population.[35] Information on the construction of Table 3.5 is contained in Appendix D.2.

3.3.2 Public Infrastructure

The public infrastructure that will be available for transportation in the year 2020 is easier to predict than other parts of the transportation system. It is easier to predict, for example, than the number and type of vehicles that will be using the system in 2020. This is because (i) public infrastructure is long-lived, (ii) long-range planning is done for many types of public infrastructure, and (iii) the total quantity of transportation infrastructure (especially freeways and major arterials) is growing slowly relative to population. Despite this, we do not try to provide a detailed description of what we think the transportation system will look like in 2020. As discussed further in Section 4.2, we rely mainly on budgetary data to determine the costs of public infrastructure. Because of this, we do not require details on the stock of public infrastructure for our cost calculations. Our goal here is to provide a general description of expected changes in the region's transportation system, so that we make clear what is being analyzed in the remainder of this report.

[35] Some costs probably rise faster than population, however. The per capita costs of air pollution may increase with population density because, as emissions increase, each person is exposed to higher concentrations of pollutants.

Table 3.4: 1990 Census Data for the 19-County Study Area

	19-Cty Study Area	MSA (13 Ctys)	TCMA (7 Ctys)	MSA-TCMA* (6 Ctys)	Total-MSA[ʒ] (6 Ctys)
Size (Square Miles)	10,169	6,345	2,965	3,379	3,824
Total Population	2,733,115	2,538,834	2,288,721	250,113	194,281
Percent urban	85.0	88.6	95.1	29.6	38.0
Percent rural nonfarm	13.2	10.3	4.5	63.3	51.0
Percent rural farm	1.8	1.1	0.5	7.1	11.0
Median Household Income	$35,830	$36,407	$36,678	$33,600	$31,035
Percent in poverty	8.2	8.1	8.1	7.7	9.1
Percent unemployed	3.4	3.4	3.4	3.9	3.0
Commuting by Workers 16+	1,380,424	1,282,298	1,155,973	126,325	98,126
Percent driving alone	75.4	76.1	76.1	72.9	68.9
Percent in carpools	11.4	11.1	10.9	15.9	12.9
Percent using public transport	4.9	5.4	5.6	0.5	0.7
Percent using other means	0.9	0.9	0.9	0.6	1.0
Percent walking/working at home	7.4	6.5	6.4	10.0	16.4
Total Households	1,030,377	960,170	875,504	84,666	70,207
No vehicles available	8.9	9.0	9.5	4.2	7.0
Percent with 1 vehicle	31.1	31.2	31.9	24.6	29.6
Percent with 2 vehicles	41.5	41.5	41.3	43.2	42.1
Percent with 3+ vehicles	18.5	18.3	17.3	27.9	21.3
Total Housing Units	1,095,054	1,015,235	922,224	93,011	79,819
Percent owner occupied	65.3	65.1	64.4	72.2	68.3
Median value/owner occ.	$86,520	$88,220	$89,580	$72,510	$60,530
Percent single unit	66.8	66.1	64.9	77.4	75.7
Percent 10+ units	20.2	21.3	22.8	6.8	6.6

Table 3.4: Outside of the seven-county TCMA, more than 65 percent of the region was rural in 1990 and household incomes were 12 percent lower.

* The figures in this column are for the six counties that are inside the MSA but outside the TCMA.

[ʒ] The figures in this column are for the six counties that are in the region but outside the MSA.

Table 3.5: Projections of Demographic Variables

		Population			Households		
County	Area[*]	1998	2020	Percent Change	1998	2020	Percent Change
Anoka	T	292,181	350,410	19.9	99,951	135,740	35.8
Carver	T	64,674	104,420	61.5	22,346	41,640	86.3
Chisago	M	40,852	52,670	28.9	13,721	18,633	35.8
Dakota	T	342,528	456,160	33.2	122,945	183,900	49.6
Goodhue	O	43,137	47,290	9.6	16,501	20,069	21.6
Hennepin	T	1,059,669	1,216,480	14.8	444,632	520,110	17.0
Isanti	M	30,121	33,910	12.6	10,420	11,383	9.2
Le Sueur	O	25,320	28,080	10.9	9,248	10,818	17.0
McLeod	O	34,017	40,310	18.5	13,041	15,256	17.0
Pierce	M	34,547	42,052	21.7	11,929	14,867	24.6
Polk	O	37,046	37,217	0.5	13,081	13,148	0.5
Ramsey	T	485,636	537,340	10.6	199,373	222,760	11.7
Rice	O	54,106	58,560	8.2	18,345	20,836	13.6
Saint Croix	M	57,113	61,493	7.7	18,177	19,745	8.6
Scott	T	79,031	137,910	74.5	26,495	54,040	104.0
Sherburne	M	60,391	91,620	51.7	18,982	22,021	16.0
Sibley	O	14,573	14,590	0.1	5,568	5,575	0.1
Washington	T	196,486	288,670	46.9	66,667	111,130	66.7
Wright	M	85,123	105,550	24.0	28,436	27,166	-4.5
All 19 Counties		3,036,551	3,704,732	22.0	1,159,857	1,474,621	27.1
MSA		2,828,352	3,478,685	23.0	1,084,072	1,383,136	27.6
TCMA		2,520,205	3,091,390	22.7	982,408	1,269,320	29.2
ALL/MSA[ℑ]		208,199	226,047	8.6	75,785	91,484	20.7
MSA/TCMA[ℜ]		308,147	387,295	25.7	101,665	113,816	12.0

Table 3.5: From the years 1998 to 2020 the population in our study area is forecast to grow by 22 percent overall, but by only 9 percent in six outlying counties. For more information on the construction of this table see Appendix D.2.

[*] The counties in the Twin Cities Metropolitan Area are denoted with a T, the counties in the Metropolitan Statistical Area but not in the TCMA are denoted with an M, and all other counties are denoted with an O.

[ℑ] These figures are for the six counties that are in the region but outside the MSA.

[ℜ] These figures are for the six counties that are inside the MSA but outside the TCMA.

The Metropolitan Council has developed models of the road and transit networks they expect will exist in 2020. Table 3.6 contains information on the Council's road network models. They were produced using realistic assumptions about changes in population and the budget for road and transit construction. The Council has also produced the *Regional Blueprint* (Metropolitan Council, 1996a). This document contains a growth strategy through the year 2040 and included forecasts of population, housing, and employment. In addition, the Council's *Transportation Policy Plan* (Metropolitan Council, 1996b) outlines strategies for meeting the region's transportation needs. More detailed, short-range plans are also available in the region's Transportation Improvement Programs. The most recent of these is for the years 2000 to 2003 (Metropolitan Council, 1999).

One shortcoming of these planning documents is that they do not contain much detailed information on local roads. We expect that a great deal of local road construction will take place in parts of the region that are undergoing rapid development. These costs will be important, especially as a fraction of all road construction costs.[36] We define local roads to be roads that are not at least partially funded with federal or state revenue. We predict changes in local roads based on the Metropolitan Council's demographic predictions.

Except for local streets, we do not expect large changes in the total lane-miles of roads in the region. Roads that are not local are classified as trunk highways, county state aid highways, or municipal state aid streets. Local roads are classified as either county or township roads. We expect significant construction of local roads in areas where the number of households is growing rapidly. Examining 14 of the Minnesota counties in the region,[37] we estimate that an increase of 80 households leads to an increase in one lane-mile of local roads. Table 3.7 contains our projections for changes in lane-miles of local roads.

We do not try to predict the precise nature of the region's transit network in 2020. Such details are needed primarily for predicting the effects of policies, and not for determining their costs. We will provide information on some of these costs in the part of this project that focuses on the costs of alternative transportation systems.

[36] The costs of non-local road construction may decline because, while some large, expensive projects are planned, not many such projects are expected.
[37] We ignore Hennepin and Ramsey Counties because they were 99.1 and 99.9 percent urbanized in 1990. (Dakota and Anoka Counties were 94.4 and 91.9 percent urbanized, and no other county was more than 80 percent urbanized.)

Table 3.6: The Metropolitan Council's Model Road Networks

Road Type	Lane Miles 1995	Lane Miles 2020	Total Change	Percent Increase
Freeway (except HOV)	1,579	1,737	158	10
Ramp (except HOV)	242	314	72	30
HOV Freeway or Ramp	23	108	85	373
Arterial (divided or undivided)	6,689	6,827	137	2
Collector	1,392	1,416	25	2
Total	9,925	10,402	477	5

Table 3.6: The Metropolitan Council expects relatively minor changes in non-local roads in the Twin Cities region.

Overall, we do not predict large changes in the region's bus transit network. Bus ridership, routes, and operating schedules have not changed significantly over the last 20 years. In the Twin Cities metropolitan area, ridership has fallen at slightly less than one percent a year since the early 1980s (to approximately 50 million trips a year in 1996). Large changes have not been made in service areas or routes and vehicle-miles rose approximately 5 percent from 1987 to 1996.[38]

As argument can be made, however, that in 2020 the transit system will be much more extensive, and that there will be many more transit users than there are now. In 1996 and 1997, regional transit ridership increased significantly. These increases might continue because of traffic congestion and because of ambitious plans by the Metropolitan Council to expand transit service. It appears likely that a light rail line will be built along the Hiawatha Corridor.[39] In addition, the Council also has recently established goals of building additional light rail lines, one or more commuter rail lines, and several bus transitways. It is difficult at this time to assess how many of these goals will be accomplished and the importance of recent ridership

[38] Office of the Legislative Auditor (1998).

[39] This line would link the Mall of America, the Twin Cities International Airport and Downtown Minneapolis.

increases. For the most part, we rely on longer-term trends in making our projections, but we make some adjustments because of recent changes.

Table 3.7: Projections for Households and Local Roads

	Households		Lane-Miles of Local Roads			
	1998	2020	1998*	2020	Change	% Change
Anoka	99,951	135,740	2,644	3,087	444	16.8
Carver	22,346	41,640	1,198	1,437	239	20.0
Chisago	13,721	18,633	1,308	1,369	61	4.7
Dakota	122,945	183,900	2,734	3,490	756	27.6
Goodhue	16,501	20,069	2,130	2,174	44	2.1
Hennepin	444,632	520,110	6,904	6,904	0	0.0
Isanti	10,420	11,383	1,386	1,398	12	0.9
Le Sueur	9,248	10,818	1,226	1,245	19	1.6
McLeod	13,041	15,256	1,441	1,468	27	1.9
Pierce	11,929	14,867	1,463	1,500	36	2.5
Polk	13,081	13,148	1,477	1,478	1	0.1
Ramsey	199,373	222,760	2,429	2,429	0	0.0
Rice	18,345	20,836	1,591	1,622	31	1.9
Saint Croix	18,177	19,745	1,541	1,560	19	1.3
Scott	26,495	54,040	1,198	1,540	342	28.5
Sherburne	18,982	22,021	1,369	1,407	38	2.8
Sibley	5,568	11,358	1,470	1,542	72	4.9
Washington	66,667	111,130	2,172	2,723	551	25.4
Wright	28,436	27,166	2,429	2,429	0	0.0
All 19 Counties	1,159,857	1,474,621	38,109	40,802	2,693	7.1
MSA	1,084,072	1,383,136	28,774	31,272	2,498	8.7
TCMA	982,408	1,269,320	19,278	21,610	2,332	12.1
MSA - TCMA	101,665	113,816	9,496	9,663	166	1.8
ALL - MSA	75,785	91,484	9,335	9,529	195	2.1

Table 3.7: Most increases in local road construction are projected to occur within the TCMA because that is where most new households are expected to locate.

* The numbers for the Wisconsin counties are estimated from a regression we ran on fourteen of the Minnesota counties. We assumed that no more local roads would be built in Hennepin and Ramsey Counties because both are already so highly urbanized. Our regression predicted a small decrease in lane miles of local roads in Wright County, but we assumed no change would occur.

3.3.3 Private Expenditures

Private expenditures on transportation do not usually receive as much attention as public expenditures or externalities. They are important, however. One reason is their size—they are significantly larger than public expenditures or external costs. Delucchi found that internal, monetary costs accounted for between 37 and 53 percent of the total costs of motor vehicle use. Updating his cost estimates to 1998, private expenditures on transportation would average between $5,800 and $7,900 dollars per person. Private expenditures are also important because they affect travel behavior. Auto travel, for example, is constrained by the availability of a vehicle and parking and is influenced by vehicle operating costs.

Our projections of expenditures are based on income trends because (i) we know more about how income changes over time than how the purchases of most other goods change, and (ii) we expect that purchases of many types of goods will vary in a systematic way with income. We have good data on income growth that goes back a few decades. Income growth has been fairly stable, much more so than, for example, purchases of automobiles or most other consumer durables. The way purchases vary with income is summarized by the income elasticity of demand. The *income elasticity of demand for good X* is defined to be the percent increase in the quantity of good X that is purchased when income rises by one percent. Goods are defined to be *inferior goods, luxuries,* or *normal goods* depending on whether their income elasticity of demand is negative, greater than one, or between zero and one, respectively. Our standard assumption will be that the income elasticity of demand for transportation-related goods and services is one unless we have specific evidence that this is not the case.

We assume that personal income will grow at 1.0 percent per year in the Twin Cities region. This is based on projections from the U.S. Bureau of Economic Analysis.[40] The Bureau estimated that U.S. per capita income grew at a yearly rate of 1.31 percent from 1978 to 1998 and that this rate will slow to 0.92 percent from 1998 to 2020. The primary reason for the slower rate is that the ratio of retired people to employed people is expected to rise. Estimates and projections for the United States are shown in Figure 3.2. Given the strong economic performance of the last four years, we use a slightly higher estimate of income growth than does the Bureau of Economic Analysis. We assume that per capita income will grow 1.0 percent a year.

We estimate the number of vehicles owned by residents of the region from demographic trends. There were 4,178,000 vehicles of all types, and

[40] See U.S. Department of Commerce (1995).

2,402,000 private and commercial autos, registered in the state of Minnesota in 1998.[41] These numbers include vehicles registered by individuals, corporations, and units of government. We assume that the per capita rate of vehicle registration is the same for the 19-county region as it is for Minnesota as a whole. This yields an estimate of 2,685,000 vehicles of all types and 1,544,000 private and commercial autos in the region in 1998.

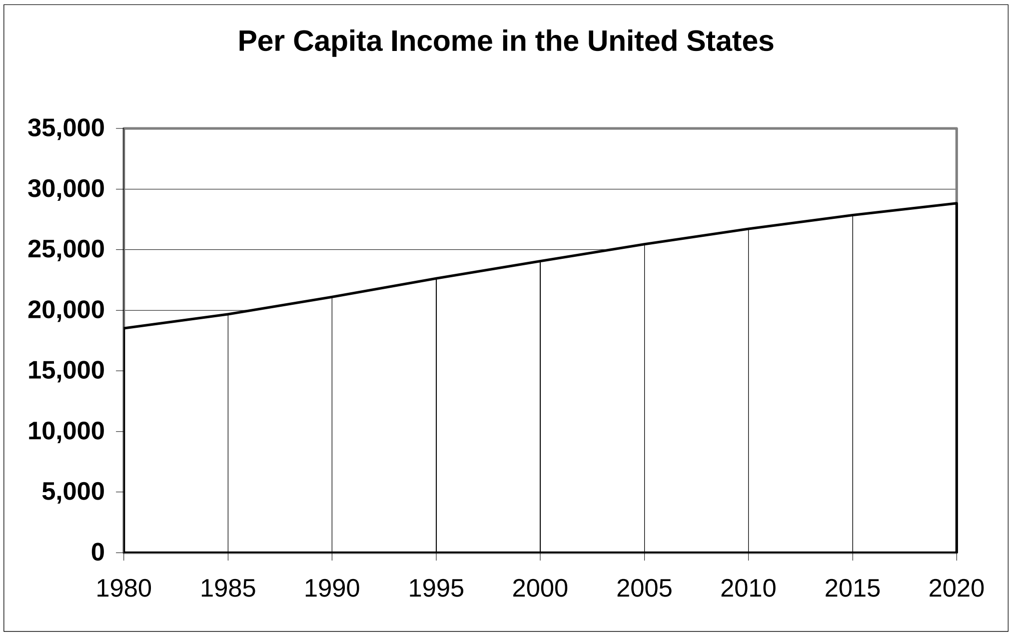

Figure 3.1: Real Per Capita Income in the U.S.

The Bureau of Economic Analysis predicts that real per capita income in the United States will grow at a yearly rate of 0.92 percent from 1998 to 2020.

We project that the ratio of registered vehicles to the driving age population will rise from 1.09 to one in 1998 to 1.11 to one in 2020.[42] Long term trends show that this ratio rising but more and more slowly as almost everyone gains access to at least one vehicle.[43] The proportion of the region's population that will be at least 15 years old is expected to rise from 78.4 percent in 1998 to 82.6 percent in 2020.[44] From these numbers, we project

[41] FHWA (1999).
[42] The driving age population is defined to be the number of people at least 15 years of age.
[43] FHWA (1998a), page 17, shows the trend for 1950 to 1996.
[44] Minnesota Planning (1998).

that there will be 3,514,000 vehicles of all types, and 2,021,000 private and commercial autos, in the region in 2020.

For a variety of reasons, it would be useful to have more detailed projections for the vehicle fleet. It would be useful, for example, to know more about the size and age of the fleet. Unfortunately, we do not know as much about these factors as we would like. Vehicle attributes, such as the quality or the safety of the fleet, are even more difficult to predict or even to quantify. We examine these aspects of the vehicle fleet on an individual basis as they affect our cost estimates.

We assume that the amount of infrastructure devoted to parking, the numbers of garages, parking spaces, and the lane-miles of private drives, will rise in proportion to the number of vehicles. This is a gross simplification, of course, but we are not aware of any studies that have tried to quantify the amount of this infrastructure for the region.

We assume that the fuel efficiency of the region's motor vehicle fleet will not change between 1998 and 2020. It would not be surprising if the fleet fuel efficiency rose or fell between now and 2020. There are two opposing trends. First, technological progress is making vehicles more fuel efficient, and second, the average size of vehicles is increasing. Our best guess is that these trends will offset each other and there will be no net change in efficiency. Based on the fact that in Minnesota in 1997, cars, trucks and buses consumed fuel at a rate of one gallon per 16.4 miles,[45] we project that 1.45 billion gallons of fuel will be used in 1998 and 2.01 billion gallons will be used in 2020.

3.3.4 Travel in 2020

Our projections of travel in the Twin Cities region are based on the Metropolitan Council's travel demand models and trends in regional travel behavior. For the trends in travel behavior, we relied on Barnes (1999b). The construction of our estimates of travel time is discussed in Section 6.1.2. Our projections are summarized in Table 3.8 and are discussed in more detail in Appendix D.2.

[45] This covers gasoline, gasohol, and diesel and calculations include estimates to account for fuel lost to evaporation (Federal Highway Administration (1998b)).

Table 3.8: Summary of Regional Demographic and Travel Projections

	1998	2020	% Change
Population	3,036,600	3,704,700	22.0
Driving Age Population	2,382,000	3,061,900	28.5
Households	1,159,900	1,474,600	27.1
Per Capita Income	$30,300	$37,200	22.4
Vehicles	2,685,000	3,514,000	30.9
Annual Person-Hours of Vehicle Travel (1000s)	1,206,000	1,618,000	34.2
Annual Vehicle-Hours of Travel (1000s)	959,000	1,331,000	38.8
Annual Vehicle-Miles of Travel (1000s)	25,914,000	36,689,000	41.6
Annual Gallons of Fuel Consumed (1000s)	1,580,000	2,237,000	41.6

Table 3.8: We estimate that per capita travel time will increase by 10.0 percent, but that per capita vehicle-miles of travel will increase by 16 percent. For more information on these projections see Appendix D.2 and Section 6.1.2.

4 Governmental Costs

Governments undertake a wide range of activities and incur significant costs to facilitate transportation. The goal of this section of the report is to provide information that can help governments to provide transportation-related goods efficiently and equitably. Public involvement in the transportation sector is significant, whether measured by the size of government expenditures on transportation or when compared to government involvement in other sectors of the economy. One reason for this high level of involvement is that markets might fail to provide many transportation-related goods and services efficiently. A number of types of market failure have been linked to the private provision of roads,[46] for example, and roads are responsible for the largest share of governmental costs.

While governmental costs often receive close scrutiny and may be the subject of intense debate, government provision will not, by itself, solve transportation problems. The absence of markets means that (i) the normal forces that push prices towards efficient levels are also absent and (ii) costs can be shifted between one user group and another or between users and nonusers. User fees, when they exist at all, may be only indirectly tied to the costs users impose. This lack of a necessary connection between user fees and costs opens the door to both equity and efficiency concerns. Finally, all of these problems may be exacerbated because it can be difficult to measure the quality and the value of transportation services.

Public choices are made in a political arena that has its own rules. Analyzing public choice mechanisms—for either the positive purpose of predicting the types of choice that will be made, or for the normative purpose of comparing mechanisms—is outside the scope of this report.[47] Our goal is to gather data on governmental costs that will facilitate analyses of policies that will affect the efficiency and equity of the region's transportation system. This goal requires information on cost incidence (i.e., we need to determine who bears and imposes the costs of transportation), which will be done in the next stage of this study.

[46] Problems include thin markets for land, high transaction costs in charging for road use, the fact that roads have some of the properties of a public good when they are not congested, and indivisibilities that may result in high fixed costs and increasing returns to scale for some types of roads.
[47] Part V of the Transportation and Regional Growth Study will analyze the public institutions that make transportation and land use decisions.

To say that governmental production of a good results in an efficient outcome means that the good is provided and utilized without waste. Waste is defined as occurring when there is a way to save resources (money) without making at least one person worse off. Consider the case of a road. Efficiency requires that resources are not wasted when producing the road. If an asphalt road is cheaper than a concrete one and performs as well, then producing a concrete road would be inefficient. It also requires that the right amount of the good be produced. For example, the road would be inefficiently provided if people could be made better off by shifting resources from producing the road to operating buses. Finally, efficiency requires that the good be utilized by the right number of people and by the people who value the road the most. When there is severe congestion, the road is probably being used inefficiently.

The equity or fairness of government spending is also a subject of special concern. Indeed, concerns about equity are often more tangible than concerns about efficiency and hence may override efficiency considerations. Producing politically viable legislation will generally require sensitivity to the way the resulting benefits and costs are distributed. Notions of fairness may require costs and benefits to be distributed in certain ways across income levels, geographic regions, or political jurisdictions.

We attempt to provide the data needed for studies of the equity and efficiency of goods that are provided by the government. Especially when determining equity, we need to distinguish goods provided by the Federal Government, by the State of Minnesota, and by local governments. Fortunately, most of our cost data comes from budgets of the various governmental units. Also important to studies of equity is treatment of user fees. In some respects, our treatment of roads and transit is inconsistent. We deduct user fees (fares) from the governmental costs of transit, but we do *not* deduct gas taxes or vehicle registration fees from the governmental costs of roads. A potential justification of this difference is that transit fares may be more directly tied to services than fuel taxes or vehicle registration fees. This is not a wholly satisfactory explanation, however, and our main reason for the different treatment is convention. Future work on cost incidence will examine the taxes and fees in more detail.

We divide this part of the report into six sections. Section 4.1 provides some general information on our cost calculations. Sections 4.2, 4.3, and 4.4 explain how specific governmental cost items are calculated—the costs of roads in 4.2, the costs of transit in 4.3, and all other costs in 4.4. Section 4.4 covers four types of costs—the costs of police, fire, and safety; protecting the environment; spending for energy security; and assorted costs to governmental agencies. Section 4.5 discusses two items that we consider to be important but do not consider to be governmental costs of transportation—fiscal impacts and regulations. The last part of this section summarizes governmental costs.

The most detailed list of cost items in this report is contained in Table 2.2. To simplify our analysis, we do not calculate all of these costs separately. Table 4.1 lists the sections of this report in which the governmental cost items from Table 2.2 are analyzed.

4.1 Governmental Cost Calculations

The budget-making process may be complicated, but once a budget is agreed upon, calculating most governmental costs is a relatively straightforward process. Detailed budgets are usually available. In addition, governmental costs are monetary, so it is not necessary to infer the costs of nonmonetary goods. While straightforward, calculating costs involves organizing data from many levels of government. Our study area includes parts of two states, 19 counties, and over 200 local units of government. Given this scope, we are not able to calculate most governmental costs directly from budgets. In many cases, we rely on other studies that summarize these costs at the state or national level.

While the methodology for calculating governmental costs is, for the most part, straightforward, difficulties do arise. Two are of particular importance—determining the cost of the economic (verses accounting) depreciation of public infrastructure and determining the share of any particular expenditure that is due to transportation. The cost of economic (or actual) depreciation is not usually included in budgets. Consider the example of a road that must be resurfaced every five years at a cost of $1,000,000. The infrastructure cost of this road in any given year is the roughly $200,000 worth of depreciation it experiences. Over the life of the road, governmental expenditures will equal total depreciation. Relying on expenditure data from only one year, however, we would either under- or over-estimate the true cost of the road. This might not be a problem when analyzing a large area because such expenditures can average out. Even for a large area, however, problems could occur due to particularly large construction projects or because of political or economic cycles.

Table 4.1: Computations for Governmental Cost Items		
Cost Item	Description	Report Section
1.1	Federal, state, and local spending for road construction, maintenance, and management	4.2
1.5	Federal, state, and local transit subsidies	4.3
1.3 & 1.4	Law enforcement and traffic safety	4.4.1
1.6	Transportation-related environmental protection and cleanup	4.4.2
1.7	Energy security costs	4.4.3
1.2 & 1.8	Off-street parking and assorted costs to governmental agencies	4.4.4
NA*	Regulatory costs imposed on the private sector	4.5.1
NA*	Fiscal impacts	4.5.2

Table 4.1: Some of the cost items from Table 2.2 are grouped together for computational purposes.

The other important methodological problem is determining the share of expenditures that are due to transportation. For many costs this is not an issue. All spending for road construction and maintenance are easily assigned to transportation. What share of fire protection or national defense is due to transportation, however? In most cases, such questions can be answered with a reasonable degree of accuracy. In other cases, as with defense, there is no easy way to disentangle the purposes of the expenditures. Even when the purposes can be disentangled, there may be problems in determining the right share of expenditure to assign to each purpose, because the purposes may complement or detract from each other. This problem is similar to the one of determining cost responsibility across user groups.[48]

* These items are not considered to be governmental costs of transportation. Fiscal impacts are not considered costs of transportation and regulations are included with the internal costs of transportation.

[48] Problems arise, for example, when trying to assign cost responsibility between autos and heavy trucks. Roads may be built thick to stand up to heavy trucks and wide to accommodate large volumes of autos. While methods exist for determining the share of the costs of roads that should be paid for by different user groups, they are not without controversy (see, for example, FHWA (1997)).

In presenting numbers, the handling of user fees is important. With the exception of transit fairs, we do not deduct user fees from governmental costs. This means that we do not estimate the share of governmental spending for transportation that is borne by the general public. In the United States, direct user fees do not generally appear to pay for the full costs of road construction and maintenance.[49] Should the share of costs that are covered by fuel taxes be considered internal or governmental? For simplicity, we consider all of the expenditures made by governments to be governmental costs, regardless of the revenue source. Again, the role of user fees for transportation will be studied more in the portion of this research that focuses on cost incidence.

Uncertainty in our estimates of current governmental costs is primarily due to the two methodological problems just discussed and to our inability to examine in detail the budgets of all of the units of government that provide transportation services in the region. For our predictions of costs in 2020, this uncertainty is compounded by economic trends and political decisions that are difficult to predict. We attempt to illustrate this uncertainty by providing low, high, and midrange estimates for governmental costs.

To understand the projections that follow, it is useful to have some perspective on aggregate government spending. Over the last 30 years, there has been little change in total governmental spending or in total transportation-related governmental spending when examined as a share of U.S. GDP. This is true for aggregate spending by states and local governments and for national non-defense spending. These trends are shown in Figure 4.1.

Government spending is constrained, at least in the long run, by revenue collections. While governments may use general revenue to finance transportation spending or use revenue from transportation sources to finance general spending programs, revenues collected for transportation are likely to have an important influence on governmental transportation spending. At the state level these revenues are mainly received from fuel taxes and vehicle registration fees (in 1996 these sources accounted for 47 and 42 percent of the revenue for Minnesota's trunk highway fund).[50] Revenue trends are shown in Figure 4.2.

Placing our cost projections in perspective can be difficult because of the changes that we expect between 1998 and 2020. In particular, we expect significant changes in population, per capita income, and the general price

[49] For some evidence of this for the Twin Cities region, see Ryan and Stinson (1999).
[50] Office of the Legislative Auditor (1997b), pages 23 and 24.

level. We adjust for changes in the price level by converting virtually all values into 1998 dollars. In most cases, nominal costs can be estimated using projections of the consumer price index. Changes in the costs of many governmental services have closely followed changes in the general price level over the last 30 years. The costs of road construction and maintenance are notable exceptions, however. Significant technological progress appears to have kept these costs down. To help keep cost changes in perspective, in relation to population, we report many costs in per capita and per vehicle terms. Putting cost projections in perspective relative to changes in per capita income is more problematic. In most cases, it is probably easiest to understand costs as a share of per capita income. Comparing changes in the costs of road construction to changes in per capita income, for example, would probably be a good way to start thinking about whether the region's 2020 road network is affordable. We report most costs in three ways: in aggregate terms, in per capita terms, and as a share of per capita GDP.

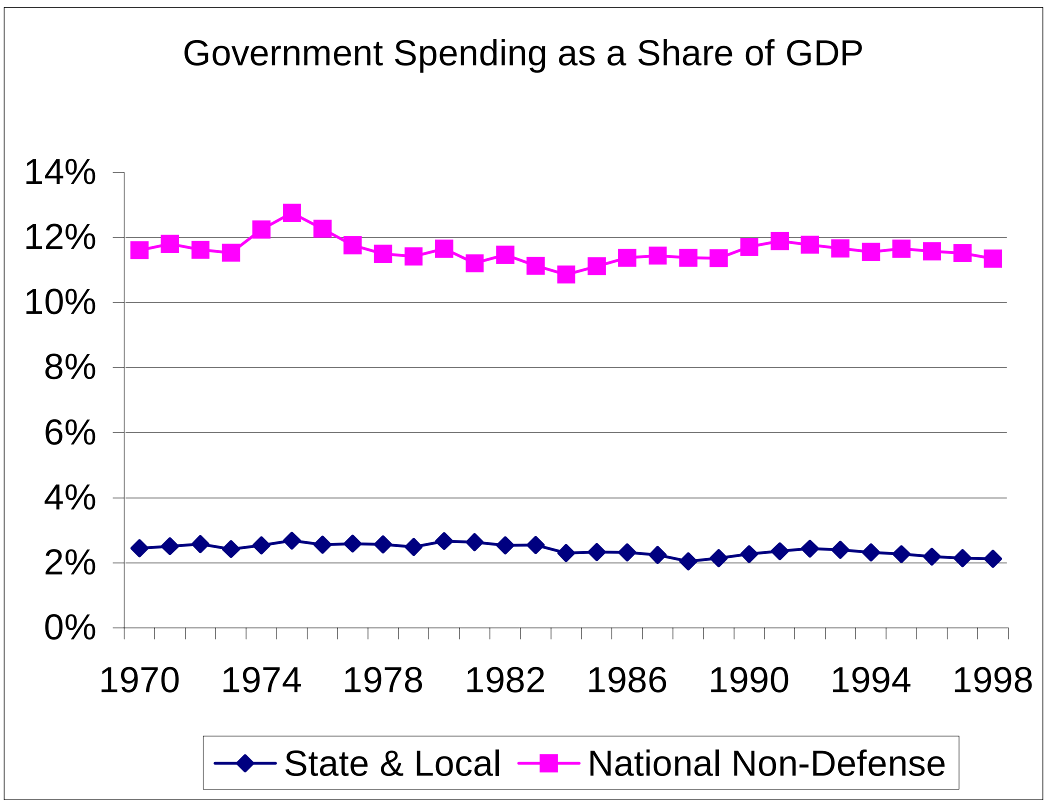

Figure 4.1: Government Spending as a Share of GDP

Between 1970 and 1998, both national non-defense spending and spending by states and local governments have consumed approximately constant shares of U.S. GDP.

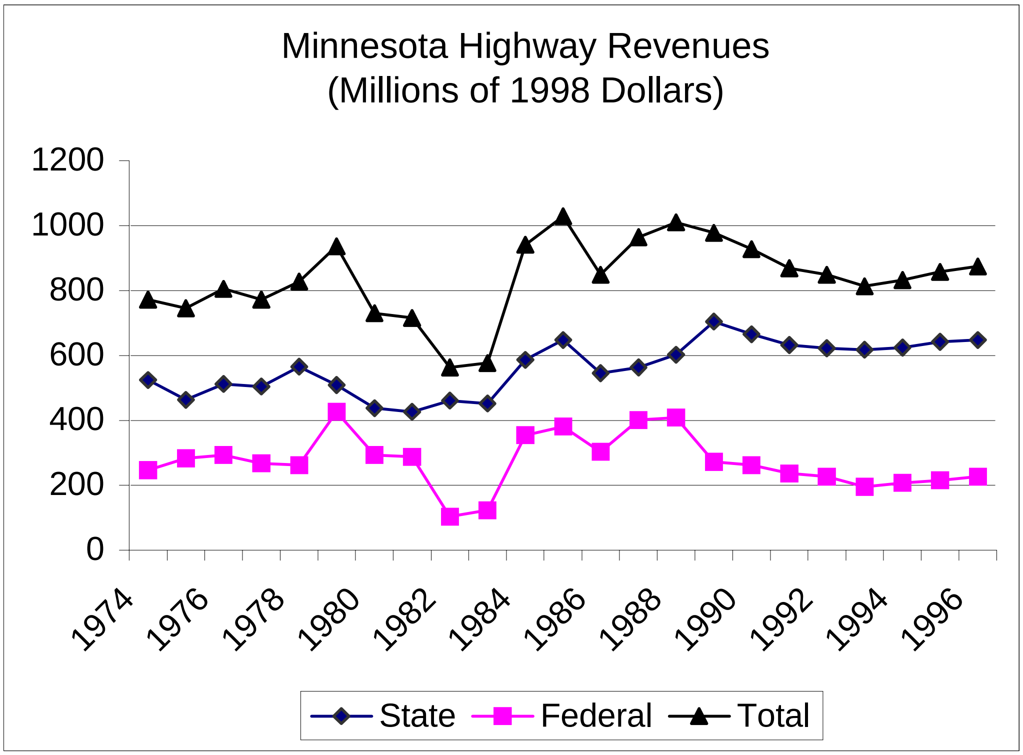

Figure 4.2: Minnesota Trunk Highway Revenues

Total revenues for Minnesota's trunk highway system have fluctuated, but have not risen greatly, in real terms over the last 20 years.[51]

[51] Office of the Legislative Auditor (1997b).

4.2 Road Construction and Maintenance

This category includes construction and maintenance costs, overhead costs of managing the roadway, and the value of the land used for roadways. This is the largest category of governmental costs, so calculating these costs accurately is important. All of these costs are included in budgets except for some of the costs of land. Current costs will be discussed in Section 4.2.1 and projections for the year 2020 will be covered in Section 4.2.2.

4.2.1 Construction and Maintenance Costs in 1998

We rely on budgetary data to make our cost calculations.[52] Maintenance and especially construction costs vary from year to year, with business cycles, as major projects are undertaken, and with special governmental initiatives. The potential problems caused by fluctuations in spending for maintenance are mitigated because (i) the data we use follow long-term trends and (ii) the condition of the road network does not appear to be changing appreciably. The Legislative Auditor of the State of Minnesota concludes that, at least for highways, overall pavement quality improved slightly between 1985 and 1995.[53]

Our basic numbers for the costs of roads come from the Office of the Legislative Auditor (1997b). The Legislative Auditor estimates that the State of Minnesota spent $804 million on streets and highways in 1993 and that other levels of government (cities, counties, and townships) spent $1649 million. This gives us a good estimate of statewide costs, but we do not know the fraction of these costs that are incurred in our 19-county study area. It is plausible that Mn/DOT does not spend as much money on highways, per capita, in the Twin Cities region as it does outside of the region. This is because Minnesota has a very large trunk highway network, and most of it is located outside the Twin Cities region. Our low-range estimate is that

[52] An alternative approach would be to estimate some costs by calculating the depreciation for road infrastructure. We do not use this approach because, given the time constraints of our study, we do not feel it would give us more precise cost estimates than we can obtain from budgetary data. However, calculating depreciation directly appears to offer important advantages which it may be valuable to explore. The ideas underlying such an approach are developed in Minnesota Department of Transportation (1998).

[53] Office of the Legislative Auditor (1997b), page 31.

Mn/DOT spends 40 percent of its highway funds in the region, our mid-range estimate is 51 percent, and our high-end estimate is 62 percent.[54]

We assume that spending on streets and highways for local governments closely reflects their share of the state's population. Our study area has higher than state average levels of income and government spending per capita. We expect that some of this will be reflected in higher spending on streets and highways. Mitigating this fact, however, the Twin Cities region may have lower per capita costs because of the region's higher densities. We estimate that per capita street and highway spending by local governments in the 19-county region is between 90 and 105 percent of per capita spending by local governments in the state as a whole.

Our estimates of the governmental costs of streets and highways are shown in Table 4.2. These estimates only partially include two costs—those of collecting highway user-fees and the costs of land. Our cost estimates only include the costs of collecting and administering highway user fees that are borne by Mn/DOT. They do not include costs that are borne by other state government agencies or by the federal government because we have not found any data on them. We feel these costs are probably small, however.

The road network consumes a significant amount of land. Parsons Brinkerhoff Quade & Douglas, Inc. (1998) estimated that one center-line mile of road consumed 5.16 acres of land. This is equivalent to assuming that the average road has a right of way that is 43 feet wide. The average road in this region, however, may have as much as 60 feet of right of way. We estimate that the road network in the 19-county area runs nearly 30,000 center-line miles. Given these numbers, the road network consumes between 145,000 and 200,000 acres of land (between 225 and 315 square miles of land or between 2.2 and 3.1 percent of the region's land area).

We include almost none of the costs of this land in our estimates. The only land costs that we account for are the costs of land purchased for new construction. Land purchases from previous years are not included. In theory, two types of land costs can be calculated: the marginal cost of land and the total cost of land. Defining the marginal cost of land is straightforward; it is just the market price of the land. When conducting cost-benefit analyses, it is important to account for these (marginal) land costs. We do not try to calculate the marginal cost of land because it varies so much across parcels. It needs to be calculated on a case-by-case basis.

[54] We use a fairly large range here because of the difficulty of determining these numbers precisely. Our mid-range estimate agrees fairly well with Ryan and Stinson (1999).

It is not clear that determining the *total* cost of land devoted to roadways would be useful, even if it were possible. Calculating such a number might be misleading because building roads may increase the value of land. To the extent that roads do increase land values, including the current cost of land as a cost of the road network would mean labeling some of the *benefits* of roads as opportunity costs of roads. To guard against this problem, we would need to estimate the total value of land in the absence of roads. We are not aware of anyone who has tried to make such an estimate.

4.2.2 Projections for 2020

Our forecast is that spending on streets and highways will grow slowly between now and 2020. Between 1977 and 1993, this spending grew by 17 percent in Minnesota and 11 percent in the United States as a whole on a real per capita basis.[55] This works out to yearly growth rates of 0.98 and 0.65 percent, respectively. Note that this spending was fairly flat compared to GDP (see Figure 4.1). These trends may reflect highway revenues, which grew by only 5 percent over the same period (although these revenues did fluctuate for some of this period, see Figure 4.2). They may also reflect increases in productivity for highway construction and maintenance. The productivity in these sectors appears to be following national trends that show higher productivity growth in the construction and manufacturing industries than in services.

Our forecast is that the per capita yearly growth rate in spending for streets and highways will be between 0.50 and 0.90 percent. The low growth projections reflect three main factors. First, spending on roads has been growing more slowly than per capita income and we expect this trend to continue. Second, we expect the large productivity gains for road construction and maintenance to continue. This will allow increases in the extent and quality of transportation infrastructure to occur, even with slow growth in spending. Were this not possible, one might expect that the demands on the system caused by our projected 42 percent increase in VMT would force up spending levels. The third factor is that current transportation plans do not include many large new road-building projects. This lack of a large amount of new road construction will probably help keep costs down, even considering how expensive large road construction projects in developed areas can be. Our low-end estimate is that costs will increase by 12 percent between 1998 and 2020 and our high-end estimate is that costs will increase by 22 percent. These estimates are shown in Table 4.2.

[55] Office of the Legislative Auditor (1997b), page 16.

Table 4.2: Governmental Costs of Streets and Highways

	Total Spending in the 19-County Twin Cities Region (Millions of 1998 Dollars)					
	1998			2020		
Spending Source*	Low	Mid	High	Low	Mid	High
State	345	445	550	470	640	815
Local	995	1,090	1,185	1,350	1,555	1,755
Total	1,340	1,535	1,735	1,820	2,195	2,570
	Per Capita Spending					
	1998			2020		
Spending Source*	Low	Mid	High	Low	Mid	High
State	$115	$145	$180	$125	$175	$220
Local	$325	$360	$390	$365	$420	$475
Total	$440	$505	$570	$490	$595	$695

Table 4.2: Total budgetary costs are expected to rise between 36 and 48 percent in real terms and between 12 and 17 percent in per capita terms.

4.3 The Costs of Transit

The full cost of transit is the sum of three components: subsidies to transit, internal transit costs (mostly fares and time costs), and external transit costs. The governmental costs of transit are the subsidies to transit from any level of government (i.e., the difference between the full cost of running the transit system and the fare revenue generated by the system). Note that governmental costs do not include transit fares, which we consider to be internal costs.

* Sources are classified by whether or not spending is locally administered or administered by the state. The classification is *not* by the source of the revenues. The numbers include the spending of federally provided funds.

4.3.1 Transit Costs in 1998

The governmental costs of transit are relatively easy to determine from agency budget data. The Metropolitan Council publishes such information (in the *Transportation Policy Plan*), as does the Federal Transit Administration (in the *National Transit Database*). Both agencies publish data that is classified by funding source and route characteristics.

The Metropolitan Council runs by far the largest transit service in the region, Metro Transit. This service includes regular route bus service and Metro Mobility, which provides door-to-door transit service for people with disabilities. The latest federal data, from 1995, lists total operating costs of $132 million, capital costs of $35 million, and total revenue of $47 million. This yields total subsidies of $119 million. There is no significant difference between these figures and those published by the Metropolitan Council.

