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A Review of the Literature on the Social Cost of Motor Vehicle Use in the United States

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ABSTRACT

Over the past five years, analysts and policymakers have become increasingly interested in the "full social cost" of motor vehicle use. Not surprisingly, there is little agreement about how to estimate the social cost or why, with the result that estimates and interpretations can diverge tremendously. In this situation, policymakers and others who wish to apply estimates of the social cost of motor vehicle use might find it useful to have most of the major estimates summarized and evaluated in one place. Toward this end, we review the purpose, scope, and conclusions of most of the recent major U.S. studies, and summarize the cost estimates by individual category. We also assess the level of detail of each major cost estimate in the studies.

INTRODUCTION

Over the past five years, analysts and policymakers have become increasingly interested in the full social cost of motor vehicle use. Researchers have performed social cost analyses for a variety of

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reasons, and have used them in a variety of ways, to support a wide range of policy positions. Some researchers have used a social cost analysis to argue that motor vehicles and gasoline are terrifically underpriced, while others have used them to downplay the need for drastic policy intervention in the transportation sector. In any case, social cost analyses excite considerable interest, if only because nearly all of us use motor vehicles.

Interest in full social cost accounting and socially efficient pricing has developed relatively recently. From the 1920s to the 1960s, major decisions about building and financing highways were left to "technical experts," chiefly engineers, who rarely if ever performed social cost-benefit analyses. Starting in the late 1960s, however, "a growing awareness of the human and environmental costs of roads, dams, and other infrastructure projects brought the public's faith in experts to an end" (Gifford 1993, 41). It was a short step from awareness to quantification of the costs not normally included in the narrow financial calculations of the technical experts of the past.

Today, discussions of the social costs of transportation are routine. In most accounts, the social costs of transportation include external, nonmarket, or unpriced costs, such as air pollution costs, as well as private or market costs, such as the cost of vehicles themselves. Government expenditures on motor vehicle infrastructure and services usually are included as well.

Purposes and Uses of Social Cost Analyses

By itself, a social cost analysis does not determine whether motor vehicle use on balance is good or bad, or better or worse than some alternative, or whether it is wise to tax gasoline or encourage alternative modes of travel. A social cost analysis can provide cost data, cost functions, and cost estimates, which can help analysts and policymakers evaluate the costs of transportation policies, establish efficient prices for transportation services and commodities, and prioritize research and funding. Let us examine these uses more closely[1]:

Use #1: Evaluate the costs of transportation projects, policies, and long-range scenarios. In cost-benefit analyses, policy evaluations, and scenario analyses, analysts must quantify changes to, and impacts of, transportation systems. The extent to which a generic national social cost analysis can be of use in the evaluation of a specific transportation policy or system depends, of course, on its detail and quality. At a minimum, a detailed, original social cost analysis can be mined as a source of data and methods for cost evaluations of specific projects. Beyond this, if costs are a linear function of quantity, and invariant with respect to location, then estimates of national total or average cost, which any social cost analysis will produce, may be used to estimate the incremental costs for specific projects, policies, or scenarios. Otherwise, analysts must estimate the actual nonlinear cost functions for the project, policy, or scenario at hand.

Use #2: Establish efficient prices for, and ensure efficient use of, those transportation resources or impacts that at present either are not priced but in principle should be (e.g., emissions from motor vehicles) or else are priced but not efficiently (e.g., roads). Again, at a minimum, the data and methods of a detailed social cost analysis might be useful in analyses of marginal cost prices. Beyond this, the average cost results of a social cost analysis might give analysts some idea of the magnitude of the gap between current prices (which might be zero, as in the case of pollution) and theoretically optimal prices, and inform discussions of the types of policies that might narrow the gap and induce people to use transportation resources more efficiently. And to the extent that total cost functions for the pricing problem at hand are thought to be similar to the assumed linear national cost functions of a social cost analysis, the average cost results of the national social cost analysis may be used to approximate prices for the problem at hand.

Use #3: Prioritize efforts to reduce the costs or increase the benefits of transportation. The total cost or average cost results of a social cost analysis can help analysts and policymakers rank costs (e.g., whether road dust is more damaging than ozone), track costs over time (e.g., whether the cost of air pollution is changing), and compare the costs and benefits of pollution control (e.g., whether expenditures on motor vehicle pollution control devices are more or less than the value of the pol-

[1] See also Lee (1997).

lution eliminated). This information can help people decide how to fund research and development to improve the performance and reduce the costs of transportation.

Overview of the Debate in the Literature

Not surprisingly, there is little agreement about precisely which costs should be counted in a social cost analysis, which costs are the largest, how much the social cost exceeds the market or private cost, or to what extent, if any, motor vehicle use is "underpriced." On the one hand, many recent analyses argue that the "unpaid" costs of motor vehicle use are quite large—perhaps hundreds of billions of dollars per year—and hence that automobile use is heavily "subsidized" and underpriced (e.g., MacKenzie et al 1992; Miller and Moffet 1993; Behrens et al 1992; California Energy Commission 1994; Apogee Research 1994; COWIconsult 1991; KPMG 1993; Ketcham and Komanoff 1992; Litman 1996). Others have argued that this is not true. For example, the National Research Council (NRC), in its review and analysis of automotive fuel economy, claims that "some economists argue that the societal costs of the 'externalities' associated with the use of gasoline (e.g., national security and environmental impacts) are reflected in the price and that no additional efforts to reduce automotive fuel consumption are warranted" (NRC 1992, 25). Green (1995) makes essentially the same argument. Beshers (1994) and Lockyer and Hill (1992) make the narrower claim that road-user tax and fee payments at least equal government expenditures related to motor vehicle use, and Dougher (1995) actually argues that road-user payments exceed related government outlays by a comfortable margin.

We could cite other examples. This extraordinary disagreement exists because of differing accounting systems, analytical methods, assumptions, definitions, and data sources. The root of the problem is that there are few detailed, up-to-date, conceptually sound analyses. With few exceptions, the recent estimates in the literature are based on reviews of old and often superficial cost studies. Moreover, some of the current work confuses the meaning of *externality*, *opportunity cost*, and other economic concepts. And, because there is no single, universally accepted framework for conducting a social cost analysis of motor vehicle use, it is often difficult, if not impossible, to make meaningful comparisons of the results from different studies.

In this situation, policymakers and others who wish to apply estimates of the social cost of motor vehicle use might find it useful to have most of the major estimates summarized in one place. This is the purpose of our paper: to review much of the present literature on the social cost of motor vehicle use in the United States as an aid to those who wish to use the estimates. Although we are not able to provide a simple evaluation of the overall quality of the studies, we do offer, as a partial indicator of quality, an evaluation of the degree of detail of the cost estimates in each study.

Our Review

The studies reviewed are presented in chronological order. Generally, we review the purpose, scope, and conclusions, and summarize the cost estimates by individual category. We also assess the level of detail for each major cost estimate in the studies.

In each review, the definitions and terms are those of the original study. For example, we report as an "external cost" what each study calls an external cost; we do not define external cost ourselves and then categorize estimates of each study with respect to this definition. This of course means that what may appear in different studies to be estimates of the same cost—the external cost of accidents, for example—might actually be estimates of different costs. Because of this, and because of differences in scope, timeframe, and so on, one must be careful when comparing estimates.

The bulk of the paper consists of a set of relatively detailed reviews, with tabulations of the estimates of cost and level of detail of some of the more frequently cited studies. In the main set of detailed reviews, we include only U.S. studies whose primary purpose is to estimate some significant part of the social cost of motor vehicle use. We do not include studies where the use, review, or development of estimates is secondary to application or theoretical discussion. Also, we do not review here studies of a single cost category, such as air pollution or noise (these studies are reviewed in the appropriate report of the social cost series of

Delucchi et al 1996). Although this literature review focuses specifically on U.S. studies, European studies are summarized at the end of the paper.

KEELER AND SMALL (1975)

Keeler and Small is one of the most influential and widely cited studies of the costs associated with automobile use. It was one of the first attempts to quantify the nonmarket costs of automobile use, such as time and pollution, as well as the direct costs, such as operation and maintenance. Although most of the costs in this report are now outdated, and many of the methods have been improved, we summarize Keeler and Small because of its influence on subsequent research.

Goals and Methodology

This report develops estimates of the costs of peak-hour automobile transportation in the San Francisco Bay Area. To facilitate intermodal comparisons, the authors also develop similar cost estimates for bus and rail work trips. They divide automobile trips into three main components, and estimate costs associated with each: 1) residential collection (i.e., going from a residence to the freeway interchange), 2) line-haul trip (i.e., travel by freeway to the edge of the central business district), and 3) downtown distribution. They evaluate two alternative trip lengths: 1) a 6-mile line-haul trip with an average feeder distance of 1 mile, and 2) a 12-mile trip with an average feeder distance of 2 miles. For both trips, the downtown distribution is assumed to be about 0.75 miles in length.

Capital and Maintenance Costs

To estimate highway capacity costs, Keeler and Small develop statistical cost models for construction, land acquisition, and maintenance for 1972. The data used in the three models covers all state-maintained roads in the Bay Area, including expressways, arterials, and rural roads. The construction cost model, which accounts statistically for the effects of urbanization and economies of scale on expressway construction costs, allows them to estimate the cost of a lane-mile of freeway under different degrees of urbanization and road widths. Land acquisition costs are modeled in a similar manner. Finally, maintenance costs per lane-mile are expressed as a function of the average annual vehicles per lane on the relevant stretch of road.

User Benefits and Costs of Speed

Keeler and Small recognize that there is a tradeoff between highway traffic speed and capacity utilization: faster speeds save travel time, but result in lower capacity utilization and increased fuel consumption.[2] This tradeoff is represented by speed-flow curves. They develop a model that calculates optimal tolls and volume-capacity ratios for each period as a function of time values and lane capacity costs. To develop the model, the authors adjusted the results of a study by the Institute of Transportation and Traffic Engineering that estimated speed-flow curves for the Bay Area. On the basis of a literature review, they assume the value of time in the vehicle is $3 per hour per person. Finally, they use data on hourly vehicle flows to determine the peaking characteristics of traffic.

Public Costs

For Keeler and Small, public costs include environmental costs, the costs of police and supporting social services (e.g., city planning, fire department, courts), and any maintenance costs related to the number of vehicles that use the road (as opposed to the capacity of the road). To estimate police and social service costs, the authors cite an earlier, unpublished paper (Keeler et al 1974), in which they estimated the average costs of police and supporting social services was about 4.5 mills[3] per vehicle-mile in the Bay Area. They assume that the marginal and average costs are about the same.