In addition to transit service provided by the Metropolitan Council, there are four other types of services on which we have data: 1) private operators, 2) small urban public transit services, 3) rural public transit services, and 4) "opt-out" public transit services. The private operators run a variety of fixed route services. The small urban and rural operators provide transit outside of the Metropolitan Council's main service area. The opt-out communities have decided to provide their own transit services, even though their communities lie within the Metropolitan Council's main service area. The Metropolitan Council performed a financial review of these services in 1997. Their total costs were just over $22.5 million and their total revenues were $4.5 million. Total governmental costs were $18 million.

One area we have not analyzed in great detail is school bus transportation. It accounts for a significant share of all transit costs, however. To make an approximate estimate of these costs, we use a study by the Puget Sound Regional Council of regional transportation costs in 1995.[56] The Twin Cities region is similar in population and income to the Puget Sound region, so we assume that we spend the same share of income on school buses. From this assumption, we estimate that this region spent $97 million on school buses in 1998, and that it will spend $146 million in 2020.

4.3.2 Transit Cost Projections for 2020

One problem with projecting the costs of transit in 2020 is that older plans, specifically the region's *Transportation Policy Plan* (TPP) and the *Regional*

[56] Puget Sound Regional Council (1996), Table 1.

Blueprint, project lower transit ridership and costs than do current plans.[57] As discussed in Section 3.3.2, there are reasons to believe that the region may have and use significantly more transit in 2020 than today. Because we are not fully able to assess the recent changes in transit policy and ridership, we rely mainly on longer-range trends to predict the costs of transit.

The cost of the capital improvements described in the TPP is $714 million over 20 years. This works out to $36 million per year. We use this as our low-end estimate of capital subsidies for bus transit in 2020. For our high-range estimate of capital subsidies for bus transit, the prediction is that capital costs will rise with ridership. The TPP predicts that transit ridership will increase at 0.7 percent a year between 1998 and 2020.

Operating costs are not projected in the TPP. They will be influenced by a variety of factors including service area, ridership, and the costs of labor. We predict that operating costs will rise more quickly than capital costs, mainly because we assume that technological improvements will allow the costs of capital to stay constant. For our low-end projection, we predict that transit routes and ridership will be essentially unchanged in 2020. This assumption follows recent trends. There has been no significant growth in transit ridership over the last two decades and, aside from light rail, there are no plans for significant expansions of transit service. Our low-end projection also assumes that the costs of operating this system will rise with the cost of labor, which is one of transit's most costly inputs.[58] The cost of labor is predicted to rise with per capita income at the rate of 1.0 percent per year.

Our high-end operating cost estimates assume that costs will rise because of increases in the costs of labor and increases in ridership or higher public support for transit. We predict labor costs will increase at the same rate as region-wide personal income—1.0 percent per year. Ridership is projected to increase by 0.7 percent, but we feel operating subsidies may outpace this because public support in the region for transit seems to be increasing. Public concern about problems such as traffic congestion and urban sprawl is one factor that seems to be driving this push for more governmental investment in transit. Alternatively, ridership may grow faster than the Metropolitan Council predicts. We guess that public support or higher than expected ridership may lead costs to increase 50 percent faster than ridership, at 1.05

[57] See Metropolitan Council (1996a), Metropolitan Council (1996c), and Metropolitan Council (2000).

[58] Transit services are labor-intensive and it seems unlikely that large productivity gains will be realized for the transit sector. The main constraint on productivity gains is that one driver can only operate one bus. Some gains may occur because of improvements in scheduling and routing, but we would expect these to be modest.

percent per year. Our projection for the high-end growth rate is 2.1 percent per year.

We also predict that subsidies for smaller operators will increase with subsidies for Metro Transit. The smaller operators carry passengers, for the most part, in less densely populated parts of the region. Areas with lower densities are generally experiencing faster growth than more densely populated areas, but transit does not appear to be as good a substitute for auto travel in regions with low densities. Overall, we assume these factors will cancel each other out, and that the small operators will grow at the same rate as Metro Transit. Table 4.3 contains our predictions of the governmental costs of transit.

The Metropolitan Council's current goals for 2020 are to build two light rail lines, five dedicated busways, and three commuter rail lines. The Council estimates that each LRT line will cost $500 million, that each busway will cost $110 million, and that each commuter rail line will cost $220 million. Over a 22-year period, this works out to $100 million per year. Their estimates of the total annual operating costs of these projects are about $75 million.[59] Overall, we estimate that these projects would more than double the costs of the Metro Transit's fixed route transit system. While the construction of the Hiawatha LRT line appears very likely, it is difficult to predict how many of these other projects will actually be funded. For our low-end estimate we assume only the Hiawatha LRT line is funded. For our high-end estimate, we assume that the projects that are funded will cost twice as much as the Hiawatha LRT will.

4.4 Governmental Services for Transportation

This is a catchall category that contains many relatively small governmental programs run by different levels of government. Because of the range of programs, we rely for our estimates primarily on a study by Delucchi et al. (1996). He made a very thorough study of the annualized costs of transportation in the United States. We calculate most costs by inferring the share of Delucchi's national costs that the Twin Cities region is responsible for, which is generally between 1.1 and 1.3 percent of U.S. costs.

[59] These numbers are from Metropolitan Council (2000).

Table 4.3: Governmental Costs of Transit

Metro Transit—Traditional Bus (Thousands of 1998 Dollars)

	1998			2020		
	Low	Mid	High	Low	Mid	High
Operating Costs	135,900	138,100	140,400	169,200	195,200	221,200
Revenue	48,600	49,400	50,100	60,500	69,700	79,000
Op. Subsidy	87,300	88,700	90,200	108,700	125,400	142,100
Capital Cost	35,700	35,700	35,700	35,700	38,700	41,700
Metro Transit Total	123,000	124,400	125,900	144,400	164,100	183,900

Metro Transit—Special Projects (Thousands of 1998 Dollars)

	1998			2020		
	Low	Mid	High	Low	Mid	High
Operating Subsidy	0	0	0	12,000	18,000	24,000
Capital Cost	0	0	0	23,000	34,000	45,000
Light Rail Total	0	0	0	35,000	52,000	69,000

Costs of Other Regional Transit Providers (Thousands of 1998 Dollars)

	1998			2020		
	Low	Mid	High	Low	Mid	High
Private	5,200	5,200	5,300	6,400	7,400	8,400
Small Urban	500	500	500	600	700	800
Rural	4,300	4,300	4,400	5,300	6,100	7,000
Opt-Out	8,000	8,200	8,400	9,800	11,700	13,300
School Bus	87,700	97,500	107,200	131,000	145,600	160,100
Non-Metro Total	105,700	115,700	125,600	153,100	171,500	189,600

	1998			2020		
	Low	Mid	High	Low	Mid	High
Total for Region	246,700	258,300	269,900	354,600	413,500	472,000

An important complication with many of the governmental programs examined in this section is that they support purposes beyond transportation. This presents no theoretical problems unless the provision of a service is subject to increasing returns to scale.[60] The more critical problem is the empirical one of determining how much program activity supports transportation. This question has not received a great deal of study in the transportation literature and there is no consensus on the shares of defense expenditures or police activity, for example, that are devoted to transportation.

Our projections of the costs of governmental services are generally based on overall trends in government spending. Many of the services discussed here seem likely to follow general government trends for spending on services.

4.4.1 Law Enforcement and Safety

This category includes cost items 1.3 (police and fire protection) and 1.4 (the public costs of licensing drivers and registering vehicles). The costs of licensing drivers includes the costs of driver's education courses, testing drivers, and issuing licenses. We assume that all of the costs of training drivers are internal, i.e., that they are paid for by drivers.[61] The costs of issuing driver's licenses, registering vehicles, and recording the transfer of vehicle titles were included with the costs of roads and highways covered in Section 4.2. However, these costs are relatively small. We estimate that they were approximately $9 million in 1998 and $13 million in 2020. These costs are based on cost estimates from the Office of the Legislative Auditor (1994),[62] and on our estimates of the annual number of licenses issued, vehicles registered, and titles transferred.

Cost item 1.3 includes the transportation-related costs of (i) fire and emergency services and (ii) police protection, courts, and corrections. The transportation-related costs of general public protection services, as opposed to services specifically devoted to transportation such as the highway patrol, are difficult to measure. Determining the share of costs that transportation is

[60] When the provision of a service is subject to increasing returns to scale, providing more of the service lowers the average cost of provision. Cost allocation problems occur in this situation because it is not clear how the savings (the lower average costs) should be divided among the various programs the service supports.

[61] It is possible, however, that some of these costs are subsidized through the educational system, for example, by providing free classroom space for driver's education courses.

[62] The Legislative Auditor estimated that it costs from $2 to $3 to issue a driver's license, register a vehicle, or transfer a title.

responsible for presents one problem. An additional difficulty is that these services are provided primarily at a local level. (The U.S. Department of Justice (1997) estimated that counties and municipalities covered 71 percent of the costs of police protection in 1992). This complicates data collection. Our estimates are based on Delucchi's national study of these costs. The starting points for Delucchi's estimates are the total costs of each type of government service. This number is adjusted to account for (i) the level of government services that would be provided in the absence of motor vehicles and (ii) the presence of economies of scale in the provision of the service. Delucchi admits both of these adjustments are based mostly on personal judgement.[63]

Delucchi estimated the motor vehicle related costs of the highway patrol, general police protection, fire protection, judicial and legal proceedings, and corrections. We assume that per capita spending in the Twin Cities region for these services is roughly the same as that of the nation as a whole. There is a possibility that the per capita costs in this region are significantly different than the national average, but we think this is unlikely. In general, the region spends less than the national average on justice (police protection, corrections, and the legal and judicial systems), $220 per capita as opposed to $315 per capita for the nation as a whole.[64] This large difference probably does not reflect spending differences on transportation-related protection, but rather, differences in rates of serious and violent crimes and differences in the handling of these crimes. Minnesota's incarceration rate in 1995 was 105 per 100,000, while the average for all states was 389.[65] We don't feel differences of this magnitude are present in the region's transportation-related justice costs, and our low-range estimate is that the state costs are 90 percent of the national costs on a per capita basis. We feel there is a small possibility that our costs are higher than the national average, so our high-range cost estimate is 105 percent of national per capita costs. This reflects the fact that the region has a relatively high auto usage and that the region pays relatively high wages to government employees. Table 4.4 shows our estimates of regional costs. Note that the estimates of general police protection and fire protection are quite uncertain. This is because of

[63] To appreciate the difficulty of this problem, consider the costs of protecting motor vehicles against break-ins and theft. If there were no motor vehicles, there might be many more crimes of other types, perhaps home break-ins or robberies. In addition to determining how crime would redistribute itself, we also need to determine how the costs of police protection would change. Protecting vehicles may be relatively more or less expensive than protecting other types of property. In addition, there may be economies of scale in police protection, so that protecting vehicles may be relatively inexpensive if other types of property already must be protected.
[64] Lindgren (1997), Table 8.
[65] U.S. Department of Justice (1997), Table 5.4.

difficulties in determining the shares of these costs that are due to transportation.

Table 4.4: Governmental Costs of Law Enforcement and Safety

	Millions of 1998 Dollars					
	1998			2020		
	Low	Mid	High	Low	Mid	High
Highway Patrol[66]	94	109	124	155	194	233
General Police	10	33	56	17	61	106
Fire Protection	9	25	41	15	46	78
Legal and Judicial	61	76	92	100	136	172
Corrections	49	70	92	82	127	172
Total	223	314	405	368	565	761

Table 4.4: Our midrange estimate is that the costs of law enforcement and safety associated with transportation will grow 33 percent faster than the population.

Trends for the transportation-related costs of law enforcement and safety are difficult to determine because there have not been many studies of these costs. Total national spending on all justice, not just the transport-related component, has been increasing rapidly. Real, per capita spending on justice in the U.S. grew by 65 percent between 1982 and 1992, while personal income grew by only 15 percent.[67] We do not feel that transportation-related costs necessarily have, or will continue to, rise this rapidly for two reasons. First, increases in all spending on justice will probably slow over the next decades as crime rates fall or remain steady and incarceration rates rise more slowly. Second, the large increases that occurred in overall spending on justice probably reflect changes in the handling violent crimes and drug-related offenses. Changes in the transportation-related component of justice may have been relatively minor. Our low-range estimate is that costs will rise at 90 percent of the rate of growth in personal income and with population growth. Our high-range estimate is that costs will rise at 150 percent of the rate of growth in personal income and with population growth. The low-end

[66] These numbers are based Delucchi's estimates and are higher than Minnesota's statewide budget for highway patrol. We have not yet resolved this discrepancy.
[67] Lindgren (1997), Table D.

estimate is that costs will grow at a slightly lower rate than overall government spending. The high-end estimate reflects the fact that law enforcement is relatively labor-intensive and probably will not experience large gains in productivity. It also reflects the current record of rapid growth in justice expenditures. While these growth rates will probably slow and while they may not be wholly applicable to transportation-related justice, they may still be indicative of future costs.

4.4.2 Environmental Protection and Cleanup

This category covers governmental spending for cleanup, abatement, and monitoring of environmental damage caused by transportation. Examples of these costs include subsidies to remove leaking gas tanks from the ground or programs to monitor auto emissions. Spending for these cost items is divided between the federal government and state and local governments. Large portions of the budget of the U.S. Environmental Protection Agency and the Minnesota Pollution Control Agency are included. To a lesser extent, this also includes portions of the budgets of state and federal organizations that are responsible for urban planning, protecting natural resources, and regulating energy use.

These costs are not controversial in that most agree they are costs of transportation, but some would count them as external costs. We keep them here because we use a narrow definition of external costs. Note, however, that there is an important relationship between these costs and certain types of external costs that government actions can affect. When analyzing noise, for example, it may be useful to know all of the costs associated with it. These would include the (i) governmental costs of noise barriers, monitoring, and research, (ii) the internal costs associated with soundproofing, and (iii) the external costs to the people who experience the noise. Such information would be essential for determining whether the net social costs resulting from noise pollution are being minimized. Our accounting system does not always divide costs up in this way, but it is designed to facilitate such analyses.

We rely on Delucchi's study to provide a starting point for our estimate of the region's share of these costs. Delucchi estimated the costs for the nation as a whole and we assume that the region's share is proportional to its share of GDP. Average costs for the region might differ from those of the U.S. for a number of reasons.

- The region is highly urbanized. Most of the external costs of transportation are significantly higher in urban areas than in rural areas. Governmental costs probably reflect this. The importance of this factor may be mitigated because the costs air pollution, for example, may be significantly higher in even larger urban areas such as Los Angeles or New York.

- The region's environment may affect costs. The region's geography and climate help to reduce some types of air pollution costs. Smog is generally less of a problem here than in cities of a similar size that are in warmer climates. The flat topography helps air pollution to disperse. On the other hand, cold winter weather may impose some extra costs. Pollution that occurs when catalytic converters are cold may be increased. The frequent use of chemicals to de-ice roads may harm water resources.
- Some of the region's resources may require extra protection. The region's water resources seem particularly vulnerable to pollution. This factor may be mitigated because spending to protect water is probably considerably smaller than that to protect the air.

These considerations will cancel each other out to some extent. We do not feel any of them are overwhelming. In addition, Delucchi includes a relatively large range of cost estimates (his high estimate is 2.5 times his low estimate), so we feel that his range is wide enough to cover the variation between the region and the U.S. as a whole.

We project that the costs of environmental monitoring and cleanup will rise at the same rate as GDP. A summary of expenditures on pollution control and abatement found that spending in the U.S. has ranged between 1.7 and 1.8 percent of GDP from 1975 to 1994.[68] While these expenditures include private spending plus government spending and include goods that are not transportation-related, we think the trend is probably the same for the restricted categories of these costs that we are interested in. One argument that spending growth should be faster than GDP growth is that environmental protection is probably a luxury good. Spending for luxuries increases as a fraction of income when income rises. The lack of an increase in such spending from 1975 to 1994 may have occurred because of rapid technological progress in pollution control technology. Technological progress in emissions control devices, for example, enables us to purchase much more pollution protection, relative to many other types of goods and services, now than we could in the mid-1970's. Because of uncertainty about future technological progress and the luxury nature of pollution control, we assume that costs will grow between 80 and 120 percent of the rate of GDP growth. We estimate that these costs were between $60 million and $155 million in 1998 and will be between $90 and $245 million in 2020.

[68] Vogan (1996).

4.4.3 Energy Security

We divide the costs of energy security into four categories: (i) the costs of ethanol subsidies, (ii) spending for research and development to improve energy security, (iii) costs of maintaining the Strategic Petroleum Reserve, and (iv) military expenditures for the protection of foreign oil supplies. Ethanol subsidies are government payments to producers, distributors, and consumers of ethanol. They are included here because a common justification for them is that they reduce our dependence on foreign oil. Governmental spending for research and development includes programs to make vehicles more fuel-efficient and develop alternative energy sources. The federal government maintains the Strategic Petroleum Reserve to provide protection in case foreign oil supplies are interrupted. There are costs of holding oil and of operating and maintaining the reserve. Some argue that none of the costs of protecting oil supplies should be included as costs of transportation. We feel that they are costs of transportation *if* the U.S. spends more on defense because we rely on imported oil for transportation. Determining the size of these costs is then just an empirical question, albeit one that is difficult to answer because there is no easy way to identify what the U.S. military would look like if we did not have an interest in protecting oil supplies.

Most ethanol in the U.S. is produced from corn, mixed with gasoline, and sold as a fuel for transportation. For some purposes these subsidies can be considered transfers instead of costs (subsidies from public revenue sources to producers, distributors, and consumers of ethanol). We include them as costs because these subsidies, together with the amount consumers pay for ethanol, add up to the full social cost of ethanol. We estimate that the region is responsible for perhaps $6 million in federal subsidies and $15 million in state subsidies.[69] We feel these cost estimates are fairly accurate so we increase and reduce them by 10 percent to get our high- and low-end figures. In projecting these costs forward to 2020, we assume that they will grow at the same rate as other energy security costs.[70]

Except for ethanol subsidies, most of the other costs of energy security are federal. We rely on Delucchi's analyses to determine these costs, and assign responsibility to the region based on estimates of the region's share of U.S. oil use for roadway transportation. We estimate that the region consumes

[69] The federal government subsidizes ethanol distributors at a rate of 5.4 cents per gallon. The state also subsidizes producers of ethanol. In 1996 Minnesota spent approximately $16 million on ethanol subsidies. Office of the Legislative Auditor (1997a) and Renewable Fuel Association (1997).

[70] The future of these subsidies is uncertain. It is possible that they will be phased out, but especially if the price of oil rises sharply, they may be increased.

1.18 percent of U.S. oil for transportation.[71] Our high- and low-range estimates for the costs of energy security were found by taking 1.18 percent of Delucchi's high- and low-range estimates and scaling them up to account for economic growth since 1990. Because some of these estimates are quite uncertain, we use the geometric mean of our high and low estimates to get our mid-range estimate.[72]

We feel that it is most likely that these costs will rise with GDP, but since these costs seem particularly uncertain, we predict a wide range of growth rates. On the low end, we predict that growth will be 80 percent of income growth on a per capita basis. On the high end, we predict it will be 200 percent of income growth. The high-end estimate reflects the fact that by 2020 oil supplies may be significantly tighter than they are today. If significant progress has not been made in making transportation more fuel efficient or in switching to alternative fuels, then the combination of declining oil reserves and increasing world-wide demand for oil may make energy security much more important. Table 4.5 contains our estimates of energy security costs.

Table 4.5: Energy Security Costs for the Twin Cities Region

	Millions of 1998 Dollars					
	1998			2020		
	Low	Mid	High	Low	Mid	High
Research & Development	5.2	6.7	8.6	7.5	11.1	16.3
Strategic Petroleum Reserve	1.7	5.5	17.3	2.5	9.0	32.5
Ethanol Subsidies	19.2	21.3	23.4	27.8	35.1	44.2
Military Protection of Oil	10.4	35.4	120.8	15.0	58.5	227.6
Total	36.5	68.9	170.1	52.8	113.7	320.6

Table 4.5: Our midrange estimates are that the costs of energy security will grow by 60 percent between 1998 and 2020.

[71] These figures are based on our estimate of fuel consumption for the region and on the FHWA's estimate of national fuel consumption (FHWA (1999)). This compares to our estimate that in 1998 the region contained 1.12 percent of the nation's population and produced 1.29 percent of its GDP.
[72] Compared to the arithmetic mean, the geometric mean weights low-end estimates more highly than high-end estimates. For many situations involving uncertainty, using the geometric mean will give one a better idea of average cost than the arithmetic mean.

4.4.4 Parking and Costs to Other Governmental Agencies

This section covers two final categories of governmental costs: (i) the costs of parking and driveways and (ii) spending to support transportation services by governmental agencies not included above. The costs of parking and driveways are much larger than the other costs. The other costs include minor services for transportation by a variety of agencies.

The costs of parking covered here do not include parking on streets, since this cost is included with the costs of roads in Section 4.2. A large share of the costs covered here are for “free” parking provided at government buildings, but some are associated with subsidized parking at municipally operated parking lots. Note that only subsidies are included here. Fees paid by drivers for parking are considered to be internal costs.

We rely on Delucchi et al. (1996) for our estimates of the costs of government parking and drives.[73] The yearly costs can be divided into three components: operating and maintenance costs, rental costs of land, and costs of depreciation on capital (or the amortized cost of construction). Construction costs per parking space are significantly higher for parking ramps than for at-grade parking. Costs are calculating based on the estimated number of government-provided parking spaces in ramps and at-grade, and the estimated cost of each type of space. We adjust Delucchi’s cost estimate based upon the region’s share of U.S. housing value, which we think is a good proxy for the value of parking. This because it is related to land costs and also because it rises rapidly in areas that are densely populated. The region contained 1.17 percent of the nation’s housing value in 1990. We estimate the region’s governmental costs of parking and drives in 1998 to be between $205 and $340 million.

We do not feel that the trend in median home prices is a good proxy for the trend in the costs of parking. The reason is that home prices reflect improvements to housing and increases in housing size and these factors are largely irrelevant for parking costs. Parking costs will rise with land costs as housing prices do, but the size and quality of parking spaces is not changing much. Meanwhile, improvements in construction techniques may do a great deal to hold down the costs of parking. Overall, there is significant uncertainty in projecting parking costs. Relatively small increases in land prices could lead to large increases in parking costs if the price increases lead to significant amounts of new ramp construction. We project that parking

[73] Delucchi’s estimates of these costs seem high to us, but we have not identified a good reason to adjust them downward. They are between 10 and 20 percent of the costs of the parking and drives provided by businesses.

costs will rise at a rate of between 80 and 120 percent of GDP per capita. We estimate that costs in 2020 will be between $295 and $540 million.

The costs incurred by other governmental agencies in support of transportation do not include costs to governmental agencies covered previously or the costs of goods and services purchased by government agencies for *their own* transportation. Note especially that we do not include the costs of owning and operating public vehicles (except for the vehicles used to support transportation by the agencies covered above). Most of these costs are considered to be internal costs. The reason is that, while governments pay for these costs, they are not costs that it would make sense to charge to transportation users. For example, highway patrol vehicles provide services for transportation, but the vehicles used by the Post Office do not provide services to the public for transportation. While the vehicles are costly, we do not consider these costs to be ones that might reasonably be paid for by the users of the public transportation system.

The costs of support for transportation incurred by other governmental agencies are quite small. We base our estimate on Delucchi and assume that the region's share of them is proportional to GDP. We also assume that these costs will grow at within 10 percent of the rate of aggregate government spending growth. We estimate that these costs were between $1.9 and $3.8 million in 1998 and will be between $2.8 and $5.9 million in 2020.

4.5 Costs not Included

This section contains two categories of costs that we do not classify as governmental, but that we felt were potentially too important to ignore. The costs of regulations are not included because they are considered to be internal costs of transportation. From an equity standpoint, this classification makes sense. With other governmental costs of transportation, it usually seems fair to charge users fees or taxes to pay for these costs. This is not true for the costs of regulation, since the costs are already borne primarily by transportation users. It is important to know the costs of regulations in order to determine the right level of regulation for efficiency purposes. We want to be able to answer questions such as how safe should cars be, how clean should their emissions be, or how quiet should their exhaust systems be. We do not perform a detailed analysis of these costs, but we discuss their importance and make some rough estimates of their magnitude.

Fiscal impacts are not included as a cost of transportation because we consider them a cost of land use. We recognize, however, that transportation investment can have important effects on land use. In addition, fiscal impacts and their relationship to transportation investment are a major concern of the Transportation and Regional Growth Study. We calculate a measure of the potential impact of transportation on land use and the potential efficiency gains that are forgone by not using transportation policy to affect land use.

4.5.1 Regulations

The goal of this section is to provide insight into the extent of "special" government involvement in the transportation sector. Most broad studies of the costs of governmental regulations divide costs into three categories: paperwork, entry restrictions and price controls, and environmental protection and risk reduction.[74] We focus on regulations that are associated with the environment or risk reduction, because these seem likely to be the ones that are specially associated with transportation.[75] It should be noted that not including these costs as governmental costs does not mean that we are not including them at all. They are included as internal costs. These numbers should *not* be used to argue that transportation is underpriced because these costs are already borne by travelers.

Hopkins estimated the cost of all government regulations for the environment and for risk reduction to be $243 billion in 1996. The Office of Management and Budget (1997) estimated them to be $148 billion in 1996. The OMB's number is probably lower because of an assumption they make about the cost of older regulations. The OMB assumes that most regulations over ten years old are not binding and hence have no costs.[76]

We have not found an estimate of the costs that such regulations impose on transportation. We feel they are probably large relative to transportation's share of GDP because transportation involves significant safety and environmental concerns. Han and Fang (1998) estimate that transportation final demand has accounted for approximately 11 percent of U.S. economic activity over the last ten years. Because transportation seems likely to be heavily regulated relative to other sectors of the economy, we use 15 percent as a lower bound for the share of regulatory costs that are imposed on transportation. Transportation makes up 28 percent of the parts of the

[74] For example, Hopkins (1995) estimated these costs for all governmental regulations in 1995 and found that they were responsible for 33, 34, and 33 percent of the total costs of regulation, respectively.

[75] The costs of paperwork seem to be costs of operating in our economy. We have no reason to expect that if we consumed less transportation and more of any other good that these costs would be reduced.

[76] A regulation is not binding if companies would comply with it even if the regulation didn't exist.

economy that we feel experience heavy safety and environmental regulation.[77] We use 25 percent as an upper bound. Finally, we assume that the region's share of these costs is equal to its share of U.S. GDP. Our estimate is that the region's costs for 1998 were between $290 and $825 million dollars.

We assume these costs will grow with GDP, because this seems to have been the case for the regulatory costs discussed in Section 4.4.2. Our low estimate is that these costs grow at 90 percent of the GDP growth rate, and our high estimate is that they will grow at 110 percent of GDP. We predict that the region's cost for 2020 will be between $430 and $1,320 million.

4.5.2 Fiscal Impacts

We define fiscal impacts to be the costs that transportation imposes on units of government by promoting inefficient land use. This category of costs is problematic because there is no agreement on the definition of fiscal impacts or on whether fiscal impacts should be considered costs of transportation.[78] Delucchi (1997) argues that they are not costs of transportation because they are the result of locational decisions and not "an effect of motor vehicle use per se."[79] Others, including Litman (1994), argue that they are costs of transportation. Litman is the only person we are aware of who attempts to quantify the costs of fiscal impacts. We feel that fiscal impacts are *not* costs of transportation, but that it may be possible to use transportation policy to mitigate fiscal impacts.

We argue that fiscal impacts are not costs of transportation. The reason is that, for the most part, transportation and land use serve separate needs—mobility and shelter, respectively. The markets for transportation and land use are separate, but they are linked in a special way. Specifically, auto transportation and low-density, dispersed development are complements. In economic jargon, complements are goods that are consumed jointly. The demand for a good increases when the price of a complementary good falls. Drive-in movies and autos are probably complements. If the price of autos declines, we expect that, other things equal, the demand for drive-in movies will increase. We do not consider drive-in movies to be a cost of transportation, however.

[77] According to Han and Fang (1998), transportation final demand accounts for 11 percent of GDP, food for 13 percent, and health care for 15 percent.
[78] Underlying these disagreements are questions about the relationship between transportation and land use.
[79] Report #1, pages 75–76.

While fiscal impacts are difficult to define and quantify and may not even be costs of transportation, we feel it is important that we examine them in some detail. The purpose of the Transportation and Regional Growth Study is to provide policymakers and the general public with the information they need to better coordinate transportation and land use planning. If transportation policies have significant impacts on the costs of public infrastructure, it is important to understand the nature of these impacts. We feel we can sort out some of the conflicting claims surrounding fiscal impacts, and that we can also shed some light on the magnitude of these impacts.

We use a very simple model to explain the relationship between transportation and land use. A full explanation of the model is contained in Appendix D.3. Because the markets for transportation and land use are interconnected, we can use transportation policy to influence the land use market. First, suppose that the subsidies for transportation are eliminated, i.e., that transportation is priced so that people pay the full costs of transportation. This yields an efficiency gain in the transportation market. Because of the connection between the transportation and housing markets, it also yields a "bonus" through its effect on the housing market.

Second, suppose that there is no way to reduce the subsidies in the market for housing, except through transportation policy. We can produce net efficiency gains by putting a small tax on transportation. (Note that this possibility occurs because of the (inefficient) subsidies in the land use market.) For plausible parameter values, however, the gains from this tax turn out to be almost ridiculously small.

While our model is simplistic, the size of the potential efficiency gains that comes from trying to use the transportation system to influence land use sends a potentially important message. Setting transportation policies to improve the efficiency of the transportation market alone may produce significant social gains. These gains may be augmented by gains in the land use market. Beyond this, it may be very difficult to do anything with transportation pricing policies to improve the efficiency with which land is used.

We also feel this analysis sheds some light on the debate about whether fiscal impacts should be considered a cost of transportation. There is some sense in which some of the losses in the land use market are a cost of transportation, but they are *not* a cost that should be charged to transportation. The charges that should be levied on transportation to receive the bonus are based on the full cost of *transportation*. They do not depend on what is happening in the land use market, i.e., there should be no "land use surcharge" placed on transportation.[80]

4.6 Summary of Governmental Costs

The governmental costs of transportation are summarized in Table 4.7. Streets and highways account for 60 percent of our midrange cost estimate. After streets and highway, law enforcement and parking are the next largest costs. There is a fair degree of uncertainty in our estimates of both of these costs. Our most uncertain estimates are of energy security. These costs, however, account for a relatively small share of governmental costs, and are almost entirely determined by national policy. Transit accounts for approximately 10 percent of governmental costs, and spending on the environment, for approximately 4 percent.

We expect governmental costs to grow, in real terms, by 51 percent between 1998 and 2020. This is only 24 percent growth on a per capita basis, and we do not expect governmental costs to grow at all as a share of regional income. The costs of streets and highways are expected to increase by 43 percent. This relatively slow increase in spending reflects both expected productivity gains and the lack of major system-wide construction projects. The costs of law enforcement and safety are projected to grow by 80 percent overall. This large increase is primarily due to trends that show overall law enforcement costs have risen rapidly in the U.S. over the last two decades. These trends may not apply particularly well to Minnesota or to transportation-related costs of law enforcement, and more modest increases in these costs are plausible. Figure 4.3 shows the shares of the governmental costs for our midrange 1998 estimates.

The classification of most governmental cost items is not controversial, but estimates of the costs can be. For energy security costs and law enforcement costs, most of the uncertainty is due to the problem of determining the portion of these costs that should be assigned to transportation. Uncertainty in other categories, and particularly for parking, is primarily due to the lack of comprehensive local studies of these costs. Many of our cost estimates could be improved through detailed examinations of state and local budgets, but these are examinations that we have not been able to undertake because of the scope of this study.

[80] Our model actually shows that there should be a very small land use surcharge placed on transportation in the case where it is not possible to solve problems in the land use sector in any other way.

Our cost estimates do not include (i) most of the costs of the land used for roads, (ii) fiscal impacts of transportation on land use, or (iii) the costs of environmental and safety regulations. The last costs may be large (perhaps $560 million in 1998 and $875 million in 2020), but they are accounted for as internal costs of transportation. For policy purposes, the important costs of land are the marginal costs, and these can be determined from market transactions. We do not try to calculate the total cost of land because this would require that we determine the value of land in the region if there were no roads. In any event, it is not clear that the *total* cost of land is relevant for policy purposes.

A difficult question is whether fiscal impacts should be considered costs of transportation. We feel that they should not be, but that good transportation policy might mitigate fiscal impacts. We used a simple model to show that improved transportation policy may reduce fiscal impacts, but that these policies should be based on the costs of transportation alone, not on the effects of transportation on land use.

It should be noted that governmental costs of transportation do not necessarily represent subsidies to users of the transportation system. To determine whether or not subsidies exist, one would need to account for fees paid by travelers (fuel taxes, vehicle registration fees, etc.). We will examine these payments in our report on transportation cost incidence.

Table 4.6: Summary of Governmental Costs of Transportation

	Total Spending in Millions of Dollars					
	1998			2020		
Cost Items	Low	Mid	High	Low	Mid	High
Streets and Highways	1,340	1,535	1,735	1,820	2,195	2,570
Transit	245	260	270	355	415	470
Law Enforcement and Safety	225	315	405	370	565	760
Environmental Protection	60	105	155	90	165	245
Energy Security	37	69	170	53	114	321
Parking and Drives	205	270	340	295	415	540
Costs to Other Agencies	2	3	4	3	4	6
Total Costs	2,120	2,560	3,080	2,990	3,870	4,910

	1998			2020		
Measures of Full Cost	Low	Mid	High	Low	Mid	High
Cost per Capita	$695	$840	$1,015	$805	$1,045	$1,325
Cost per Vehicle	$790	$950	$1,145	$850	$1,100	$1,400
Share of Personal Income	2.3%	2.8%	3.3%	2.2%	2.8%	3.6%
Cost per Vehicle-Mile	8.2¢	9.9¢	11.9¢	8.1¢	10.6¢	13.4¢

Table 4.6: Our midrange projections are that the costs of streets and highways will rise by 43 percent and all costs will rise by 49 percent. We expect the governmental costs of transportation to account for an almost constant share of regional income.

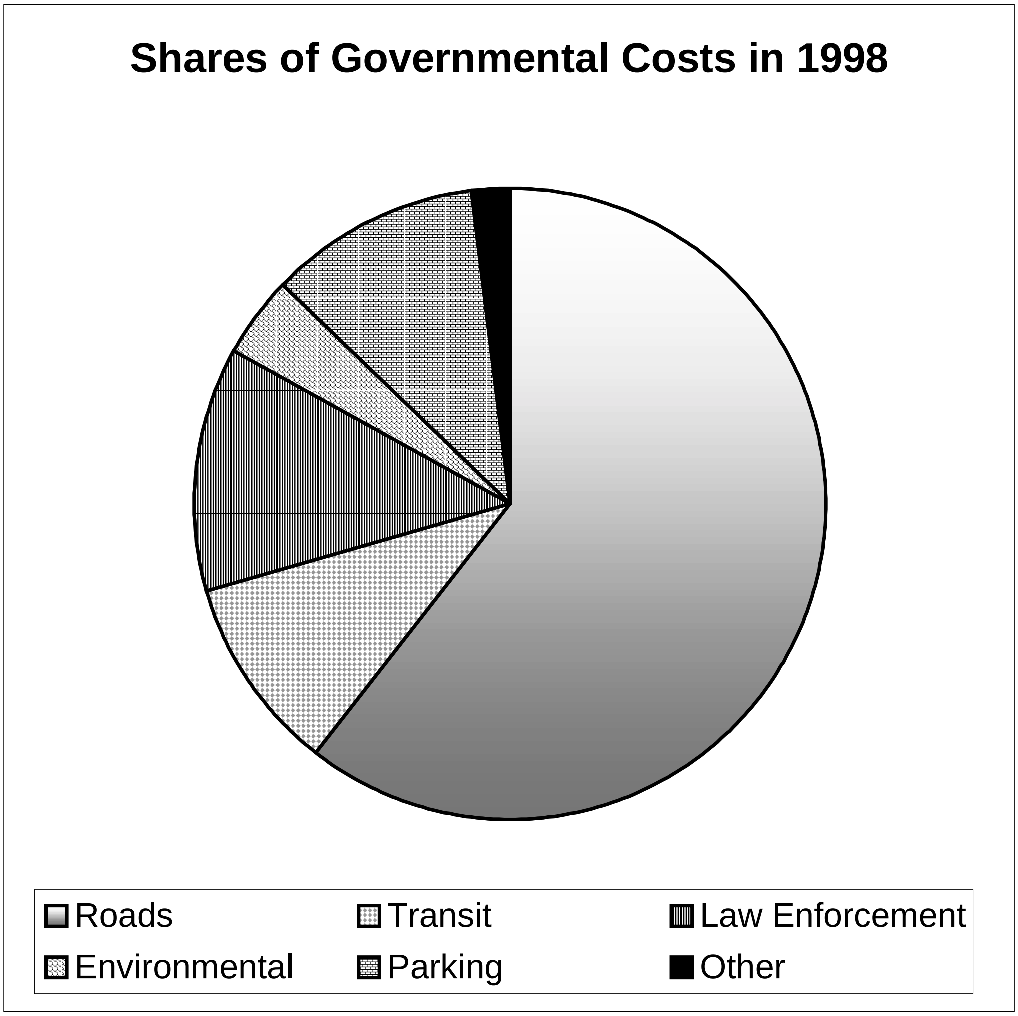

Figure 4.3: Shares of Governmental Costs in 1998

The costs of roads make up almost 64 percent of the total costs of travel. The next largest cost item is law enforcement and safety, which accounts for 13 percent of our midrange estimate of governmental costs.

5 Internal Costs

The internal costs of transportation are the costs of transportation that are borne by the people who cause them. We analyze most internal costs in less detail than we do when we analyze external costs and governmental costs. This is because internal costs do not usually generate the same efficiency and equity concerns. In addition, it is easier to determine many of these costs because the goods and services are traded in markets and can therefore be observed directly.

Even with fewer efficiency and equity concerns, it is important to quantify the internal costs of transportation. One reason is that internal costs provide information about travelers' preferences. Knowing travelers' preferences is useful for determining the effects of policies—both how people will likely respond to policies and how policies would affect the welfare of travelers.

While there are fewer efficiency concerns for internal costs than for external costs, there are efficiency concerns for certain types of internal costs. Three areas that have received special attention are parking, insurance, and crashes. Parking may present problems because it is frequently sold as a bundled good, and insurance because the market is subject to a variety of informational problems. Crashes are problematic if, as is sometimes argued, drivers do not perceive risks of injuries and deaths correctly.

This section is divided into five parts. Section 5.1 covers most of the monetary costs of vehicles. Section 5.2 covers the costs of transit. Sections 5.3 and 5.4 cover the internal costs of time and crashes, respectively. Section 5.5 covers the costs of bundled goods. Much of the analysis of time and crash costs is done in Section 6, which covers external costs. This is because it is necessary to properly allocate time and crash costs between internal and external costs.[81] Total and external time costs are covered in Section 6.1 and total and internal crash costs in Section 6.2.

5.1 Internal Vehicle Costs

We calculate the costs of owning and operating vehicles in this section. The costs are divided into two types—fixed and variable. Fixed costs are those which do not change significantly with vehicle operation; variable costs increase with the number of miles a vehicle is driven. This section covers

[81] Some crash costs are also borne by units of government. These are discussed in Section 5.4.

almost all of the internal monetary costs of owning and operating vehicles. A few monetary costs are included in other sections because related cost items were covered there. The costs of transit fares are covered in Section 5.2. The costs of property damage and medical bills from crashes are covered in Section 5.4 and the costs of parking are covered in Section 5.5. Taxes and user fees are not considered opportunity costs (they are considered transfers) so the cost of fuel, for example, does not include state or federal taxes.

We use three methods to estimate the costs in this section.

1. We use baseline estimates of the number of vehicles and vehicle-miles of travel, and other sources' estimates of the cost per vehicle or per vehicle-mile.
2. We use population projections and estimates of per capita expenditures in the region.
3. We use national data, either national product accounts or Delucchi's cost estimates.

Because the costs calculated in this section are monetary, they can be determined with a good deal of accuracy. It also helps that we have more than one source of data with which to estimate costs.

Table 5.1: Vehicle Costs Based on Mileage

	Millions of Dollars	
	1998	2020
Depreciation and Interest	4,820	6,180
Fuel and Oil	890	2,150
Maintenance	670	950
Tires	270	380
Other	310	450
Total	7,410	10,820

Table 5.1: Mid-range estimates of the costs of owning and operating vehicles based on Runzheimer International (1998). Note that we assume that fuel costs will rise faster than other costs.

Making projections is more problematic, but we would expect that most of the goods covered in this section are normal goods and that spending on them will rise in rough proportion with income. Technological progress in manufacturing has generally led to decreases in the cost of vehicles and improvements in vehicle quality. Our baseline estimate is that transportation services will remain a constant share of personal income. This is based on national income and product accounts (NIPA) data that show that transportation services have accounted for roughly 3.1 percent of GDP from 1987 to 1997. Our estimate for the costs of manufactured goods is that the costs of these goods will fall by 10 percent between now and 2020. This is based on NIPA data that show the value of manufacturing output for vehicles and other transportation equipment fell from approximately 2.0 percent of GDP in 1987 to 1.8 percent of GDP in 1997. The cost of fuel is difficult to predict. Our baseline estimate is that costs will not rise because long-range trends show that commodity prices in general have remained stable or fallen. It would not be surprising, however, if the costs of fuel rose significantly due to increasing worldwide demand for oil and because it seems unlikely that many large new oil reserves will be discovered. Our high-end estimate is that the costs of fuel, per gallon, will double between 1998 and 2020.[82]

We estimate that there were 25.9 billion vehicle-miles of travel in the region in 1998, and 36.7 billion in 2020. The assumptions on which these estimates were based are explained in Appendix D.2. Runzheimer International (1998) estimated the cost per vehicle-mile for a typical automobile.[83] Using their estimates, we calculate that the costs of owning and operating vehicles in the region is $7.4 billion in 1998 and that they will rise to $10.8 billion in 2020 (see Table 5.1). We account for the costs of operating heavy trucks by assuming that they make up five percent of total traffic and have operating costs that are three times higher than that of the average auto.[84]

Data from the Bureau of Labor Statistics produce cost estimates that are similar to those shown in Table 5.1. The Bureau estimates that the average household in the Twin Cities MSA spent $3200 on vehicle purchases and $1400 on fuel and oil in 1997. Using our estimates of the number of households in the region and adjusting to account for fuel taxes and trucks, this yields cost estimates of $4.1 billion for vehicle purchases and $1.1 billion for fuel and oil. The estimate for vehicle purchases, which should match up with depreciation and interest in the long run, agrees fairly well with the estimate in Table 5.1. The estimate of fuel and oil costs, however, is about 30 percent higher than that in Table 5.1.