Their estimate of the environmental costs (i.e., noise and pollution) are also drawn from a previous paper (Keeler and Small 1974). They argue that marginal noise costs are likely to be low, no more than one or two mills per vehicle-mile, because costs are high only on quiet residential streets where an extra vehicle is likely to be

[2] However, fuel consumption is not by any means a simple linear function of speed, and in some cases a increase in the overall average speed reduces fuel consumption.

[3] One mill equals one-tenth of a cent.

noticed. They estimate that composite pollution (the average from all vehicle types) in 1973 cost about 0.92¢ per vehicle-mile. They note that this is a conservative figure, because it assumes that the cost of human illness and death is only equal to hospital bills and foregone wages. On the other hand, they expect that this cost will decline as more rigorous standards come into effect.

Accidents and Parking Costs

To estimate accident costs, Keeler and Small first compute a national average accident cost figure, and then use the results of two earlier studies (May 1955; Kihlberg and Tharp 1968) to allocate costs among the different highway types and locations. Parking costs are derived by combining the results of two engineering cost studies (Meyer et al 1965; Wilbur Smith and Associates 1965). From this, they derive estimates of the annual cost per parking space for five types of facilities (lot on central business district—CBD—fringe, lot in low land value CBD, and garage in low-, medium-, and high-value CBD). They compare the results of these studies with actual rates at privately owned parking facilities in San Francisco and find that they are consistent.

Related Work

The work of Keeler and Small spawned additional work by Small (1977) on air pollution costs. The objective of Small (1977) is "to provide some rough and aggregate measures of the economic costs imposed on society by air pollution from various transport modes in urban areas." Small uses the work of Rice (1966), Lave and Seskin (1970), and the Midwest Research Institute (1970) to estimate the total health and materials costs of air pollution. He then disaggregates the total pollution cost by specific pollutant and geography. Finally, he estimates the motor vehicle contribution to each pollutant and hence to air pollution damages. The result is an estimate of $1.64 billion in air pollution damages by automobiles, and $0.55 billion by trucks, in 1974.

FEDERAL HIGHWAY ADMINISTRATION (1982)

Goals and Methodology

In the introduction, the authors state:

> This report . . . responds to the [congressional] request for: (1) an allocation of Federal highway program costs among the various classes of highway vehicles occasioning such costs; (2) an assessment of the current Federal user charges and recommendations on any more equitable alternatives; and (3) an evaluation of the need for long-term monitoring of roadway deterioration due to traffic and other factors (p. I-1).

Although the primary focus of the report is the allocation of federal highway expenditures, appendix E of the report contains a discussion of some of the social costs and provides estimates of efficient highway user charges for some of these costs in 1981.[4] The authors focus solely on costs that vary with vehicle-miles of travel (VMT). Of 11 cost items mentioned in the report, the authors attempt to estimate costs on a VMT basis for 6: pavement repairs, vibration damages to vehicles, administration, congestion, air pollution, and noise. Costs associated with the first two items are significant for trucks, but negligible for automobiles on a VMT basis. The authors note that of the five costs not estimated in cents per VMT, "accidents looks to be the only category that might lead to a substantial increase in user charges if more were known about causal relationships. Other marginal costs may be large in the aggregate but small in relation to VMT" (p. E-52). In their conclusion, they estimate that "efficient user charges could raise almost $80 billion annually (ignoring collection costs and assuming revenues from different types of charges are additive), in contrast to the $40 billion currently spent on highways by all levels of government or the $22 billion now raised by user fees" (p. E-7). In addition, appendix E also contains a fairly detailed discussion of the standard economic theory on which their analysis is based.

[4] "Efficient highway user charges are those which will lead to the greatest surplus of benefits over costs, for a given stock of capital facilities" (p. E-17).

KANAFANI (1983)

Kanafani is a review of published estimates of the social costs of motor vehicle noise, air pollution, and accidents. As he puts it:

> the purpose of this report is to review and assess recent attempts at the evaluation of the social costs of road transport. It is intended to provide a comparative evaluation of the economic magnitude of the social costs of road transport in selected countries, particularly as occasioned by the environmental and safety impacts of motor transport" (p. 3).

He defines social costs as "those costs that are incurred by society as a whole, not solely by the users as direct costs, nor those that are incurred solely by the nonusers (pp. 2–3). He discusses the key cost components for each of these categories, and summarizes the results from other studies.

Kanafani reviews studies from several different countries, including the United States, France, and West Germany. Based on a literature review, he estimates that the social cost of noise in the United States is between $1.3 billion and $2.6 billion (0.06% to 0.1% of GDP), the social cost of air pollution ranges between $3.2 billion and $9.7 billion (0.14% to 0.36% of GDP), and accidents cost between $33.0 billion and $37.0 billion (about 2% of GDP). (The year of these estimates varies, because Kanafani reports estimates from the literature without converting or updating the dollars to a base year.)

FULLER ET AL (1983)

Background and Scope

Fuller et al was prepared in conjunction with the Federal Highway Administration (FHWA) Cost Allocation Study (1982). Although the FHWA report discusses external costs, its primary focus is on allocating government outlays. Fuller et al, on the other hand, focuses exclusively on external costs. The costs identified in this report are: congestion or interference (including accidents), air pollution, and noise damages. The analysis was performed using data for 1976 to 1979, with forecasts for 1985.

Although the report "does not undertake to develop new techniques for the measurement of damages," and instead performs "a comprehensive review of the literature and data available for each type of damage" (p. 4), it does in fact use detailed models to estimate marginal and total costs, particularly for noise.

The work of Fuller et al was incorporated into the FHWA study, and has been cited in a number of others.

Congestion and Accident Costs

Fuller et al model traffic interference and marginal accident rates as a function of the volume-to-capacity ratio on several different functional classes of roads (interstates, arterials, collectors, and local roads in rural and urban areas). They combine these functions with estimates of the value of time by functional road class, and the injury, fatality, and property damage costs of accidents, to produce marginal cost curves for the different functional classes of roads.

Air Pollution Costs

Fuller et al estimate air pollution costs in three steps. First, they review and analyze the literature on the health, vegetation, and materials damages of air pollution (e.g., Small 1977; Lave and Seskin 1970) in order to estimate dollar damages per ton of each pollutant. Second, they multiply the dollars per ton estimates by the U.S. Environmental Protection Agency estimates of grams per mile of emissions, for each pollutant, and sum across all of the pollutants, to obtain dollars per VMT. Finally, they "correct" the dollars per VMT estimates for "microscale" differences in exposure, meteorology, and other factors.

Noise Costs

Fuller et al calculate the dollar cost of motor vehicle noise in residential areas as the product of three factors:

1. the number of housing units in each of up to three distance/noise bands along roads: moderate exposure (55 to 65 dBA), significant exposure (65 to 75 dBA), and severe exposure (more than 75 dBA);
2. excess dBA of noise, equal to the noise level at the midpoint of each distance/noise band minus the threshold noise level (assumed to be 55 dBA);

3. the dollar reduction in property value per excess dBA (estimated to be $152 per excess dBA in 1977 dollars).

They use a 1970s-vintage noise generation equation to delineate the distance/noise bands, and national average data on housing density, housing value, and traffic volume. They do not consider noise costs outside of the home.

MACKENZIE ET AL (1992)

Goals and Methodology

The goal of this report is to quantify the costs of motor vehicle use in the United States that are not borne by drivers. Because it is one of the more widely cited studies on the social cost of motor vehicle use in the United States, we provide some additional comments on the derivation of their cost estimates.

Two types of costs are identified in this study: market and external. "Market costs are those that are actually reflected in economic transactions . . . (They) represent the direct, ordinary, expected costs of owning and operating a motor vehicle" (p. 7). Examples of this include vehicle purchase, fuel and maintenance costs, and road construction and repair. External costs, or externalities, are those costs, such as global warming and illnesses resulting from pollution, that are not incorporated into market transactions. Social costs are the sum of market and external costs.

The results of this study are summarized in table 1. MacKenzie et al estimate that the annual market costs not borne by drivers in 1989 was about $174.2 billion, and that the annual external costs not borne by drivers totaled $126.3 billion, for a total of approximately $300 billion.

Most of the cost estimates provided by MacKenzie et al are direct citations from another work or simple extrapolations from someone else's analysis. In the following sections, we discuss some of the estimates derived by MacKenzie et al. The costs in table 1 that we do not discuss below are essentially direct citations from other studies.

TABLE 1 Annual Social Costs of Vehicle Use not Borne by Drivers: 1989
MacKenzie et al 1992

Market costs	**$ billion**
Highway construction and repair	13.3
Highway maintenance	7.9
Highway services (police, fire, etc.)	68.0
Value of free parking	85.0
Total market costs	*174.2*
External costs	
Air pollution	10.0
Greenhouse gases	27.0
Strategic petroleum reserve	0.3
Military expenditures	25.0
Accidents	55.0
Noise	9.0
Total external costs	*126.3*
Total social costs	*300.5*

Highway Services

In this category, MacKenzie et al mean to include police motorcycle patrols and details for auto theft, parking enforcement, accident aid, fighting garage fires, and various public works expenses, such as traffic and road engineering. Their estimate of the cost of these services is from Hart (1986), which in turn is based on Hart's earlier, more detailed analysis (Hart 1985).

Hart's (1986) estimates of the national cost of highway services is an extrapolation of his detailed estimate for the city of Pasadena. This extrapolation is questionable. Moreover, it appears that some of the costs that Hart (1985; 1986), and hence MacKenzie et al, count as highway service costs are actually highway capital and operating costs in FHWA (1990), and hence are double counted in MacKenzie et al.

Employer-Paid Parking

MacKenzie et al assume that 86% of the workforce commute by car, and that 90% receive free parking, and use this to calculate that 85 million Americans receive free parking at work. Assuming that the average national value of a parking space is $1,000 (Association for Commuter Transportation 1990),[5] MacKenzie et al estimate that the annual parking subsidy for workers is about $85 billion.

[5] This estimate probably is too high (Delucchi et al 1996).

MacKenzie et al note that their estimate is for the cost of free parking at work, and therefore it does not include the cost of free parking for other kinds of trips. Because commuting to work constitutes only 26% of all vehicle trips, the cost of free parking for nonwork trips is probably not trivial.