[82] Another possibility is that fuel costs will fall because of technological progress. Either new vehicles will become so efficient that they will consume less oil, or new (and cheaper) fuel sources may be adopted. We discount this possibility because even very efficient private vehicles would require significant amounts of energy, and new technologies may lead to partially offsetting increases in other types of costs.

[83] These numbers agree well with those in FHWA (1997). The FHWA finds that the ratio of maintenance costs to fuel costs is approximately 0.35 to 1.0, and that the ratio of the cost of tires to that of fuel is approximately 0.15 to 1.0.

[84] The five percent figure is from the 1990 TBI. The factor of three is based on fuel consumption.

We also calculate costs based on Delucchi's estimates. These costs are shown in Table 5.2. The costs of depreciation and interest, and the cost of fuel and oil, are very similar to our consumer expenditure estimates. Maintenance costs are higher probably because Delucchi also includes the costs of such items as towing, cleaning, and storage. Delucchi also separates out two costs that were not calculated separately elsewhere—the costs of insurance overhead and the costs to businesses of managing fleets of vehicles. Note that the costs of insurance overhead represent only the transactions costs of insurance, and they are *not* the costs of insurance that directly cover crashes or thefts. Also note that the range for Delucchi's cost estimates is narrow compared to the ranges for his estimates for other types of costs.

Table 5.2: Vehicle Cost Estimates Based on Delucchi

	Millions of Dollars		
	Low	Mid	High
Depreciation and Interest	4,150	4,650	5,200
Fuel and Oil	1,100	1,150	1,250
Maintenance	2,300	2,350	2,450
Insurance Overhead	300	300	300
Business Fleet Overhead	1,350	1,500	1,700
Total	9,250	10,050	10,850

Table 5.2: Regional costs for 1998 based on Delucchi. These calculations were made by assuming that the region's share of national costs is equal to the region's share of national GDP.

Our overall estimates and projections for the costs of vehicles are shown in Table 5.3.[85] They are based largely on Delucchi, but the costs were adjusted somewhat to reflect all three sets of cost estimates. We rely main on Delucchi for two main reasons (i) his costs are calculated net of taxes and (ii) he specifically includes the costs of operating commercial vehicles.[86] His estimates of the costs of maintenance were adjusted downward somewhat, and we made the range of estimates larger to reflect the lower estimates provided by the other sources. Our midrange projections are that the costs of

[85] We make a small adjustment to the costs of fuel and oil to account for fuel and oil consumed because of congestion. We assume that these are external costs of transportation (see Table 6.3). We also assume two relatively small costs are included with the fixed costs of vehicles. These are the costs of licensing and registering drivers. These costs are so small (perhaps $9 million in 1998 and $13 million in 2020) that we do not try to calculate them separately. See the note on this calculation in Section 4.4.1.

[86] While the data from the Runzheimer and the Bureau of Labor Statistics does include taxes, taxes only account for a large share of fuel costs (they accounted for approximately 30 percent in 1998).

vehicles will decline by five percent, that the cost of a gallon of gas will rise by 45 percent, and that most other costs will rise with the total amount of travel.[87]

Table 5.3: Vehicle Cost Estimates and Projections

	Millions of Dollars					
		1998			2020	
	Low	Mid	High	Low	Mid	High
Depreciation and Interest	4,150	4,650	5,200	5,650	6,400	7,100
Fuel and Oil	1,000	1,050	1,150	1,350	2,100	3,250
Maintenance	1,200	1,600	2,000	1,700	2,250	2,850
Insurance Overhead	200	300	400	300	450	550
Business Fleet Overhead	1,300	1,500	1,700	1,850	2,150	2,400
Total	7,850	9,100	10,450	10,850	13,500	16,150

Table 5.3: The total costs of owning and operating vehicles in the Twin Cities region may rise by almost 50 percent. This increase is driven largely by an expected 42 percent increase in vehicle miles traveled.

5.2 Internal Transit Costs

In this section we calculate the private costs of public transit. The private costs include fares and the costs of the time spent walking to, waiting for, or riding on transit vehicles. We cover only the costs of public vans or buses and potential future rail modes. Note that questions about how many new rail systems will be built are less important when analyzing internal costs than they were when analyzing governmental costs. The reason is that internal costs tend to be closely related to ridership, and buses will continue to carry by far the largest share of transit passengers. We do not include the costs of private shuttle vans or taxis in this section because we did not find the data

[87] Also note that fuel prices in 1998 were low by historic standards. The price of crude oil averaged approximately $12 a barrel in 1998, but it was at least $5 a barrel higher throughout most of the 1990s and averaged over $30 a barrel in the 1980s.

that would enable us to separate these costs from those of other commercial vehicles.[88]

We calculate transit fares using the same data sources that we used to estimate the governmental costs of transit—the Metropolitan Council and the Federal Transit Authority. Table 4.3 contains our estimates of fare revenue for Metro Transit. Our low-end estimate was based on the assumption that ridership would not increase, and that operating costs would rise with personal income. Our high-end estimate was that ridership would increase by 1.0 percent a year, which is 50 percent faster than the Metropolitan Council's projection, and that operating costs would rise with personal income. We assume that fare revenue will remain a constant 36 percent share of operating costs for Metro Transit buses. Fare revenue projections for other regional transit providers were made under the same assumptions as for Metro Transit. Our midrange estimates are that fare revenue for Metro Transit will rise from $49 million in 1998 to $70 million in 2020, and that revenue will rise from $5 million to $7 million for the other operators.

Metro Mobility averaged approximately 80,000 trips per month in 1998, and charged fares of $2.00 during off-peak periods and $2.50 during peak periods.[89] From this we estimate that passengers paid approximately $2 million per year in fares in 1998. We do not have ridership projections for Metro Mobility for 2020, but we expect that ridership may increase significantly because the share of the population that is elderly will rise. From statewide projections, we estimate that the number of people in the state over 65 will grow by 55 percent between 1998 and 2020.[90] We use this for our baseline estimate for ridership increases. We assume that fares will rise with personal income. This yields an estimate that costs will rise by 93 percent between 1998 and 2020, to $3.9 million.

Estimating time costs for transit is more difficult than estimating time costs for autos because transit time is more varied. Time is spent walking to buses, waiting for buses, and riding on buses and the value of the time generally varies across activities.[91] Barnes (1995) finds evidence that waiting time values are two or three times higher than riding time values. Offsetting this

[88] The costs of privately provided transit services are accounted for with those of other commercial vehicles. The operating costs are covered in Section 5.1, for example, and the time costs in Section 5.3. We also do not include the time costs of school buses here because we do not have good data on trip lengths or the value of time to school children.
[89] Metropolitan Council (1999).
[90] Minnesota Planning (1998).
[91] Auto travel also involves walking time, but the ratio of driving time to walking time will usually be much higher.

effect is the fact that transit riders generally have lower incomes, and hence probably lower values of travel time, than the average driver. We make the following assumptions

(i) The average transit rider has an income that is 25 percent lower than the average income for people in the region.
(ii) The average rider spends one-quarter of his or her trip waiting.
(iii) The value of riding and walking time is the same as that for autos.
(iv) The value of waiting time is 2.5 times the value of riding time.

From 1990 TBI data, we estimate that the residents of the region spend 30 million hours per year using public transit. Barnes (1999b) finds that travel time per trip has been fairly stable for transit in the region between 1958 and 1990. Using our estimates of ridership increases, we calculate that total travel time for 2020 will be between 30 million hours and 42 million hours. From Section 6.1, our low-range and high range estimates of the value of time are between $3.85 and $6.60 in 1998 and between $4.80 and $8.20 in 2020. Our low-end estimate is that the value of travel time for transit in 1998 is $120 million and our high-end estimate is $205 million. For 2020, our estimates are $210 million and $355 million, respectively.

5.3 Internal Time Costs

Time is responsible for a sizable share of the costs of transportation. We consider four types of time costs. The largest is the cost of time spent travelling. This includes the values of the time spent travelling while at work (i.e., time for which the driver is paid by his or her employer) and the time spent travelling while not at work. Time costs are calculated for motorized travel (autos, trucks, and transit).[92] Costs are not calculated for walking and bicycling because we did not feel we had enough data on these modes.[93] Our estimates of the internal costs of travel time do not include the costs of delays due to congestion. Such delays are considered to be external costs. The time costs of transportation also include the three smaller costs of non-market time: time spent maintaining vehicles, time spent buying or selling vehicles, and time spent learning to drive vehicles. The costs of the market time devoted to these activities in other categories.[94]

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[92] This also includes the time costs of walking to and from vehicles, not just the in-vehicle portion of the cost.
[93] They are discussed further in Appendix E.1.
[94] The costs of maintaining vehicles by professionals—mechanics or body-shop workers, for example—are mostly accounted for with the costs of maintenance (cost items 2.2.1 or 2.2.3) or with the external costs of crashes (cost item 5.2). The costs to dealers of buying and selling vehicles are included in the purchase price of vehicles and shows up in our accounting system as part of
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We calculate the costs of travel time in three steps.[95] First, total travel time is computed using TBI data. Second, congested travel time is computed based on the Metropolitan Council's network flow models and Schrank and Lomax (1997). Third, the value of internal (uncongested) travel time is calculated. There is evidence that travelers value time less when they are in uncongested conditions.[96] We estimate that travelers' time costs in uncongested conditions are between 35 and 60 percent of their after tax wage rates. This yields midrange values of travel time of $5.20 in 1998 and $6.50 in 2020.[97] Our midrange estimates of uncongested travel time are 1.2 billion vehicle-hours in 1998 and 1.5 billion in 2020 (see Table 6.2). Our estimates for the internal cost of travel time are shown in Table 5.4. They are based on our mid-range estimates of vehicle-occupancy rates, which are 1.26 for 1998 and 1.21 for 2020.

We also calculate the value of personal time that is devoted to transportation, but is not devoted to travel. This is time spent maintaining vehicles, buying or selling vehicles, and learning to drive vehicles. The costs of maintaining vehicles are the largest of these three. This cost includes personal time spent refueling, repairing, and cleaning vehicles. We base our estimates of these costs on Delucchi et al. (1996). We assume that these costs are the same in the region, on a per capita basis, as they are for the nation as a whole. We also assume that these costs will grow with population and perhaps with personal income as well. As people become wealthier, their leisure time becomes more valuable, but they also become more likely to hire people to perform services for them.[98] Our low-range projection is that the value of time, per capita, spent maintaining vehicles doesn't rise at all with personal income, and our high-range estimate is that it rises in proportion to personal income. Our midrange estimate is that the cost of maintaining vehicles will rise from $1.2 billion in 1998 to $1.4 billion in 2020.

The last two non-market time costs, the time spent buying or selling vehicles and time spent learning to drive vehicles, are quite small on a per capita basis (perhaps five or ten dollars per driver per year). We base our estimates of the costs of buying and selling vehicles on Delucchi. We assume that per capita

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depreciation (cost item 2.1.1). The costs to firms of training drivers are considered part of overhead (cost item 2.1.2).

[95] We discuss the costs of travel time in more detail in Section 6.1 (both the internal and external costs of travel time).

[96] See, for example, Calfee and Winston (1998).

[97] For more on this estimate, see Section 6.1. One reason these time values are rather low is that they include all of the people in the region, not just adults or just commuters.

[98] This does not necessarily mean that costs decline overall, only that costs that were formerly non-monetary, will become monetary.

costs are the same in the region, as they are for the nation. We estimate the cost of training drivers by assuming that each licensed driver spends between 10 and 30 hours learning to drive (not including time actually on the road, which is included with travel time), and that people value this time at between $5 and $15 per hour. We average these costs over what we assume will be 50 years of driving. We estimate these time costs for 2020 by assuming that they will grow with population and personal income.[99]

Table 5.4: Internal Costs of Time in the Twin Cities Region

	Millions of 1998 Dollars					
	1998			2020		
	Low	Mid	High	Low	Mid	High
Travel Time	6,780	8,910	11,060	10,890	14,440	18,070
Maintaining Vehicles	760	1,217	1,674	927	1,438	1,948
Other Time Costs	14	27	41	18	36	54
Total	7,550	10,150	12,780	11,830	15,920	20,070

Table 5.4: Our midrange estimates are that the costs of time will increase by 57 percent. The travel time estimate includes both time while at work and nonmonetary time costs (i.e., the value of time that is substituted for leisure). The remaining values cover only nonmonetary time costs.

5.4 Internal Crash Costs

Crashes cause significant costs. They cause damage to vehicles and other property, and injuries and deaths to people. They also frequently cause traffic delays, but these costs are accounted for with external time costs.[100] The risks presented by crashes are a major reason that drivers require insurance, so most of the costs of insurance could also be considered a cost of crashes. We do not do this; we account for the damages covered by insurance separately. These are mainly losses from crashes and from thefts. We then include

[99] We do not assume that these costs will grow more slowly than personal income as we did for the costs of maintaining vehicles because there do not seem to be the same benefits from hiring people to perform these services.
[100] They cause the majority of non-recurring congestion delays. See Tables 6.2 and 6.2.

insurance overhead, the transactions costs of insurance, in a separate category (see Section 5.1.2).

The difficulty in calculating the costs of crashes is not so much in quantifying the total costs of crashes but in determining the shares of these costs that are internal and external. To provide a coherent treatment for crash costs, we analyze both internal and external crash costs in Section 6.2. Our midrange estimate is that the total costs of crashes will rise from $1.4 billion in 1998 to $2.0 billion in 2020. Compared to other studies, we classify a relatively large share of costs as internal. We estimate that 100 percent of the costs of single-vehicle crashes are internal, that 91 percent of the costs of multi-vehicle crashes are internal, and that 44 percent of the costs of collisions with pedestrians or cyclists are internal.[101] Our estimates of the internal costs of crashes are shown in Table 5.5.

We project that the total number of crashes causing injuries will increase modestly between 1998 and 2020, and the costs per crash will rise fairly rapidly. This is based on national trends that show crash rates, per vehicle-mile traveled, declining.[102] The increase in the cost per crash is based on our assumptions that there will be relatively high levels of medical inflation, and that people will place increasing values on safety. Our midrange estimate is that the internal costs of crashes will rise by 45 percent between 1998 and 2020.

5.5 Private Parking, Garages, and Roads

In this section we analyze the costs of privately provided parking and the costs of private roads and garages. We cover costs to individuals and businesses. In most cases these goods are bundled, i.e., they are usually purchased with other goods. A house with an attached garage provides one example. The house and garage are generally purchased together. Similarly, the "free" parking provided at a grocery store is paid for by the storeowner and bundled into the price of the groceries that the store sells. In this region, only a small fraction of parking is not bundled. This is the parking people pay for, by the hour, day, or month, at lots or garages.

The parking provided by employers presents some interesting questions for transportation policy. This is partly because parking is a policy that is relatively easy to influence at a local level and partly because of concerns that parking is being provided inefficiently. Parking policy, while not able to

[101] See Section 6.2 for an explanation of these numbers.
[102] See, for example, NHTSA (1999).

target congestion or air pollution as selectively as road-pricing systems, is easy to implement locally and probably has lower transactions costs. Parking policy has been a focus of programs aimed at reducing air pollution in areas that are not in compliance with the Clean Air Act Amendments of 1990 (Mayer (1995)).

Worries that parking may be provided inefficiently center on at least three questions. First, is the bundling of “free” parking provided by businesses with other goods efficient? Second, do tax breaks subsidize the free parking provided by firms to their employees? Third, does parking use so much land that it forces businesses to locate too far apart? The first question probably depends in large part on the costs of collecting parking fees. Moore and Thorsnes (1994) feel that a regional tax on parking spaces may be a way of overcoming the fact that it is costly for businesses to collect parking fees. As to the second question, current tax laws allow companies to provide parking as a tax-free fringe benefit. This encourages firms to provide free parking for employees because firms can purchase it more cheaply than employees can. Voith (1998) provides a different rationale for new parking policies. He argues that there are cases where it makes sense for cities to raise revenue for public transit by taxing parking spaces. In his model, a city can increase overall accessibility to a dense, productive central business district with the right mix of transit and auto use.

While important for many policy questions, accounting for the cost of parking is problematic because it is usually sold as a bundled good. We wish, for example, to know the cost of a garage, but the garage is sold with a house and the house is not a cost of transportation. In principle, the costs we want can be broken out, but most data sources do not do that. The Bureau of Economic Analysis, for example, produces yearly estimates of capital stock and investment, but it includes garages with residential and non-residential structures.[103]

[103] See, for example, Katz and Herman (1997).

Because of a lack of local data, we base most of our estimates on Delucchi et al. (1996), who examined these costs at a national level. We use the region's share of housing value as a proxy for the region's share of parking costs. The costs of housing are used as a proxy because they reflect the costs of land and construction. This relationship probably does not hold in very dense areas, however, because the cost of parking per space is much higher for ramps than it is for surface parking.[104] Because such regions with such high density make up a relatively small share of the nation and of our region, we feel share of housing value serves as a good proxy for share of parking cost.

Table 5.5: The Internal Costs of Crashes

	1998 (millions of 1998 dollars)		
	Low	Mid	High
Single-Vehicle	300	395	540
Multi-Vehicle	680	870	1,110
Pedestrian or Cyclist	45	70	115
Total	1,115	1,365	1,810
	2020 (millions of 1998 dollars)		
	Low	Mid	High
Single-Vehicle	435	580	785
Multi-Vehicle	1,015	1,295	1,645
Pedestrian or Cyclist	65	105	175
Total	1,640	2,005	2,635

Table 5.5: We estimate that the internal costs of crashes will rise by approximately 45 percent between 1998 and 2020.

The long-term trend for parking cost will be influenced by the cost of land and the cost of construction. The costs of land has generally risen more quickly than personal income. This is because the demand for land is inelastic, and metropolitan populations have been increasing. The costs of construction have historically risen much more slowly than inflation because of significant productivity gains. Because construction costs are a relatively small share of the costs of surface parking, we feel that the cost per parking

104 Shoup (1997) estimates that the costs of constructing a new parking space in a ramp at UCLA between 1977 and 1994 averaged $25,000, and that the full cost per month, including maintenance, was $130. The cost of surface parking might be only a tenth as much.

space will rise in real terms. We assume that the rate of increase will be approximately equal to the increase in personal income.

Residential Garages and Driveways

Delucchi estimates that the national cost of residential garages and driveways is between $18 and $47 billion in 1990. There was considerable uncertainty in his estimates, especially given that these are monetary goods. The uncertainty reflects mainly the problem of unbundling garages and drives from housing in general. The median value of a housing unit in this region was 91 percent of the median value in the U.S. Assuming that the number of housing units in the region is the same as the U.S. average, per capita, we estimate that the region is responsible for 1.0 percent of national costs.

We predict that the number of residential garage spaces and the amount of space devoted to residential driveways will increase with the number of vehicles at slightly less than 1.4 percent a year. We also predict that the value of these spaces will rise with personal income, at 1 percent a year. Our midrange estimate is that the annualized cost of residential parking and drives will rise from $350 million in 1998 to $585 million in 2020. Our low and high-end cost estimates are shown in Table 5.6. We did not project low and high growth rates for these costs because we felt Delucchi's estimates already accounted for a great deal of uncertainty.

Parking, Roads, and Drives Owned by Businesses

Delucchi estimates that the costs of the parking lots, roads, drives owned by businesses in 1990 were between $70 billion and $275 billion. Roads or drives accounted for approximately 25 percent of these costs. The uncertainty in these estimates is even greater than that for residential parking and drives, primarily because the costs of private roads were difficult to determine. Using the same reasoning as for residential parking and drives, we estimate that the region is responsible for 1.0 percent of these costs.

We predict that the number of parking spaces and the amount of space devoted to drives, owned by businesses will increase with the population at 0.9 percent per year. This is a slower growth rate than for residences, because businesses usually only need temporary storage for vehicles. As with residential spaces and drives, we estimate that the value per unit will rise with personal income. Our midrange estimate is that the cost of residential parking and drives will rise from $1.6 billion in 1998 to $2.4 billion in 2020. Our low and high-end cost estimates are shown in Table 5.6.

Unbundled Parking

We have not been able to obtain much data on the aggregate cost of parking in the region outside of the Minneapolis central business district (CBD). The City of Minneapolis collected data on parking within the CBD and found that in 1998 there were 51,000 parking spaces and the average daily rate was $7.00.[105] We assume that most parking fees are levied during weekdays. We further assume that monthly and other types of discounts to drivers and parking taxes roughly balance out higher fees for special events, fees levied on weekends, and other parking in the region. Most of the pay parking in the region is at the Minneapolis-Saint Paul International Airport, the University of Minnesota, the Minneapolis CBD, and the Saint Paul CBD. Of these, the Minneapolis CBD has the highest rates and the largest number of parking spaces.[106] This yields a baseline 1998 estimate of $90 million in parking costs. Our low-range estimate is that parking costs are 25 percent lower, and our high-range estimate is that they are 50 percent higher.

Predicting the costs of parking for 2020 is problematic because they are so closely tied to the number of jobs and the price of land in the Minneapolis CBD. A relatively small increase in the total number of jobs could lead to a large increase in the price of parking because the number of spaces is limited. The construction of new ramps can increase the number of spaces, but spaces in parking ramps are costly relative to surface parking spaces. Our low-end estimate is that the cost of paid parking will rise at the same rate as other parking. Our high-end estimate is that it will rise 50 percent faster.

Table 5.6: The Costs of Private Parking and Driveways

	1998			2020		
	Low	Mid	High	Low	Mid	High
Residential Parking & Driveways	215	350	570	360	585	950
Business Parking	655	1,195	2,185	990	1,815	3,315
Business Roads and Driveways	160	405	1,035	245	615	1,570
Pay Parking	70	90	135	105	150	240
Total	1,100	2,040	3,925	1,700	3,165	6,075

Table 5.6: A range of estimates of the costs of parking and driveways for the Twin Cities region. All figures are in millions of dollars.

[105] Minneapolis Department of Public Works (1998).
[106] The University of Minnesota, for example, charged $2.50 per day for parking, and lots close to the Saint Paul CBD charged $4 or $5 per day.

5.6 Summary of Internal Costs

The internal costs of transportation are summarized in Table 5.7. Our midrange estimate for 1998 is that the costs of vehicles and time account for almost 85% of all internal costs. The costs of vehicles that are largely fixed and the cost of travel time account for two-thirds of the total internal costs of travel. Note that the costs of vehicles are large, on a per capita basis, because they include the costs of heavy trucks as well as the overhead costs of managing fleets of commercial vehicles. Most of the time costs are nonmonetary and therefore do not show up as personal income in economic accounts. This means the figures that show internal costs as a share of income should only be used to gain perspective on the burden of these costs.

The costs of crashes and the costs of parking and driveways account for approximately 15 percent of the internal costs of travel. While these costs make up only a modest share of internal costs, they are large in absolute terms (together they are larger than the governmental costs of transportation, for example). The costs of transit are relatively small because only a small fraction of all vehicle-trips are made by transit. Figure 5.1 shows the share of our mid-range internal cost estimates for a number of cost items.

Our midrange estimate is that internal costs will grow by 52 percent between 1998 and 2020. The costs of travel time are expected to increase by 62 percent, based on assumptions that the value of time will rise in proportion with regional income and the travel time per capita will increase slightly.[107] We estimate that the fixed costs of vehicles will grow more slowly than other internal costs because of increases in manufacturing productivity. Variable vehicle costs are expected to rise by 64 percent, mainly because of increases in the costs of fuel and oil.

[107] Based on Barnes (1999b), we expect travel time per *traveler* will remain approximately constant. We predict that small increases in driving age population, residential location, and access to vehicles will lead to a modest increase in travel time per capita.

Table 5.7: Summary of the Internal Costs of Transportation

	Total Spending in Millions of Dollars					
	1998			2020		
Cost Items	Low	Mid	High	Low	Mid	High
Fixed Vehicle	5,650	6,450	7,300	7,800	9,000	10,050
Variable Vehicle	2,200	2,650	3,150	3,050	4,350	6,100
Transit Fares	50	55	60	75	80	90
Transit Time	120	165	205	210	285	355
Travel Time	6,780	8,910	11,060	10,890	14,440	18,070
Other Time	770	1,240	1,720	940	1,480	2,000
Crashes	1,115	1,365	1,810	1,640	2,005	2,635
Parking and Driveways	1,100	2,040	3,925	1,700	3,165	6,075
Total	17,800	22,900	29,250	26,300	34,800	45,400

	1998			2020		
Measures of Full Cost	Low	Mid	High	Low	Mid	High
Cost per Capita	$5,860	$7,550	$9,640	$7,110	$9,460	$12,290
Cost per Vehicle	$6,620	$8,540	$10,910	$7,500	$9,980	$12,960
Share of Personal Income	19.3%	24.9%	31.8%	19.1%	25.4%	33.0%
Cost per Vehicle-Mile	69¢	89¢	113¢	72¢	96¢	124¢

Table 5.7: Our midrange projections are that the total internal costs of travel will rise by slightly more than 50 percent, but these costs will rise only slightly as a share of regional income.

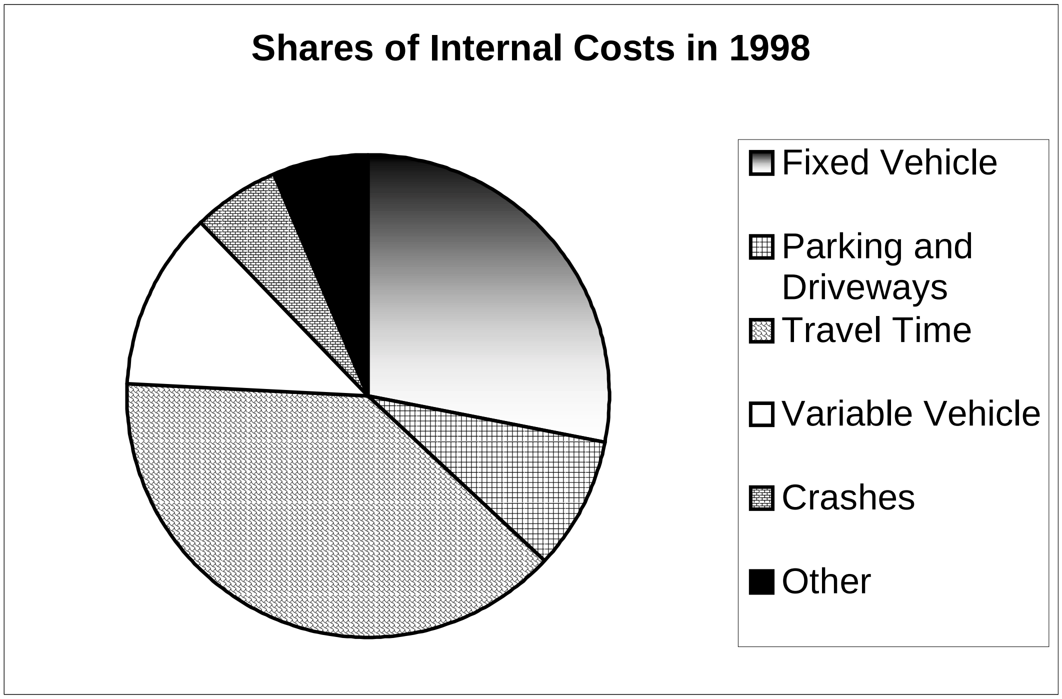

Figure 5.1: Shares of Internal Costs in 1998

Somewhat more than half of the internal costs of travel are variable. Most of the "other" category of costs are the time costs of fueling and maintaining vehicles.

6 External Costs

The nature of transportation seems to make it prone to generating a number of negative side effects. Not only does transportation consume a great deal of energy, but moving goods and people leads naturally to encounters and conflicts. Travel can cause congestion, crashes that injure people or damage property, air or noise pollution, and a variety of other negative impacts. An interesting source of evidence that modern transportation is especially prone to negative externalities comes from the field of tort law. Tort litigation, which provides a means of dealing with harmful, but not criminal, impacts was seldom used in England until the first railroads. The advent of railroads, however, caused an explosion of lawsuits, which led to significant changes in tort law.[108]

The externalities produced by transportation have inspired a great deal of interest among economists. Knight (1924) analyzed congestion externalities, and Vickrey (1994) analyzed externalities resulting from crashes. Transport externalities have also received attention from public officials resulting in a wide range of policies and regulations designed to promote safety, reduce congestion, or mitigate environmental impacts.

While a great deal of effort has been devoted to quantifying the external costs of transportation, most estimates remain quite uncertain. One reason is that large portions of these costs are nonmonetary. We need to determine the values people place on such goods as leisure time, a quiet environment, health, and the absence of pain. Difficult scientific questions also arise. We need to know how noise propagates, how emissions are produced and disperse, and the health effects of various pollutants.

Much of the uncertainty in our cost estimates is unavoidable, but the nature of this uncertainty can have important policy implications. We might, for example, decide against a policy that is very risky because, even though its expected cost is low, it has a small chance of resulting in catastrophically high costs. For this reason, we attempt to quantify the uncertainty in our cost estimates. We provide low, high, and mid-range cost estimates. Our mid-range estimates represent the cost values we feel are most likely to pertain. Our low and high-range estimates are not designed to be lower and upper

[108] Landes and Posner (1987), pp. 2–3.

bounds on costs. These estimates merely reflect values below and above which we feel costs are unlikely to fall.[109]

Arriving at our estimates requires making specific assumptions about parameters that affect costs. Some of the more technical discussions are confined to appendices. Ideally, all of our parameter estimates would be based on careful econometric studies or exhaustive examinations of the literature. Unfortunately, the scope of this study does not allow us to determine good statistical bases for all of our parameter estimates. Some of our estimates are based on rather limited data and our own judgement.

This section of the report focuses primarily on four types of externalities: congestion, crashes, air pollution, and noise. These are probably the most studied external costs of transportation. Congestion, crashes, and air pollution are usually found to account for most of the external costs associated with transportation.

Sections 6.1 and 6.2 cover time and crash costs, respectively. These sections contain our primary analyses of both the internal and the external costs of time and crashes. Sections 6.3 and 6.4 cover the costs of air pollution and noise, respectively. In Section 6.5 we quantify three additional external costs of transportation, the costs of petroleum consumption, fires, and robberies. Section 6.6 discusses some impacts that we feel impose external costs (perhaps even large costs), but that we are not able to quantify.

6.1 Congestion

Congestion occurs when travelers impose delays on one another. These delays may be due to normal traffic flows or may be caused by incidents such as crashes or stalled vehicles. Delays due to the weather or road construction are not external costs of travel because they are not caused by other travelers. We account for all congestion externalities in this section, including those due to crashes. Congestion adds to the time costs of travel by increasing total travel time; by making travel less pleasant; and by making travel time less certain and thereby increasing scheduling costs.

Traffic congestion is important for several reasons. It is the subject of a great deal of public concern. Polls often report that people in urban areas rank traffic congestion as a top concern. Congestion can add significantly to travel time costs, which are the largest variable costs of travel. Congestion costs are

[109] While we cannot be rigorous about this, our goal is to produce low and high-end estimates so that there is a 90 percent chance that actual costs will fall between the two numbers.

also a concern because they appear to be rising rapidly. Schrank and Lomax (1997) found that traffic delays for the average driver in the U.S. rose at almost five percent a year between 1982 and 1994. These results imply that the costs of congestion are rising faster than population or GDP. Time costs also probably influence travelers' choices about when, where, and how to travel, much more than do the costs of crashes or air pollution. Congestion also influences other costs of travel indirectly by affecting travelers' choices and directly by affecting fuel consumption and air pollution.

The growth of congestion, and the accompanying public concern, has made congestion an important public policy issue. There do not appear to be any easy solutions. Expanding roadway capacity seems an obvious answer, but this is expensive, especially in urban areas. Although technology has significantly reduced the costs of air pollution, it appears unlikely to do much to reduce the costs of congestion. Intelligent Transportation System (ITS) technology can provide information to warn drivers of delays, but this technology does nothing to reduce the underlying externality that causes congestion. Better transit is often advocated as part of the solution, but it seems unlikely that transit will solve a very large part of the problem in this region because transit's mode share is so small. Other policies aimed at reducing congestion by reducing auto travel have been largely ineffective, or have proven unpopular, or both. Attacking congestion directly, with congestion tolls, has been widely advocated by economists, but building politically influential coalitions in favor of such tolls has proven difficult.

6.1.1 Technical Background

To an economist, congestion delays are a clear example of an externality. It is sometimes argued, however, that congestion does not represent an externality because all of the costs of congestion are borne by drivers. If drivers bear all of the costs of congestion themselves, the argument goes, then drivers must be imposing costs equal to the costs they experience and there can be no externality. Green (1995), for example, says that roads should be considered a club good[110] and, in part because of this, congestion should not be considered an externality. While thinking of roads as club goods may be useful for some purposes, clubs do not eliminate externalities; they merely limit the effects of externalities to members.

To see more clearly why congestion is an externality, consider a simple example. Suppose that 1800 drivers an hour use a certain stretch of highway. With no congestion, the section of highway would take 10 minutes to

[110] A club good is a good that is consumed jointly by a group of people, who purchase and consume the good and can exclude others from consuming the good.

traverse, but when 1800 drivers per hour cram onto the highway, it takes 25 minutes to traverse. The extra 15 minutes of travel time per hour is a congestion delay. To see that the delay is an external cost of travel, it helps to distinguish between the costs that drivers impose and the costs they experience. Suppose an extra driver wishes to use the road, and further suppose that every additional driver slows traffic by one second. The driver would experience 25 minutes of travel time, plus what is to him a negligible one second. The second is not negligible to all other drivers, however. The driver imposes costs equal to 55 minutes—25 minutes on himself and 30 minutes (1,800 times 1/60 minutes) on other drivers.[111] The 30-minute delay that the driver causes for others is an externality. This externality causes inefficiency, which represents wasted resources. It does not matter, for efficiency purposes, that all of the external costs are borne by drivers.

Models of Congestion

Models of congestion can be divided into three types: static (or flow) models, dynamic models, and simulations. Static models assume that travel time on a section of road is a function of traffic flow on the road. The models are static in the sense that traffic flows are assumed to be constant for a period of time (typically an hour). Knight (1924) used a flow model to illustrate that traffic equilibrium may be inefficient, and that marginal cost pricing (tolls) would insure that an efficient equilibrium results. The standard, four-step model of travel behavior uses a static flow model of traffic.

While widely used, flow models have a number of limitations. Perhaps the most important is that they abstract from scheduling considerations. In static models, drivers' departure times are fixed. Many dynamic models of traffic congestion make departure time choice endogenous. Vickrey (1969) developed one such model. His model has been extended to more general settings (see, for example, Arnott et al. (1990)) and the parameters of the model were estimated by Small (1982). Friesz et al. (1996) describes numeric algorithms that allow Vickrey's models to be extended to networks. While these algorithms have been used for research purposes, they have not been widely adopted by practitioners.

Traffic congestion can also be modeled using simulations. Simulations allow more realistic modeling of congestion at a microscopic level. They can model, for example, congestion at interchanges or congestion caused by flows of heterogeneous drivers. One large project currently underway,

[111] Note that 25 minutes is the average cost of travel, and it equals the marginal private cost of travel. The marginal social cost of travel is 55 minutes, and the marginal external cost of travel is 30 minutes.

TRANSIMS, is designed to use simulations to model congestion in a city at a region-wide level.[112] These models have not yet been implemented, however.

Congestion delays can be divided into two types—recurrent and non-recurrent. Recurrent delays are delays that travelers face every day. They correspond to the normal ebbs and flows of traffic. Non-recurrent delays are those that are unexpected. They may be caused by crashes, stalled vehicles, or unusually heavy traffic.[113] Basic models of the three types discussed above are not stochastic and can be only be used to model recurrent congestion. Stochastic versions of all three types of models exist, but practitioners seldom use the models.

Studies of Congestion in the Twin Cities Area

Schrank and Lomax (1997) estimated the cost of congestion for 50 urban areas in the U.S. They calculated the cost for the years 1982 to 1994. Almost all areas experienced increases in congestion. They estimated that congestion in the Twin Cities area increased from nine hours per eligible driver in 1982, to 25 hours in 1994. The total cost of congestion in the Twin Cities in 1994 was estimated to be $630 million.

Schrank and Lomax determined traffic conditions by using the Highway Performance Monitoring System database. The database is maintained by the Federal Highway Administration and contains information collected from state and local agencies. The database contains broad measures of aggregate highway performance such as aggregate vehicle miles and average peak period speeds.

The Metropolitan Council regularly models traffic equilibrium in the TCMA. They use travel demand models, which are described in more detail in Section 3, for planning purposes and to monitor compliance with federal air quality standards. The Council models congestion with a static flow model of traffic. Traffic flows are predicted on all major roads in the region for five congested time periods.[114] Anderson and Mohring (1996) used the Metropolitan Council's networks and data to analyze the efficiency losses due to congestion. They found, for recurrent congestion in the morning peak travel hour, that efficiency losses (i.e., the net social losses that result from congestion) might be as high as 10 percent of the cost of congestion.

[112] For information on TRANSIMS, see Nagel et al. (1999).
[113] They may also be caused by weather or by road construction. We consider the delays caused by the weather to be internal costs and delays caused by road construction to be governmental costs. We do not model either type of delay explicitly.
[114] The models are of weekday travel. The time periods are 6:30 – 7:30 a.m.; 6:00 – 6:30 a.m. and 7:30 – 8:00 a.m.; 3:40 – 4:40 p.m.; 4:40 – 5:40 p.m.; and 3:00 – 3:40 p.m. and 5:40 – 6:00 p.m.

6.1.2 Total Travel Time and Congestion Costs

Our estimates of current congestion costs are based on the Metropolitan Council's network flow models, the travel times people reported in the 1990 TBI, and actual observations of road conditions. First, we estimate total travel time from the TBI. For residents of the TCMA in 1990, the probability of taking a trip by auto on any given day was approximately 85 percent, and the average person who did travel, spent 71 minutes traveling. This average travel time figure has been stable; it was 68 minutes in both 1958 and 1970.[115] The percentage of people who travel on any given day has been rising, but there is not much room for it to rise further. Because these numbers seem so stable, we use them to estimate total travel time in 1998 and 2020.

Aggregate Travel Time

Our estimates of total travel time are shown in Table 6.1. While we expect travel time per person and the fraction of travelers to remain fairly stable, we allow for modest growth in both. The fraction of travelers has risen steadily since the 1970s, but the factors which have driven this rise, such as a large increase in the percentage of women who are in the workforce, have largely played themselves out. Public concerns about sprawl and congestion have led to fears that per capita travel time will rise rapidly in the Twin Cities region. While this is possible, we do not predict very large increases in per capita travel time because (i) trends have not indicated that travel time per capita is rising and (ii) congestion is not a particularly large portion of total travel time. Overall, even large increases in congestion would cause relatively modest increases in total travel time. The TBI data discussed above applies only to travel within the TCMA. We estimate travel for people outside the TCMA based on the facts that people who live further from the center of an urban area are somewhat less likely to travel than people who live nearer the center, and also such people are likely to spend slightly more time traveling.[116] All of the parameters that describe how we determined total travel time are contained in Appendix D.4.

[115] The data for 1990 are contained in Metropolitan Council (1994a). Barnes (1999b) compares regional travel times in 1958, 1970, and 1990.

[116] Barnes (1999b) finds that in 1990, people who traveled on a given day and who lived more than 15 miles from the center of the region averaged almost 80 minutes of travel on that day, while those who lived less than 10 miles from the center averaged 70 minutes.

Recurrent and Non-recurrent Congestion

We estimate the amount of travel time results from congestion in three steps. First we estimate recurrent congestion in 1995. The second step is to estimate non-recurrent congestion in 1995. Finally, we project congestion costs forward to 1998 and 2020. We have two sources of data on regional congestion for 1995—the Metropolitan Council's network models and Schrank and Lomax (1997). Schrank and Lomax estimated that each day there were 69,000 vehicle-hours of recurrent delay in the Twin Cities MSA in 1994.[117] The Metropolitan Council estimated that there were 52,000 vehicle-hours of recurrent congestion in the TCMA in 1995. We do not expect that much congestion occurs outside the seven-county TCMA, so we use 45,000 hours as our low-range estimate of recurrent congestion and 80,000 hours as our high-range estimate. The average auto operating in an urban area had 1.25 occupants in 1994.[118] This number has fallen significantly over the last 20 years; the corresponding number for the TCMA was 1.50 in 1970 and 1.29 in 1990,[119] but the number cannot fall much further. We assume that congestion occurs only on weekdays, and that there are 250 weekdays in a year.

Non-recurrent congestion is harder to estimate than recurrent congestion. One problem is that the standard model of traffic flows, the four-step model, is not stochastic and cannot predict non-recurrent congestion.[120] Lindley (1989) estimated that the ratio of recurrent to non-recurrent congestion in the U.S. may be as high as 3 to 2. For the Twin Cities region he estimated that the ratio in 1994 was 1.03 to one. This seems reasonable. We are not aware of any other studies that attempt calculate this ratio, so we view this estimate as fairly imprecise. We assume that the ratio of recurrent to non-recurrent delays is between 0.8 and 1.2 to one. As with recurrent congestion, we assume that non-recurrent congestion only occurs in the seven TCMA counties.

Schrank and Lomax found that congestion grew at an average rate of almost five percent per year in 50 U.S. urban areas between 1982 and 1994. This growth rate would result in a 280 percent increase in hours of delay if it were sustained to 2020. As large as this increase seems, the Metropolitan Council predicts even larger increases in congestion. They estimate that recurrent

[117] Schrank and Lomax did a follow-up study to determine congestion in 1996, but we have not analyzed their new numbers.
[118] Schrank and Lomax (1997).
[119] Metropolitan Council (1994a), p 31.
[120] A further complication is that levels of recurrent and non-recurrent congestion may be interdependent. The relationship between the two types of congestion is analyzed in Anderson (1996). We ignore such complications in the present analysis.

congestion will rise by 545 percent between 1998 and 2020 (approximately eight percent per year). These increases are shown for TCMA freeways in Figures 6.1 and 6.2. We feel that actual growth rates will be equal to, and perhaps less than, those of Schrank and Lomax. One reason we feel this way is that travel time budgets are generally so stable (i.e., the average person usually spends almost the same amount of time traveling across a wide range of situations).[121] Another reason is that there was a large increase in vehicle-miles of travel per capita between 1982 and 1994, and some of the factors that influenced this increase will not have such large effects between 1998 and 2020. For example, the fraction of women in the work force and the ratio of vehicles to drivers appear to be stabilizing. While the Metropolitan Council predicts larger increases than Schrank and Lomax and has more detailed models of congestion, the increases that the Council predict are so large that we mostly discount them. We feel their predictions may be due to shortcomings inherent in the most widely used travel demand models. Travel demand models, though detailed, simply do not allow travelers to make all of the adjustments they would in real life. The Council's models only allow travelers to change routes in response to congestion. Other potential responses to congestion are not modeled. These include making fewer trips, traveling at different times, traveling to different destinations, changing residential locations, or using a different mode. Some of these choices are implemented partially in the Council's models, but these choices cannot be fully implemented because of limitations in the current state of travel demand modeling.[122]

Our estimates of recurrent and non-recurrent congestion are shown in Table 6.2. Overall, congested travel time accounts for a small share of total travel time (2.7 percent in 1998 and 5.4 percent in 2020). This is because most travel is done at times and in places where traffic is not heavy. It should be noted that, while small in relative terms, congestion is significant in absolute terms especially because most people appear to value time spent in congestion more than time spent driving in free-flow conditions.[123]

[121] See Barnes (1999b).