Climate Change

Because there is so much uncertainty about the magnitude, effects, and costs of climate change, MacKenzie et al assume that "it is not possible to accurately estimate the actual costs of the current buildup of greenhouse gases" (p. 14). Instead, they develop an "imperfect" estimate, based on Jorgenson and Wilcoxen (1991), that a phased-in carbon tax that reached $60 per ton of carbon emissions (about 20¢ per gallon of gasoline) in the year 2020 would reduce emissions to 80% of the 1990 level by 2005. By assuming that motor vehicle fuel consumption would continue at roughly 1990 levels, MacKenzie et al estimate that a phased-in tax of 20¢ per gallon would eventually cost motorists about $27 billion per year, which they use as an estimate of the cost of climate change. We emphasize that this is not an estimate of the damage cost of global warming at all, but rather an estimate of the aggregate revenue from a somewhat arbitrarily assumed carbon tax on gasoline.

KETCHAM AND KOMANOFF (1992)

Goals and Methodology

Ketcham and Komanoff are concerned about the inefficient use of New York City's transportation infrastructure. They believe that the compactness of New York City creates an opportunity to provide people with a greater variety of transportation alternatives, but that public policies are skewed toward motor vehicle use and prevent these opportunities from materializing. They argue that New York City's "transportation and air pollution problems are solvable, through an approach that systematically charges motorists for a fair share of the fiscal and social costs of driving and invests much of the revenues in transit and other non-motorized modes" (p. 3). Their paper explains this approach, and how it can "benefit the vast majority of residents in the region" (p. 3).

In their report, costs are divided into four categories. 1) The costs that motorists pay when they drive are called "the direct costs of roadway transportation borne by users." Examples of these direct costs include vehicle purchase, fuel, insurance, and maintenance and repair. 2) The costs of building and maintaining roads, net of user fees such as tolls and taxes, are called "the direct costs of roadway transportation borne by non-users." 3) The portion of motor vehicle externalities, such as congestion, noise, and accidents, that is borne by motorists in the act of driving is called "the externality costs borne by users." 4) Finally, environmental damages and other external costs that are borne by society as a whole are called "externalities borne by non-users."

Much of the paper is devoted to public policy issues that focus primarily on New York City. However, a portion of the paper provides an analysis of the social costs of motor vehicle use for the whole United States. Our review focuses on Ketcham and Komanoff's national estimates, most of which they derived from their review of other published studies, particularly FHWA (1982), Eno Foundation (1991), and MacKenzie et al (1992). The results of their study are shown in table 2, and discussed in more detail below.

Direct Costs of Roadway Transportation

Ketcham and Komanoff's estimates of the direct costs borne by drivers—vehicle ownership, taxi services, school bus transport, and freight movement by truck—are from the Eno Foundation (1991). They do not estimate the national costs associated with off-street parking. Their estimates of the direct costs not borne by drivers—costs associated with roadway construction, maintenance, administration and services—are calculated from FHWA data on highway finances (FHWA 1990).

Externalities of Roadway Transportation

Accidents and congestion. In Ketcham and Komanoff, the two largest external costs are congestion ($168 billion) and accidents ($363 billion), which combined represent almost 75% of their total estimated external costs of roadway transport. To estimate congestion costs they use the cost factors in the FHWA Cost Allocation Study (1982), adjusted to

TABLE 2 Costs of Roadway Transportation in the United States: 1990
Ketcham and Komanoff 1992

Direct costs of roadway transportation borne by users	**$ billion**
Personal transportation (auto)	510.8
Taxi/limousine services	7.5
School bus transport	7.5
Freight movement by truck	272.6
Roadway construction and maintenance	48.1
Off-street parking	n.e.
Total direct costs of roadway modes (A)[1]	*798.4*
Direct costs of roadway transport borne by non-users	
Roadway construction, maintenance, admin. services	16.0
Parking	n.e.
Total direct costs not borne by users (B)	*16.0*
Externality costs borne by users	
Congestion costs	142.8
Air pollution: health and property costs	1.5
Accident costs	290.4
Noise costs	1.1
Pavement damage to vehicles	15.0
Total externality costs borne by motorists (C)	*450.8*
Externality costs borne by non-users	
Congestion costs	25.2
Air pollution: health and property costs	28.5
Accident costs	72.6
Noise costs	21.1
Vibration damage to buildings and infrastructure	6.6
Land costs	66.1
Security costs	33.4
Climate change	25.0
Total externality costs borne by non-users (D)	*278.5*
Total cost of roadway transport (A+B+C+D)	*1,544*
Direct cost of roadway transport (A+B)	*814*
External cost of roadway transport (C+D)	*729*
Roadway costs borne by everyone (B+D)	*295*

n.e. = not estimated.

[1] It is unclear why Ketcham and Komanoff did not include the cost of "Roadway construction and maintenance" in this total. It probably was an oversight. In any case, we report the totals as they are shown in the original source.

1990 dollars, but not to 1990 congestion levels. Their estimate of the national cost of motor vehicle accidents is from the Urban Institute (1991). The bulk of these two external costs is borne by users.

Land costs. According to Ketcham and Komanoff, the land cost of motor vehicle use is one of the largest external costs borne by nondrivers. They estimate the land cost nationally by scaling the estimated cost in New York City. They estimate the cost in New York City on the basis of three assumptions: that street space is one-third of the city's land area; that half of the street space is needed for movement of public vehicles, bicycles, and pedestrians (and therefore is not to be assigned to motor vehicle use); and that the value of the land in New York City is 45% of the city's $26 billion budget derived from property taxes. They then estimate the national land cost by scaling up the cost in New York City on the basis of population and labor force.

One can question all three of the assumptions that Ketcham and Komanoff use to estimate the value of land devoted to motor vehicle use in New York City. Certainly, one can question the basis for scaling the result from New York City to the entire country. Beyond that, however, it is not clear to us why they consider all of the estimated land value to be an external cost: FHWA's estimates of the cost of road construction (FHWA 1990), which Ketcham and Komanoff use in their national analysis, include the cost of acquiring rights-of-way for roads. Hence, at least some of the cost of the land is counted as an infrastructure cost, and is partially recovered from users through user fees.

Air pollution and noise. Ketcham and Komanoff derive their estimate of the cost of air pollution ($30 billion) from the estimates in the FHWA Cost Allocation study (1982), which the authors say are consistent with the ranges published in other studies. (Actually, on basis of these other studies, the authors feel that their estimate of $30 billion is conservative.) Noise cost estimates are derived from a 1981 study for FHWA by the Institute of Urban and Regional Research at the University of Iowa (Hokanson et al 1981), which estimates the nationwide costs of noise in 1977. Ketcham and Komanoff make some adjustments to this figure to account for differences between 1977 and 1990.

HANSON (1992)

Goals and Methodology

Hanson's article "delineates the nature and magnitude of automobile subsidies in the United States and considers their significance for transportation and land use policy. The central argument . . . is that the U.S. transportation system, based on and designed largely for the automobile, has been systematically subsidized in a way that produces a more dispersed settlement pattern than would have otherwise evolved" (p. 60).

In Hanson, an automobile subsidy is any direct cost of providing for and using the automobile system that is not paid for privately or through a transportation fee. Hanson uses data provided by the state of Wisconsin, supplemented with a review of existing studies, to estimate these subsidies. Wisconsin is used because it is near the national average for the percentage of state highway user revenues shared with local governments, and because Wisconsin is unique in its extensive reporting requirements.

Direct Costs

Hanson divides direct costs into three major categories. Highway construction includes right-of-way acquisition, engineering, signage, and construction costs for pavement, bridges, culverts, and storm sewers. Highway maintenance includes maintenance of pavements, bridges, culverts, storm sewers, and traffic control devices, and snow plowing. Other highway infrastructure includes machinery and vehicles, buildings, debt service payments, and street lighting. Hanson analyzes government data to make these estimates. After estimating the gross direct costs, Hanson nets out offsetting user revenues to calculate the subsidy to motor vehicle use.

Externalities and Other Indirect Subsidies

Hanson estimates the external costs of air pollution, water pollution resulting from road salt use, personal injury and lost earnings associated with accidents, land-use opportunity costs for land removed from other sources, and petroleum subsidies. Hanson points out that there are a number of other external costs, such as noise and community disruption, that he has not attempted to quantify.

In order to estimate air pollution costs for Madison, Wisconsin, he notes that the midpoint estimate in the studies of national costs that he reviewed was $7 billion. To allocate a share of this to Madison, he multiplied this midpoint figure by the ratio of the population of Madison to the population of the United States.

To estimate the personal injury costs associated with accidents, Hanson multiplies the number of accidents in 1982 (1,628 according to the Wisconsin Department of Transportation, WDOT) by the personal injury cost per accident ($7,700). He also uses a WDOT estimate of the cost of lost earnings, $1.6 million. These estimates do not include a value for fatalities.

Hanson also uses WDOT data to generate an estimate of the value of property damages resulting from accidents. However, in quantifying the amount that should be considered a subsidy, he assumes that "because a substantial portion of property damage is insured by automobile users via separate insurance coverage, and to a lesser degree by direct payments, those costs are mostly internalized and, therefore, not included."

Hanson assumes that "a land opportunity cost occurs when land, used for roads, could have been used for some other purpose." A subsidy will result if more than the "optimal" amount of land is used for highways. To provide a rough estimate of this subsidy, Hanson assumes that one-third of the surface area of highways in Madison is unnecessary. This is based on two assumptions. First, according to Cervero (1989), local roads provide 80% of the lane-miles, but only 15% of the vehicle-miles. Second, he assumes that higher travel costs would reduce travel demand and alter land use in the long run. He uses foregone property tax revenues to estimate the cost of land, and calculates that, with the existing property tax rates, Madison would gain $1 million in revenues if the area of roadways was reduced by one-third.

Hanson notes that air emissions from motor vehicles contribute to water pollution and acid rain, but believes there are few reliable published estimates of the damages. As a result, he focuses only on damages from road salt. He begins with the estimates provided by Murray and Ernst (1976), adjusts their figures to avoid double counting, converts their estimate to 1983 dollars, and finally allocates a portion of the cost to Madison on the basis of the population in the snowbelt "salt zone."

To estimate petroleum subsidies, Hanson uses Hines' (1988) estimates of the depletion allowances and other tax breaks received by the petroleum industry in 1984. This is allocated to Madison by combining gasoline consumption for personal travel in Madison with the subsidy level per British thermal unit (Btu).