[122] See Barnes (1999a) for more on the limitations of travel demand models.

[123] Levinson argues that congestion costs should include time spent waiting at signalized intersections (Levinson (1998)). We feel this is a sensible way to think about congestion costs, but we do not have good data on how much intersection delay slows traffic in the region. In addition, we are unsure of the implications of this viewpoint are for marginal congestion costs.

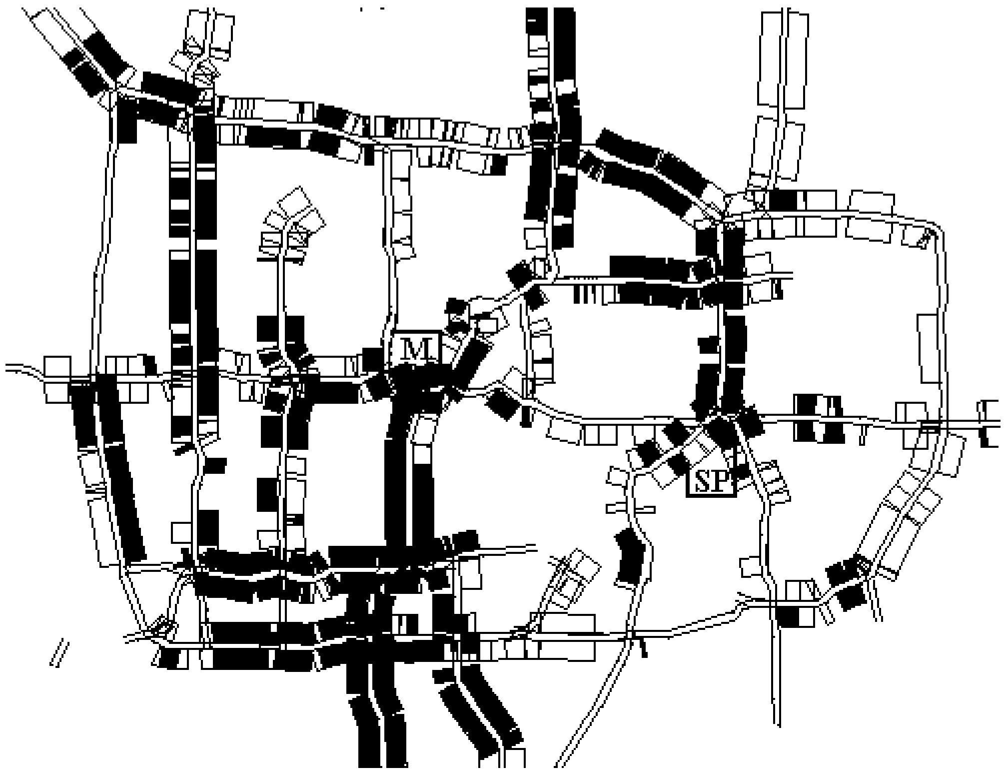

Figure 6.1: Growth in Moderately Congested Freeways

The figure shows freeway segments on which peak period congestion results in delays of at least ten percent of travel time. Segments with such delays in 1998 are shown as white rectangles. Black rectangles show the additional segments on which such travel conditions are predicted to occur in 2020. The locations of the Minneapolis (M) and Saint Paul (SP) central business districts are indicated on the map.

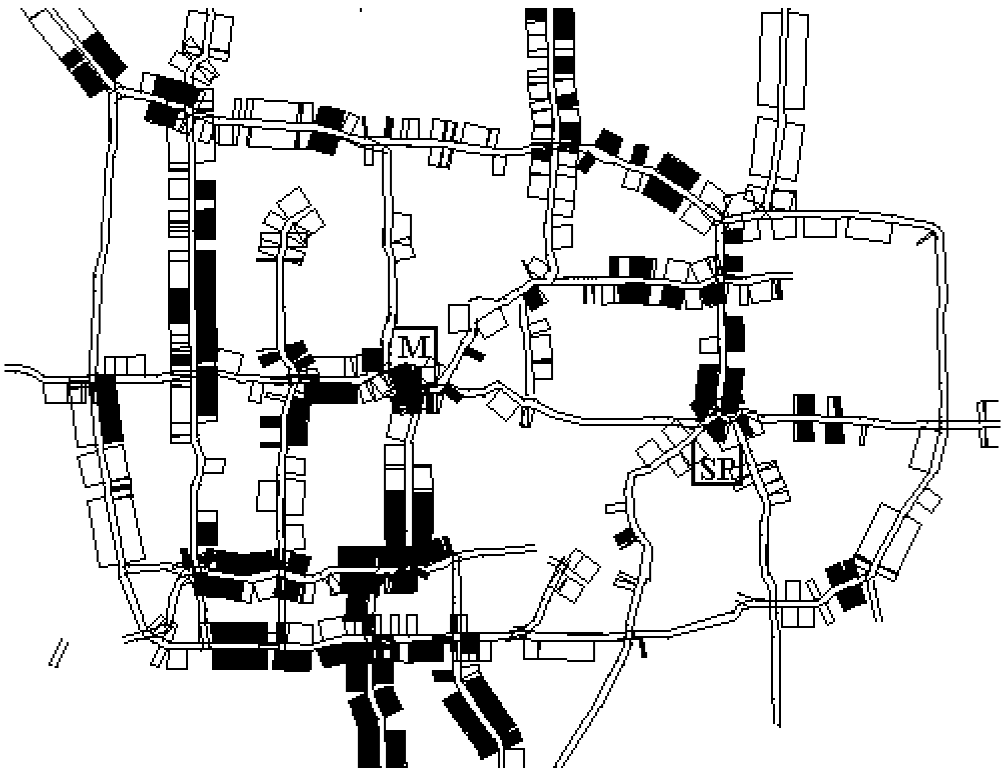

Figure 6.2: Growth in Severely Congested Freeways

The figure shows freeway segments on which peak period congestion results in delays of at least 15 percent of travel time. Segments with such delays in 1998 are shown as white rectangles. Black rectangles show the additional segments on which such travel conditions are predicted to occur in 2020. The locations of the Minneapolis (M) and Saint Paul (SP) central business districts are indicated on the map.

Table 6.1: Travel Time Estimates for the Twin Cities Region

	TCMA Counties					
	1998			2020		
	Low	Mid	High	Low	Mid	High
Probability of Travel	0.850	0.875	0.900	0.850	0.885	0.920
Average Time per Traveler	72	74	76	75	80	85
Average Time per Capita	62	65	67	66	71	77
Millions of Hours per Year	955	990	1,030	1,235	1,340	1,445
	Non-TCMA Counties					
	1998			2020		
	Low	Mid	High	Low	Mid	High
Probability of Travel	0.825	0.850	0.875	0.840	0.880	0.920
Average Time per Traveler	72	76	80	75	83	90
Average Time per Capita	63	68	73	67	75	83
Millions of Hours per Year	200	215	230	250	280	310
	Twin Cities Region					
	1998			2020		
Probability of Travel	0.846	0.871	0.896	0.848	0.884	0.920
Average Time per Traveler	72	74	77	75	80	86
Average Time per Capita	62	65	68	66	72	78
Millions of Hours per Year	1,155	1,205	1,260	1,485	1,620	1,755

Table 6.1: Our mid-range estimate is that total travel time in the region will increase by 34 percent overall and by ten percent on a per capita basis.

Table 6.2: Congested and Uncongested Travel in the Twin Cities Region

	1998 (millions of hours) Low	Mid	High
Uncongested Travel	1,136	1,175	1,214
Recurring Congestion	9	16	23
Non-recurring Congestion	8	16	24
Total Travel Time	1,155	1,205	1,260
	2020 (millions of hours) Low	**Mid**	**High**
Uncongested Travel	1,440	1,530	1,620
Recurring Congestion	24	43	65
Non-recurring Congestion	23	44	67
Total Travel Time	1,485	1,620	1,755

Table 6.2: Our mid-range estimate is that congested travel time in the region will increase by 175 percent in the region overall, and by 125 percent on a per capita basis. Congestion is estimated to account for only 2.7 percent of travel time in 1998 and 5.4 percent in 2020.

The Value of Travel Time

A key parameter in this analysis is the value of time. As with other goods and services, we feel that people trade off money for time, and that the rate at which they make this tradeoff gives us a good idea of the value of travel time. Sometimes this tradeoff is made in a market as when firms hire drivers, but most times the tradeoff is not. When people are not paid to drive, the value of travel time depends of a variety of personal characteristics, the most important of which is probably the wage rate. The value also depends on trip characteristics, e.g., whether the trip is made via auto or bus, or on congested or uncongested roads.

Many studies have estimated the value of time as a function of wage rate. The precise relationship between wage rate and value of travel time is an empirical matter, and the value of travel time could, in theory, increase or decrease relative to the wage rate as the wage rate rises. Lisco (1967) found that the value of travel time increased linearly relative to wage rate for people with below average incomes until it was equal to approximately 50 percent of the wage rate. For people with higher incomes, the value of time was approximately 50 percent of wages.[124] Anderson and Mohring (1996) applied Lisco's method to TCMA travelers, and estimated that the average value of travel time in the region was $12 per hour in 1990.

Boardman et al. (1997) examined 32 studies of the value of commuting time. The mean value was 51 percent of the hourly, after-tax wage rate, and the median was 40 percent. Of the 32 studies, 15 were of travel in North America, and they had a mean of 59 percent of the after-tax wage rate and a median of 42 percent. Wardman (1998) reviewed 105 British studies of the value of travel time. He found a great deal of variability in the estimates. The values of the highest ten percent of estimates were found to be at least five times higher than the values of the lowest ten percent of estimates. Wardman found no significant difference between the value travelers place and commuting time and on non-commuting time, however.

We base our travel time values mostly on Boardman. For free-flow travel time, we use 35 and 60 percent of the hourly, after-tax wage rate as our low and high time value estimates, respectively. There is evidence that travelers find travel time more costly under congested circumstances than under non-congested circumstances. MVA Consultancy et al. (1987) found that the value might be 50 percent higher under congested conditions. Calfee and Winston (1998) confirm this finding in a study that relied on survey data. Morhing et al. (1987) found that the value of time spent in a queue is higher than the value of time spent driving under free-flow conditions. Noland and Small (1995) showed that the value of non-recurrent congestion would be higher than that of recurrent congestion if schedule-delay costs were linear. However, we do not have good data on how much higher the costs of non-recurrent congestion are than those of recurrent congestion. We assume that the value of recurrent congestion is between 40 and 70 percent of hourly, after-tax wage rate, and that the value of non-recurrent congestion is between 50 and 90 percent. We estimate the average, after-tax wage rate *per capita* in the region was $11.00 per hour in 1998, and will be $13.70 in 2020.[125]

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[124] Let $\underline{W}$ be the average wage rate, and let W be the wage rate of the person in question. Lisco found that if W was less than $\underline{W}$, then the value of time was $0.5 * W^2 / \underline{W}$, and if W was greater than $\underline{W}$, then the value of time 0.5 W.

[125] Bureau of Economic Analysis (1998). This wage rate is based on per-capita disposable income. We calculated the wage rate per capita, i.e., for all people in the region whether they work or not because travel time includes the time of workers and non-workers.

The values just discussed do not apply to commercial vehicles because the drivers of commercial vehicles are compensated for their travel.[126] Note that at this point in our analysis we are not concerned with which vehicles cause congestion (large trucks probably cause more congestion than smaller vehicles) but only with how much congestion is experienced. The responsibility of vehicles for causing congestion will be examined in the section of this study that deals with cost incidence. The standard measure of the value of time for drivers who are being compensated is the wage rate, net of taxes, but including fringe benefits.[127] The average weekly wage rate for motor vehicle operators in the U.S. was $503 in 1998.[128] We estimate that the wage rate was 15 percent higher in the Twin Cities region in 1998 because per capita income was 15 percent higher. We also project that the wages of motor vehicle operators will rise with per capita income. This yields an estimate that the wage rate of motor vehicle operators was $14.40 in 1998 and will be $18.00 in 2020. This average wage rate includes taxes, but not fringe benefits. We assume taxes and fringe benefits are roughly equal, so we estimate that time costs are between 90 and 110 percent of these wage rates. We further assume that costs for commercial vehicle operators do not depend on whether traffic conditions are free flow or congested. This is not completely satisfactory because non-recurrent congestion in particular may increase costs of firms by increasing scheduling uncertainty, and perhaps inventory costs. We ignore this effect because (i) it is probably small and (ii) the operators of commercial vehicles probably have an easier time scheduling trips to avoid congestion than other drivers.[129]

The Metropolitan Council estimates that between four and five percent of traffic in the TCMA is commercial truck traffic. Preliminary results from studies of commercial vehicles in the Twin Cities region and in Atlanta reveal that commercial vehicles travel between 10 and 15 percent of all vehicle-miles. We assume that commercial vehicles account for ten percent of all travel. For more information on the parameters that we used for our congestion estimates, see Appendix D.4.

Our cost estimates are summarized in Table 6.3. The costs of congestion are small relative to the costs of all travel time, but they are not insignificant. The costs amount to 3.3 percent of all time costs in 1998 and 6.7 percent in 2020. The costs of congestion are expected to grow very rapidly, more than tripling from 1998 to 2020. This is due mainly to increases in the amount of

[126] Their costs are monetary; whereas the values discussed previously were non-monetary.
[127] We want to determine the real cost to society of employing a driver. These include fringe benefits but not taxes (taxes are merely transfers).
[128] Bureau of Labor Statistics (1999).
[129] In any event, we would need a model of commercial vehicle logistics to estimate these time values, and we do not know whether such a model exists.

congestion and, to a lesser extent, to increases in the value of time. Both the amount and value of congested travel time is uncertain. Our high range estimates are that congestion costs are roughly three times higher than our low-range estimates. This is a significant difference, but it is not too surprising given that most time costs are nonmonetary.

We make one adjustment to these numbers to account for the costs of fuel. We base our estimates on Shrank and Lomax (1997) who find that the average ratio of congestion time costs to fuel costs is approximately ten to one in most urban areas (including the Twin Cities).

Table 6.3: The Cost of Travel Time in the Region

	1998 (millions of dollars)		
	Low	Mid	High
Commercial Vehicles Uncongested	1,170	1,290	1,420
Commercial Vehicles Congested	18	34	54
Non-Commercial, Uncongested Travel	5,610	7,620	9,640
Non-Commercial, Recurring Congestion	60	118	182
Non-Commercial, Non-recurring Congestion	73	150	242
Fuel Cost Due to Congestion	15	30	48
Total for Congested Travel Time	151	302	478
Total Congestion Costs Including Fuel	166	332	526
Total for All Travel Time	6,950	9,240	11,590
	2020 (millions of dollars)		
	Low	Mid	High
Commercial Vehicles Uncongested	1,880	2,090	2,300
Commercial Vehicles Congested	60	118	187
Non-Commercial, Uncongested Travel	9,010	12,360	15,780
Non-Commercial, Recurring Congestion	204	407	646
Non-Commercial, Non-recurring Congestion	248	518	856
Fuel Cost Due to Congestion	51	104	169
Total for Congested Travel Time	512	1,043	1,689
Total Congestion Costs Including Fuel	563	1,147	1,858
Total for All Travel Time	11,450	15,600	19,940

Table 6.3: Our mid-range estimate is that the total cost of congestion will increase by 245 percent in the region overall, rising from 3.3 percent of the total time cost of travel to 6.7 percent.

6.2 Crashes

Motor vehicle crashes occur infrequently for most drivers, but a single crash can impose high costs. In aggregate, these crashes impose significant costs. To make matters worse, most of the damage they cause is usually borne by just one or two individuals. While no technology is completely safe, and from a purely economic point of view it would seldom be efficient to make a technology completely safe, the immediate and concentrated costs of crashes will continue to place efforts to reduce these costs high on the public agenda.

Crashes cause a variety of monetary and nonmonetary costs. Their monetary costs include repairing or replacing damaged property, medical treatment for injuries, and the services of emergency response vehicles. Nonmonetary costs include pain and suffering from injuries, loss of life, and time lost due to traffic delays.

In this section, we attempt to quantify all of these costs except the cost of delays, which are included with congestion costs.[130] Crashes also cause some governmental costs, especially the costs to law enforcement and safety, which are analyzed in Section 4.4.1. To avoid double-counting, in this section we calculate crash costs net of these governmental costs.

The nature of crashes has led to two developments that make the costs of crashes (mainly the external costs of crashes) and policies to mitigate crash costs difficult to analyze. First, because of the very high costs that crashes can impose, significant legal restrictions have been imposed on driving. We license drivers, proscribe dangerous maneuvers, and patrol roadways. We fine or, in the most serious cases, imprison drivers who violate traffic laws. The use of civil and criminal penalties to regulate traffic safety has important policy implications. Crashes, unlike congestion or air pollution, probably cannot be regulated solely by imposing fees on users.[131] There are some types of unsafe behavior that society will probably always feel should be considered criminal. To the extent that new policies are designed to improve transportation safety, they will have to coexist with the web of laws governing drivers.

The second development, which also results from the immediate and concentrated nature of crash costs, is that crashes result in risks that individuals will often choose to insure against. The presence of insurance

[130] It would make sense to separate delay costs caused by crashes from other delay costs, but we did not do this because of a lack of data.
[131] Under the right circumstances, low transactions costs, perfect information, etc., economically efficient levels of congestion or pollution will result from the right set of user fees.

markets greatly complicates our analysis of crashes. Insurance markets are heavily regulated, and must operate in an environment with high transactions costs and asymmetric information. One piece of evidence that these markets are very different from the economists ideal, perfectly competitive market is the presence of a great deal of price dispersion, i.e., identical products are often sold at very different prices.[132] Because insurance insulates people to some extent from their actions, some argue that costs of crashes borne by insurance are external.[133]

While the external costs of crashes are difficult to calculate, the total costs of crashes can be calculated in a relatively straightforward fashion. Excellent data exist on the number, location, and severity of crashes. In addition, a number of good studies have been done of the costs of crashes with different levels of severity. After reviewing some of the literature on the costs of crashes, we calculate the total costs of crashes, outline a method of determining the external costs of crashes, and estimate these costs.

6.2.1 Technical Background

The National Highway Traffic Safety Administration (NHTSA) compiles data on crashes and has conducted some studies of the costs of crashes. *Traffic Safety Facts 1997* provides details on many aspects of crashes—the characteristics of the individuals and vehicles involved, summary data by state, and information on crash trends. *The Economic Costs of Motor Vehicle Crashes* compiled data on the tangible (mostly monetary) costs of crashes. Costs are determined for seven types of crashes—those resulting in at least one fatality, those causing one of five levels of injuries (MAIS 1–5), and those resulting only in property damage (PDO). Per person economic costs ranged from $300 for PDO crashes, to $880,000 for crashes that resulted in a fatality. NHTSA estimated the total cost of motor vehicle crashes in 1994 to be $161 billion. Their cost estimates are low, relative to some other estimates, because they do not include most nonmonetary costs of crashes (especially the costs of pain and suffering and people's willingness to pay to avoid risks of death).[134]

The Federal Highway Administration (1991) calculates the full (comprehensive) costs of highway crashes. The full costs of crashes include the nonmonetary costs of crashes, which are mainly pain and suffering from

[132] See, for example, Dahlby and West (1986).
[133] This assumption was made by the FHWA (1997) for their high-end estimate of the costs of highway crashes.
[134] The only non-monetary cost they include is the cost of time lost due to delays resulting from crashes.

crashes and deaths. The FHWA found that the total cost of crashes in the U.S. was $437 billion. This calculation was based on estimated costs for crashes that were fatal, for those that caused property-damage only, and for those resulting in three levels of injury. Per person costs ranged from $1700 for PDO crashes, to $3.1 million for crashes that resulted in a fatality.[135] The report also contains information on who pays the costs of crashes. The Federal Highway Administration (1994) updated these cost estimates.

Miller (1997) analyzed the costs of crashes in the U.S. in 1993 and found that they totaled $368 billion. Miller used the same seven categories for classifying crash severity as NHTSA, but he estimated the full costs of crashes including nonmonetary costs. He describes three types of research that he feels is needed to improve estimates of crash costs. First, better estimates are needed of willingness-to-pay for reducing risks of injuries and deaths. Second, Miller feels better insurance data is needed to determine who pays for crashes. Third, up-to-date medical cost data is needed. Miller notes that this is especially important when medical inflation is high, as it was through the last half of the 1980s.

Miller cites three alternative definitions of external costs.

(i) All costs not borne by vehicle occupants or by insurance. He estimates that these costs are $56 billion.
(ii) All costs not borne by vehicle occupants, i.e., the costs borne by pedestrians and cyclists are external. He estimates that these costs equal $39 billion.
(iii) The costs borne by households that do not own vehicles. These costs are approximately $6 billion because approximately ten percent of households do not own vehicles (and the costs not borne by occupants or insurance is $56 billion).

Miller notes that motor vehicle insurance does not cover all of the costs of crashes. He estimates that 18 percent of costs are covered by insurance and that 65 percent are internal costs paid by drivers. The remaining 17 percent of costs are covered by health insurance, life insurance, workers' compensation, units of government, charities, other travelers through delays, pedestrians, and cyclists.

Gomez-Ibanez (1997) discusses external crash costs. He feels that pain, suffering, and lost productivity from injuries and fatalities are the largest costs of crashes, and that most of these costs are borne by the individuals involved in the crashes. He notes that different studies have alternative methods for computing crash costs. Two of the studies he examines do not

[135] The FHWA finds significantly higher costs for PDO accidents than does NHTSA because they have a higher threshold for classifying a crash as causing injuries.

include pain and suffering as external costs. Litman (1994) considers any costs not reimbursed by insurance companies as external costs. Miller and Moffet (1993) considers grief caused to friends and relatives from crashes to be external costs. Another study includes costs not paid for by insurance, grief caused to friends and relatives, and costs to vehicle occupants who were not at fault. Gomez-Ibanez feels that drivers do not perceive risks correctly, and that this could be considered a type of externality. Aside from this problem, however, he feels that the external costs only result from crashes if there is a non-linear relationship between vehicle volume and crash costs. Such a relationship, if one exists, would have to be determined from empirical studies, and he feels that no reliable studies of this type exist. He says there is some evidence that the average cost of crashes first rises with vehicle volume and then falls.

The Minnesota Department of Public Safety collects data on motor vehicle crashes and publishes an annual report. Minnesota Department of Public Safety (1999a) breaks down crashes by severity and by mode (motorcycle, automobile, truck, train, pedestrian, and bicycle). It also contains data on crash trends. The monetary costs of crashes in Minnesota in 1998 were estimated to be $1.6 billion. Fatal crashes and injury crashes each imposed costs of $600 million, while PDO crashes imposed costs of $400 million.

6.2.2 Total Crash Costs

The Minnesota Department of Transportation maintains a database that contains data on crashes—the Transportation Information System (TIS). This database is particularly useful to us because it breaks down crashes by road types, crash type, severity, and by county. We did not obtain similar data for the three Wisconsin counties in the region, so we scale up our crash estimates to account for the fact that approximately four percent of the region’s population resides in Wisconsin.

To calculate the full costs of crashes in the region we need first to estimate the number of crashes of different levels of severity that will occur in the region in 1998 and 2020. The TIS divides crashes into five levels of severity—property damage only, three levels of injury, and fatal. The levels are defined in Table 6.4.[136] We determined baseline crash levels for the years 1995 and 1996, which were the two most recent years for which we had complete data. Our baseline numbers were lower than the average for the state. The region has a population that is 63 percent of the size of the state’s, but the region had only 35 percent as many fatalities as the state and 46

[136] These levels were defined by the American National Standards Institute and are described in more detail in FHWA (1991), pp 6–8.

percent as many injuries. This probably reflects that the region does not have nearly as many high-speed, undivided highways as the rest of the state. Travel on freeways and low-speed roads in urban areas is relatively safe.

There were two problems in adjusting the raw crash reports to determine crash levels for 1998 and 2020. The first is that not all crashes are reported. While significant underreporting probably does occur, we feel that (i) the problem is probably not as severe in this region as it is in other large urban areas and (ii) underreporting is most significant for crashes resulting in property damage only or in relatively minor injuries. The first point reflects in part the fact that the region has a relatively low share of uninsured motorists, and uninsured motorists are probably unlikely to report incidents. The Minnesota Department of Public Safety estimates that 12 percent of vehicles in the state are uninsured.[137] This seems a plausible number for the 19-county Twin Cities region. The second point means that many of the unreported crashes are minor enough that they would result in very little damage to people or property. It would not be surprising if, for example, unreported property damage only crashes resulted in much lower average costs than those that were reported.

Data are available on crash trends at national and state levels. National Highway Transportation Safety Administration (1999) reports trends for fatalities, injuries and property-damage only crashes from 1988 to 1998. The three-year trend shows that for all types of crashes, both the crash rate per 100 million vehicle-miles traveled (VMT) and the absolute numbers of crashes have been declining. The most dramatic declines occurred over the first half of the decade, however. Fatal crash rates, for example, declined from 2.3 per 100 million VMT in 1988, to 1.7 in 1992 and then dropped to 1.6 in 1997. Rates for injury and property damage only (PDO) crashes also seem to have stabilized nationally over the last five or six years. The rates are now approximately 135 and 265 per 100 million VMT for injury and PDO crashes, respectively.

Crash trends for Minnesota look similar to national trends. Although the state has a significantly lower rate of crashes than the national average (the fatal crash rate in Minnesota was 1.4 from 1991 to 1995 and it was 1.8 nationally), crash rates have declined slowly in recent years.[138] Changes over the last decade may have reflected significant initial progress in reducing alcohol-related crashes and relatively little progress in the last few years. Changes also probably reflect improved safety equipment, especially the introduction of air bags, and higher rates of seat belt use.

[137] See Minnesota Department of Public Safety (1999b).

[138] One difference is that the absolute number of some types of crashes has increased in Minnesota. Compare Minnesota Department of Public Safety (1999a), Table 1.02 and NHTSA (1999).

Overall, we feel that crash rates will continue to decline as new technological innovations are introduced and as public safety initiatives continue, but that these declines will be modest. We predict that the total number of crashes will increase, mostly because we expect a relatively large 42 percent increase in VMT. We expect that the fatal crash rate will decline by 25 percent, injury crashes will decline by 15 percent, and property damage only crashes will decline by 10 percent.

Table 6.4: Crash Severity Levels

Severity Level	Definition
Fatal	An injury that results in an unintentional death within 30 days.
Severe Injury	A non-fatal injury that prevents the injured person from continuing the activities he or she was capable of performing before the injury occurred.
Moderate Injury	An injury, such as abrasions or bleeding, that is evident to the officer at the scene of the crash, but one not normally requiring hospitalization.
Minor Injury	An injury that is reported by a person involved in the crash but for which no cause is immediately evident. Examples include dizziness or nausea.
Property Damage Only	A crash involving only property damage and no injuries.

Table 6.4: Mn/DOT's Transportation Information System classifies crashes by location, type, and by five levels of severity.

We base our estimates of the cost per incident on an update of FHWA (1991) which provides an estimate of the cost per crash for 1997. We feel fairly confident in the FHWA's estimates. Their studies, along with NHTSA's studies have done very thorough jobs of accounting for the various costs associated with incidents of different types. Except for the nonmonetary costs, which NHTSA does not cover, their numbers agree very well. The major area of uncertainty comes from the estimates of willingness-to-pay to avoid risks of death and injury. These costs are important, because they make up more than half of the costs of fatalities and a large fraction of the costs of injuries. While uncertain, enough studies have been done that estimates of the costs of fatalities and injuries have become fairly well established. We feel that the FHWA's numbers accurately reflect current mid-range estimates of these costs.

We make some small adjustments to the FHWA's numbers to avoid double-counting and to make 1998 and 2020 projections. NHTSA (1995) breaks down crash costs into categories, three of which have been accounted for elsewhere in this report—emergency and medical services provided by the government and travel delays. We project that the costs of injuries and fatalities will rise ten percent faster than per capita income. This reflects our assumption that medical costs will rise faster than inflation and that people will continue to value safety at higher and higher rates. We project that the costs of property damage will rise ten percent more slowly than per capita income. This is because we expect that the cost of manufacturing vehicles and parts for vehicles will continue to decline, relative to income. Our mid-range projections of the cost of various incidents are shown in Table 6.6.

Table 6.5: Crash Projections by Type and Severity

	1998 Crashes by Severity Level					
Crash Type	**Fatal**	**Severe**	**Moderate**	**Minor**	**PDO**	**Total**
Single-Vehicle	65	405	1,745	2,075	14,350	18,655
Multi-Vehicle	105	1,135	4,980	10,890	36,975	54,100
Non-Motorist	25	280	825	905	45	2,095
Total	205	1,830	7,555	13,875	51,375	74,850

	2020 Crashes by Severity Level					
Crash Type	**Fatal**	**Severe**	**Moderate**	**Minor**	**PDO**	**Total**
Single-Vehicle	70	490	2,100	2,495	18,285	23,450
Muliti-Vehicle	115	1,365	5,990	13,100	47,115	67,695
Non-Motorist	30	340	990	1,090	55	2,520
Total	220	2,200	9,090	16,690	65,460	93,670

Table 6.5: We project a six percent increase in the number of fatal crashes, a 20 percent increase in the number involving injuries, and a 27 percent increase in crashes that cause only property damage.

We calculate the total cost of crashes from our projections of crash numbers and cost per crash. There are sources of uncertainty in these numbers that are difficult to quantify. One source is the classification of crash severity. The five levels are defined by the American National Standards Institute, but classifying injuries will sometimes be a judgement call. Also, the classification is not made by medical personal, but by a police officer at the scene of the crash. Determining the costs of fatalities is difficult because of the difficulty placing an economic value on the risk of death. Our low-end estimate is that costs are 75 percent of baseline and our high-end estimate is that costs are

150 percent of baseline. The cost per injury is somewhat easier to quantify than the cost per fatality, but reporting is more uncertain. Our low-end estimate is that costs are 75 percent of baseline and our high-end estimate is that costs are 125 percent of baseline. We estimate that property damage only crash costs are within 20 percent of baseline. Our total cost estimates are shown in Table 6.7.

Table 6.6: The Cost per Crash in 1998 and 2020 (1998 dollars)

	1998	2020
Fatal	2,879,220	3,662,580
Severe Injury	199,080	252,180
Moderate Injury	39,760	50,360
Minor Injury	20,080	25,440
Property Damage Only	2,120	2,640

Table 6.6: These numbers show the total cost per crash. Small adjustments are made in these final numbers to account for the fact that some of the costs of crashes are accounted for as governmental costs or as external time costs.

6.2.3 External Crash Costs

We have not been able to find a consensus on a method for determining the external costs of crashes; instead, we find that a variety of approaches have been used to produce a wide range of cost estimates.[139] We do not feel we can resolve all of these differences, but we do feel we can rule out some approaches. The first approach that we reject is to label costs external because drivers may not perceive them correctly. We agree that drivers may fail to assess costs accurately, that this may present problems, and that these problems may justify policy responses. These types of problems do not fit the economic definition of an externality, however. An externality occurs when a driver imposes costs on others, not when he or she imposes costs on himself or herself. Overall, the concern that drivers do not perceive costs correctly seems valid to us, and it shows up for other categories of costs.

[139] See Gomez-Ibanez (1997) for a discussion of a number of these approaches.

Unfortunately, we are not aware of rigorous studies that have quantified these effects, or of policies that would eliminate these effects if they existed.

We also reject the idea that some of the costs covered by insurance should be considered as external costs. Our reasoning is similar to that just used. Insurance markets may be inefficient, but that does not mean that they result in externalities. By definition, operations that take place within markets are not externalities. Insurance markets may mask costs to consumers, but it is not clear how this problem should be solved. We probably would not, for example, want to make each driver involved in a crash pay all of the costs of the crash that he or she could pay because most people would prefer to avoid such a risk. As in the case above, there is ample reason for policy concern, but there is an absence of good data on the problem and on policies that might solve the problem. Simply labeling some of the costs of insurance as external will not provide this data.

We have identified four factors that we feel cause external crash costs. The first occurs if the average cost of crashes per vehicle rises with the number of vehicles. If average costs did rise with the number of vehicles, we would have a situation similar to congestion (with congestion the average *time* cost rises with the number of vehicles). This situation would clearly be an example of an externality. Some studies have been undertaken to answer the question of how crash costs vary with traffic volume, but the relationship appears complicated. Gomez-Ibanez, for example, feels there is evidence that average costs decline at high volumes, presumably because vehicles slow down enough that severe injuries become unlikely. Because this relationship appears weak, we expect that it is responsible for only a small share of external costs and so we ignore them.[140]

[140] Ideally, we would use a model of traffic flows and accident rates, such as was done by Delucchi et al. (1996) or the FHWA (1997).

Table 6.7: The Total Costs of Crashes			
	1998 (millions of dollars)		
	Low	Mid	High
Fatal	440	590	885
Severe Injury	255	340	430
Moderate Injury	210	280	350
Minor Injury	205	275	340
Property Damage Only	80	105	125
Total	1,190	1,590	2,130
	2020 (millions of dollars)		
	Low	Mid	High
Fatal	605	805	1210
Severe Injury	395	525	655
Moderate Injury	320	430	535
Minor Injury	315	415	520
Property Damage Only	130	165	195
Total	1,765	2,340	3,115

Table 6.7: Our midrange estimate is that the cost of all crashes will rise by 47 percent and the cost of fatal crashes will rise by 36 percent.

The second factor that causes external costs occurs if drivers injure pedestrians or bicyclists and do not fully compensate the non-drivers. This seems a clear example of an external cost, but the situation is a little more complicated than it first appears. The problem, from an efficiency point of view, is that we wish drivers and non-drivers to take the right amount of care to insure the safety of themselves and of others. While it may seem counter-intuitive, economic efficiency generally dictates that non-drivers bear some of the costs of crashes. Another complication arises when the non-driver is clearly responsible for the crash.[141] We ignore both of these complications, however, and in the cases in which drivers injure non-drivers, we consider all of the crash costs not covered by insurance to be external. We estimate that insurance usually pays only for the monetary costs of crashes and hence undercompensates victims by approximately 60 percent. Our high-end

141 Suppose, for example, that someone runs onto a busy freeway. The person risks serious injury or death and reducing the number of vehicles substantially will not alter this risk very much. This means there is no efficiency gain in this case from reducing the number of drivers, so the actions of any one driver do not create an externality.

estimate is that drivers undercompensate non-drivers by 70 percent per incident, and our low-end estimate is that drivers undercompensate non-drivers by 50 percent.[142] We assume that all of the costs are imposed on the pedestrian or the bicyclist.

The third situation that results in external costs results when (i) vehicles of different weights collide, (ii) the drivers are both at fault, and (iii) the driver of the safer (heavier) vehicle bears less of the cost of the crashes than the other driver. This situation is similar to the second situation. Pedestrians, bicyclists, and drivers of light vehicles are particularly vulnerable to crashes. The efficient economic policy is to charge users so that they choose the proper types of vehicles. When drivers choose heavy vehicles, they generally reduce their costs from crashes but increase those of other drivers. If both drivers had to split the costs of the crash (because they were both equally at fault), then the incentive to drive heavier vehicles merely to protect against other vehicles would be reduced.

We calculate crash costs in this situation by assuming that drivers bear roughly equal responsibility for crashes in 50 percent of two-vehicle crashes. We also assume that average crash is between one vehicle and another one that is 30 percent heavier and thus imposes approximately 30 percent higher costs on the lighter vehicle.[143] The external costs in this case are 15 percent of the total cost, which is the difference between what the heavy and light vehicles pay for the crash. Our low-end estimate is 10 percent and our high-end estimate is 25 percent.

The fourth situation that we feel results in external costs occurs when there is a multi-vehicle crash in which one driver is at fault and doesn't fully compensate the other driver. This situation is analogous to the case of the person running onto a freeway. One person's actions are imposing costs, and no other individual driver really is, or should be, held responsible. We assume that 15 percent of two-vehicle crashes fall into this situation, and that drivers who are clearly at fault generally have to pay a larger portion of compensation to other drivers. We assume that victims in these crashes are only under-compensated by 30 percent on average, and by 10 percent in our low-end estimate and 50 percent in our high-end estimate. Our estimates of the external costs of crashes are shown in Table 6.8.

[142] Our high-end estimate includes under-compensation because of drivers who are uninsured.
[143] We assume that damage costs are inversely proportional to weight.

Table 6.8: The External Costs of Crashes			
	1998 (millions of 1998 dollars)		
	Low	Mid	High
Multi-Vehicle	64	119	197
Pedestrian or Cyclist	87	104	121
Total	151	223	319
	2020 (millions of 1998 dollars)		
	Low	Mid	High
Multi-Vehicle	96	177	295
Pedestrian or Cyclist	133	159	186
Total	228	336	481

Table 6.8: We estimate that between 10 and 20 percent of the costs of crashes are external.

6.3 Air Pollution

Most of the costs of air pollution that we can quantify probably result from adverse health effects. Air pollution may cause discomfort, disability, and even early death, and may increase the need for a variety of medical services. Air pollution may also reduce visibility, and do harm to crops, forests, wildlife, materials, and the global climate. Except for effects on global climate, these costs are likely to be small relative to effects on human health. The largest costs of air pollution are nonmonetary—those costs resulting from pain, suffering, and death, or from changes to the global climate. The monetary costs include doctor's visits, hospital stays, and medication taken because of the effects of air pollution. They also include damage to crops, materials, and some of the damages to forests.

Air pollution is one of the most politically sensitive externalities associated with autos. Its negative impacts are easier to see and its costs are probably much larger costs than noise. The external costs of crashes and of congestion are of the same order of magnitude as air pollution, but these effects are concentrated among users of the transportation system. Because of this, the externalities associated with crashes and congestion seem to be more difficult for the general public to conceptualize. In addition, the fact that users bear major portions of the external costs of crashes and congestion means that equity is less of an issue.

Perhaps for these reasons—air pollution's effect on non-users and its clear status as an externality—air pollution has been heavily regulated. The U.S. Environmental Protection Agency (EPA) has mandated that vehicles use certain types of emissions control equipment, as well as a variety of other strategies, to reduce air pollution. In some cases state governments (especially California) have imposed stricter regulations than the EPA has.

While air pollution has received a great deal of attention, quantifying the costs of air pollution is difficult. Technical problems make predicting emissions and the dispersion of emissions difficult. Empirical problems make the linkage between emissions and health effects uncertain. In addition, there are problems in determining the valuations that people attach to various health effects of pollution.

In this section we analyze the costs of air pollution resulting from health effects, damage to crops and forests, reduced visibility, damage to materials, and effects on the global climate. Section 6.3.2 covers the costs of the health effects, and Section 6.3.3 covers the costs of the other effects.

6.3.1 Technical Background

A number of studies have examined the costs of air pollution. Many have used the *control-cost method*, which calculates the costs of reducing emissions. Some studies have used the *damage-value method*, which attempts to determine the costs of damage from pollution. Both methods are discussed in Wang and Santini (1995). We use the damage value approach, because we feel that it is the correct way to determine the opportunity costs of pollution.[144]

A relatively small number of studies have examined the costs of air pollution from motor vehicles. Small and Kazimi (1995) estimated the costs of air pollution from motor vehicles for the Los Angeles region. They calculated the health effects from emissions and found that the cost for the average vehicle on the road in 1992 was approximately three cents per vehicle-mile.

We are only aware of two studies that have carefully modeled emissions, dispersion, and health impacts for air pollution in the region. One was a study of power plant emissions, Desvousges et al. (1994). That study analyzed the health damage costs for six types of pollutants—particulate matter (PM), nitrogen oxides without sulfur, nitrogen oxides with sulfur, sulfur dioxide, carbon monoxide (CO), and lead. The estimates of

[144] Only under special circumstances will the control cost method provide a good estimate of the opportunity costs of pollution. This issue is discussed in Appendix C.5.

Desvousges et al. are similar to the estimates obtained by Delucchi et al. (1996), who conducted the other study of the air pollution in the region.

Delucchi et al. (1996) calculated upper and lower bounds on the costs of air pollution from motor vehicles for the Twin Cities region and ten other urban areas in the U.S. He analyzed the production and dispersion of five types of pollutants—PM, CO, nitrous oxides (NO), sulfur oxides (SO), and volatile organic compounds (VOC). Sources analyzed included emissions from gasoline and diesel vehicles, road dust created by vehicles, and emissions caused in the production of vehicles. He estimated the responsibility of these pollutants for a variety of adverse health effects. These included early death, chronic illness, asthma attacks, and a variety of cancers. Values were assigned to each adverse health effect, and costs were calculated.

Delucchi estimated that a 10 percent reduction in emissions in the Twin Cities region in 1990 would have reduced the costs of air pollution by between $35 and $540 million. In his low-end estimates, vehicle emissions caused two-thirds of damages, and the remainder is divided equally between vehicle production and road dust. For the high-end estimates, vehicle emissions cause approximately 60 percent of costs, and almost all of the remaining costs are caused by road dust. Emissions of particulate matter caused over 90 percent of costs in both scenarios. Delucchi concluded that ozone is the least damaging of the pollutants he analyzed, and that CO emissions were at least twice as costly.

Delucchi emphasizes a few points about his estimate of air pollution costs. First, he is uncomfortable with the high-end estimates. These estimates rely on only one study, which finds very high risks to health from PM. Delucchi feels that estimates of the risks of small particles, and especially those 2.5 microns or less, are highly uncertain. A second point is that not enough is known about emissions caused by sources other than motor vehicles. Assumptions about the air pollution caused by other sources have important effects on his cost estimates for motor vehicle-related air pollution. Thirdly, Delucchi's estimates are high compared to other estimates mainly because he includes the costs of chronic illnesses. Other studies have ignored these costs because of a lack of information on the effect of air pollution on such illnesses. A fourth point is that his estimates are from 1990, which is the same year that the Clean Air Act Amendments of 1990 (CAAA) were passed. He felt that this legislation was likely to reduce the costs of air pollution. Finally, Delucchi notes that his work did little to model the effects that different seasons have on the costs of air pollution.