CONGRESSIONAL RESEARCH SERVICE (BEHRENS ET AL 1992)

Goals and Methodology

Congress asked the Congressional Research Service (CRS) to summarize for the U.S. Alternative Fuels Council what is known about monetary estimates of the side effects (external costs) of oil used in highway transportation. In its analysis, CRS considers three kinds of costs: economic costs stemming from the dependence on world oil markets, national defense costs, and health and environmental impacts. They review previously published studies, and develop what they believe are reasonable low- to mid-range estimates of the monetary value of these external costs.

The results of this study are summarized in table 3. Note that CRS, like Kanafani (1983), reports estimates directly from the literature without converting or updating the dollars to a base year.

TABLE 3 Estimated External Costs of Oil Used in Transport
Congressional Research Service
(Behrens et al 1992)
(Billions of dollars)

Cost category	Low	High
Risk of supply disruption	3.2	4.9
Monopsony effects	11.3	13.0
Military expenditures	0.3	5.0
Air pollution—human health	3.6	3.6
Air pollution—crop damages	1.1	1.1
Air pollution—material damages	0.3	0.3
Air pollution—visibility	0.8	0.8
Oil spills	n. e.	n. e.
Total with monopsony effects[1]	*10.5*	*17.0*
Total without monopsony effects[1]	*21.8*	*30.0*

n.e. = not estimated.
[1] The estimates in each category and the totals shown here are those reported in Behrens et al and are based on a review of the literature. The authors did not convert the dollar estimates in the literature to a single dollar base year. The totals are the overall estimates, not the sum of the individual estimates.

Economic Costs of Oil Dependence

CRS considers two effects on the economy due to oil dependency: the risk of a supply disruption, and the market power or monopsony effect. The former is the result of exposure to "possible market manipulation or disruption by exporting nations" (p. 7). Some of the potential adverse impacts include higher inflation and unemployment, as well as possible balance of payments and exchange rate effects. The range of estimates of the costs associated with this are from zero to $10 per barrel. Multiplying the results of a mid-range estimate by U.S. oil imports for 1990, the authors estimate a $6 billion to $9 billion cost to the economy due to the risk of disruption.

According to CRS, "the market power or monopsony component reflects the influence on the world price that a large importer such as the United States causes" (p. 7). The economic cost of this is the failure to transfer wealth to U.S. citizens by reducing U.S. oil imports (which would result in lower world oil prices). Based on a literature review, the authors use a mid-range estimate between $21 billion and $24 billion for not exploiting this power.

National Defense Costs

CRS considers military expenditures that could be avoided if the United States and other industrialized countries did not need to import oil from the Persian Gulf (p. 23). In developing its estimate, CRS reviews the estimates provided by the U.S. General Accounting Office (1991), Ravenal (1991), and Kaufmann and Steinbruner (1991).

CRS discusses at length some of the difficulties of attributing military expenditures to the defense of Persian Gulf oil interests. As a result of these difficulties, cost estimates can range from a few cents to a few hundred dollars per barrel. The authors conclude that attempts to reduce U.S. dependence on imported oil will probably have little effect on the amount spent in the Persian Gulf. They also note that attempts to internalize these costs may not have a significant impact on reducing the costs.

Health and Environmental Impacts

CRS estimates the impacts of motor vehicle pollution on human health, crop yields, certain species in forests, materials, and visibility, but not climate change. The authors acknowledge that there will be damage to ecosystems resulting from oil spills, but believe that there are no "defendable estimates of the monetary value of the external costs associated with oil spills" (p. 55).

CRS emphasizes that "the effects on the environment and health . . . are imperfectly understood. And how these environmental and health damages can be approximated in monetary terms is controversial" (p. 10).

On the basis of a literature review, the authors conclude that a "reasonable estimate of the lower range of health and welfare damages resulting from transportation-related pollution is between $5 and $6 billion per year" (p. 52). We note that this is one of the lower estimates in the literature.

MILLER AND MOFFET (1993)

Through a survey of existing literature, Miller and Moffet attempt to develop estimates of the full cost of transportation in the United States in 1990. In addition to estimating the costs associated with automobile transportation, they also estimate these costs for bus and rail transportation. Table 4 summarizes their estimates of the costs of automobile use.

They consider three categories of costs. "Personal costs," which include the costs to purchase, register, maintain, and operate a car, are borne solely by the vehicle owner. "Government subsidies" include direct construction and maintenance expenditures plus other government expenses directly associated with providing transportation services. Miller and Moffet's estimate of these costs are net of user fees. "Societal costs" include all other indirect costs, or what is often referred to as externalities. Examples of this include energy dependence, pollution, and congestion.

Miller and Moffet estimate that the full annual costs of automobile transportation were between $1.1 trillion and $1.6 trillion in 1990. They estimate that $72 billion of this was government subsidies, between $310 billion and $592 billion were societal costs, and the remaining $775 billion to $930 billion were personal costs incurred by the vehicle owners. However, one must be cautious in interpreting their estimate of the full annual costs of automobile transportation. The bulk of this estimate is comprised of personal costs entirely borne by vehicle users, and it can be somewhat confusing when this figure is added to net government expenditures, rather then gross government expenditures. Total unpaid social costs, that is, net government subsidies plus societal costs, totaled between $378 billion and $660 billion in 1990.