6.3.2 The Health Costs of Air Pollution

We rely on Delucchi for our baseline estimates of the costs of air pollution. He calculates the opportunity costs of air pollution in four steps.

(i) Estimate the emissions from motor vehicles and other sources.
(ii) Determine how motor vehicle emissions will disperse and how they will affect ambient levels of air pollution.
(iii) Determine the health effects of the increases in air pollution levels caused by motor vehicle emissions.
(iv) Calculate the costs of air pollution by assigning values to health effects.

All of these steps involve difficulties. The first two, and to a lesser extent the fourth, require detailed geographic models. The third and fourth rely on empirical estimates that are quite uncertain.[145]

Reproducing first two steps of Delucchi's cost estimation method would be so time-consuming that it's well outside the scope of this project. Fortunately, we feel that Delucchi's study used the best available methods to determine the costs of air pollution. His study was very comprehensive and focused on exactly the costs we want to quantify—the damage costs of air pollution caused by motor vehicles. One factor that gives us additional confidence in Delucchi's estimates is that they match up well with those of Desvousges (1994). The estimates are not strictly comparable because Desvousges' were for a power plant, and one would expect different dispersion patterns. Still, Desvousges' estimates for particulate matter and NO were close to Delucchi's midrange estimates, and his estimates for CO and SO were approximately 10 percent of Delucchi's. The differences for CO and SO are not as large as they seem, especially given that Delucchi's estimates are higher than those of most similar studies and given the uncertainty inherent in such work.

Of the main types of pollution Deluchi examined, he estimated that particulate matter caused the highest health costs—perhaps 90 percent of the total. Delucchi divided emissions into three different sources—emissions from vehicles, road dust, and upstream emissions. Upstream emissions are those emissions that result from any stage in the production of vehicles or from the processing and distribution of fuel for vehicles. Emissions from vehicles were estimated to cause more than half of the costs of air pollution, but road dust may be responsible for almost 40 percent of health costs. Most

[145] We rely on Delucchi's estimates of people's willingness to pay to reduce deaths to assign some of the values of in step (iv). Delucchi used a standard method of determining this value, but recent work suggests he may have over-estimated these values by failing to account for changes in these values over people's lifetimes.

of the costs of pollution resulted from increased mortality as opposed to cancer or morbidity. These results are summarized in Table 6.9.

Delucchi estimates that a 10 percent reduction in motor vehicle related air pollution would have reduced health costs in the Twin Cities region in 1990 by between $35 million and $540 million. This is a wide range, but it is typical of studies of the costs of air pollution. It largely reflects uncertainty about the health impacts of pollution and uncertainty about how to value these impacts. Small and Kazimi (1995) review studies of the value of a statistical life, for example, and find high-end estimates are more than five times the size of low-end estimates. Delucchi says that the costs of air pollution are reasonably linear, but we think it would be surprising if air pollution costs did not rise to some extent with pollution levels. We assume that the value of a 100 percent reduction in air pollution from vehicles in the region would have resulted in reduction in costs 7.5 times as large as a 10 percent reduction. We base our midrange estimate on the geometric mean of the high and low-end estimates. Because Delucchi's high-range estimate is so high, and because he says he does not feel comfortable with it, we discount the high-range estimate by 50 percent when we estimate the mid-range cost. Our 1990 baseline low, mid, and high-costs estimates for the region are $260, $725, and $4035 million dollars, respectively.[146]

We feel there are four main trends affecting the costs of air pollution
(i) improving technology for reducing emissions,
(ii) increases in vehicle-miles of travel,
(iii) increases in population, and
(iv) increases in the values placed on safety and in the costs of medical services, relative to personal income.

We feel we can quantify the last three trends with a fair degree of accuracy, but the first trend is extremely difficult to predict. Since the 1970s, most studies have shown steady improvements in air quality in most urban areas.

The first two trends are probably strong enough to, at least initially, outweigh the last two trends, and reduce the absolute cost of air pollution. Over the last ten years the evidence is not as clear-cut. Air quality seems to be getting worse in some rapidly growing urban areas, but it seems to be improving slightly in many other urban areas.

The uncertainty in predicting improvements in emissions control technology makes projecting Delucchi's cost estimates forward to 1998 and 2020 difficult. Overall, we assume that the costs of air pollution have not changed

[146] Our midrange estimate is very close to an estimate of the region's willingness to pay to reduce toxic air pollution—Welle et al. (1992) estimated that it was $660 million. While it is difficult for us to assess the its significance, we find the similarity of the two results interesting.

between 1990 and 1998. One could plausibly argue that costs have been reduced both because of improvements in vehicle efficiency and because of the Clean Air Act Amendments (CAAA). We discount large effects from the CAAA, because the new standards did not focus on particulate matter, which may account for 90 percent of the costs of air pollution. Other improvements in vehicle efficiency are probably more important—mostly increased use of newer cars that have cleaner burning engines. Still, we don't feel confident that improvements in technology since 1990 have more than compensated for the trends that have tended to increase the costs of pollution.

If the costs of air pollution did not decline between 1990 and 1998, there seems little hope that they will decline between 1998 and 2020. The EPA has projected that by 2005 growth in VMT will outweigh gains from cleaner vehicles, and total emissions of volatile organic compounds will begin to rise.[147] Similar trends may hold for other emissions. The most costly pollution appears to result from particulate matter. Unfortunately, particulate matter (PM) has not received as much attention from researchers as other emissions. Because of this we do not know a great deal about the costs of PM, non-vehicular sources of PM, or the effectiveness of various strategies to reduce PM. Our high-end estimate is that the costs of air pollution will rise by 25 percent, our mid-range estimate is 10 percent, and our low-range estimate is that no change will occur. Table 6.10 summarizes our estimates of the costs of air pollution in the Twin Cities region.

[147] Kessler and Schroeer (1995), page 247.

Table 6.9: Health Costs by Effect and Pollutant

	Percentage of Total Health Cost by Effect								
	Gas Vehicles			Diesel Vehicles			All Vehicles		
	VE	VP	RD	VE	VP	RD	VE	VP	RD
Mortality	30.0	6.0	13.8	13.6	1.9	6.4	45.2	6.2	20.4
Cancer	3.5	1.7	0.0	0.1	0.0	0.0	0.2	0.0	0.0
Chronic Morbidity	4.7	0.3	3.2	4.1	0.1	1.7	12.2	2.1	5.1
Acute Morbidity	4.7	1.8	0.2	0.3	0.0	1.8	6.7	0.1	0.3
Total	44.6	8.1	17.3	19.7	0.3	10.0	62.6	10.1	27.3

	Percentage of Total Health Cost by Pollutant								
	Gas Vehicles			Diesel Vehicles			All Vehicles		
	VE	VP	RD	VE	VP	RD	VE	VP	RD
Particulate Matter	37.8	8.1	17.3	17.9	2.0	10.0	57.3	8.4	27.3
Ozone	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Nitrous Oxides	2.3	0.0	0.0	0.1	0.0	0.0	2.4	0.0	0.0
Carbon Monoxide	2.6	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0
Total	44.6	8.1	17.3	19.7	0.3	10.0	62.6	10.1	27.3

Table 6.9: Health costs of air pollution by health effect and pollutant. Costs are broken down by vehicle emissions (VE), vehicle production (VP), and road dust (RD). The figures are an average of the low-end and high-end estimates from Delucchi (1996, Tables 11.A.19 and 11.A.20).

6.3.3 Non-Health-Related Costs of Air Pollution

Air pollution imposes a variety of non-health-related costs. We quantify five of them here: global warming, crop loss, effects on forests, damage to materials, and loss of visibility. We estimate that all of these costs are relatively small compared to the health-related costs of air pollution, and in total they equal approximately 50 percent of health-related costs. Examining each of these costs would be extremely time-consuming. We base our cost estimates primarily on existing literature.

Global warming is caused by the build-up of certain gases in the atmosphere. The gases are referred to as greenhouse gases because their presence traps heat in the atmosphere. There is widespread agreement among scientists that global warming is occurring. There is much less certainty about how rapidly the climate will change, the effects of these changes, and the cost of these effects. Determining the costs of global warming requires predicting all of these things—changes in the global climate, estimating the worldwide effects of these changes, and placing values on these effects. To put this problem in perspective, predicting changes in the global climate is probably the easiest of these three steps. Estimating the economic impact of global warming is difficult because we need to make assumptions about the long-term adjustments people will make because of global warming. Economic models have only limited ability to model such adjustments. There is probably no other phenomenon that require such large, long-range, and widespread adjustments be modeled, so we have no way of knowing how good the economic models of the costs of global warming are.[148]

We base our estimates of costs for global warming on Tol (1999). He examines the literature on global warming and finds most cost estimates to be between $5 and $25 per ton of carbon. Tol calculates the costs to be between $9 and $23 per ton. These estimates contain significant uncertainty and also neglect some of costs of global warming that are difficult to quantify. Because of this we use $5 per ton as our low estimate and $30 per ton as our high estimate. We use Hagler Bailly, Inc. (1997) to determine the amount of carbon that the region emits into the atmosphere. Our midrange estimate is that the costs of global warming will rise from $98 million in 1998 to $137 million in 2020. We predict that the rise is entirely due to an increase in fuel consumption, which we predict will rise with VMT. Note that these estimates are of the costs that transportation in the region imposes worldwide, and almost all of these costs are imposed outside the region.

We base our estimates of four other costs of air pollution on Delucchi. These costs result from losses in visibility and damage to crops, forests, and materials. Delucchi's studies of the costs of visibility and crop losses were particularly thorough. People's willingness to pay for improved visibility was estimated from a statistical analysis of a large number of studies. We assume that Delucchi's low-range visibility estimate is accurate. We think his high-range estimate is too high for this region because this area has relatively good visibility in winter and, in summer, visibility is often impaired by the weather. We use a high-range value for visibility that is one-third of Delucchi's.

We feel that Delucchi's estimates of effects of air pollution on crops and forests may be too low because this region is surrounded by large tracts of

[148] Working on studies of a similar scope are those researchers who are trying to quantify the control cost of global warming (i.e., the cost of reducing carbon-dioxide emissions). See, for example, Weyant (1993). While such work is important for policy evaluation, e.g., to determine the costs of complying with the Kyoto Protocol, it does not provide a measure of the opportunity costs of global warming.

farmland and forests. We use his low-end estimate as is but adjust his high-range estimate upward by 50 percent. We use Delucchi's estimates of the costs of damages to materials as is. It is plausible that these costs are low, relative to the national average, in this region because we have relatively new infrastructure and because we have a fairly harsh winter climate. Having a relatively harsh climate would probably reduce the costs of damage to materials from air pollution because it means materials may need to be replaced quickly regardless of the effects of pollution. We do not know enough about these effects to feel confident that we should adjust Delucchi's figures, however.[149]

In addition to the adjustments made above, we adjust Delucchi's national numbers for visibility and damage to crops, forests, and materials by assuming that this region experiences these costs on the same per capita basis as the rest of the country does. Our mid-range estimates are the geometric mean of our low and high-end estimates. Our low-end projection for the costs of air pollution's effects on crops, forests, and materials are that they will not rise. This reflects an assumption that falling commodity prices and improved emissions control technology will partially offset increased emissions. Our high-end projections are that the costs will rise with vehicle-miles traveled. This reflects assumptions that pollution control technology will not improve and that the value of commodities will be essentially constant. Our low-end projection for visibility is that costs will not rise because of improving technology. Our high-end projection is that costs will rise with VMT and with per capita income.

The costs of air pollution are summarized in Table 6.10. Overall, we estimate that the costs of air pollution will rise by 16 percent, and the non-health related costs of air pollution will rise by 32 percent. This increase in costs is driven largely by our estimate that the costs of global warming will rise by 42 percent (because we assume that there will be a 42 percent increase in VMT and that fuel economy will not improve). We project that the costs of most other types of air pollution will grow less rapidly because of improving technology.

[149] It might be that sunnier climates do more damage to materials, or it might be that cold winters somehow interact with air pollution to cause additional damage to materials.

Table 6.10: The Cost of Air Pollution						
	1998			2020		
	Low	Mid	High	Low	Mid	High
Health	261	725	4,033	261	798	5,042
Global Warming	31	98	183	43	137	260
Visibility	64	100	154	64	132	272
Crops	21	40	74	21	47	105
Materials	5	23	101	5	27	144
Forests	4	12	38	4	14	54
Total	386	997	4,583	398	1,155	5,876

Table 6.10: Air pollution imposes a wide variety of costs. Technological progress probably brought declines in the costs of air pollution in the 1970s and 1980s, but our mid-range estimate is that costs will increase by 16 percent between 1998 and 2020.

6.4 Noise

Transportation is responsible for a significant amount of noise. Much of this noise comes from engines, exhaust systems, and tire friction. There are methods of mitigating the costs of noise by constructing noise barriers or adding insulation to housing units, for example, but the ability to reduce the noise produced by vehicles seems more limited. Engines with proper exhaust can be (and usually are) made to run quietly. Tires, however, can produce a great deal of noise in the normal course of operation, and there does not appear to be any easy technological solution to this problem (although some types of pavements and tires can reduce noise levels). Noise from tires is especially significant on high-speed roads.

Most of the effects of noise are subjective and cause temporary discomfort instead of permanent harm, but the sum total of this discomfort is a cost to society. The subjective nature of noise costs, depending as they do on the state of mind of the individuals and the activities the individuals are engaged in, makes estimates of noise costs quite uncertain.

The standard method for estimating noise costs is to infer these costs from effects on housing values. This is in contrast to methods of estimating most other nonmonetary costs such as time, air pollution, or crashes. In those cases, estimates were made of the costs of effects on individuals. Noise costs are estimated from effects on property values both because of the subjective nature of noise costs and because of the fact that noise costs change rapidly with distance from noise sources.

We treat the noise produced by vehicles as a cost that is entirely external. Drivers, of course, may experience uncomfortably high levels of noise because they are so close to the noise sources. We include these costs with the time costs of travel for a technical reason. No studies of which we are aware, separate the noise costs imposed on drivers from the other time costs that drivers experience.[150]

As was the case with air pollution, we use the *damage-value*, as opposed to the *control cost*, method for determining the costs of noise. This means that we determine the costs that noise actually imposes instead of the cost of controlling noise. Given the goal of this report, which is to determine the full economic (opportunity) cost of travel, we feel that using the damage value method is the correct way to calculate costs.[151] Unfortunately, the actual cost of the damages from noise can only be determined with a significant amount of uncertainty.

One important note concerning the opportunity costs of noise is that they are independent of legal considerations. Specifically, costs do not depend on whether roads are in compliance with state and federal noise regulations. We do find that noise causes damages. This does *not* mean that existing noise regulations are not beneficial or that they are inadequate or that the region is not in compliance with the regulations. It merely reflects the common sense observation that noise may impose some costs even when it is produced in compliance with legal requirements. Indeed, we believe that the roads in this region are largely in compliance with noise regulations. The questions of whether the regulations are beneficial, and of whether they could be improved, are outside the scope of this report. It should be noted that the optimal (i.e., efficiency maximizing) regulation of an externality does *not* usually require that the externality be eliminated. The optimal regulation will balance the costs of the externality against the benefits brought by producing the externality. The question of whether any given type of externality should be eliminated, or merely reduced, is an empirical one.

Most of the following work focuses on the cost of noise in the urban parts of the Twin Cities region. Approximately 15 percent of the people in the 19-county region live in rural areas, and it is not clear that noise costs in these

[150] In other words, the studies do not determine the value of time to drivers under the current, noisy conditions, and then determine what the value of time would have been if the drivers had experienced no noise. This problem also arises for air pollution and, perhaps, for some crash costs.
[151] See Appendix C.5 for a fuller discussion of this issue.

areas are small. Due to a lack of data, however, we simply assume that rural residents in the region experience noise at the level of the regional average.

Vibrations cause costs that are related to noise costs. We assume that the costs of noise in this region are very low, essentially zero. There are three reasons: (i) the costs seem to be quite low nationally, (ii) the costs are probably confined to a few older cities with dense truck traffic, and (iii) vibrations at the level usually experienced in this region are probably at least partially accounted for in the costs of noise.

6.4.1 Technical Background

Miller and Moffet (1993) reviews the literature on the costs of noise. They found only a few studies that quantify the costs of road noise, and from these studies, they estimated that the total cost of noise in the U.S. in 1993 was between $2.7 and $4.4 billion ($14 and $23 per vehicle). They feel that the relationship between noise level and housing value may be nonlinear. They also discuss the noise costs associated with bus and rail transportation and conclude that the average bus is about twice as loud as the average car and that rail noise varies considerably with the type of system.

Federal Highway Administration (1997) estimated the cost of noise on U.S. highways for the year 2000. The study used a three-step method to calculate the costs of noise.

1. Model noise production and attenuation to determine noise levels near existing roads.
2. Gather data on development patterns in areas affected by traffic noise.
3. Use studies of the relationship between noise levels and property values to determine the cost of noise.

The Federal Highway Administration (FHWA) developed the Traffic Noise Model[152] (TNM) to model noise production and attenuation. Estimates of noise production depend on factors such as traffic levels, vehicle types and speeds, and rates of acceleration and deceleration. Noise attenuation is affected by the presence of noise barriers and ground cover. The FHWA's low-end estimate of annual noise costs was $1.2 billion; its midrange estimate was $4.3 billion and its high-end estimate was $11.4 billion ($5, $20, and $53 per vehicle, respectively).

Delucchi et al. (1996) estimated the cost of noise on all U.S. roads for the year 1990. He used the same three-step method to calculate costs and also used the TNM. His low estimate was $0.1 billion per year ($0.20 per vehicle)

[152] This model was previously known as STAMINA.

and his high estimate was $48 billion ($250 per vehicle), but he felt that the cost was not likely to exceed $6 billion ($25 per vehicle). Delucchi estimated that between 69 and 80 percent of all noise costs were associated with highway travel (the remaining costs resulted from travel on arterials, collectors, and local roads).

Delucchi felt that there were four main sources of uncertainty in his cost estimates and made four recommendations for reducing this uncertainty.

1. Collect primary data for each study area on vehicle speeds, housing density, and housing value.
2. Account more carefully for noise attenuation with improved data on ground cover and the subtending angle.[153]
3. Use econometric analyses to improve estimates of the relationship between noise level and housing value, explicitly considering the possibility that the relationship is nonlinear.
4. Include the presence of non-vehicular noise sources in the model.

6.4.2 Estimating Noise Costs

We feel that the three-step method used by Delucchi and the FHWA is the most accurate way to determine noise costs. An alternative method would be to try to determine the effects on individuals, from stated preference data, instead of through effects on housing values. This method, however, would probably produce very uncertain estimates because stated preference data is hard to interpret, and there is currently a lack of stated preference data on the costs of noise.

Our model, and much of the data we use to calculate noise costs, comes from Delucchi et al. (1996). We feel that we have the ability to improve significantly on Delucchi's work because we are focussing on just one metropolitan area. We have detailed data on the Twin Cities that Delucchi was not able to assemble—data on the region's geography, road network, traffic, housing stock, and ground cover. Because of the scope of this study, however, our ability to improve on Delucchi's work must go largely unrealized for now.

We estimate that the cost of noise, *C*, from the following formula.[154]

$$C = NI \cdot HV \cdot (AD \cdot AV) \cdot (T_0 \cdot AF)$$

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[153] The subtending angle is a factor used to account for obstructions between houses and noise sources. Obstructions include hills, trees, and other houses.

[154] A slightly more general version of this formula is presented in Appendix D.5.

where

NI	represents noise impacts (the number of square miles of excess decibels[155] of transportation-related noise),
HV	is the percentage loss in housing value per excess decibel,
AD	is the average density of housing units per square mile,
AV	is the average value of housing per square mile,
T_0	scales costs upward to account for the portion of noise that is experienced away from home, and
AF	is the annualization factor, which adjusts one-time changes in home values to determine costs for one year.

We obtain our estimate of noise impacts, NI, from Delucchi's study of transportation costs in the Twin Cities region. Noise impacts are measured as the number of square miles of "excess decibels" (excess decibels are defined to be decibels above some threshold value). Delucchi used the Traffic Noise Model (TNM) to estimate noise impacts. He made some simplifying assumptions when running the model, in particular, he assumed that roads are smooth, that there was no noise from horns or sirens, and that there was no wind. We have not rerun the TNM for this study, but we have used Delucchi's work to predict noise impacts for 1998 and 2020 and to quantify some of the uncertainty in the noise impact estimates. This work is described in Appendix D.7. Our midrange estimates of noise impacts are shown in Table 6.11.

The percent loss in housing value per excess decibel, HV, is determined from studies of the effects of noise on property values. An underlying assumption of our model is that this value depends only on excess decibels. This is unrealistic; it seems obvious that at some level, noise will become increasingly costly. This assumption is not unique to our work and was also cited as problematic by Miller and Moffet (1993) and Delucchi et al. (1996). In the absence of new empirical work on the way HV varies with excess decibels, however, the best we can do is use a constant value. We use between 0.2 and 1.5 percent (i.e., each excess decibel lowers the value of a home by between 0.2 and 1.5 percent). This is a wide range that reflects the lack of a consensus in the literature on the proper value to use. It also reflects our assumption that this region probably has higher than normal values for HV. We make this assumption because of what we see as a limitation of existing studies—they do not adjust for a region's average housing value. The reason this is important is that the costs of noise result from effects on individuals and not on property. If property speculation doubled the price of all Twin Cities real estate tomorrow, the costs of noise would not change, but

155 Excess decibels are decibels above some threshold value. Noise levels below this threshold are not assumed to impose any costs. The costs of noise are very sensitive to the threshold. Our assumptions about the threshold are discussed in Appendix D.5.

our model would say they have. Because this region has relatively low housing prices, we feel that studies, most of which have been conducted in areas with higher average housing values, will underestimate the costs of noise here.

Average housing density and average house value, AD and AV, are found from census data. We assume, quite unrealistically, that these values are constant across the region. We obtained the scaling factor T_0 from Delucchi, who based it on an estimate of waking time spent away from home. The annualization factor is based on the discount rate, and it represents the equivalent yearly loss of a one-time decline in housing value.

The first parameter is based on Delucchi's work. He examined the time the average person in California spent at a variety of locations. Then he calculated the ratio of the total time spent in all locations that are affected by noise from motor vehicles to the total time spent at home. We adjust his estimates downwards, because we ignore noise cost people incur while in transit.[156] The annualization factor was based on a real interest rate of between four and seven percent and an average lifetime for a house of between 30 and 40 years. The percentage loss in housing value for each decibel of noise impact, HV, was inferred from a review of the literature. The average density and average value of housing were found from census data. Our high and low-range estimates for these parameters are shown in Table 6.11.

We estimate that the costs of noise in 1998 are between \$5 million and \$29 million, and our mid-range estimate is \$16 million. We predict that costs will rise to between \$8 million and \$45 million in 2020 with a mid-range estimate of \$25 million. The midrange cost estimates are not large compared to some of the other external costs of travel. Averaged across the entire region, the costs seem small (perhaps \$10 per person per year), but they are much larger for people who live near roads and especially those who live near freeways. A rough calculation is that most noise impacts fall on households within 100 yards of a freeway. Given that the region has approximately 250 center-line miles of freeway, this means that most noise impacts fall on roughly 32,000 households. The average cost for these households in 1998 was approximately \$400 per year.

[156] We think this might result in double-counting, given the methods by which travel time values are calculated. See the discussion in Appendix A.4.

Table 6.11: Noise Impacts in the Twin Cities Region

	Square Miles of "Excess Decibels" in 1998			
	Interstate	Other Freeways	Principal Arterials	Minor Arterials
No Barrier	181.3	91.5	14.3	13.8
Low Barrier	1.7	0.4	0.0	0.0
Med. Barrier	0.6	0.1	0.0	0.0
High Barrier	0.1	0.0	0.0	0.0
Total	183.7	92.0	14.3	13.8
	Square Miles of "Excess Decibels" in 2020			
	Interstate	Other Freeways	Principal Arterials	Minor Arterials
No Barrier	236.0	119.1	18.6	18.0
Low Barrier	2.2	0.6	0.0	0.0
Med. Barrier	0.8	0.2	0.0	0.0
High Barrier	0.2	0.0	0.0	0.0
Total	239.1	119.8	18.6	18.0

Table 6.11: Our midrange estimate is that noise impacts on housing will grow 30 percent from 1998 to 2020 in the Twin Cities MSA. Over 90 percent of noise impacts are caused by freeway traffic.

Significant uncertainty results because of scientific questions about the propagation of noise and because of difficulties in valuing noise impacts. Our projection for 2020 is that the costs of noise will rise moderately, mostly because of increases in VMT and housing density. We do not expect that there will be much technological progress that will reduce noise costs. The ability to reduce the noise that is produced from tires may be limited; improvements in our ability to reduce impacts through soundproofing may be more likely. Some gains may also be made if new engine technologies reduce the costs of faulty mufflers.

Table 6.12: Noise Model Parameters		
	Estimates	
Parameter	Lower	Upper
Aggregate noise impact, *NI* (1998)	156	517
Aggregate noise impact, *NI* (2020)	200	684
Ratio of time affected by noise to time at home, T_0	1.25	1.35
Annualization factor, *AF*	0.05	0.08
Percent loss in housing value per excess decibel, *HV*	0.2	1.5
Average units of housing per acre, *AD* (1998)	1.15	1.45
Average units of housing per acre, *AD* (2020)	1.25	1.75
Average value of each housing unit, *AV* (1998)	$110,600	$110,600
Average value of each housing unit, *AV* (2020)	$137,600	$137,600

Table 6.12: Key parameters used in the model of the costs of noise. The noise impact parameter was obtained from a Monte Carlo simulation described in Appendix D.5. It has units of square miles of excess decibels.

6.5 Petroleum Consumption, Fires, and Robberies

This section covers three external costs of transportation—the costs of petroleum consumption, fires, and robberies. The externalities associated with petroleum consumption may be large, but mitigating these costs would mainly need to be done at the national level. Fires and robberies are relatively small costs of transportation, but they may be responsive to policies at a local level.

6.5.1 Petroleum Consumption

We discuss two impacts of petroleum consumption in this section. The first is the “cost” of higher import prices that the U.S. pays because it does not act as a monopsonistic buyer of oil. In theory, the U.S. could, because it is such a large consumer of oil, reduce the cost of oil by purchasing less of it. This is not really a cost, it is a transfer from the U.S. to oil-producing countries, but we include it here to give policymakers as much information as possible about our transportation options. The second cost is the cost of expected losses to GDP due to oil price fluctuations. The idea behind this cost is that higher petroleum consumption makes us more vulnerable to oil price fluctuations, and these fluctuations will impose a cost by lowering GDP.

The cost of higher import prices was estimated to be between $25 and $30 billion per year for the U.S. by the Office of Technology Assessment (1994) and between $5 and $10 billion by Delucchi. We feel more confident of Delucchi's conservative estimates. One reason is that it is not clear how easy it would be for the U.S. to set up and enforce a policy to restrict oil supplies, and how good a job it would be able to do of reducing the price of oil. We estimate that this cost will rise with the region's personal income. While there is the possibility that costs may rise much faster if oil markets get tighter and prices rise significantly or get more volatile, there is also the possibility that new markets and technologies will keep fuel prices relatively flat as they have been since the late 1970s.

Losses to GDP due to oil price fluctuations are difficult to predict. The evidence seems to be that oil price shocks in the 1970s led to recessions, which significantly reduced U.S. output. Some economists, however, argue that the recessions were more a result of government policy than of the oil price shocks themselves.[157] The Congressional Research Service estimated that U.S. costs were between $7 and $10 billion and Delucchi estimated that they were between $2 billion and $35 billion. Delucchi's range of estimates reflects the great uncertainty involved in computing these costs. We see no way of resolving this uncertainty, but we reduce the range of his estimates by two-thirds. This is because our goal is not to provide, as Delucchi did, upper and lower bounds, but a range in which it seems quite likely that costs will fall. We base our projections on the same growth rates as we did for the costs of not acting as a monopsonist. We estimate the region's share of U.S. petroleum consumption costs based on the region's share of fuel consumption. Our cost estimates are shown in Table 6.13.

6.5.2 Vehicle Fires

The external costs quantified here are the costs of fires that (i) are not borne by the owner of the vehicle that causes the fire (or by the owner's insurance) and (ii) that do not result from crashes. The first type of cost is an internal cost, and the second type is accounted for with the costs of crashes. The costs include damage to buildings and injuries to individuals for which the victims are not compensated. Fires are relatively rare—less than one percent

[157] For a short discussion of this issue, see Office of Technology Assessment (1994, p 126–28).

of crashes result in fires—and fires not related to crashes even less common.[158]

Delucchi et al. (1996) made a careful estimate of the cost of these fires. His estimates included both damage to property and injuries to people. His estimates were based on data on the number of fires caused by motor vehicles, and standard estimates of the cost of various injuries or damage. We feel Delucchi's estimates are quite accurate, and we can think of no reason why this region would not be fairly representative of the nation in the cost per capita of fires. We guess that the costs of fires will rise more slowly than the growth in the number of vehicles because we expect that vehicles will continue to become safer. We assume that the costs will grow at 0.7 percent per year, which is one-half the rate at which we project the number of vehicles will grow. Our midrange estimate is that these costs were $2 million in 1998 and will rise to $2.4 million in 2020.

6.5.3 Robberies

The costs of robberies includes such items as replacing stolen merchandise, repairing damage to vehicles due to robberies, and the costs of injuries to victims of robberies. Calculating these costs correctly means calculating them net of substitute crimes.[159] The costs quantified in this section do not include the costs of police protection, or of judicial services or incarceration because these costs were accounted for with the governmental costs of transportation. It should be noted that these are costs that are imposed on the people who use the transportation system, and they are not, as are all of the other external costs covered here, costs that users of the system impose on society.

The classification of these costs as external is somewhat controversial. Some would argue that these are costs, not of transportation, but of delinquent behavior. We take an empirical view. *If* autos are particularly vulnerable to robbery, then widespread use of autos will lead to higher crime costs. If autos are not particularly vulnerable, then less auto use will not reduce these costs because criminals will just commit other types of robberies.

Delucchi has again made a careful estimate of these costs. We feel his numbers provide good estimates of national costs, but we are not sure that this region is typical of the nation as a whole. Minnesota spends, on a per capita basis, only about 70 percent of what the nation spends on justice

[158] NHTSA (1998).
[159] They should also be calculated net of gains to criminals because gains to criminals are merely transfers.

(police, corrections, and legal and judicial services).[160] Our low-end estimate is that the region spends 70 percent of the national average on a per capita basis. Our high-end estimate is that the region spends 100 percent of the national average. The reasoning in this case is that the region may be more similar to the rest of the nation in the costs of motor vehicle-related crimes, than it is for justice as a whole. Overall differences in the costs of justice may be driven more by differences in the way more serious crimes are treated.

It is difficult to predict how the costs of crime will change over time. Crime rates rose rapidly in the 1980s but have fallen significantly in the 1990s. Technological advances will probably help protect vehicle owners, but they could help criminals, too. Because of the falling crime rate in the 1990s, we guess that crime costs did not rise between 1990 and 1998. Overall we estimate that after 1998, the costs of crimes will rise with the number of vehicles, at a rate of 1.3 percent a year. Our midrange estimate is that these costs will rise from $22 million in 1998 to $30 million in 2020.

Table 6.13: The Cost of Four Smaller Transportation-Related Externalities

(Millions of 1998 Dollars)

	1998			2020		
	Low	Medium	High	Low	Medium	High
High import prices*	60	90	135	90	135	205
Oil price fluctuations	95	205	440	145	310	665
Vehicle Fires	0	2	4	0	2	5
Robberies	11	22	43	15	30	58

Table 6.13: We estimate that the costs of robberies and fires are very low, but that the cost of petroleum consumption was almost $300 million in 1998 and could rise by 80 percent between 1998 and 2020.

6.6 External Costs Not Quantified

Our goal in this report has been to account for all of the costs of transportation, even if they are difficult to measure. There are some costs, however, which we are have not been able to quantify. We divide these costs into four broad categories: effects on natural habitat, the effects of land and

[160] Lindgren (1997).

* These are not opportunity costs; they are transfers from the U.S. to oil exporting nations.

water pollution, effects on neighborhoods, and equity. Only a handful of studies have attempted to quantify these costs and, for the most part, these studies take an ad hoc approach. We do not use these cost estimates because we do not feel they are accurate enough to be helpful. An additional reason we do not attempt to quantify some of these costs is that we are not experts on them, and we do not wish to apply results in a simplistic or misleading fashion. We are not pessimistic about the ability to obtain useful cost estimates for many of the goods discussed in this section, and indeed, we feel that further studies of many of them would be valuable.

Two objections are often raised to trying to place values on the goods we discuss in this section. The first is that there is no way to accurately determine values for such nebulous goods as equity or esthetics. We feel there is a valid economic way of defining the costs of these good, but agree that estimates are not useful unless they can be made with a reasonable degree of accuracy. We define the value of a good as peoples' willingness to pay for the good. Significant progress has been made in recent years in valuing such goods as wetland preservation, a healthy Baltic Sea, or biodiversity.[161] The key is that studies are designed carefully, and that the uncertainty in the work is understood. We do agree that we would probably be better off relying on judgement, or tradition, or whatever method is currently used to make decisions, than we would be relying on highly inaccurate cost estimates. For this reason, we do not quantify costs that we do not feel are reasonably accurate, or on which we cannot at least place reasonable bounds on their accuracy.

A second objection to trying to measure the values of goods such as saving a natural habitat or reducing the risk of a death is that these goods should be preserved at all costs, and we should not trade them off against economic resources. While we feel there are situations where we can and should preserve certain goods regardless of any measure of the economic value of the good, often tradeoffs must be made. Money that could be spent to improve highway safety, thereby saving lives, could be spent on medical research where it would also save lives. More development in one area usually means less development in another area. When data on people's willingness to pay for various goods and amenities is available, it usually should be an important factor in shaping policies that affect those goods.

Effects on Natural Habitat

In this category we include the costs of transportation-related impacts on natural habitat. This could include such things as roads reducing the health of

[161] See Gren et al. (1994), Soderqvist, T. (1998), and Hanley et al. (1995), respectively.

ecosystems by acting as barriers and preventing migration; vehicles harming wildlife; or air pollution from vehicles damaging trees. We are not biologists and our knowledge of these impacts is limited, but it seems clear that transportation has important effects on the natural environment and that people value preserving the natural environment.

Measuring the effects of transportation on the environment is a daunting task, and placing values on these effects even more so, but we feel that useful studies have been conducted. We have not tried to apply such studies to this region, however. Part of the reason is that studies of values for other regions are not easy to adapt to this region because of the tremendous variety of natural systems. The value that visitors to Lake Tahoe place on the environment there may not tell us much about the values the residents of Minnesota place on Lake Mille Lacs. Given our lack of experience in assessing such studies, we do not try to apply them to this region.

Land and Water Pollution

In addition to air pollution, transportation also causes land and water pollution. Most of the pollution of land is probably caused by the disposal of tires and vehicles. Water pollution can be caused by oil spills, leaking fuel storage tanks, and runoff from roads. These effects result in at least two types of costs—those stemming from effects on health and those stemming from effects on the environment. Measuring effects on health is difficult; health effects are generally more difficult to tie to land or water pollution than to air pollution.

We feel that quantifying the costs of water pollution is a particularly important problem in this region because of the presence of so many lakes, streams, and wetlands. Delucchi et al. (1996) discusses a number of studies of the costs of water pollution, but (i) the costs are small, perhaps only $5 or $10 per person in the U.S., and (ii) he does not feel his estimates of these costs are based on particularly accurate research. This regions' water resources seem unique enough that we feel that studies of other areas will not be particularly applicable. We suspect that the cost of water pollution may be high in this region compared to the national average (mainly because of the number of wetlands and the need for a great deal of road deicing in winter), but we do not have ways of assessing this assumption.

Effects on Neighborhoods

This is a broad category that includes a variety of ways that transportation negatively impacts neighborhoods. It includes (i) esthetics, the tendency of some types of suburban development to be widely perceived as unattractive, (ii) damage to historic sites, the effects that road construction or emissions have on historic buildings, and (iii) the social costs of roads when they act as barriers. It is perhaps not surprising that these costs are difficult to quantify. Delucchi did not attempt to quantify these costs in his study. Litman (1994) discusses esthetics and barrier effects, but says he is really only able to make educated guesses about the size of these costs.

These costs are perhaps best studied at a regional level, and not at a national level as Delucchi and Litman tried to do. We would like to know more about all of these costs, but we have not been able to examine any of them in detail. There seems to be a consensus that certain types of development associated with roads is unattractive, but we feel that sometimes the case is overstated. There are many parts of cities that are not attractive, and new development may become more attractive as architects learn to design for the auto and as society becomes richer and replaces cheap or shoddy structures that were built in earlier waves of suburban development with more attractive buildings. Damage to historic sites might best be analyzed on a case-by-case basis. The costs of roads when they act as barriers seem possible to assess. Hopefully parts of the Transportation and Regional Growth Study that deal with designing corridors will help in assessing and in designing roads that mitigate some of these costs.

Equity

Obviously equity is an important issue, and in principle values can be associated with equity, but such estimates are seldom made. Litman (1994) attempts to estimate the costs of inequity caused by our transportation system, but we feel his assumptions, both about the amount of inequity caused by transportation and society's demand for equity, are somewhat arbitrary. We have not been able to find any information that would allow us to improve upon Litman's estimates, however. Because of this, and because of some more technical issues, [162] we do not attempt to put a value on equity.

We do discuss equity in some more detail in Appendix C.1. The main point of that discussion is that, while our transportation system may increase or decrease the amount of equity, it is not generally a good idea to try to use the transportation system itself to reduce inequity. It would usually be a better idea, for example, to provide poor people with money that they could spend to meet a variety of their needs, including their transportation needs, than to try to subsidize transportation for poor people. While we do not assign a cost to equity, we will gather a great deal of information to help policymakers

[162] One complicating factor is that subsidies to transit may increase efficiency by making possible for people without autos to get better jobs. Another is that some transit subsidies are probably intended to reduce inequity, and we do not want to count this cost twice

assess the effects of transportation on equity in the next part of this study, which deals with cost incidence.

6.7 Summary of External Costs

The external costs of transportation are summarized in Table 6.14. Our 1998 estimate is that the health costs of air pollution are the largest external cost of transportation. The external costs of congestion, crashes, petroleum consumption, and other air pollution (most of which result from global warming and reduced visibility) are of roughly equal size, and account for nearly all of the remaining costs. The costs of noise are small relative to other external costs, but they are also concentrated with most of their costs affecting the relatively small portion of people who live near freeways.

We project some significant changes for 2020. We expect the costs of air pollution and petroleum consumption to rise modestly, the costs of crashes to rise by almost 50 percent, and the costs of congestion to more than triple. The increase in congestion costs reflects a 15-year trend of steadily rising congestion. The increases in the costs of crashes reflect expected increases in the amount of travel, in the value people place on safety, and in medical costs. The modest increases in the costs of air pollution are based on our expectation that improvements in emissions-control technology will mostly offset increases in population and vehicle-miles traveled.

Our estimates of the external costs of transportation are significantly more uncertain than our estimates of the governmental and internal costs of transportation. The costs of air pollution are particularly uncertain because of uncertainty about the health effects of air pollution. In addition, because of the complicated nature of the models of the costs of air pollution, we had to rely almost wholly on Delucchi’s estimates.

There are a number of costs, e.g., effects on neighborhoods and water pollution, that we did not quantify. There is not much information on these costs. In some cases there are studies of these costs for other areas, but we do not feel that their results would apply well to this region.

Table 6.14: Summary of the External Costs of Transportation						
	Total Spending in Millions of Dollars					
	1998			2020		
Cost Items	Low	Mid	High	Low	Mid	High
Congestion	165	330	525	565	1,145	1,860
Crashes	150	225	320	230	335	480
Air Pollution (Health)	260	725	4,035	260	800	5,040
Air Pollution (Other)	125	275	550	135	355	835
Noise	5	16	29	8	25	45
Fires and Robberies	11	24	47	15	32	62
Petroleum Consumption*	155	295	575	235	355	870
Total	870	1,890	6,080	1,450	3,050	9,190
	1998			2020		
Measures of Full Cost	Low	Mid	High	Low	Mid	High
Cost Per Capita	$285	$620	$2,000	$390	$820	$2,480
Cost Per Vehicle	$325	$705	$2,265	$415	$865	$2,615
Cost as a Share of Income	0.9%	2.1%	6.6%	1.1%	2.2%	6.7%
Cost per Vehicle-Mile	3.4¢	7.3¢	23.5¢	4.0¢	8.3¢	25.1¢

Table 6.14: Our midrange projections are that the external costs of travel will rise by almost 70 percent, driven largely by increases in congestion.

* Approximately one third of the figures for petroleum consumption represent transfers from the U.S. to oil producing nations and not opportunity costs.

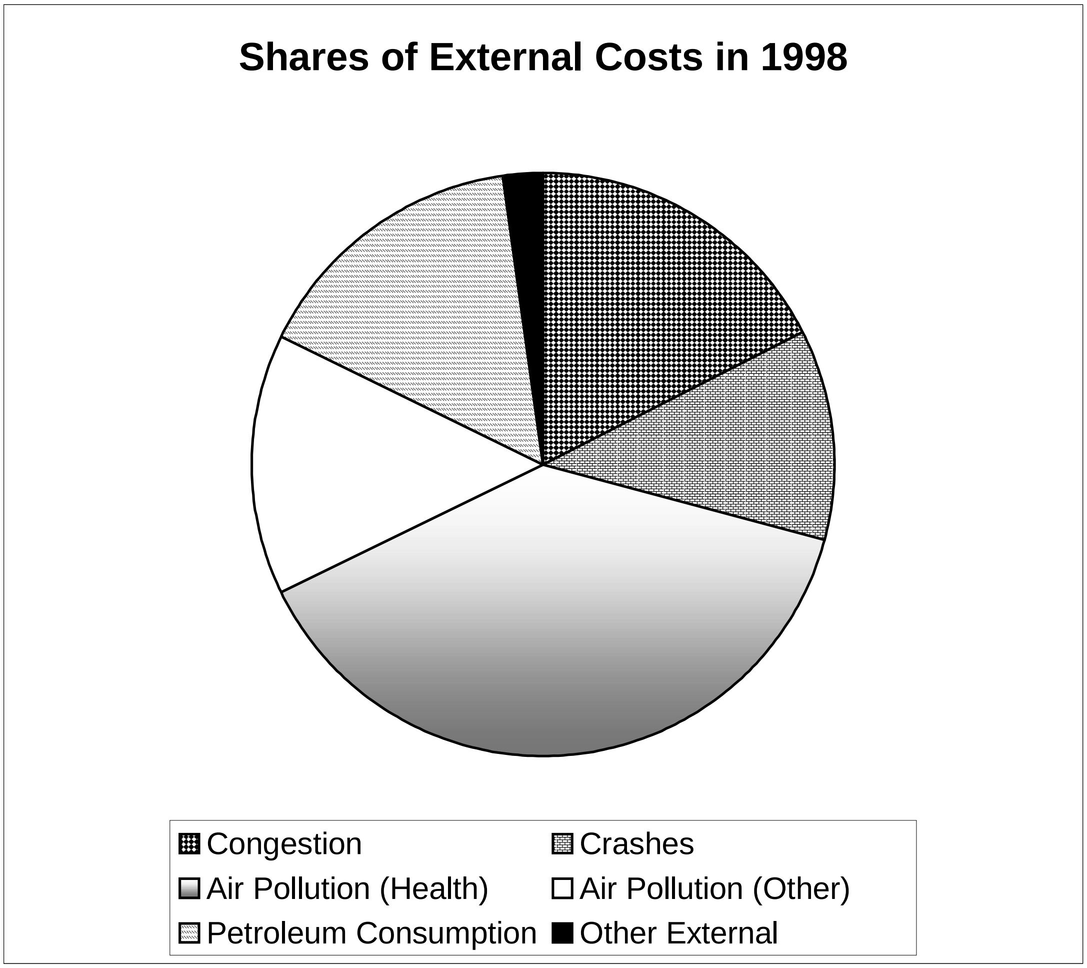

Figure 6.3: Shares of External Costs in 1998

Our midrange estimates for 1998 are that the health effects of air pollution account for 38 percent of the external costs of transportation. Most of the remaining external costs are divided between congestion, crashes, and petroleum consumption.

7 Summary

The full costs of transportation in the Twin Cities region are extremely high. Our mid-range estimate is that they were $27.4 billion in 1998 and that they will be $41.7 billion in 2020. This amounts to approximately $9,000 per capita in 1998 and $10,2000 in 2020. The costs are high relative to our estimates of per capita income, which are $30,300 in 1998 and $37,200 in 2020, but the estimates are not directly comparable. One reason is that our estimates contain many costs that do not show up in national income and product accounts. The nonmonetary costs of time spent in vehicles is the most important of these, and it accounts for 35 percent of the total cost of transportation. The full costs of travel in the Twin Cities region are summarized in Table 7.1.

The internal costs of travel account for 84 percent of the full costs in our mid-range estimates, while governmental costs account for nine percent, and external costs for seven percent. The external costs are quite uncertain, however. For our high-end estimates they account for 16 percent of the total costs of travel.

Our mid-range estimate is that all three types of costs will rise by approximately 50 percent in real terms between 1998 and 2020. This means a significant (25 percent) increase in the per capita cost of travel. We expect that many types of consumer and government spending will increase roughly in proportion with regional income, and overall we estimate that there will be almost no change in the ratio of costs to regional income. This means that, while the costs of transportation will rise in real terms, transportation is not expected to consume a significantly larger share of the region's resources than it does today. We estimate that the costs of transportation will rise only modestly on a per vehicle and per vehicle-mile basis (by 16 and 8 percent respectively).

We have tried to quantify the uncertainty in our cost estimates. Our estimates of internal costs are fairly accurate because many of these costs are monetary and there are a number of sources that assemble data that can be used to calculate these costs. Our estimates of governmental costs are somewhat less accurate because it is difficult to determine the share of some types of governmental spending that is due to transportation. Our external cost estimates are even more uncertain. This level of uncertainty results because many external costs are nonmonetary and because of problems inferring the health effects of air pollution.

The accuracy of our cost estimates could be improved in a number of ways. Governmental costs could be determined more precisely by examining local budget data in more detail. Internal cost estimates could be improved by accounting for the costs of trucks more carefully.

External costs could be improved by examining the major cost items in more detail: congestion, crashes, air pollution, and noise. Based on TTI data, we estimated that slightly more than half of all congestion costs are due to non-recurrent (incident) delay, but more data on the amount and value of these delays would be useful. Another problem is that the Metropolitan Council's estimate of congestion for 2020 is significantly higher than the level we would predict based on the trend in TTI's congestion estimates. The external costs of crashes are difficult to estimate because no one has established a standard method of determining the share of crash costs that are external and the share that are internal. We relied on Delucchi for our estimate of the cost of air pollution. While we feel his study was by far the best available on local air pollution costs, it would be valuable to rerun it for current conditions. Significant changes may have occurred in the region since the Clean Air Act Amendments of 1990, including increases in vehicle size, changes in vehicle mix, and an increase in population. The costs of noise are relatively small at an aggregate level, but they may have significant impacts on people who live near high-traffic or high-speed roads. It would be useful to gather data on noise levels in the region, and to identify the neighborhoods where noise costs are largest.

We feel that our estimates of the full costs of transportation will provide a good basis for further studies that will help address many important types of policy questions. One future report will estimate cost incidence, i.e., which people bear and impose the costs of transportation. This will be useful for addressing political and equity concerns. As part of this work we will also calculate how the costs of transportation vary across the transportation network. Another future report will calculate the full costs of alternative transportation systems. As part of this future report, more detailed information on how the costs of transportation vary with the amount of travel will be developed (i.e., we will estimate the marginal costs of travel). Our marginal cost estimates will be useful for comparing various types of transportation policies.

Table 7.1: The Full Cost of Travel in the Twin Cities Region

	The Full Cost of Travel in Millions of 1998 Dollars					
	1998			2020		
	Low	Mid	High	Low	Mid	High
Governmental	2,120	2,560	3,080	2,990	3,870	4,910
Internal	17,800	22,900	29,250	26,300	34,800	45,400
External	870	1,890	6,080	1,450	3,050	9,190
Total	20,800	27,400	38,400	30,700	41,700	59,500

	1998			2020		
Measures of Full Costs	Low	Mid	High	Low	Mid	High
Cost Per Capita	$6,850	$9,010	$12,640	$8,300	$11,260	$16,060
Cost Per Vehicle	$7,740	$10,190	$14,290	$8,750	$11,870	$16,930
Cost as a Share of Income	22.6%	29.7%	41.7%	22.3%	30.3%	43.2%
Cost per Vehicle-Mile	80¢	106¢	148¢	84¢	114¢	162¢

Table 7.1: Our mid-range estimate is that governmental and external costs account for approximately nine and seven percent of the full costs of transportation respectively. Our high range estimate is that external costs may account for as much as 16 percent of the full costs of transportation.

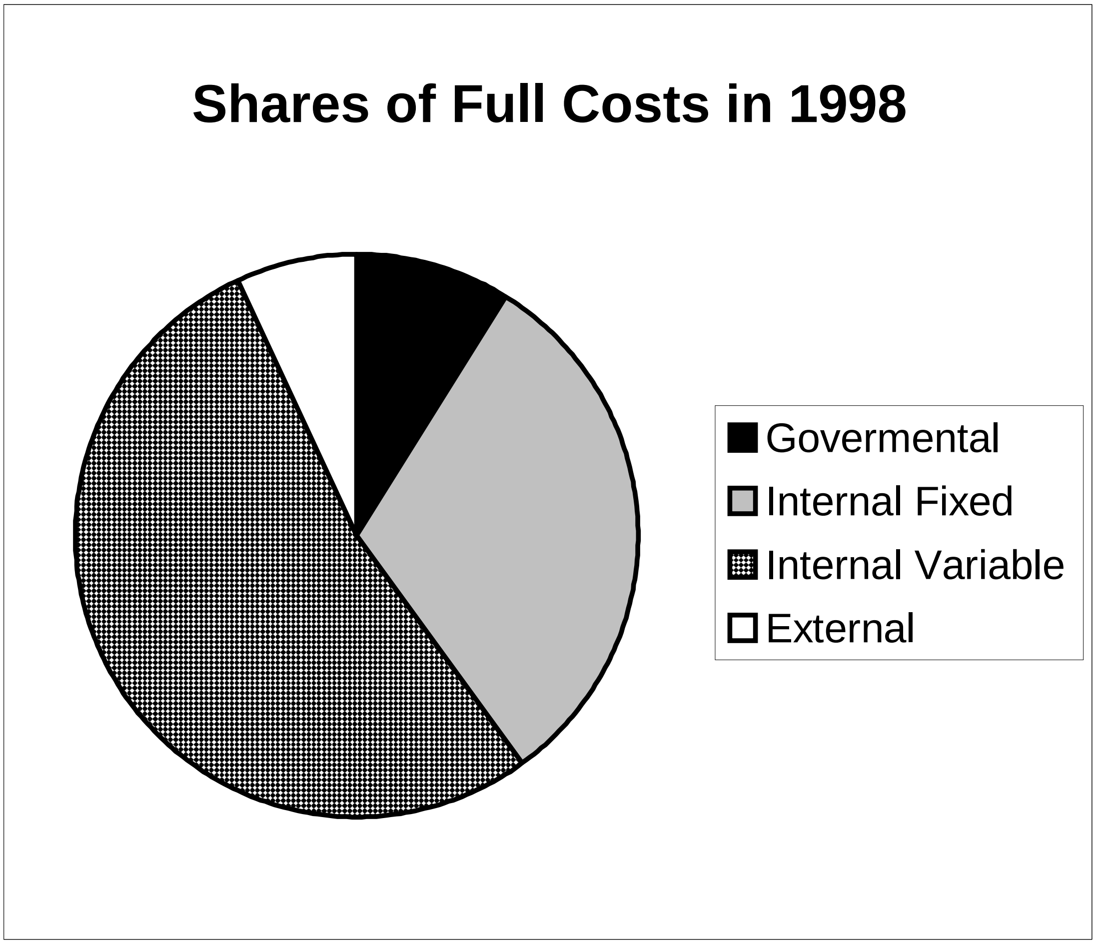

Figure 7.1: Shares of Full Costs in 1998

Our mid-range estimate of the full costs of transportation in the Twin Cities region for 1998 is $9,000 per person. Internal variable costs, of which travel time is the largest component, account for 53 percent of the full costs of transportation. Internal fixed costs account for 31 percent of full costs, governmental costs for nine percent, and external costs for seven percent.

References

Adams, J., and Wyly, E., *Commuter Linkages Among Counties in the Twin Cities and Greater Minnesota,* Research Report 94–02, Center for Transportation Studies and Minnesota Department of Transportation, September 1993.

American Trucking Association, *1997 F&OS Motor Carrier Annual Report*, American Trucking Association Information Services Incorporated, Alexandria, VA, 1997.

Anderson, D., *The Cost of Random Delays when Scheduling is Endogenous,* working paper, March 1997.

Anderson, D., and Mohring, H., *Congestion Costs and Congestion Pricing for the Twin Cities,* Minnesota Department of Transportation Report 96–32, August 1996.

Arnott, R., and Stiglitz, J., "Aggregate Land Rents and Aggregate Transport Costs," *Economic Journal* 91, pp. 331–47, June 1981.

Arnott, R., de Palma, A., and Lindsey, R., "Economics of a Bottleneck," *Journal of Urban Economics* 27, pp. 111–130, 1990.

Apogee Research Inc., *The Costs of Transportation: Final Report,* prepared for the Conservation Law Foundation, March 1994.

Association of American Railroads, *Principles of Road User Charges,* prepared by Putnam, Hayes, Bartlett, Inc., September 1991.

Barnes, G., *The Values of Waiting Time and a Seat on the Bus: Some Evidence from Singapore,* Ph.D. dissertation, University of Minnesota, December 1995.

Barnes, G. (1999a), *Understanding Urban Travel Demand: Problems, Solutions, and the Role of Forecasting,* prepared as part of the Transportation and Regional Growth Study, August 1999.

Barnes, G. (1999b), *Predicting and Evaluating Travel Demand Response to Policy*, presentation for the Transportation and Regional Growth Study, August 1999.

Boardman, A., Greenberg, D., Vining, A., and Weimer, D., "'Plug-in' Shadow Price Estimates for Policy Analysis," in *The Annals of Regional Science* 31, pp. 299–324, 1997.

Bureau of Economic Analysis, *Personal Income and Outlays, June 1998*, Bureau of Economic Analysis News Release, August 1998.

Bureau of Labor Statistics, *Monthly Labor Review, January 1999*, Office of Employment and Unemployment Statistics, January 1999.

Calfee, J., and Winston, C., "The Value of Automobile Travel Time: Implications for Congestion Policy," in *The Journal of Public Economics* 69, pp. 83–102, 1998.

Ciborowski, P., *Minnesota Greenhouse Gas Inventory*, commissioned by the Minnesota Pollution Control Agency, March 1995.

Dahlby, B., and West, D., "Price Dispersion in an Automobile Insurance Market," in *The Journal of Political Economy* 94, pp. 418–38, April 1986.

Delucchi, M., et al., "The Annualized Social Cost of Motor Vehicle Use in the U.S. Based on 1990–1991 Data," in 20 reports, University of California, Institute for Transportation Studies, Davis, CA, 1996.

Delucchi, M., "The Annualized Social Cost of Motor Vehicle Use in the U.S. Based on 1990–1991 Data: Summary of Theory, Data, Methods, and Results," in *The Full Costs and Benefits of Transportation*, D. Greene, D. Jones, and M. Delucchi, editors, 1997.

Desvousges, W., Johnson, R., and Banzhar, H., *Assessing the Environmental Costs for Electricity Generation*, Triangle Economic Research working paper #G-9402, December 1994.

Federal Highway Administration, *Motor Vehicle Accident Costs*, U.S. Department of Transportation, Technical Advisory #T 7570.2, Washington, DC, October 1991.

Federal Highway Administration, *The Costs of Highway Crashes*, U.S. Department of Transportation, Washington, DC, October 1994.

Federal Highway Administration, *Final Report on the Federal Highway Cost Allocation Study*, U.S. Department of Transportation, Washington, DC, August 1997.

Federal Highway Administration (1998a), *Our Nation's Highways*, prepared by the Office of Highway Information Management, Washington, DC, Publication #FHWA-PL-98-015, 1998.

Federal Highway Administration (1998b), *Highway Statistics 1997*, prepared by the Office of Highway Information Management, Washington, DC, 1998.

Federal Highway Administration, *Highway Statistics 1998*, prepared by the Office of Highway Information Management, Washington, DC, 1999.

Friesz, T., Bernstein, D., and Stough, R., "Dynamic Systems, Variational Inequalities and Control Theroetic Models for Predicting Time-varying Urban Network Flows," *Transportation Science* 30, pp. 14–31, 1996.

Green, K., *Defending Automobility: A Critical Examination of the Environmental and Social Costs of Auto Use*, Policy Study No. 198, Reason Foundation, Los Angeles, CA, December 1995.

Gren, I., Folke, C., Turner, K., and Bateman, I., "Primary and Secondary Values of Wetland Ecosystems," in *Environmental and Resource Economics* 4, pp. 55–74, 1994.

Gomez-Ibanez, J., "Estimating Whether Transport Users Pay Their Way: The State of the Art," in *The Full Costs and Benefits of Transportation*, D. Greene, D. Jones, and M. Delucchi, editors, 1997.

Hagler Bailly, Inc., *Transportation and Global Climate Change*, prepared for the Federal Highway Administration, 1997.

Han and Fang, "Measuring Transportation in the U.S. Economy," *Journal of Transportation Statistics*, January 1998.

Hanley, N., Spash, C., and Walker, L., *Problems in Valuing the Benefits of Biodiversity Protection*, Kluwer Academic Publishing, April 1995.

Hensher, D., "Behavioral Value of Travel Time Savings in Personal and Automobile Commuting," in *The Full Costs and Benefits of Transportation*, D. Greene, D. Jones, and M. Delucchi, editors, 1997.

Hopkins, T., *Profiles of Regulatory Costs*, prepared for the U.S. Small Business Administration, November 1995.

Katz, A., and Herman, S., "Improved Estimates of Fixed Reproducible Tangible Wealth, 1929–95," produced as part of the *Survey of Current Business* for the Bureau of Economic Analysis, May 1997.

Kessler, J., and Schroeer, W., "Meeting Mobility and Air Quality Goals: Strategies that Work," in *Transportation* 22, pp. 241–272, 1995.

Ketcham, B., and Komanoff, C., "Win-Win Transportation: A No-Losers Approach to Financing Transport in New York City and the Region," draft, Transportation Alternatives, 1992.

Knight, F., "Some Fallacies in the Interpretation of Social Cost," *Quarterly Journal of Economics* 38, pp. 582–606, 1924.

Landes, W., and Posner, R., *The Economic Structure of Tort Law*, Harvard University Press, 1987.

Lee, D., "Uses and Meanings of Full Social Cost Estimates," in *The Full Costs and Benefits of Transportation*, D. Greene, D. Jones, and M. Delucchi, editors, 1997.

Levinson, D., "Speed and Flow on Signalized Arterials," *ASCE Journal of Transportation and Engineering* 124:3, pp. 258–264, 1998.

Lindgren, S., *Justice Expenditure and Employment Extracts 1992*, prepared for the U.S. Department of Justice, January 1997.

Lindley, J., "Urban Freeway Congestion Problems and Solutions: An Update," *ITE Journal*, pp. 21–23, December 1989.

Lisco, T., *The Value of Commuters Travel Time: A Study in Urban Transportation*, Ph.D. dissertation, University of Chicago, 1967.

Litman, T., *Transportation Cost Analysis: Techniques, Estimates, and Implications*, Draft 2, Victoria, British Columbia, Canada, May 1994.

MacKenzie, J., Dower, R., and Chen, D., *The Going Rate: What it Really Costs to Drive*, World Resources Institute, Washington, DC, 1992.

Mayer, S., "Implementing the Clean Air Act Amendments of 1990: Where Are We Now?" prepared for the Congressional Research Service, January 1995.

Metropolitan Council (1994a), *1990 Travel Behavior Inventory Summary Report*, Metropolitan Council publication #35-94-009, June 1994.

Metropolitan Council (1994b), *TBI Model Calibration Memo #9: Highway Assignment Model for the Minneapolis-Saint Paul Region*, prepared by Strgar-Roscoe-Fausch, Inc., June 1994.

Metropolitan Council (1996a), *Transportation Policy Plan*, Metropolitan Council publication #35-97-010, December 1996.

Metropolitan Council (1996b), *Transportation Policy Plan Appendix*, Metropolitan Council publication #35-97-010A, December 1996.

Metropolitan Council (1996c), *Regional Blueprint*, December 1996.

Metropolitan Council, *2000–2002 Transportation Improvement Program*, July 1999.

Metropolitan Council, *Transit 2020 Master Plan*, January 2000.

Miller, T., "Societal Costs of Transportation Crashes," in *The Full Costs and Benefits of Transportation*, D. Greene, D. Jones, and M. Delucchi, editors, 1997.

Miller, P., and Moffet, J., *The Price of Mobility: Uncovering the Hidden Costs of Transportation,* Natural Resources Defense Council, San Francisco, CA, October 1993.

Minneapolis Department of Public Works, *Downtown Parking 1998–99*, September 1998.

Minnesota Department of Public Safety (1999a), *Minnesota Motor Vehicle Crash Facts 1998*, produced by the Office of Traffic Safety, 1999.

Minnesota Department of Public Safety (1999b), *Registration and Insurance Study*, 1999.

Minnesota Department of Transportation, *Principal Arterial Pavement Preservation Study*, prepared by the Office of Investment Management and the Office of Construction and Materials Engineering, April 1998.

Minnesota Planning, *Faces of the Future*, State Demographic Center, September 1998.

Mohring, H., Schroeter, J., and Wiboonchutikula, P., "The Values of Waiting Time, Travel Time, and a Seat on the Bus," in *The Rand Journal of Economics* 18, pp. 40–56, 1987.

Moore, T., and Thorsnes, P., *The Transportation/Land Use Connection: A Framework for Practical Policy*, published by the American Planning Association, 1994.

MVA Consultancy, Institute for Transport Studies-University of Leeds, and Transport Studies Unit-University of Oxford, *Value of Travel Time Savings*, Policy Journals, Newbury, 1987.

Nagel, K., Beckman, R., and Barrett, C., *TRANSIMS for Transportation Planning*, Los Alamos National Laboratory, February 1999.

National Highway Traffic Safety Administration, *The Economic Costs of Motor Vehicle Crashes*, U.S. Department of Transportation, 1995.

National Highway Traffic Safety Administration, *Traffic Safety Facts 1997*, U.S. Department of Transportation, November 1998.

National Highway Traffic Safety Administration, *Traffic Safety Facts 1998—Overview*, U.S. Department of Transportation, 1999.

Noland, R., and Small, K., "Travel-Time Uncertainty, Departure Time Choice, and the Cost of Morning Commutes," in *Transportation Research Record A* 1493, pp. 150–158, 1995.

Office of Management and Budget, *Report to Congress on the Costs and Benefits of Federal Regulations*, prepared by the Office of Information and Regulatory Affairs, Washington, DC, September 1997.

Office of Technology Assessment, *Saving Energy in U.S. Transportation*, Report #OTA-ETI-589, 1994.

Office of the Legislative Auditor, *Motor Vehicle Deputy Registrars*, State of Minnesota, Report #94-05, March 1994.

Office of the Legislative Auditor (1997a), *Ethanol Programs*, State of Minnesota, Report #97-04, February 1997.

Office of the Legislative Auditor (1997b), *Highway Spending*, State of Minnesota, Report #97-06, March 1997.

Office of the Legislative Auditor, *Transit Services*, State of Minnesota, Report #98-03, February 1998.

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

Puget Sound Regional Council, *The Costs of Transportation: Expenditures on Surface Transportation in the Central Puget Sound Region for 1995*, October 1996.

Quinet, E., "The Full Social Cost of Transportation in Europe," in *The Full Costs and Benefits of Transportation*, D. Greene, D. Jones, and M. Delucchi, editors, 1997.

Renewable Fuel Association, *Ethanol Report*, Issue #57, Washington, DC, October 1997.

Runzheimer International, "Where Does Your Automotive Dollar Go?" news release, June 1998.

Ryan, B., and Stinson, T., *The Public Sector Transportation Funding Baseline for the Twin Cities Metropolitan Area*, presented for the Transportation and Regional Growth Project, October 1999.

Schrank, D., and Lomax, T., *Urban Roadway Congestion—1982 to 1994, Volume 1: Annual Report*, Texas Transportation Institute, 1997.

Shoup, D., "The High Cost of Free Parking," *Journal of Planning Education and Research* 17, pp. 3–20, Fall 1997.

Small, K., "The Scheduling of Consumer Activities: Work Trips," *American Economic Review*, 72(3), pp. 467–479, 1982.

Small, K., and Kazimi, C., "On the Costs of Air Pollution from Motor Vehicles," in *The Journal of Transport Economics and Policy* 29, pp. 7–32, 1995.

Soderqvist, T., "Why Give up Money for the Baltic Sea?" in *Environmental and Resource Economics* 12, pp. 249–254, 1998.

Tol, R., "The Marginal Costs of Greenhouse Gas Emissions," in *The Energy Journal* 20, pp. 61–81, 1999.

Transportation Research Board, *Paying Our Way: Estimating Marginal Costs of Freight Transportation,* Transportation Research Board Special Report #246, 1996.

U.S. Department of Commerce, *Regional Projections to 2045*, Bureau of Economic Analysis, August 1995.

U.S. Department of Justice, *Corrections Populations in the United States, 1995*, June 1997.

Vickrey, W., "Congestion Theory and Transport Investment," *American Economic Review* 59, pp. 251–60, May 1969.

Vickrey, W., "Automobile Accidents, Tort Law, Externalities, and Insurance: An Economist's Critique," in *The Economics of Transport, Volume 1*, Herbert Mohring, editor, 1994.

Vogan, C., "Pollution Abatement and Control Expenditures, 1972–94," *Survey of Current Business*, U.S. Bureau of Economic Analysis, September 1996.

Voith, R., "The Downtown Parking Syndrome: Does Curing the Illness Kill the Patient?" in *Business Review*, Federal Reserve Bank of Philadelphia, pp. 3–14, January 1998.

Wang, M., and Santini, D., "Monetary Values of Air Pollution Emissions in Various U.S. Regions," in *Transportation Research Record* 1475, pp. 33–41, 1995.

Wardman, M., "The Value of Travel Time: A Review of the British Evidence," in *The Journal of Transport Economics and Policy* 32, pp. 285–316, 1998.

Welle, P., Hagen, D., and Vincent, J., "Economic Benefits of Reducing Toxic Air Pollution: A Minnesota Study," prepared for the Minnesota Pollution Control Agency, May 1992.

Weyant, J., "Costs of Reducing Global Carbon Emissions," in *The Journal of Economic Perspectives* 7(4), pp. 27–46, 1993.

Appendix A
Definitions

A. Appendix: Definitions

1. Acronyms

Table A.1: List of Acronyms

CAAA	Clean Air Act Amendments of 1990
CO	Carbon Monoxide
CPI	Consumer Price Index
CTPP	Census Transportation Planning Package
EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
GDP	Gross Domestic Product
HOV	High Occupancy Vehicle (an automobile containing two or more people)
ITS	Intelligent Transportation Systems
LRT	Light Rail Transit
Mn/DOT	Minnesota Department of Transportation
MSA	Metropolitan Statistical Area (for the Twin Cities area, as defined by the Census Bureau)
NHTSA	National Highway Traffic Safety Administration
NO	Nitrous Oxides
OMB	U.S. Office on Management and Budget
PCA	Minnesota Pollution Control Agency
PDO	Property Damage Only (a crash involving)
PM	Particulate Matter
SO	Sulfur Oxides
TAZ	Traffic Analysis Zone
TBI	1990 Travel Behavior Inventory (for the TCMA)
TCMA	Twin Cities Metropolitan Area (the Metropolitan Council is the Metropolitan Planning Organization for the TCMA)
TIS	Transportation Information System (a roadway database maintained by Mn/DOT)
TNM	Traffic Noise Model (a model of noise generation and propagation that was developed by the FHWA)
TPP	Transportation Policy Plan
VMT	Vehicle Miles Traveled

2. General Terminology

Opportunity Cost

Economists use the word cost in a special way. To accountants and most other people, any expense is a cost. To economists, the term means opportunity cost. The opportunity cost of an activity is the value of the next best alternative that was forgone to undertake the activity.

To illustrate the difference, suppose taxi services are provided free. This does not mean the service is costless. First, there are the resources the taxi company puts into travel. These might include gasoline, the use of the vehicle, and the driver's services. These resources could be used elsewhere if there were no taxi service. Second, even though the traveler incurs no direct expenses, the trip takes time. This imposes a cost because the time could be used for other activities.

Full, Social, Private, and Governmental Costs

The full cost of travel, sometimes called the social cost of travel, is the total opportunity cost of travel. This includes costs to individuals, firms, and governmental organizations. These costs include direct spending and nonmonetary costs, such as time. Full costs can be divided between governmental and private costs. Governmental costs are those paid for by any level of government, and private costs are those paid for by individuals or private corporations.

Costs, Prices, and User Fees

The private costs of some goods are easy to determine because, at least under ideal conditions, they equal the price of the good. These conditions occur when the firm selling the good (i) produces the good efficiently, (ii) makes no economic profits, and (iii) causes no externalities. Note that taxes are not costs because they merely transfer money between people. Money collected by a unit of government for using a public service is called a user fee. A user fee may, or may not, be approximately equal to the cost of the service received.

External and Internal Costs

An externality occurs when one person's actions affect another person outside of the market. External costs, sometimes called indirect costs, are costs that result from an externality. Suppose, for example, you crash your vehicle and this delays traffic. The extra time and gasoline others use are external costs. Internal (or direct) costs are those borne by the person who causes them or are borne by another person through the market. The costs you pay because of a crash you cause are internal costs.

Sometimes people speak of a cost being internal to a group of people. This means that the group bears the entire cost. Congestion, for example, is internal to the group of all motor vehicle users. It still represents an externality, however, because each driver causes congestion for which she does not pay. Since this terminology is potentially confusing, we will try to avoid it.

Fixed, Variable, and Marginal Costs

Fixed costs are costs that can be avoided only in the long run and not in the short run. Variable costs are those that can be avoided in the short run. Determining which costs are variable and which are fixed depends on the time period being considered, i.e., on the definition of short and long run. The cost of a road is usually considered fixed, for example, but will be variable over a long enough time period. The costs of fuel are usually considered to be variable because they can be avoided by driving less. The marginal cost of a good is the opportunity cost of using one more unit of the good. Marginal costs are often useful for policy evaluation because they provide information about how costs will change when relatively small changes in behavior occur.

Monetary and Nonmonetary Costs

Monetary costs are the costs of goods and services that are purchased in markets (i.e., with money). Nonmonetary costs are the costs of goods and services that are not purchased with money. Examples of nonmonetary costs are the time cost of driving a car while not at work and the cost of noise. Nonmonetary costs are real opportunity costs, but they can be difficult to quantify.

Bundled Goods and Complements

Bundled goods are goods that are normally sold together. Garages and houses provide one example. Another is provided by the groceries and the “free” parking provided by the grocery store. Because these goods are normally sold together, it can be difficult to determine the costs of each individual good. Two goods are complements if they are normally consumed jointly. Autos and drive-in movies are an example. The demand for a good rises when the price of a complement falls, and demand falls when the price of a complement rises.

3. Descriptions of Cost Items

Governmental Cost Items

1.1 Federal, state, and local roads
This category includes some of the largest public costs of transportation. This category is broadly construed, especially the costs of maintenance, which include such costs as street sweeping and snow and ice removal.

1.1.1 Construction
This includes almost all of the costs of building roads. It includes the costs of getting approval to build and of actually constructing the road. It does not include the cost of land, which are included in category 1.1.3.

1.1.2 Maintenance
This includes the average annual costs of repairing damage to roads. The damage may result from vehicles, the weather, or other factors. It also includes the costs of cleaning roads and of snow and ice removal.

1.1.3 Land and Overhead
These are costs to governmental agencies that manage the transportation system (mainly the Department of Transportation). Examples of these costs include system planning and the providing information to drivers on crashes. This category also includes the costs of the land that is used for roadways.

1.2 Subsidies for parking
This does not include on-road parking because these costs are included with the costs of roads in category 1.1. This category includes only subsidies to parking; it does not include the fees that drivers pay for parking.

1.3 Law enforcement and safety
Most researchers agree that transportation imposes some costs on law enforcement. It is not easy to determine the share of these costs that transportation is responsible for. We include costs of law enforcement devoted entirely to transportation. We also include *increases* in costs resulting because transportation requires increases in the levels of some general services.

1.4 Traffic safety (except for law enforcement)

These costs include subsidies to driver training and licensing. The shares of these costs that are paid for by licensing fees are included as internal costs (under item 2.1.5). This category also includes the costs of monitoring transportation safety. These costs are incurred by agencies such as the Minnesota Department of Public Safety and by the National Highway Traffic Safety Administration.

1.5 Subsidies for transit
These costs include subsidies to transit from any level of government. They do not include transit fares.

1.6 Transportation-related environmental spending
Most agree these costs should be included, but some would count them as external costs. We keep them here for simplicity and consistency. Examples include subsidies to remove leaking gas tanks from the ground or spending to mitigate the effects of runoff (especially runoff from roads that have been salted). Note that these costs do not include most of the damages caused by environmental externalities. Most damages are included as items under category 5 or 6. Also note that some of these costs are covered by user fees. In particular, the costs of removing leaking gas tanks is covered in Minnesota by funds earmarked from fuel taxes and the cleanup of oil spills in federal waters are covered by fees on oil tankers. For simplicity, we consider these costs to be governmental, not internal.

1.7 Energy security
The first category (military protection of oil supplies) is especially controversial. *If* the U.S. spends more on defense because we consume imported oil, this would be a real cost of travel. The difficult part is determining how much less we would spend if we did not use oil for regional transportation. We feel reasonable estimates of this cost are available.

1.8 Costs to other governmental agencies
These costs include all government spending for transportation by agencies that are not listed above.

Internal Cost Items

The following categories are intended to include only internal costs. They include costs to individuals and businesses. Properly allocating costs between internal and external is often difficult. The costs of crashes and of congestion present special problems

2.1 Fixed costs of private vehicles

These are costs that are largely fixed with regard to the operation of vehicles. The costs of security devices and depreciation are examples. They vary somewhat with the number of miles a vehicle is driven, but they vary much more with other factors, such as where the vehicle is stored or the age of the vehicle.

2.2 Variable costs of private vehicle operation
This category covers costs that depend a great deal on how much a vehicle is driven. Crashes, for example, depend on many factors, but the probability a person will be involved in a crash increases significantly as the person drives more.

2.3 Fees for parking and transit
These costs are parking fees and transit fares. These exclude the costs of bundled parking, which are covered in categories 3.1 and 3.2.

3.1 Home garages and driveways
These costs are bundled because garages and driveways are usually included in the price of housing. Most of the costs of driveways and garages result from auto use, however.

3.2 Parking lots, driveways, and roads provided free by businesses
Some people consider these costs to be externalities. We classify them as internal costs because we use a narrow, economic definition of externality. This does *not* mean, however, that we feel these goods are currently provided efficiently.

4.1 Pain and suffering from crashes and fires caused by the driver
This is an important cost item, but when crashes involve more than one vehicle it is difficult to determine which portions of the crash costs are internal and which are external.

4.2 Personal time
This category includes the time costs of transportation that (i) do not result from congestion and (ii) for which individuals are not compensated. Time spent in transit, repairing vehicles, etc. while at work is included in categories 2.2.5 or 5.1. Personal time spend in delays is included in category 6.1.

External Cost Items

External costs tend to generate a great deal of debate because the presence of an externality often justifies some type of government action. The costs in categories 5.1 to 5.6 are monetary costs and the costs in categories 6.1 to 6.6 are nonmonetary.

5.1 Congestion

These costs include the value of delays caused by high traffic volume and by crashes or other incidents. Most researchers agree that the costs of congestion are external, but sometimes it is argued that congestion isn't a true externality because it is borne by the people who use the transportation system (see, for example, Green, 1995). The standard economic definition of an externality does not, however, depend on which group of people bear the costs of the externality; it depends on whether each individual bears all of the costs he or she imposes.

5.2 Crashes

These costs include damage to vehicles and property. Compensation by insurance companies is included unless the responsible party's insurance company pays for the crash. Additional costs are included if the average cost of these crashes increases with traffic flow. If this were the case, then even if everyone were fully insured, driving would cause negative external crash costs. Congestion caused by crashes is included in categories 5.1 and 6.1.

5.3 Pollution

This category includes monetary health costs such medical services purchased because of the effects of air pollution. It also includes damage to output due to pollution. This is potentially a difficult category to measure, but Delucchi et al. (1996) has analyzed many of these costs in detail. The costs of global warming present special problems.

5.5 Petroleum consumption

These costs have been controversial. We feel that the loss to the U.S. because it does not act as a monopsonistic buyer of oil (category 5.4.1) is not a true cost of oil consumption. Rather, it is a transfer between nations (from the U.S. to oil-producing nations). We include this "cost" to provide policymakers as much information as possible about transportation options.

Category 5.4.2 covers potential losses to GDP due to oil price fluctuations. This cost item is difficult to quantify, in part because the oil price shocks of the 1970s were accompanied by governmental regulation of the oil market that may have caused significant macro-economic problems. Different analysts have produced very different estimates of this cost.

5.5 Robberies

This category includes the costs of replacing stolen merchandise and the costs of repairing damage to vehicles due to robberies, net of the gain to criminals. If autos are particularly vulnerable to robbery, then widespread use of autos will lead to higher crime costs. If autos are not particularly vulnerable, then less auto use will not reduce these costs because criminals will just commit other types of robberies. Note that this category is a special type of externality in that it is an externality that is imposed on transportation users by other members of society.

5.6 Fires
This is a relatively small category because most of the costs of fires are born by the responsible party.

6.1 Congestion
This category includes time costs to people who are not working. The costs can be due to traffic volume or unexpected incidents such as crashes.

6.2 Crash
These are the costs of the pain and suffering caused by crashes. These costs are not included if the sufferer caused the crash (these costs are accounted for in category 4.1) or if the sufferer is compensated by the responsible party (this case is accounted for in category 2.2.3). As with cost item 5.2, additional costs are included if the average cost of these crashes increases with traffic flow.

6.3 Pollution
As with category 5.3, these are difficult costs to measure. Delucchi (1996) and others have analyzed some of these costs in detail, however.

6.4 Other nonmonetary effects on land or neighborhoods
The costs in this category are difficult to quantify. Although our estimates may be quite uncertain, we expect these costs to be fairly small. The difficulty in determining these costs is partially mitigated by the fact that this is a regional study. Some of the effects on recreational areas and plants and animals could be included in the value of the land used for roads, but we calculate them separately.

6.5 Robberies
This category includes pain and suffering due to robberies. As with category 5.5, these costs are calculated net of the costs of alternative crimes. Note again that this category is special in that it is an

externality that is imposed on transportation users by other members of society.

6.6 Fires
As with category 5.6, this is a relatively small cost item.

4. Cost Items Not Included to Avoid Double-Counting

Double-counting occurs when the same cost is counted more than once. The cost of a transit system, for example, equals the costs of operating the transit system plus costs to transit users. When calculating the total costs of transit, it is essential that fares not be counted twice. We must either calculate transit costs as subsidies (operating costs net of fares) plus user costs or as operating costs plus nonmonetary user costs (user costs net of fares).

We have been careful to avoid double-counting. This means some cost items are not included in Table 2.2 because they are counted in other places. We discuss three here—the impact of roads on property values, the negative impact of roads on the efficiency with which transit operates, and the internal costs of air and noise pollution.

Roads can have negative, as well as positive, effects on property values. We do not account for either of these effects. We do not account for the negative effects, because we analyze them in other places. Primarily, these costs are counted as costs of noise as barrier effects. The positive effects are more problematic, but the standard way to measure the benefits of transportation is through reductions in the costs experienced by users of the system. In general, reductions in costs balance out gains in property values, so both effects should not be counted.[163]

The average cost of transit service generally falls as service becomes more frequent. One reason is that users of the system experience lower time costs because they do not have to wait as long. To the extent that autos cause reductions in transit service, the additional costs of service could be considered to be costs of autos. We do not count these effects as costs of autos, however, because they are already included as costs of transit service. The purpose of this report is not to assign responsibility for these costs but to compute total costs and we must avoid double-counting. The question of cost responsibility will be discussed in more detail in the next report, which deals with cost incidence.

[163] The costs and benefits do not always balance exactly; see Arnott and Stiglitz (1981).

We do not account for the internal costs of noise and air pollution (the noise and air pollution experienced during travel and inflicted on oneself). Delucchi et al. (1996)[164] feels that these costs may be significant, but we know of no study that attempts to quantify them. Fortunately, we feel that these costs are included in our estimates of the costs of travel time. The reason is that, to the best of our knowledge, all studies of the value travelers place on time, calculate this value under actual operating conditions. They do not calculate the value of time net of the costs of noise and pollution.

5. Cost Items Not Quantified

Ideally, we would quantify all of the costs of transportation. There are some cost items, however, which we do not know how to quantify. These cost times are equity; esthetics; land and water pollution; the social costs of barriers; fear and avoidance of motor vehicles; and damage to historic sites. Except for one study that includes equity, we have found no studies that attempt to quantify these costs. Some of these costs are also discussed in Section 6.6.

The primary reason we do not include *equity* in Table 2.2 is that we do not feel we can quantify it. Determining the costs of inequity require answering two difficult questions: “How much additional inequity is caused by our transportation system?” and “How much demand does society have for equity?” We know of no good way to answer either question. Litman (1994, p. 3.9–6) estimates this cost but says he has found no other quantified estimates. He estimates that auto use decreases equity and diversity in transportation by 75 percent and that demand equals four-thirds of current transit subsidies. To us, these estimates seem arbitrary.[165] Equity is discussed in Section 4.1 and we will analyze it further when we determine the incidence of transportation costs.

[164] See Report #1, page 68.

[165] A secondary reason we do not include equity is to avoid double-counting. Following Litman’s reasoning, some transit subsidies are made to reduce inequity. We do not want to include this cost twice.

Appendix B
Literature Review

B. Appendix: Literature Review

This section describes several recent studies of the costs of transportation. It provides summaries of the major results of these studies. It also identifies important areas that must be addressed by our cost accounting system—in particular, areas where cost estimates are especially uncertain, difficult to classify, or difficult to attribute to transportation.

1. Review of Four Recent Studies

The first part of this review covers four recent studies of the full costs of transportation. They are Delucchi et al. (1996), Litman (1994), Quinet (1997), and the Puget Sound Regional Council (1996). The first two studies were selected because they are detailed, comprehensive, and up-to-date. Delucchi's study actually consists of 20 separate reports and contains a great deal of original research. Litman's study is also comprehensive and it takes special care to include all conceivable costs of transportation. Quinet's study analyzes the costs of transportation in Europe, offering an international perspective. The Puget Sound Regional Council's report is covered because it identifies issues that are important in accounting for regional, as opposed to national, transportation costs.

Delucchi

Delucchi et al. (1996) is probably the most comprehensive study of the full costs of transportation to date. Although their focus is on the full cost of motor vehicle travel in the United States, these costs are a large component of total transportation costs and the framework they develop to analyze them can be applied to most other types of transportation. Their study treats all major cost items in detail and even devotes entire reports to categories with relatively small costs. Report 12 determines the cost of crop losses caused by ozone pollution, and Report 13 determines the cost of reduced visibility due to pollution. Their report was funded by several organizations,[166] lasted three years, and conducted a great deal of original research.

[166] The funding came from the FHWA, Office of Technology Assessment, University of California Transportation Center and Energy Research Group, and the Pew Charitable Trusts.

Table B.1: Delucchi's Cost Estimates (Cost per Vehicle in 1998 Dollars)			
Type of Cost	Cost Category	Low	High
Internal, Private Costs	Costs born by individuals that are not caused by externalities and for which the individuals are not monetarily compensated. An example is the time you spend maintaining your car. (Personal nonmonetary costs)	$3,422	$5,995
	Bundled goods and services purchased by individuals that are not due to externalities. These are goods that are usually purchased in combination with other goods—garages and driveways, for example. (Bundled private-sector goods and services)	$478	$1,756
	Non-bundled goods and services purchased by individuals that are not due to externalities. These are goods that are usually purchased by themselves—a vehicle, fuel, or insurance. (Non-bundled private sector goods and services)	$5,079	$5,783
Governmental Costs	Government-provided goods and services charged partly to motor vehicle users. Road maintenance costs, for example.	$830	$1,516
Governmental Costs and Monetary Externalities	Externalities that cause damage to monetary goods and services and government-provided services not clearly charged to motor vehicle users. An example is property damage due to crashes that is not paid for by the responsible party. (Monetary externalities)	$189	$780
Nonmonetary Externalities	Externalities for which people are not monetarily compensated. Examples include noise and air pollution. (Nonmonetary externalities)	$434	$4,750
Total Cost		$10,442	$20,580

Table B.1: Delucchi et al. (1996) estimates that the total, per-vehicle[167] cost of motor vehicle use in the United States in 1990 was between $10,400 and $20,600. (Note that these estimates are for cars, trucks, and buses.)

[167] These estimates include all vehicle types from compact cars to heavy trucks.

Delucchi divides all costs into the six categories shown in Table B.1. (Note that these costs are for all vehicle types (cars, trucks, and buses) and include many items not usually included in the Gross Domestic Product accounts.) His accounting system makes several distinctions. One is between internal and external costs. *Internal costs* are the costs associated with goods and services that are born by the person who causes them. An example is the depreciation of a motor vehicle. *External costs* occur when a person affects another's utility outside the market. The distinction between internal and external costs helps identify goods and services that may be inefficiently priced.

Another distinction is between public and private costs. *Public costs* result from spending by all levels of government—local, state, and federal. *Private costs* are incurred by individuals or corporations. This distinction also helps identify goods and services that may be inefficiently priced. The system further distinguishes between monetary and nonmonetary costs. *Monetary costs* are the costs of goods that are purchased with money, a vehicle, for example. *Nonmonetary costs* are the costs of goods and services not purchased with money, pain and suffering from crashes or personal time, for example. This distinction helps identify costs that are hard to measure and which do not appear in GDP accounts (the nonmonetary ones).

The system also divides private-sector costs into bundled and non-bundled goods. *Bundled goods* are goods that are usually purchased along with other goods, garages and driveways, for example, are purchased with homes. *Non-bundled goods* are purchased by themselves. This division is useful because bundled goods may not be provided as efficiently as non-bundled good. Also, many people feel bundled goods are not provided equitably. For example, both drivers and non-drivers pay for "free" parking lot spaces at shopping malls.

The Delucchi study finds that the full cost of motor vehicle use in the U.S. in 1990 was between $1.97 and $3.89 trillion. This amounts to between $10,400 and $20,600 for each motor vehicle registered. The study estimates that external costs (monetary and nonmonetary) were between $120 and $1,050 billion dollars (between $620 and $5,500 per vehicle, or $0.05 and $0.49 per vehicle-mile).

Table B.2: Litman's Cost Estimates

(Cost per Vehicle in 1998 Dollars)

Internal Costs	Low	High	External Costs	Low	High
Vehicle ownership	$2,230	$4,460	External crash	$120	$1,240
Vehicle operating	$1,240	$1,860	External parking	$370	$1,240
User time	$1,360	$4,210	Congestion	$230	$810
Internal crash	$370	$2,110	Roadway facility	$120	$370
Internal parking	$370	$990	Roadway land	$120	$1,240
			Municipal services	$40	$190
			Equity/Option value	$0	$620
			Air pollution	$120	$2,480
			Water pollution	$10	$320
			Noise	$20	$740
			Resource use	$100	$970
			Barrier effect	$60	$250
			Land use impacts	$250	$2,480
			Waste disposal	$0	$60
Total Internal Cost	$5,570	$13,630	Total External Cost	$1,560	$13,010
Total Cost				$7,130	$26,640

Table B.2: Litman (1994) estimates that the per-vehicle[168] cost of motor vehicle use in the Unites States ranged from $7,100 to $26,600 in 1993. Costs for each category constructed using Litman's low and high estimates of cost per vehicle-mile.

Litman

Litman (1994) was conducted for the Victoria Policy Institute in Victoria, British Columbia. It was the result of several years of research and was meant to provide a comprehensive overview of current methods used to determine the full costs of transportation. It derives most of its cost estimates from literature reviews and not from detailed analyses of data. The reviews are useful, though, because Litman explains how the original estimates were made and why estimates differ.

[168] These estimates include all vehicle types from compact cars to heavy trucks.

Litman's study includes 18 types of costs—three of which Delucchi does not include: equity/option values, barrier effects, and land use impacts. *Equity/option values* are the values society places on the increased equity and increased modal options people would have if less auto use led to more transit service. *Barrier effects* are the costs roads impose by creating barriers to pedestrians. *Land use impacts* are the costs motor vehicles cause by contributing to low-density development.[169] Litman estimates each cost for 11 modes. Estimates are also made for urban peak, urban off-peak, and rural travel. Litman's estimates are shown in Table B.2.

Litman argues that many cost-benefit analyses ignore important transportation costs. The reason is that the costs are thought to be

1. insignificant,
2. unrelated to driving,
3. impossible to quantify,
4. outweighed by the benefits of the project, or
5. difficult or politically unacceptable to incorporate into decision-making procedures.

In fact, Litman feels that techniques are now available to assign costs in most of these situations.

Litman's study also addresses cost categories that are ignored or given little attention in other studies. One issue is generated traffic. Road expansion is usually thought to increase traffic speed and induce more travel on the expanded road. Litman is concerned with the potential for road expansion to generate more *total* vehicle travel on all roads. He is not so concerned with traffic that is diverted from other routes, because this does not impose additional costs. He refers to data from previous expansions to conclude that total generated traffic increases greatly over the years. These increases can be calculated using time-dependent demand elasticities of travel.

Another cost category Litman stresses is land use impact, especially the cost of low-density development (sometimes called sprawl). Litman estimates the cost of this impact by defining four land-use densities, assigning an average service cost to each, and assuming that automobiles induce 50 percent of households to move to a residence that is one step lower in density. These costs are hard to quantify. He feels they are between $250 and $2,480 per vehicle per year and his "best-guess" estimate is $380 per vehicle ($0.025 per vehicle-mile).

[169] Delucchi argues that low density development is not a cost of motor vehicles but results from locational decisions that have costs only if other public resources are mispriced. This is discussed in Section 3.4.

Litman estimates the total cost of motor vehicles in the U.S. is between $7,100 and $26,600 per vehicle. Litman's estimate of the total external cost of motor vehicle use is between $1,500 and $13,000 per vehicle (between $0.13 and $1.14 per vehicle-mile). The range of these estimates is larger than the range of Delucchi's estimates.

Quinet

Quinet (1997) surveys several European studies of the full costs of transportation. He focuses on the parts of the studies that analyze the external costs of travel, non-market goods, and infrastructure costs. He explains that he does this because

(i) it is generally assumed that private goods are priced efficiently,
(ii) the costs of privately produced goods are usually easier to determine than the costs of goods in the other categories, and
(iii) the public is often concerned about external costs.

A summary of some of the cost estimates given in Quinet is shown in Figure B.1. The estimates are in cents per hundred passenger-miles.

Quinet points out that impacts on the environment and safety cause special problems because there are different methods of valuing these impacts. Methods include the cost of protection or abatement, the cost of damage, and the willingness to pay. Quinet feels that willingness to pay may underestimate the true cost of some effects, since these effects are often not fully perceived by those who experience them.

Quinet finds a wide range of estimates of external and infrastructure costs in different parts of Europe. Interestingly, he argues most of the variability is attributable to variation in actual costs. For example, congestion, air pollution, and infrastructure costs are generally much higher in urban areas than in rural areas. Quinet does not summarize total costs for the studies he analyzes.

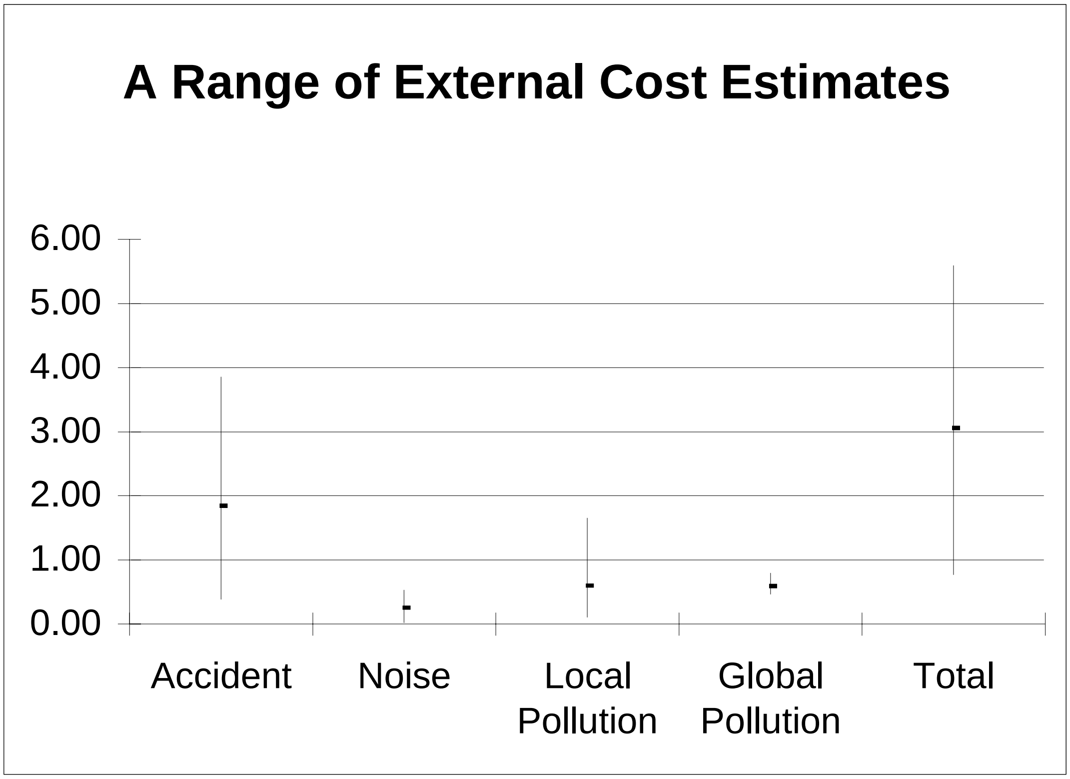

Figure B.1: A Range of External Cost Estimates

The studies that Quinet reviews estimate that the major external costs of the automobile—crashes, noise, local pollution, and global pollution—add up to 3.1 cents per 100 passenger-miles. This figure shows high, low, and average cost estimates (in cents per 100 vehicle-miles) from studies of 11 European countries.

Puget Sound Regional Council

The Puget Sound Regional Council (1995) calculated the full costs of regional transportation as an aid to its travel demand management plans. The study is reviewed here because it addresses several issues that are relevant for a study of *regional* transportation.

The Council divided costs into direct private, direct public, and indirect costs. Direct costs are out out-of-pocket expenditures paid for by the people who caused them. These costs are not caused by externalities and they do not include non-market costs such as travel time. Direct public costs are transportation-related costs that are paid for by governments. Indirect costs are external costs. These include monetary and nonmonetary costs. They also include some public costs in this category.

The Council's report does not attempt to include all costs. It excludes three categories:

(i) costs that cannot be assigned,
(ii) costs that cannot be paid, and
(iii) costs for which the region cannot make a difference.

The council takes a conservative view of which costs cannot be assigned. It designates these costs as *impacts*, using global warming as an example. A cost cannot be paid if there is no way to pay the cost *and* undo the damage caused. The council uses ozone depletion as an example because they feel there is no amount of expenditure that will repair the ozone layer once it has been depleted.

Costs for which the region cannot make a difference are costs that are caused mostly by people in other parts of the nation or the world. The Council ignores these costs because it feels these involve problems that need to be solved at a national or international level. The example of national defense expenditures to protect oil supplies is given by the Council.

The Council calculates that the total cost of transportation in the Puget Sound Region in 1995 was $9,900 per vehicle. It also calculates the external costs of travel in the region. Because the Council ignores some costs most studies include, its estimates are significantly lower than most other studies—only $490 per vehicle (4.9 cents per vehicle-mile). The major cost categories used in the Council's report are shown in Table B.3.

Table B.3: The Puget Sound Regional Council's Cost Estimates (Cost per Vehicle in 1998 Dollars)		
Cost Type	**Cost Category**	**Cost**
Private	Auto Ownership, Operating, and Parking	$6,110
	Freight	$2,390
	Transit and Taxi	$60
	Pedestrian	$10
	Bike	$1
	Total Direct Private Costs	$8,571
Direct Public	Capital and Debt	$370
	Maintenance and Operations	$270
	School bus	$40
	Other services	$140
	Total Public Costs	$820
Indirect Costs	Congestion	$320
	Air pollution	$130
	Water impacts	$10
	Solid Waste disposal	$2
	Noise	$20
	Total Indirect Costs	$492
Total Cost		$9,883

Table B.3: The Puget Sound Regional Council estimates that the regional cost of travel in 1995 was $9,900 per vehicle. All estimates are normalized by the total number of motor vehicles in the region. They do not depend on the costs estimated for autos, freight, or buses.

2. Studies of Special Types of Costs

This section covers three special studies that were selected because each attempts to calculate important types of costs in a comprehensive way. The Transportation Research Board (TRB) examines marginal costs in detail; Miller and Moffet examine external costs in detail; and the Federal Highway Administration studies highway costs in detail.

Transportation Research Board

The Transportation Research Board (1996) brought together a variety of researchers to find out if it is possible to determine the marginal social cost of various freight modes.[170] The group conducted several detailed case studies of freight shipments and recommended areas for further research. The report divides costs into the seven categories shown in Table B.4.

The case studies conducted by the Board emphasize that the marginal cost of transportation varies greatly with the situation. Marginal congestion and crash costs depend on the type of shipment, the corridor it travels on, and when the shipment is made.

The Board conducted sensitivity analyses to try to determine the accuracy of various cost estimates. A significant problem encountered was that the study could not accurately determine the relationship between crashes and traffic volume. The Board also could not determine the health costs of motor vehicle emissions. This led to significant uncertainty in final cost estimates.

Table B.4: Marginal Freight Cost Estimates

Type of Marginal Cost	Cost Using a Direct Route	Cost Using the Interstate
Infrastructure	$41	$65
Congestion	$10	$6
Crash	$49	$28
Air Pollution	$7	$7
Energy Security	$3	$4
Noise	$2	$0
Total Marginal Cost	$112	$110
Carrier’s Average Cost	$481	$564

Table B.4: The Transportation Research Board estimated the costs of travel, per truckload, for two shipments of grain from Walnut Grove, Minnesota to Winona, Minnesota. The table contains the marginal external costs and average internal costs for two alternative routes.

Miller and Moffet

The research of Miller and Moffet (1993) was conducted for the Natural Resources Defense Council (NRDC). The NRDC’s goal was to encourage

[170] The Transportation Research Board panel worked with the National Research Council and the Committee for Study of Public Policy for Surface Freight Transportation.

planners and policymakers to account for the full costs of transportation when making decisions. The NRDC felt many external costs of travel have been ignored. Their study is reviewed here because external costs are often the center of environmental concerns about the costs of transportation and because the NRDC study compared three passenger modes—auto, rail, and bus. Table B.5 summarizes the major costs the NRDC identified.

Miller and Moffet did not conduct a sensitivity analysis of their estimates, but they did explain the way the estimates were derived. Most of the research consisted of analyzing and compiling cost figures from other studies. Some cost values were notably uncertain. High and low estimates of the costs of subsidized parking, energy externalities, and air pollution varied by factors of 4, 3.3, and 1.8, respectively.

The authors had trouble determining the value of the subsidy to parking for two reasons. First, the cost of parking spaces was difficult to determine. Second, the proportion of the cost that is subsidized was difficult to determine because parking spaces are subsidized indirectly though tax breaks.

Determining the value of energy externalities was also difficult because Miller and Moffet had to hypothesize about the effects of energy usage on (i) the economy as a whole and (ii) the U.S. defense budget. Predicting the effects of large-scale changes in energy usage on either introduced a great deal of uncertainty.

Estimates of the costs of air pollution varied because air pollution has far-reaching effects on health, crops, and the climate. The authors noted that the threat of global warming is less certain than other risks of air pollution, but that it is also potentially the most serious. This uncertainty led some authors cited by Miller and Moffet to estimate values by using the cost of abatement instead of using damage estimates.

Miller and Moffet estimate the external cost of auto travel in the U.S. in 1993 to be between $445 million and $775 billion (between $3,200 and $5,500 per vehicle). These estimates are within the bounds of Delucchi’s 1990 estimates.

Federal Highway Admistration

The Federal Highway Administration (FHWA) conducted its 1997 Highway Cost Allocation Study to account for all of the costs associated with highway travel. The study includes information on external and marginal costs for different highway modes. It also includes information on costs incurred by different levels of government.

The FHWA identifies several non-agency costs that it recognizes but does not estimate. These include air pollution, greenhouse gas emissions, water quality, free parking, sprawl, and energy security costs. The study does estimate the total and marginal costs of noise, congestion, and crashes. It also provides detailed estimate of infrastructure costs for different classes of vehicles. Some of the FHWA's estimates are shown in Table B.6.

The FHWA notes several problems in determining the full costs of transportation. One is that congestion costs vary significantly by time of day and location. The FHWA also concludes that models of pavement deterioration should be improved. Improved models would be used to better determine the impact of various vehicle classes on infrastructure costs. Finally, the FHWA feels that more work should be done to synthesize information on the external costs of travel.

Table B.5: Miller and Moffet's Cost Estimates

	Costs for Autos (per vehicle)		**Costs for Buses** (per passenger-mile)		**Costs for Rail**	
Type of Cost	Low	High	Low	High	Low	High
Personal cost	$6,480	$7,770	$0.139	$0.139	$0.164	$0.164
Net capital operating costs	$530	$530	$0.239	$0.239	$0.359	$0.359
Local government services	$70	$70	$0.003	$0.003	$0.000	$0.000
Energy externalities	$380	$1,250	$0.011	$0.032	$0.005	$0.014
Congestion	$90	$90	—	—	$0.000	$0.000
Subsidized parking	$210	$840	—	—	—	—
Crashes	$820	$820	$0.008	$0.008	$0.005	$0.005
Noise	$30	$30	$0.000	$0.000	$0.000	$0.000
Building damage	$0	$0	—	—	—	—
Air pollution	$1,000	$1,840	$0.016	$0.043	$0.023	$0.073
Water pollution	$30	$30	—	—	—	—
Total External Cost	$3,160	$5,500	$0.277	$0.325	$0.392	$0.451
Total Cost	$9,640	$13,270	$0.415	$0.464	$0.560	$0.615

Table B.5: Miller and Moffet estimate the cost of passenger travel in the United States for three modes. Some of the costs of bus and rail travel were not estimated.

Table B.6: Federal Highway Administration Cost Estimates				
	Midrange Estimate Of Total Cost	Marginal External Cost (Cents per vehicle-mile)		
Cost category	(in millions)	Low	Mid	High
Noise	$4,500	0.05	0.17	0.43
Congestion	$63,600	1.28	4.84	14.22
Crashes	$350,100	1.14	2.03	6.30
Total	$418,200	2.47	7.04	20.95

Table B.6: The Federal Highway Administration estimates that the total cost of three externalities caused by travel on U.S. highways is $418 billion. The estimates are for all vehicle types in the year 2000.

3. Methodological Studies of Full Cost Accounting

There are many other studies that deal with the problem of determining the full costs of transportation. It is not possible to review them all. In this section we review papers that discuss methodological problems that recur in many studies. Gomez-Ibanez (1997) discusses the problem of defining external costs. Green (1995) also analyzes the external cost problem. Hensher (1997) examines the problem of determining the value of travel time.

Gomez-Ibanez

Gomez-Ibanez (1997) analyzes the external costs incurred in five areas that he sees as particularly problematic: parking, crashes, air pollution, energy, and infrastructure. He reviews various studies that attempt to account for these costs.

Gomez-Ibanez argues that *free parking* does not generally constitute an externality. Instead, he says the free parking provided by firms is an example of a bundled good, i.e., a good that is usually sold with other goods. At a retail establishment, for example, the parking is sold with the store's regular merchandise. Moreover, private businesses commonly bundle goods, even in highly competitive markets. This provides strong evidence that the bundling of goods is usually in consumers' private interests.

Gomez-Ibanez notes that classifying crash costs also presents problems. Three of the five studies he reviews misclassify some crash costs as external. Pain and suffering is the most important crash cost—accounting for up to two-thirds of total crash costs. Gomez-Ibanez argues that the pain and suffering of vehicle occupants can be considered an internal cost if occupants consider the risks when deciding to travel. He also points out that some studies assign crash costs to the heaviest vehicle involved in the crash and he feels this is arbitrary.

When measuring the cost of air pollution, Gomez-Ibanez says it is preferable to know the cost of damages, rather than the cost of averting the pollution. Unfortunately, damage costs are more uncertain than the costs of averting pollution. In determining the costs of infrastructure, Gomez-Ibanez feels marginal costs are more important than average costs. Average costs, however, are more often used because they are easier to calculate.

Gomez-Ibanez identifies three potential externalities resulting from energy use—special tax breaks for the petroleum industry, the costs of relying on imported oil, and the effect of U.S. oil consumption on world oil prices. He feels that these external costs of energy use may be small. He also feels that studies incorporating these costs sometimes use inconsistent perspectives. Tax breaks for petroleum industry should be accounted for only if other tax breaks (to public highways and mass transit, for example) are included. Likewise, if the losses to the U.S. from higher world oil prices are counted as a cost of travel (and the gains to the rest of the world are ignored), then costs to the rest of the world caused by global warming, for example, should also be ignored.

Gomez-Ibanez feels a major deficiency of most studies of the costs of motor vehicle use is that they use annual highway expenditures as a proxy for annual highway capital costs. He points out that some researchers feel that the U.S. highway system is depreciating faster than it is being repaired. Ignoring the marginal costs of travel leads some studies to the implausible conclusion that off-peak highway capital costs are higher than peak costs. Gomez-Ibanez also argues that Litman and Miller and Moffet engage in double-counting by including as external costs both congestion and highway capacity.

Green

Green (1995) comes to different conclusions from most other studies about which costs of auto transportation represent externalities. His focus is to determine which costs should actually be billed to auto users. He divides externalities into environmental and social. Table B.7 shows his cost estimates.

Green says an externality should be billed to automobile users only if it satisfies four criteria.

(i) It is quantifiable with reasonable levels of certainty.
(ii) It is avoidable without doing more harm than good.
(iii) The externality is proportionally attributable to auto users.
(iv) Fees are divisible to auto users in accordance with their individual contribution.

Using his criteria, Green finds that only three externalities should be billed to auto users—air pollution, crash costs to non-users, and tax subsidies to employer-provided parking. He calculates that auto users more than cover these costs with surpluses generated by current user fees.

Hensher

The value of time is an important factor in calculating the cost of travel. Hensher (1997) examines the problem of determining the value of travel time. He discusses several reasons this is complicated. First, there are differences in the value of time across people. Second, the value of time also varies across activities. The value of time spent in a car depends on driving conditions and differs from time spent in a bus, walking to a bus, or waiting for a bus.

Hensher discusses several ways of determining the value of travel time. These include both revealed and stated preference methods. Revealed preference methods are limited in the richness of data available and are useful primarily for short-run forecasting. Stated preference methods are more useful for understanding longer-term changes in behavior. Combining both types of methods is desirable.

Table B.7: Green's External Cost Estimates		
Cost Category	**Cost/Auto**	**Explanation**
Air pollution	$39	These are the single best example of an externality.
Water pollution	$0	Auto impacts are hard to sort out from other sources and the costs are difficult to quantify.
Impacts on agriculture	$0	The effects of carbon dioxide may offset the costs of ozone-induced crop damage.
Global warming	$0	The costs are speculative, and people may not be willing to accept lower standards of living to reduce them.
Wetlands loss	$0	The definition of wetland is ambiguous and the impact of auto use on wetlands is not known.
Noise	$0	Property owners considered the impacts when buying.
Resource consumption	$0	Markets induce efficient use of resources.
Waste generation	$0	These costs are the result of government failures to cover waste-handling costs.
Damage to persons	$5	Only the portion of taxes paid by non-users to subsidize harm to non-users is considered.
Parking	$1	The share of tax benefits for employee parking borne by non-users.
Congestion	$0	The costs are not borne by non-users.
Barrier effects	$0	Property owners considered the effects when buying.
Land value of roadways	$0	Changes in the economy resulting from less auto use may change the value of the land used for roadways.
Land use impacts	$0	The link between auto use and land use is complex.
Equity	$0	It is difficult to know the effects of other transportation systems on equity.
Resource acquisition	$0	Oil use may not lead to increased defense expenditures.
Damage to historic sites	$0	Deciding which sites are historic is arbitrary, and auto users pay taxes that help preserve such sites.
Effects on property values	$0	Property owners considered the effects when buying.
Total	$45	

Table B.7: Green estimates that the total external cost of automobile use in the United States is $8.5 billion.

Hensher analyzes empirical evidence on the cost of travel time. He finds values of time that range between 10 and 71 percent of wage rates. Time values are found to be higher for personal business and recreational travel than for commuting or travel while at work. Also, he finds that valuations of time per hour of travel decrease as travel time increases.

Summary

Table B.8 contains cost estimates from six recent studies of the costs of transportation. The reports by Delucchi, Litman, the Puget Sound Regional Council, and Miller and Moffet were reviewed in Section 2.1. MacKenzie et al. (1992) estimated the costs of motor vehicle use in the United States that are not borne by drivers. Ketcham and Komanoff (1992) estimate the social costs of motor vehicle use in the United States. Their study also analyzes public policy issues concerning New York City.

Table B.8: Summary of Six Studies of the Cost of Travel

		Total Cost/Vehicle		External Cost/Vehicle	
Study	Year	Low	High	Low	High
Delucchi	1990	$10,400	$20,600	$600	$5,500
Litman	1995	$7,100	$26,600	$1600	$13,000
Puget Sound	1995	$9,800	$9,800	$500	$500
Miller and Moffet	1993	$12,800	$18,800	$3,200	$5,500
MacKenzie	1989	——	——	$1,900	$1,900
Ketcham and Komanoff	1990	$9,100	$9,100	$4,600	$4,600

Table B.8: The full costs of travel are estimated to be between $7,100 and $26,600 per vehicle. The external costs are between $500 and $13,000 per vehicle.

Appendix C
Issues in Full Cost Accounting

C. Appendix: Issues in Full Cost Accounting

1. Using Cost Information

Four Uses of Transportation Cost Information

There are at least four potential uses for transportation cost data:
(i) evaluating the costs of alternative transportation projects or policies,
(ii) prioritizing transportation research and research funding,
(iii) identifying prices and other policies that increase the efficiency of the transportation system, and
(iv) establishing equitable prices or funding mechanisms.
We discuss each of these uses in turn and the demands each places on an accounting system.

Evaluating Alternatives

Cost data is often needed to evaluate alternative projects or policies. Cost-benefit analysis is the standard method of evaluating alternatives. Performing a cost-benefit analysis requires quantifying all of the costs and benefits of the alternatives being evaluated. It is important that enough data be available to determine the full costs of the alternatives. In a region-wide study, the costs of many small projects cannot be specified. The cost accounting system can still help, however, by identifying costs that should be included in project evaluations, and by providing baseline values of key decision variables. This study, for example, will provide estimates of the costs of transportation-related air pollution in the Twin Cities region. These estimates can serve as baseline values for use in cost-benefit analyses.

Prioritizing Research and Research Funding

Cost data can also be useful in prioritizing research and research funding. Because this study will show which parts of the transportation system impose the largest costs, it will help to identify areas where research may lead to significant cost savings. Suppose, for example, that delays from crashes were found to cause a significant fraction of congestion-related costs. This would suggest that research into methods of reducing minor crashes, warning drivers of crashes, and clearing crash sites quickly might yield significant benefits.

Increasing Efficiency

Increasing the efficiency of the transportation system has the potential to make all members of society better off. Establishing an efficient system can be thought of as a two-step process. In the short run the current infrastructure must be utilized well. In the long run, the right level of investment must be made. Cost data is needed for both steps.

It is a fundamental theorem of economics that in the short run, the transportation system will be efficient when the cost to the user of accessing each part of the system equals the marginal social cost of use. If, on the other hand, user cost differs significantly from marginal social cost, resources are probably being wasted.

Consider the example of a severely congested road. Suppose an additional driver experiences 10 minutes of delay and also slows traffic enough to cause delays to other users which sum to 15 minutes. The average time cost of travel is 10 minutes, but the marginal time cost is 25 minutes. In this case, travel is being underpriced and it is likely that too much travel is being undertaken. Significant gains would probably result from increasing the price of travel or from regulations that decrease the amount of travel. The feature of the accounting system that is essential is that it identify the marginal cost of various activities. Knowing the total cost of travel is usually the first step in determining the marginal cost of travel. In this report we determine the total costs of travel, and in the next one we will determine the marginal costs of travel.

In the longer run, the correct level of investment should be made in transportation infrastructure. We wish to have the right size transportation system. Note that this does not necessarily mean that no congestion will occur. It merely means that the marginal benefits from additional investment in transportation (the reduction in congestion) will be equal to the marginal cost of the investment.

Promoting Equity

The concept of equity is not as easy to define as that of efficiency. One principle of equity says that users of the transportation system who cause the same costs should be treated the same, i.e., they should pay the same amount for using the system. Efficiency also requires that users who impose the same costs are treated the same.

Another common principle is that users of the transportation system should pay the full cost of using the system. This principle was adopted by the Federal Highway Administration (1997).[171] Implementing this principle requires that the accounting system enable one to determine who bears the costs of the system. Especially important is determining who should be responsible for various governmental costs and identifying users who impose significant external costs. To meet the goal of making people who cause costs pay for them, an accounting system needs to identify classes of users who impose similar costs on the system. These questions will be the subject of the portion of this study that deals with cost incidence. For now, our goal is merely to design our accounting system so it can provide data on different user classes.

Another goal might be to use the transportation system promote social equity more generally. While everyone needs transportation and other goods and services such as food and housing, subsidizing these goods is not necessarily a good way to promote equity. In many cases, it would be better, both for disadvantaged citizens and for the rest of society, to redistribute income through general tax and transfer mechanisms than to subsidize specific goods and services.

2. Examples of Policy Applications for Cost Information

In this section we discuss the accounting data that might be needed to evaluate some policy questions. These policies are intended only to clarify and motivate our approach to determining the full costs of transportation. The examples are not designed to identify promising policies or to cover all of the relevant issues associated with particular policies.

For the policies examined below, we divide the policy-evaluation process into three steps

(i) predict the effects of the policy,
(ii) determine the changes in costs and benefits that result from the policy's effects, and
(iii) use welfare criteria to decide if the policy should be adopted.

Policy #1: Expanded Bus Service

Suppose we wish to evaluate a policy of expanding bus service. Assume that the welfare criterion to be used is cost-benefit analysis, so the new policy will

[171] Transit is often considered to be an exception to this rule, however. Reasons include the fact that transit users tend to have lower incomes than auto drivers, transit appears to be subject to economies of scale, and transit may alleviate negative externalities associated with auto driving.

be adopted if it leads to an increase in net social benefits. We do not need to go into a great deal of detail describing the new policy to gain insight into the types of cost information we will need to evaluate the policy. Assume simply that the new policy will increase the number of buses on certain routes but will not affect bus fares. The policy will increase the frequency of bus service and also increase operating speeds. Assume that the main effect of the service improvements will be to shift riders from autos to buses. Suppose further, that the shifts will be significant, but they will not change the aggregate number of bus passengers or automobiles on the affected routes by more than ten percent. Finally, assume that auto owners do not give up their vehicles, even ones who decide to use the bus.

What type of cost information do we need to apply cost-benefit analysis to the expanded bus service policy? Because most changes in auto and bus use are not large, we can use marginal cost information to calculate changes in total costs. The policy change may affect the following costs

1. the costs to the government of transit subsidies,
2. the internal costs of riding buses,
3. the internal costs of operating (but not owning) vehicles, and
4. the external costs of operating autos and buses.

The costs to the government of increased transit subsidies can be calculated by evaluating the cost of the new service and the change in transit revenue. Some of the costs of the new service might be policy specific—depending on the exact routes used and on the way the policy is implemented. Still, it will be useful to have the following general information:

A. the cost to the transit agency of owning and operating each transit vehicle, and
B. the bus fare.

The changes in the internal costs of riding buses must be evaluated for current and new riders. In addition to bus fares, other internal costs of transit use will be affected by the policy. They include

C. the cost of time spent walking to and from buses,
D. the cost of time spent waiting for buses, and
E. the cost of time spent riding buses.

We obviously need to have good data on the various time costs of transit usage for people likely to use transit.

The internal cost of operating autos will change for the people who switch from autos to buses. Major costs that will be affected include

F. the cost of time spent driving,
G. the cost of fuel, oil, and maintenance,
H. the internal costs of crashes and insurance, and
I. parking costs.

These costs do not include major costs of owning vehicles because we assumed that vehicle owners would not give up their cars.

The drivers who switch from using auto to transit will change the costs of travel for people who continue to use autos. This is because there are external costs of operating autos. Major external costs that will be reduced include

J. the time cost of congestion,
K. the external cost of crashes, and
L. the cost of air and noise pollution.

If we know the marginal costs listed under A to L, then we can calculate the total costs and benefits (cost reductions) resulting from the new policy. We should have fairly detailed information on the costs, however, including costs of specific routes and during specific periods. When and where the reductions in auto use take place will affect the cost of air pollution and congestion.

Policy #2: Allow the Use of High Occupancy Vehicle Lanes by Drivers of Single Occupancy Vehicles Who Pay Tolls

Suppose that high occupancy vehicle (HOV) lanes were opened to single-occupancy vehicles (SOVs) provided the occupant of the SOV paid a toll. Such lanes are sometimes called high occupancy toll lanes (HOT lanes). What cost data would we need to do a cost-benefit analysis of HOT lanes?

Suppose the main effect of adopting HOT lanes is to shift a small number of drivers from normal freeway lanes to HOV lanes. Assume that HOV lanes are not congested before or after they are converted to HOT lanes. The HOT lane policy will have important effects on the following costs

1. the costs to the government of setting up the HOT lanes and collecting tolls,
2. the difference in internal costs between using HOT lanes and regular freeway lanes,
3. the external costs of operating autos on the HOT lanes, and
4. the external costs of operating autos on the regular lanes.

For simplicity we assume that the number of HOVs does not change. In addition, the cost of operating a HOV does not change because there are not enough new users to cause congestion.

The government will have costs that include

A. the cost of marking the HOT lanes and setting up new road signs, and
B. the cost of collecting tolls.

We could include the toll revenue as a negative cost, if we also included it as an internal cost of HOT lane use. Equivalently, we ignore it because it is merely a transfer.

The difference in costs between using HOT lanes and regular freeway lanes should include changes in

C. the cost of time spent driving,
D. the internal costs of crashes and insurance, and
E. the costs of other operating expenses (fuel, oil, maintenance, etc.)

Changes in the last two categories will probably be small. Changes in time costs should be more significant because they provide the primary motivation for using HOT lanes.

Whether drivers use HOT lanes or regular lanes, they produce some types of externalities. We have assumed there is no congestion on HOT lanes, but external costs of HOT lane use still include

F. the external cost of crashes and
G. the cost of air and noise pollution.

Externalities on the regular lanes will include

H. the time cost of congestion,
I. the external cost of crashes, and
J. the cost of air and noise pollution.

We need to know the costs A to J to determine if HOT lanes will pass the cost-benefit test. Marginal cost data should be available for categories F to J. For categories C, D, and E we need to know the average cost of travel on the HOV lanes and the regular lanes. One of the most significant factors in deciding if the HOT lanes pass the cost-benefit test will be the value of time savings. We need accurate data on these time costs based on the route and time period because traffic speeds vary significantly by section of freeway and time of day. The value of time savings will also depend on the demographic characteristics of HOT lane users. The most important of these characteristics is probably income or wage rate. The importance is magnified here because only the people with the highest values of travel time will use HOT lanes.[172]

Policy #3: Increase the Gas Tax to Pay for Constructing New Light Rail Lines

Consider the policy of raising the gasoline tax to pay for the construction of, and operating subsidies for, new light rail transit lines. Using the cost-benefit

[172] Another consideration is that HOT lane users may get benefits both from reducing average travel time and from reducing the variability of travel time (i.e., increasing the reliability of travel). Ideally, one would also include the benefits of reducing variability in our analysis.

criteria to evaluate this policy would be similar to, although probably more complicated than, the analysis of Policy #1 (increased bus service). Suppose instead that our goal is to evaluate the equity of Policy #3. Specifically, our goal is to determine the distributional consequences of the policy across cities and townships in the region and across income groups.

Because we are interested in distributional effects, we organize our costs somewhat differently. The policy change will affect the following categories of costs:

1. the total cost of travel for people who remain transit users,
2. the total cost of travel for people who remain auto users,
3. the total cost of travel for people who switch from autos to transit, and
4. the external costs of transportation imposed on non-travelers.

We ignore the costs to the all levels of government. This is because we assume that increases in expenditures on light rail construction and operation are balanced out by increases in gas tax revenue. We also assume that the policy has no "spill over" effects on the budgets of cities or townships.

The total costs of using transit will change for current transit users. These changes include

A. the cost of transit fares,
B. the cost of time spent walking to and from transit,
C. the cost of time spent waiting for transit, and
D. the cost of time spent riding transit.

As with Policy #1, we need good data on the various time costs of transit usage.

The new policy will change the price of gasoline. It may also affect people who continue using autos by reducing congestion enough to change other operating costs. These include

E. the cost of time spent driving,
F. the cost of fuel, oil, and maintenance,
G. some reduction in the costs of crashes and insurance, and
H. parking costs.

The most significant effect is probably the change in the price of gasoline. The change in the cost of time spent driving may also be important. The costs of oil and maintenance may change slightly. Also, reduced auto use may lead to declines in the cost of crashes and parking.

People who switch from autos to transit will incur costs A to D and will save costs E to H. As with Policy #1, assume that people who switch do not reduce vehicle ownership.

The policy will also affect costs for some people who don't travel. Significant cost changes to these people may result from

I. air and noise pollution costs and
J. costs resulting from injuries due to crashes involving vehicles.

Knowing costs A to J is the first step in evaluating the equity of Policy #3. As before, our cost estimates will be much more accurate if we have data by time of day and location. The second step in evaluating equity is to assign costs to groups of people by city (or township) and by income. This means we need data that tells us the income of travelers and the location where they reside.

3. Classifying Costs as Internal or External

Externalities represent potential sources of inefficiency and inequity. They may justify policies to mitigate external costs and fees on people who produce externalities. For these reasons, the definition of externalities can generate controversy and may pit the interests of travelers against the general public or users of one mode against users of other modes.

Wide differences do exist in estimates of external costs. Consider the studies of Litman (1994), Delucchi et al. (1996), and Green (1995). Litman calculates that total costs fall within the range of Delucchi's estimates, but he calculates external costs to be higher than Delucchi's highest estimate. Green (1995), on the other hand, finds external costs to be much lower than Delucchi's lowest estimate. These differences may represent different computational techniques, but they are also due to different definitions of external costs.

The standard economic definition says that an externality occurs when one person's actions affect another person outside of the market. A broader alternative definition is that externalities occur when users do not pay the full costs that they impose.[173] An example of a good that fits the second definition, but not the first is the "free" parking by most shopping malls.[174]

We use the standard economic definition of an externality but argue that the distinction between the two definitions is not as important as it might at first appear. There are two reasons. The first is that externalities are the only type of problem that can occur with transportation. Once we realize that social and economic problems can result for a variety of reasons having nothing to do with externalities, we can free ourselves from the temptation to classify every problem with the market for transportation as an externality. A number

[173] Green appears to be using yet another definition of external costs, but his definition is not easy to summarize because he argues that different cost items are not external for a variety of reasons.
[174] Parking is not really free, of course, it is a bundled good that is being purchased with all of the other goods that are sold at the mall.

of these problems are discussed below. The second reason that the definition of an externality may not be all that important is that not all external costs should be charged to users of the transportation system. This issue is discussed in Appendix D.5.

Problems in Transportation Markets Not Caused by Externalities

There are a number of problems that can occur in transportation markets that have nothing do with externalities. As with externalities, these problems can create inefficiency and inequity. Identifying these problems is not merely a semantic exercise. It can help to clarify debates and certain types of problems may require special remedies.

One potential problem is caused by the "free" parking provided by firms to their employees or to their customers. We consider this parking to be a bundled good because it is purchased with other goods or services. From this perspective, parking is an internal cost because it is purchased with other goods. Whether parking is classified as an internal, bundled good or as an external cost, important questions remain. Is parking being provided efficiently, and if it is not, are there policies that would make the market for parking more efficient? We do not feel these questions have been resolved, but the point is that they are relevant no matter how parking is classified.[175]

Other policy questions arise because U.S. oil consumption is so high that it probably raises the world price of oil. The U.S. might be able to exploit its position as a large buyer of oil by forcing down prices. The fact that we do not do this results in a loss to the U.S. Note that this loss is not a cost to the world as a whole, it is merely a transfer between oil-consuming and oil-producing countries. While we do not consider this to be a cost, we include it in our analysis to inform policymakers. For classification purposes, we group this impact with external, monetary costs.

Two other impacts not traditionally treated as externalities are the effects transportation has through tax policy and the mispricing of government-provided goods and services. An example of an impact created by tax policy is the effect of not taxing employer-provided parking. It is widely agreed that free parking is a fringe benefit and should be taxed the same as other income.[176] We place the costs of tax impacts such as these in the monetary externality category.

[175] Moore and Thorsnes (1994) make a plausible argument for a regional tax on free parking. Whether a simple tax scheme could actually improve efficiency, however, is an empirical question, and one that we feel would be difficult to resolve.

[176] Even Green (1995) agrees, selecting it as one of only three impacts he considers proper externalities.

Other Classification Issues

While usually not as controversial as problems in classifying costs as internal or external, problems also arise in classifying costs as governmental or non-governmental. One important consideration is whether taxes and user fees should be treated as governmental costs or internal costs. One of the main goals of a full cost analysis of transportation is usually to determine an efficient and/or equitable system of taxes and user charges. To the extent that taxes or user fees reflect the full or marginal costs of cost items procured by the government, it doesn't matter if these goods are considered internal or governmental. Depending on your goal, such goods are already being priced reasonably. Such reasoning is probably what leads most analysts to classify goods covered by user fees as internal. Examples include the costs of licensing drivers and the portion of the costs of transit that are covered by fares. This division is somewhat arbitrary, however, as the distinction between taxes and user fees is not always clear. For the most part, we follow convention in determining whether governmentally provided goods and services that are paid for by user fees are considered internal. In practice, this means that transit fares are considered internal costs, and that almost all other governmentally provided goods and services are considered governmental.

In addition to direct spending, units of government can affect the costs of transportation with regulations. Most studies ignore these costs and include them as internal costs of transportation (almost all of these costs are imposed on transportation users). We are not aware of any studies of the costs of transportation that explicitly quantify these costs. We follow the convention of treating regulatory costs as internal costs, but we make some rough estimates of these costs in Section 4.5. While many regulations governing transportation probably produce significant benefits, the costs are large enough to be of concern. The costs are likely larger than any governmental cost item except roads.

A final complication for cost accounting is that governmental spending can affect the relative share of internal and external costs. Suppose, for example, that some spending is shifted from maintenance to construction. Other things equal, this will lower the quality of roads, but increase the total lane miles of roads. One result will likely lead to an increase in internal costs because vehicle maintenance costs will be higher and a decrease in external costs because congestion costs will be lower.

4. On the Completeness of Our Accounting System

We wish to account for full costs of regional transportation. How can we be sure that all costs are included? Our primary check was a comparison to other studies. We used Delucchi et al. (1996) as a guideline because it is recent and comprehensive. Our accounting system includes all of the categories included by Delucchi. It includes some categories that Delucchi discusses but does not quantify. These are the barrier effects of motor vehicles, damages caused by vibrations, and impacts on recreational areas. We will discuss all of these costs, but we will not be able to quantify all of them.

Litman (1994) and Miller and Moffet (1993) analyze two impacts of transportation that are usually neglected in other studies. These are the fiscal impacts of low-density development and costs of land used for roads. We discuss fiscal impacts in some detail, but do not consider them to be costs of transportation. We also discuss the land costs and provide a lower-bound estimate of land costs. We feel that the marginal cost of land is important for policy evaluation, but we are not sure that determining the total cost of land devoted to transportation would be economically meaningful.

In addition to identifying individual cost items, we can assess the completeness of our system from a logical point of view. There are five main categories under which all possible costs must fall. The first distinction is between costs incurred by the government and those incurred by individuals or businesses. The cost to private individuals and businesses is divided into four mutually exclusive categories. Costs must be either internal or external, either monetary or nonmonetary. This leaves four major categories of nongovernmental costs—internal monetary, internal nonmonetary, external monetary, and external nonmonetary.

As a check on the monetary costs of transportation, we examined Gross Domestic Product accounts. These accounts list all major categories of goods and services. We checked these categories to make sure that our accounting system includes all goods and services that are used for regional transportation.

5. The Damage Value and the Control Cost Methods

We feel it is important to use the damage value method to calculate the costs of pollution. The *damage value method* determines the costs of pollution from the losses or damage caused by pollution. Suppose, for example, that air pollution from autos causes a certain type of cancer. The cost of pollution is found by the damage value method by (i) determining the number of additional cases of cancer caused by the pollution and (ii) determining the amount people would pay to avoid the risk of cancer. Both steps (determining damages and assigning values) can be difficult, but econometric techniques are available that allow us to make reasonable estimates at each.

An alternative is to use the *control cost method*. This method determines costs based on the cheapest way to reduce the amount of pollution by one unit. For example, suppose the cheapest way to reduce carbon monoxide (CO) emissions from autos is to use a new type of catalytic converter (other methods of reducing emissions might include driving less or using an alternative fuel). The control cost of reducing CO emissions is the increase in cost that would be caused by switching to the new catalytic converters.[177]

While the control cost method can be useful for policy evaluation, it is not necessarily equal to the opportunity cost of pollution.[178] The *opportunity cost* of pollution is the total value of the goods and services that must be given up to produce the pollution. These goods and services can include intangible benefits such as health or clear air. We find the opportunity costs of pollution by using the damage value method. This will give us the ability to evaluate a wide range of policies that reduce pollution because we will know the benefits (the increased opportunities available) caused by reducing pollution. The control cost method gives us no similar basis for evaluating policies (although it is useful for evaluating the effectiveness to the specific policy that it examines).

6. Interpreting Cost Data

The goals of studying the full costs of transportation often include improving the efficiency and equity of the transportation system. In general, charging users for the costs they generate will help accomplish these goals. It is important that user charges (or other policies) be established on a case-by-case basis and not be imposed merely to meet some aggregate criterion such as one that says total user fees should equal total governmental costs. Delucchi makes this point explicitly.

> *First, one should resist the temptation to add up all of the unpriced costs, and express the total per gallon of gasoline, as if the optimal strategy to remedy every inefficiency were simply to raise the gasoline tax. Rather, ... the various kinds of*

[177] We assume the new converters are more expensive than the ones that are currently being used (because otherwise they would already be in use).
[178] When an externality is produced at an efficient level, then its marginal damage cost is generally equal to its marginal control costs. There is no reason to assume, however, that most externalities are currently produced at efficient levels.

inefficiencies, or market failures or imperfections, require various kinds of remedies.[179]

The reason is that many external costs are tied only indirectly to the amount of fuel consumed. An increase in fuel taxes might not increase efficiency or equity.[180] Carefully tailoring taxes and fees to remedy specific impacts might greatly reduce opposition to them. Moreover, carefully crafted taxes and fees might be much lower than current negative impacts. This is because, if they were efficient, they might greatly reduce "external" costs.

Congestion provides one example. Anderson and Mohring (1996, p 28 and p 35) estimate that the marginal external cost of traffic congestion during the morning peak travel hour in the Twin Cities metropolitan area is $1,460,000. If congestion levels were optimal, however, the cost would be between $320,000 and $670,000, depending on the elasticity of demand for travel.

A fuel tax designed to cover the current marginal external congestion cost would probably lower overall economic efficiency without doing much to reduce congestion. The tax might lower efficiency because it imposes costs that are too high on off-peak travelers. The tax would remain at a level that is higher than it should be, however, precisely because it does little to alleviate the congestion problem it was designed to help solve.[181]

Efficiency and equity can probably be increased by billing more of the external costs of transportation to users. Taxes and fees should be carefully targeted, however. It may make sense to cover some external costs with fuel taxes, but there will other costs that should not be covered with fuel taxes. Ideally, fuel taxes would be set along with other user fees, taxes, and policies to improve regional transportation.

[179] Delucchi (1996, Report #1, p 25).
[180] This is not to say that the fuel tax never a good way to mitigate externalities. One advantage fuel taxes have over most other policies is that they are cheap to implement and easy to administer.
[181] Note that even if your concern were equity and not efficiency, it still would not make sense to bill drivers for congestion with a fuel tax. This is because drivers do not impose delays on non-drivers.

Appendix D
Data and Computations

D. Appendix: Data and Computations

1. General Notes

Dealing with Uncertainty

Many of our cost estimates will involve a significant amount of uncertainty. Our goal is to eliminate uncertainty as much as possible. Where we cannot eliminate uncertainty, we will try to quantify the uncertainty that does exist.

Uncertainty will enter our estimates in various ways. These include
(i) a lack of data on certain effects of transportation,
(ii) problems attaching monetary values to effects,
(iii) problems predicting the effects of large-scale changes in the economy, and
(iv) difficulties making projections.

The lack of scientific and engineering data on some effects of transportation is not something we can do much about. We will simply try to use the best data available and, where possible, explain the degree of uncertainty in the data.

There are a number of important areas where scientific data is lacking. One problem frequently cited is a lack of data on the effects of traffic volume on crashes.[182] This data is important for determining the external costs of travel.[183] More data on the effects of auto emissions would also be useful. Gomez-Ibanez (1997, p 166) notes that the damages caused by emissions should be used to calculate costs, but the costs of controlling emissions are often used instead.

Even when effects are known, costs may not be known. We may know that a new road will save each user ten minutes a day, but not know how much the time is worth. Fortunately, significant progress has been made recently in developing and refining techniques for attaching monetary values to nonmonetary goods.

[182] For example, see the Transportation Research Board (1996, page 115).
[183] If crash costs increase faster than traffic volume then each vehicle imposes an external cost even if all are fully insured.

Another problem arises because we have trouble predicting the effects of large-scale changes in the economy. This problem is not usually encountered when individual projects are evaluated because the projects are not big enough to affect the economy as a whole. The transportation sector as a whole, though, can exert important effects on the economy.

One example is the effect of petroleum consumption on the economy. Increasing consumption drives up petroleum prices. Also, shocks to petroleum prices may lead to fluctuations in economic output. A second example is the effect of transportation infrastructure on land values. How would the values of the land used for roads and the land adjacent to roads change if significantly more or less land was devoted to roads?

Uncertainty is also generated because we are making projections. The costs of goods that are easy to determine now—gasoline, for example—cannot be predicted with certainty for the year 2020. Changes in technology, demographics, and the regional economy also introduce uncertainty.

There are a number of ways to summarize an uncertain cost estimate. The most common is to simply calculate the expected cost. Delucchi et al. (1996) give ranges within which they expect values to fall. It is possible to extend this approach by quantifying the confidence we have in various ranges of estimates. One might say, for example, that we feel there is a 50 percent chance that the cost of a gallon of gasoline in 2020 will be between $1.00 and $2.00 and a 95 percent chance that the cost will be between $0.90 and $3.00. We will try to provide estimates of this type of uncertainty and of underlying factors that affect costs. Petroleum prices, for example, might affect a wide variety of transportation-related costs.

Calculating Costs Not Directly Observed

These are several types of costs that we do not observe directly from market transactions but need to quantify. Three types are especially important: marginal costs, the costs of bundled goods, and the costs of nonmonetary goods. Additional problems are presented by goods that are used for transportation and for other purposes as well.

Knowing the marginal cost of travel is important because this help us identify potential sources of inefficiency. Calculating marginal costs can be difficult, however. The reason is that, if we observe costs at all, we usually only observe total or average costs. To determine marginal costs we need to know how costs would change if there were more or less travel.

Quantifying nonmonetary costs can be difficult. The problem is not conceptual, but empirical. We have difficulty quantifying nonmonetary costs accurately because we do not direct observe people paying these costs. While this can make estimates of nonmonetary costs very uncertain, a great deal of progress has been made recently in using statistical techniques to quantify these costs.

Bundled goods are goods that are usually purchased with other goods. Examples include garages or parking spaces that are purchased with houses. Determining the value of bundled goods may be problematic because we do not observe them purchased separately in the market. Sometimes the value of these goods can be inferred from cases where the goods are not sold as bundled goods. The value of these goods may also be inferred from the costs of inputs. The cost of a garage, for example, may be inferred from construction costs and land costs.

Another category of goods that can cause problems is a type of unbundled goods—goods that are purchased by themselves but are used for things in addition to travel. A mobile phone that can be used outside your vehicle is an example. Many even call it a car phone, but it is not used exclusively for transportation. We call these goods, non-transportation specific goods. Another example is local police services. Police monitor traffic, but they perform many other functions as well. In determining the costs of such goods we need to decide which portion of their costs to assign to travel. The basic question we attempt to answer is, “How much more is spent on these goods because of transportation?”

2. Population Projections

Notes on Table 3.5

The 1998 population estimates were produced by the U.S. Bureau of the Census. The most recent household estimates for the Minnesota counties were for 1997. We produced the Minnesota estimates for 1998 by assuming that the number of households was growing exponentially between 1997 and 2020.

The 2020 projections for the seven counties in the TCMA were produced by the Metropolitan Council. The 2020 projections for the other nine Minnesota counties were produced by the Minnesota State Demographic Center. The 2020 population projections for the three Wisconsin counties were produced by the Wisconsin Demographic Services Center. Projections of household growth were not available for the 3 Wisconsin counties. In the 16 Minnesota counties, the median projected ratio of the yearly growth rate of household and population from 1998 to 2020 was 1.12. We used this ratio to project household growth rates in the Wisconsin counties.

The latest per capita income figures were available for 1997. The Bureau of Economic Analysis projected that per capita income would grow by 0.9 percent from 1996 to 2020. Per capita income rose 4.1 percent in nominal terms in Minnesota from 1996 to 1997. We assume that real per capita income will rise at 1.0 percent in all counties after 1997.

Notes on Table 3.8

We estimated the number of vehicles in the region as follows. From FHWA (1999) we determined that there were 4,177,841 vehicles in Minnesota in 1998 and the Census Bureau estimated Minnesota's population to be 4,725,419. The ratio of people to vehicles is 1.13. The ratio of driving age population in the U.S. to registered vehicles fell from 1.15 in 1980 to 1.12 in 1990. We used census projections to estimate that the fraction to the population that will be of driving age in 2020. We estimate that in this region, the ration of population to vehicles in Minnesota will fall to 1.10 in 2020.

We assumed that the ratio of population to registered vehicles in the region we are studying is the same as the Minnesota average. There are two factors at work, people may be better able to rely on transit in the city, but they also have higher average income. We estimated vehicle-miles traveled and vehicle-hours traveled based on Barnes (1999a). These estimates are discussed more in Section 6.1.

To estimate the number of vehicle miles of travel we used the same method that we used to calculate total travel time. We divided travelers into TCMA and non-TCMA, we determined the probability of travel for each type, we used Barnes (1999b) to estimate total VMT experienced for each type, and then we calculated total person-miles of travel. VMT was then calculated based on assumed vehicle-occupancy ratios. The probabilities of travel that we used are the same as the ones in Table 6.1. Our low, mid, and high-end estimates for miles of travel per traveler were as follows: 28, 30, and 32 for 1998 TCMA; 30, 35, and 40 for 1998 non-TCMA; 30, 34, and 40 for 2020 TCMA; and 30, 38, and 45 for 2020 non-TCMA. Our low, mid, and high-end estimates for vehicle occupancy were: 1.30, 1.25, and 1.20 for 1998 TCMA; 1.35, 1.30, and 1.25 for both 1998 and 2020 non-TCMA; and 1.25, 1.20, and 1.15 for 2020 TCMA.

3. Fiscal Impacts

This section examines a simple model of the fiscal impacts. We model transportation and land use as two separate markets, but we assume the price of transportation affects the demand for low-density housing. The model ignores other potential effects of transportation on governmental budgets and land use. Our model is static, for example, so we cannot examine the question of whether our transportation system leads to the premature abandonment of public capital. In addition, we ignore the social consequences of the fact that our transportation system makes it easier for people to segregate themselves by income or race. We also ignore other reasons, besides low-density development, that land use patterns may be inefficient. These include (i) that development follows a transportation corridor, (ii) that development is leap-frog, i.e., development proceeds so that undeveloped land remains between new developments and old, and (iii) that land-uses are spatially segregate from one another.

Our model should be used only for illustrative purposes because of the uncertainty in the parameter values we use and the simplistic nature of our models.[184] Table D.1 shows the values of the parameters in our model. The values are rough estimates that were selected to be approximately the right order of magnitude. The key variables in our analysis are the elasticities of supply and demand and the cross-price elasticity of housing for transportation.

The basic problem we are analyzing is illustrated, for the transportation market only, in Figure D.1. The demand for travel is a downward-sloping function of the full cost of travel. Travel is measured in vehicle-miles and cost in dollars. The demand for travel is given by the function D(p) and the supply by the function S(p).[185] With no subsidy, equilibrium would be at D^* and P^*. We assume that transportation is subsidized at rate s. This means that transportation users only pay the fraction of transportation costs $1 - s$. Because of the subsidy, demand shifts upward to $D(p)/(1 - s)$. The efficiency loss, shown by the shaded triangle, is equal to the lost consumer and producer surplus.

[184] One way in which our model is simplistic is in the way it treats the connection between transportation and land use. Ideally, our analysis would be based on a general model of urban form in which the connection between transportation and land use is explicitly defined.
[185] The supply function shows how the cost of travel rises as the amount of travel increases. It might rise because of congestion or because of rising factor prices.

Table D.1: Parameters in the Model of Fiscal Impacts	
Parameter	**Value**
Elasticity of demand for transportation	-0.5
Elasticity of supply for transportation	1.0
Equilibrium quantity of transportation	20 billion VMT
Equilibrium price of transportation	$0.30/vehicle mile
Current subsidy for transportation	10%
Cross price elasticity of demand for housing	-0.25
Elasticity of demand for housing	-0.5
Elasticity of supply for housing	1.0
Equilibrium quantity of housing	750,000 units
Equilibrium price of housing	$10,000/year
Current subsidy for housing	5%

Table D.1: Approximate values of parameters in our model of fiscal impacts. The model is not used to estimate costs of transportation; it is only used for illustrative purposes.

The land use market is similar to the transportation market. The market we are interested in is the market for low-density or dispersed development. This covers a wide range of development, but we just consider housing units and, quite unrealistically, treat all units the same.

The efficiency loss in each market equals $\frac{1}{2} x^2 P Q E_S E_D / (E_S + E_D)$ where x is the size of the subsidy; P and Q are the equilibrium price and quantity, respectively; and E_S and E_D the elasticities of supply and demand, respectively. Given the parameters in Table D.1, the efficiency loss in the transportation market is $10 million dollars per year and the efficiency loss in the housing market is $3.125 million. These numbers, which are only meant for illustrative purposes, mean that the region would be wealthier by $13.125 million dollars per year if its transportation and land use markets were perfectly efficient. Losses are larger in the market for transportation because the subsidy in the transportation market is larger.

Because the markets for transportation and land use are interconnected, we can use transportation policy to influence the land use market. First, suppose that the subsidies for transportation are eliminated, i.e., that transportation is priced so that people pay the full costs of transportation. This yields an efficiency gain in the transportation market. Because of the connection between the transportation and housing markets, it also yields a “bonus” through its effect on the housing market. From Table 4.6, we know that the cross price elasticity of demand of housing for transportation is -0.25. This means that when the price of transportation is raised by one percent, the demand for low-density housing declines by one-fourth of one percent. We assume that this relationship holds for the housing subsidy as well. The bonus is relatively small, approximately $50,000. This is because the end of the 10 percent transportation subsidy leads to an increase in the price consumers pay for transportation of 6.6 percent, and this increase lowers the demand, and hence the inefficiency, in the housing market by ¼ of 6.6 percent or 1.66 percent.[186] $50,000 equals approximately 1.66 percent of the original $3.125 million efficiency loss in the housing market. We do not consider the “bonus” to be a cost of transportation. We merely consider it to be the result of subsidies in the market for housing.

In the case when there is no way to eliminate the subsidies in the market for housing, there are some efficiency gains that can be captured only by raising the price of transportation above its full cost. In some sense, these are costs, or at least impacts, of transportation. We calculate that if transportation was not subsidized, and was taxed at rate x, then the social gains from the tax would be

$$\tfrac{1}{2} (y^2 R_{LU} x / 6 - R_T x^2) E_S E_D / (E_S + E_D)$$

where R_{LU} is the revenue in the land use market, R_T is the revenue in the housing market, y is the subsidy in the land use market, and E_S and E_D are the elasticities of supply and demand.[187] Social welfare is maximized when x equals $y^2 R_{LU} / 12 R_T$. Given the parameters in Table 4.6, the optimum tax is 0.026 *cents* per mile. The total charge to transportation users would be approximately $5 million, but the efficiency gains from the charge are only approximately $68.

Litman calculates fiscal impacts in a different way than we do. He estimates the impact transportation has on the subsidies for housing, not on the losses from these subsidies. To gain some insight into the difference between the two approaches, we use Litman’s method to calculate fiscal impacts given the parameters in Table D.1. Litman estimates that auto use cuts the cost of travel approximately in half. Using our parameter estimates, a 100 percent increase in the cost of travel (the increase that Delucchi estimates would result if there were no autos) would raise the equilibrium price of travel by 66 percent. This would lead to a 16.6 percent decrease in the demand for low-density housing (0.25 times 66 percent). Litman the estimates the fiscal

[186] Prices consumers pay do not rise by the full 10 percent because the supply curve is elastic.
[187] Note that the elasticities are the same for both markets.

impact as the increased government subsidy due to transportation (and not, as we do, as the efficiency losses that result because of this subsidy). Given that the housing subsidy is 5 percent of $10,000, or $500 per year, the fiscal impact of automobiles is $62.5 million dollars per year (0.166 * 750,000 * $500).

Our analysis of fiscal impacts sheds some light on the debate about whether fiscal impacts should be considered a cost of transportation. Note that the "bonus" can be thought of as a loss that results in the land use market because of subsidies in the transportation market. There is some sense in which this is a cost of transportation, but it is *not* a cost that should be charged to transportation. The charges that should be levied on transportation to receive the bonus are based on the full cost of *transportation*. They do not depend on what is happening in the land use market. There is also a sense in which we might think of the optimal charge on transportation as a cost of transportation. If we are trying to determine how to price transportation, the reasoning above tells us it may make sense to place a "land use surcharge" on transportation. Given the objections to such a surcharge raised in the previous paragraph, however, the question seems moot. Finally, we note that Litman's estimates of the land use impacts of transportation are significantly larger than anything that we would interpret as a cost of transportation. His low-end estimate of $250 per vehicle implies land use impacts of over $500 million in the region. Litman assumes that transportation has a larger impact on the land use market than we do, but using his definition of land use impacts and our parameter values still results in a cost estimate of over $60 million.

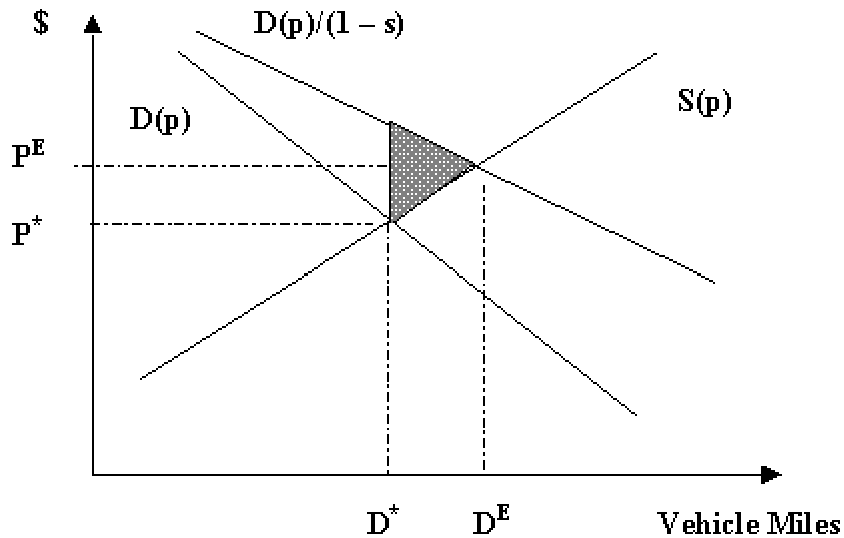

Figure D.1: Inefficiency in the Market for Transportation

When the market for transportation is subsidized, the efficiency loss represented by the shaded area results.

4. The Costs of Time

We calculate the total value of travel time to equal

$$S_c\, TV_c\, TT + S_{nc}\, (VF\, (TT - CT) + VR\, RT + VN\, NT)$$

where the first term is the monetary cost of travel and the second is the nonmonetary cost of travel. The terms in the expression are: S_c and S_{nc} (the share of commercial vehicle traffic and of non-commercial vehicle traffic, respectively), TV_c (the value of time for commercial vehicle operators), TT (total travel time), VF (the value of free flow travel time to non-commercial drivers or passengers), CT (congested travel time), VR and VN (the values of recurrent and non-recurrent congestion to non-commercial drivers or passengers, respectively), and RT and NT (the total recurrent and non-recurrent travel times, respectively).

Table D.2: Parameter Values for the Congestion Model		
Parameter	**Low**	**High**
Probability of travel in TCMA in 1998	0.850	0.900
Probability of travel in TCMA in 2020	0.850	0.920
Probability of travel outside the TCMA in 1998	0.825	0.875
Probability of travel outside the TCMA in 2020	0.840	0.920
Average time per TCMA traveler in 1998	72	76
Average time per TCMA traveler in 2020	75	85
Average time per non-TCMA traveler in 1998	72	80
Average time per non-TCMA traveler in 2020	75	90
Vehicle hours of recurrent delay in 1998 (1000s)	45	80
Vehicle occupancy in 1998 in the TCMA	1.20	1.30
Vehicle occupancy in 2020 in the TCMA	1.15	1.25
Ratio of non-recurrent to recurrent congestion	0.8:1.0	1.2:1.0
Yearly growth rate of congestion	4.0%	5.5%
Time value for commercial-vehicle operators in 1998	$9.90	$12.10
Time value for commercial-vehicle operators in 2020	$12.20	$15.05
Time value for congestion in 1998	$5.30	$9.10
Time value for recurrent congestion in 1998	$6.10	$10.60
Time value for non-recurrent congestion in 1998	$7.60	$13.65
Time value for congestion in 2020	$6.60	$11.35
Time value for recurrent congestion in 2020	$7.55	$13.20
Time value for non-recurrent congestion in 2020	$9.45	$17.00

5. The Costs of Noise

The general noise model calculates aggregate noise costs, *C*, as

$$C = \int_T^\infty K \bullet NL \left(HV \bullet AV(NL) \right) dNL$$

In this equation:

T is the threshold below which noise does no damage;
HV is the percentage loss in housing value per decibel in excess of the threshold T;
$AV(NL)$ is the aggregate value of residential property at noise level NL; and
K is a constant factor that is the product of the scale factors (the factor for time spent away from home and the annualization factor) that are described in Section 6.4.

The cost equation can be simplified if we assume that housing value, AV, does not change over the study area. In this case, the integral above can be taken independent of housing value and the other parameters, and an aggregate value for noise impacts, *NI*, can be found. The cost of noise, *C*, is given by

$$C = K \bullet NI \bullet HV \bullet AV$$

We use this simplified version of the model to calculate noise costs. Costs are calculated by multiplying *NI*, which is in units of decibels time square miles, by HV, which is in percent per decibel, and AV, which is in dollars per square mile, and by unitless scaling factors.

Delucchi found noise impacts with the Traffic Noise Model. The TNM is complicated enough that we do not attempt to present it in its entirety or to analyze the effects of most of the model's parameters on noise levels.[188] We do adjust a few of Delucchi's aggregate noise parameters to account for changes since Delucchi's study and to account for the uncertainty inherent in predicting the parameters.

We assume that most of the uncertainty in the noise impact estimates is caused by uncertainty in the three parameters—the threshold, the subtending angle, and the ground cover coefficient. The initial baseline estimates for noise impacts in 1990 are shown in Table D.3.

Noise costs are very sensitive to the first parameter, *T*, which is the threshold below which noise is not costly. The baseline figures are based on $T = 55$ decibels. Delucchi feels that 55 decibels is the right level, but notes that *T* could be as low as 50 decibels. Noise costs are very sensitive to *T* and a reduction from 55 to 50 decibels would raise them by 219 percent. The reason for this sensitivity is that housing value reductions depend only on excess decibels and not on actual noise levels. We do not have the data to rework the models to account for this limitation. Instead, we use the existing models and assume that the uncertainty brought about by *T* has a 90 percent chance of raising noise impacts between zero and 100 percent and a 10 percent chance of raising noise impacts by between 100 and 220 percent.

The second parameter we examine is the subtending angle. The subtending angle is a factor used to account for obstructions between houses and noise sources. The obstructions include objects such as hills, trees, or other houses.

[188] The model is presented in Delucchi's Report #14 (pp 3–11). Parameter estimates are discussed in the same report on pages 11 to 15.

Delucchi feels that this parameter may cause costs to vary by as much as 35 percent from his baseline estimate. We assume that there is a 90 percent chance that the impact is within 35 percent of the baseline.

Table D.3: Noise Impacts in the Twin Cities Region				
	Square Miles of Excess Decibels			
	Interstate	Other Freeways	Principal Arterials	Minor Arterials
No Barrier	102.78	51.85	8.11	7.83
Low Barrier	0.97	0.24	0.00	0.00
Med. Barrier	0.33	0.07	0.00	0.00
High Barrier	0.07	0.00	0.00	0.00

Table D.3: Baseline 1990 noise impacts for roads in the Twin Cities MSA.

The third parameter we analyze is the ground cover coefficient. Ground cover affects noise impacts because it absorbs sound. The ground cover in the Twin Cities area is thick, relative to other large urban areas in the U.S. For this reason, we ignore Delucchi's impacts for low amounts of ground cover, and look only at impacts for moderate and high levels of ground cover. Delucchi's sensitivity tests find that high levels of ground cover might lower costs by 22 percent. We assume that there is a 90 percent chance that this region's ground cover lowers noise impacts to between 78 and 100 percent.

We performed a Monte Carlo analysis to quantify the uncertainty in Delucchi's noise impact estimates. We find there is a 90 percent chance that noise impact factors are not less than 24 percent of baseline and not more than 240 percent of baseline. Our median and average noise impact estimates are 35and 43 percent above baseline, respectively. Note that we find that there is a significant chance that noise impacts will be much larger than baseline. This is because (i) uncertainty about the threshold increases our estimates of impacts and (ii) the three factors enter multiplicatively, which may cause high impacts. Our high-end and low-end estimates for the parameters in our model are shown in Table D.4.

Table D.4: Noise Model Parameters		
	Estimates	
Parameter	Lower	Upper
Aggregate noise impact, *NI* (1998)	156	517
Aggregate noise impact, *NI* (2020)	200	684
Threshold decibel level for noise to cause damage*	55	50
Subtending angle	20º	40º
Fraction of land with ground cover℥	0.50	0.30
Ratio of time affected by noise to time at home, T_0	1.25	1.35
Annualization factor, *AF*	0.05	0.08
Percent loss in housing value per excess decibel *HV*	2.0	15.0
Average units of housing per acre, *AD* (1998)	1.15	1.45
Average units of housing per acre, *AD* (2020)	1.25	1.75
Average value of each housing unit, *AV* (1998)	$110,600	$110,600
Average value of each housing unit, *AV* (2020)	$137,600	$137,600

Table D.4: Parameters used in the model of the costs of noise.

* Noise costs rise when the threshold level declines.

℥ Ground cover absorbs sound, so a higher fraction of ground cover leads to lower noise costs.

Appendix E
Special Types of Costs

E. Appendix: Special Types of Costs

In this section we discuss the costs of different modes of transportation and the marginal costs of transportation. Both of these types of costs will be examined in more detail in our report on cost incidence. The costs are not examined in more detail here because of space considerations and because the costs vary so much with vehicle, time, and location.

1. The Costs of Travel by Mode

In this section we identify some of the more important ways that costs vary across modes. We are *not* able to quantify the full costs of travel for various modes in detail. Rather, we try to explain how to use our full cost estimates to determine the costs of different modes.

Policymakers often require information about the costs of different modes of travel. This information is needed to answer such questions as, "Do fees charged to the operators of heavy trucks cover the damage that such trucks cause to roads?" or "Would accessibility be improved more by investing more money in transit or by expanding roadway capacity?"

Heavy Trucks

We define heavy trucks to be commercial, non-passenger vehicles that are larger than pickups or vans. Heavy trucks include both single-unit or combination vehicles. The costs of these trucks may vary significantly with many factors—weight, fuel consumption, number of axles, pavement thickness—so it would often be misleading to use a single cost per truck figure. Instead, it is usually better to break trucks into several categories according to the costs to be analyzed. The *Federal Highway Cost Allocation* (FHWA (1997)) is an excellent source of data on many of the costs imposed by trucks.

Governmental Costs

One important way that heavy trucks vary from other vehicles is that they can cause significant damage to pavement. Pavement damage does not increase proportionately with vehicle weight (or weight per axle, which is probably a better measure), it increases much faster so that a vehicle that is ten times as heavy as another may cause 100 or 1,000 times the damage of the lighter one. These figures depend both on how the weight of the vehicles is distributed, i.e., on how many axles the vehicle has, and on the thickness and type of pavement the vehicles are traveling on. The damage that heavy vehicles can do to pavement means that the short run marginal cost for roads of operating these vehicles can be significant, while the same costs for autos are probably small.

Heavy trucks may be responsible for increased construction costs. To reduce pavement damage from heavy trucks, for example, some roads may be constructed with thicker pavement. Accommodating trucks may also require stronger bridges, higher overpasses, wider intersections for turning, and special lanes for climbing. Quantifying all of these costs would be time-consuming, and determining the correct way to allocate such costs is also difficult. The *Federal Highway Cost Allocation Study* discusses many of these issues.

We are not aware of any studies that have tried to assign the costs of law enforcement and safety to different vehicle classes in a systematic way. A first guess is that these costs are not much different, on a per vehicle-mile basis, for trucks than for other vehicles. There are a number of factors that might roughly balance each other. Factors that tend to raise the costs of truck above those of other vehicles are (i) that trucks carry valuable cargo that may require protection and (ii) that truck crashes can be very dangerous. Factors that tend to lower the costs of trucks are (i) trucks often are equipped with communications equipment that lowers the danger of theft and may be used to inform the police of problems involving other vehicles and (ii) crashes involving trucks are relatively rare on a per vehicle-mile basis.

The costs of environmental cleanup and energy security may be closely related to fuel consumption. This seems clearest for energy security—it does not matter whether a barrel of oil is used to make gasoline for an auto or diesel for a truck, the cost per barrel is the same. The argument for environmental cleanup is less clear. Many costs may be closely related to fuel consumption, for example, cleaning up oil spills, but others will not be. In addition, some of the costs of cleanup may depend on the type of fuel used, i.e., gasoline or diesel, and trucks burn much more diesel fuel than autos.

The other large governmental cost is that of parking. It seems likely that most of these costs are related to auto use and *not* to truck use, but we are not aware of any studies that have examined this question in detail.

Internal Costs

Fixed and variable vehicle costs make up a large proportion of the internal costs of transportation. The cost of operating heavy trucks is almost certainly larger than the cost of operating autos, either on a per vehicle or a per vehicle-mile basis. The size of these costs depends on the type of vehicle. A good source of information on these costs is the American Trucking Association (see, for example, American Trucking Association (1998)).

As opposed to the time costs of passenger cars, most of the time costs of commercial vehicle operation are monetary. We calculated the time costs of truck operation based on the average wage rate for motor vehicle operators and adjusted the wage rate to reflect the cost of fringe benefits for drivers. Operators of heavy trucks probably have higher average wage rates than operators of lighter commercial vehicles. The American Trucking Association collects data on drivers' wage rates. In using this data it is important to remember to adjust wage rates to (i) account for the costs of fringe benefits and (ii) account for the wages and salaries of employees who are not drivers (mechanics or dispatchers, for example).

On a per-vehicle mile basis, truck crashes are less frequent than passenger car crashes, but more severe. National Highway Traffic Safety Administration (1998) found that in 1997 trucks were involved in 30 percent more fatal crashes per vehicle mile than passenger cars, but they were involved in 55 percent fewer crashes of other types. When trying to account for the crash costs of large trucks it is important to account for the fact that (i) trucks travel a higher share of miles in rural areas and (ii) crashes involving trucks are less likely to injure occupants, and more likely to injure non-occupants than crashes involving only passenger cars.

The costs of parking, storage, and private driveways for trucks are surely significant. As with other bundled goods, however, these costs are hard to determine accurately because it is difficult to disentangle them from other overhead costs. The costs of parking for trucks are probably of less policy concern than the costs for passenger cars. This is because not much "free" on-street parking is provided for them and neither is much "free" parking provided by retail establishments or employers.

External Costs

The costs of congestion caused by heavy trucks are likely to be larger than the costs of congestion caused by small vehicles. This is because trucks accelerate more slowly than smaller vehicles because they require larger following distances, and because they use more road space. These factors may be mitigated to some extent because truckers probably do a better job of avoiding congestion than other vehicles.

Because heavy vehicles cause more damage in crashes than lighter vehicles, it seems likely that trucks cause a disproportionate share of the external costs of crashes. This fact is mitigated somewhat because trucks are generally involved in fewer crashes, per vehicle mile, than other vehicles.[189] In addition, trucks are more likely to be insured than passenger vehicles and because trucks generally carry more insurance.

Trucks may impose different air pollution costs than other vehicles because they primarily use diesel fuel. Burning diesel fuel emits different pollutants and has different health effects than burning gasoline. Table 6.9 shows that vehicles that burn diesel probably impose larger costs, on a per vehicle basis, than those that burn gasoline.

Buses

Buses account for only a small fraction of the total number of vehicles in the region. Many internal and governmental costs can be determined from sources such as the Federal Transit Database.

Overall, bus use is generally assumed to lower the external costs of travel. This seems likely because most external costs are related to vehicle use and many passengers can ride one bus. On a per-vehicle basis, however, buses probably impose higher external costs than smaller vehicles. Overall, the external costs of buses, on a per passenger basis, depends on bus occupancy. One area of special concern for buses may be noise. This is because buses are large vehicles, they accelerate and decelerate often, and they often operate near residences.

High Occupancy Vehicles

A high occupancy vehicle (HOV) is a vehicle that is carrying two or more people. For many purposes, the cost of a high occupancy vehicle is that same as that of a normal vehicle. There are two important types of costs that are not the same. The first is the costs of crashes. More occupants usually means more injuries. The cost is probably similar for each added person.

The second type of cost that differs is time costs. The most obvious is the time of additional passengers. This is probably just equal to the time costs of people in single-occupancy vehicles, but there is a chance that the costs are lower. This is because of a second type of time cost that HOVs impose—pickup and scheduling costs. These costs may be high (the evidence is that these costs are important are because otherwise it would be easier to induce people to carpool). Scheduling and pickup costs are often ignored, but they should not be. One problem with these costs is that they are idiosyncratic.

[189] See, for example, NHTSA (1999).

Because these costs are significant, however, it seems likely that people who carpool have relatively low values of travel time.

It should be noted that policies that affect the number HOVs may not affect all of the cost of owning vehicles. The key question is whether the policy will affect vehicle ownership. In the short run, the answer is almost always no. In the longer run, the answer is less certain. In some cases, carpooling can eliminate the need for vehicles. This is probably most likely for carpooling within a household.

Walking and Bicycling

These modes generate almost no external costs. They may generate some governmental costs. It is difficult to determine the internal costs of these modes. We may infer that costs are lower if people switch to them, but people may also be income constrained. No studies have really been done to summarize these costs. The primary cost is probably the time cost. Time costs can be negative for people who enjoy walking or biking, but they could also be very high (perhaps many times the wage rate) for people who are uncomfortable walking or biking.

2. Fixed and Variable Costs of Transportation

Determining the fixed and variable costs of transportation is the first step towards calculating the marginal costs of vehicle operation. Deciding which costs are fixed and which are variable depends on the time frame being considered. In the very short run (over the period of a few days), a driver may only be able to reduce the costs of his or her vehicle by driving less and thereby reducing the variable vehicle costs of transportation. In the long run (over the period of a few years), drivers can reduce their costs by acquiring a different car, or by moving to a new location.

Most governmental costs of transportation do not vary with vehicle usage in the short run. Many of the costs of streets and highways are fixed over long periods of time. The costs of most other government-provided services for transportation can be changed more quickly, but it is not clear how much driving less will reduce these costs. In general, we would expect less than proportionate reductions in government services, because these services probably have uses beyond transportation.

Two large types of internal costs vary with vehicle use in the short run—the variable vehicle costs and the costs of travel time. Two smaller, but still very important internal costs also vary with vehicle use—the costs of crashes and most of the nonmonetary, time costs of maintaining vehicles. Two important types of costs do not vary with vehicle use in the short run. They are the fixed vehicle costs and the costs of parking and driveways. Almost all of the external cost of travel vary in the short run with vehicle use.

3. The Marginal Costs of Operating Passenger Cars

The marginal cost of transportation is the cost of one more unit of transportation. The unit most often analyzed, and the one we will examine here, is one more vehicle-mile of transportation. Marginal costs can be larger or smaller than average costs. The marginal cost of air pollution is larger than the average cost because the damage done by an additional vehicle-mile of travel rises when more pollution is in the air. The marginal cost of vehicle depreciation falls as a vehicle is driven more. The first nick that is put in the finish of a car is more costly than later nicks.

The marginal cost of transportation is generally more difficult to quantify than other costs of transportation because it cannot be observed directly. This difficulty is in addition to all of the difficulties inherent in determining the full costs of travel—problems such as determining the costs of nonmonetary goods, bundled goods, or goods that are used for purposes in addition to transportation.

Many costs of transportation are nearly fixed with respect to the number of miles of travel. Examples include the cost of a garage and the cost of managing a fleet of vehicles. Other costs vary a great deal with the type of vehicle. The amount of fuel a vehicle consumes and the damage a vehicle does to a road depend on how heavy the vehicle is. The cost of the pollution a vehicle produces depends on the type of fuel the vehicle burns, and the quality of the vehicle's emissions control systems. Some costs vary not with the total number of miles driven, but with the number of trips made. This is true of the costs of parking. The emissions of some types of pollutants depend, not just on the total amount of travel, but on the number of times a vehicle's engine is started.

Marginal cost data are very useful for policy evaluation. The reason is that policies often have relatively small effects on the amount of travel. This means that the best way to determine how costs will change as a result of the policy is to multiply the change in travel times the marginal cost of travel. When a policy does not alter travel greatly, we do not need to know the full cost of travel before and after to evaluate the policy; we can just focus on cost changes.

Below we discuss the short-run marginal cost of travel. We do not account for potential long-run changes in travel behavior. In particular, we do not account for the fact that, as people drive less they may reduce vehicle-ownership. If a policy reduced vehicle-ownership, a wide range of costs would be reduced. Of course the fixed cost of maintaining a vehicle would be eliminated. In the longer run, the costs of garages and parking might be reduced, as well as some governmental services such as the highway patrol. Not surprisingly, it is difficult to determine the costs of such long-run changes.

Marginal Governmental, Internal, and External Costs

Most governmental costs are not tied directly to the number of vehicle-miles driven. Most of the costs of road construction and maintenance do not depend on the number of passenger cars that use the road (this is not the case for heavy trucks, however). The marginal costs of many types of government services for transportation are probably less than their average costs. This is because the costs of services such as the highway patrol do not increase proportionately when vehicles are added to the transportation system.

For important types of internal costs, the marginal cost of travel is probably nearly equal to average cost of travel. This seems likely to be true for the internal costs of travel that are variable in the short run—the costs of time, the variable costs of vehicle travel, and the costs of crashes (discussed in Appendix E.2). In the short run, the remaining internal costs have no effect on the marginal cost of transportation (i.e., the fixed vehicle costs and the costs of parking).

Most of the external costs of travel are affected by the total amount of travel. Congestion rises with the total amount of travel. What is more, the marginal cost of congestion is often much greater than the average cost of congestion. The difference between average and marginal congestion costs can be determined with standard models of traffic flows. The relationship between the marginal and the average costs of crashes may depend on traffic levels and a variety of other factors. Overall, these costs may be nearly equal for crashes under most conditions. The marginal costs of air pollution are probably larger than the average costs, but they may not be much larger. Delucchi, for example, finds that air pollution costs increase almost linearly with the amount of pollution, and this means that marginal and average costs are nearly equal.