TABLE 4 The Full Cost of Transportation in the United States: 1990
Miller and Moffet 1993

Category	$ billion
Personal costs	
Ownership and maintenance	775–930
Government subsidies	
Capital and operating expenses	64.0
Local government expenses	8.0
Total government subsidies	*72.0*
Societal costs	
Energy dependence	45–150
Congestion	11.0
Parking	25–100
Accidents	98.0
Noise	2.7–4.4
Building damage	0.3
Air pollution	120–220
Water pollution	3.8
Total societal costs	*310–592*
Unquantified costs	
Wetlands lost	n.e.
Agricultural land lost	n.e.
Damage to historic property	n.e.
Changes in property value	n.e.
Equity effects	n.e.
Urban sprawl	n.e.
Total government and societal costs	*378–660*
Total costs	1,153–1,590

n.e. = not estimated.

Note: This table is reproduced directly from Miller and Moffet. Note that both the total government and societal costs and the total costs do not add up, presumably due to rounding.

KPMG PEAT MARWICK, STEVENSON, AND KELLOGG (1993)

As part of a long-range transport planning initiative, the Greater Vancouver Regional District and the Province of British Columbia hired KPMG Peat Marwick, Stevenson, and Kellogg to analyze the full costs of various modes of passenger transportation in British Columbia. The resulting study estimates the total cost of transporting people in the Lower Mainland in 1991, and calculates the average cost "per unit" of travel, by different modes, for urban peak, urban off-peak and suburban travel (p. iii). There are three specific goals of the analysis: 1) estimate the total economic costs of different modes of passenger transport in the region; 2) determine how much is paid by users of different transport modes and how much is paid by non-users; and 3) provide a broad basis for assumptions and recommendations regarding the future levels and methods of pricing the movement of people in the region.

The authors utilize a computer model to estimate these costs for five different modes of private transport (average car, fuel-efficient car, car pool, van pool, and motorcycle), four modes of public transport (diesel bus, trolley bus, SkyTrain, and SeaBus), and three modes of nonmotorized transport (bicycle, walking, and telecommuting). The costs are evaluated for travel in urban areas during peak and off-peak hours, as well as for suburban travel. They find that the total subsidy for automobile transport in 1991 was $2.7 billion Canadian dollars (C$2.7 billion).

The authors estimate that the total cost associated with the transportation in the Lower Mainland of British Columbia in 1991 was approximately C$13.6 billion. The five modes of transport via private motor vehicles accounted for C$11.7 billion (86%) of the total cost, and were subsidized at approximately C$2.7 billion, or 23% of the total cost of private transport.

CALIFORNIA ENERGY COMMISSION (1994)

Purpose

In the aftermath of the 1991 Persian Gulf War, the California legislature passed, and Governor Pete Wilson signed into law, Senate Bill 1214, which provides, in part, that:

> it is the policy of this state to fully evaluate the economic and environmental costs of petroleum use . . . including the costs and value of environmental externalities, and to establish a state transportation energy policy that results in the least environmental and economic cost to the state (CEC 1994, 1).

The task of developing a "least environmental and economic cost scenario," including the costs and values of environmental externalities and energy security, was assigned to the California Energy Commission (CEC), as part of its biennial report. To fulfill this charge, CEC analyzed the social costs and benefits of several state and national energy policies, relative to a base case. The policy measures included increasing fuel taxes, increasing fuel economy standards, and subsidizing the price of alternative fuels and vehicles. For each policy, CEC estimated the differences in travel, emissions, fuel use, and so forth, relative to the base case. The value of the differences was the net social cost or benefit of the policy.

Estimates of Avoidable Costs

CEC quantified several kinds of social costs: travel time, accidents, infrastructure maintenance and repair, governmental services, air pollution, carbon dioxide, petroleum spills, and energy security.

Travel time. CEC used the "Personal Vehicle Model," a demand forecasting model that projects vehicle stock, VMT, and fuel consumption for personal cars and trucks, to estimate that congestion costs, including the disutility of aggravation, are $10.60 per hour (1992$). CEC also estimated the actual net change in travel time in Los Angeles under the various policy scenarios.

Accidents. The cost of accidents is estimated by multiplying the cost per injury or death by the number of injuries or deaths, for several kinds of injuries. Ted Miller, lead author of the much-cited Urban Institute (1991) study of the cost of highway crashes, developed California-specific unit costs for the Commission. CEC uses the Urban Institute study to allocate costs to different vehicle classes.

Air pollution. To calculate the cost per mile of air pollution, CEC multiplied the change in total emissions (estimated using California's mobile source emissions inventory models, EMFAC and

BURDEN), by the dollar-per-ton value of emissions, and then divided by the change in travel. The dollar-per-ton values, estimated for nitrogen oxides, sulfur oxides, reactive organic gases, particulate matter, and carbon monoxide, are from the Air Quality Valuation Model, a damage function model that estimates the cost of air pollution from powerplants in California air basins. CEC acknowledges that damage values for powerplants might not apply to motor vehicles.

Carbon dioxide. Because, according to CEC, "reliable data on damage functions are not available . . . the Energy Commission uses carbon emission control costs alone to represent carbon values" (p. 3G-1). CEC adopted its own control cost estimate of $28 per ton-carbon from its 1990 electricity report. To estimate the total carbon dioxide cost of different policies, CEC multiplied the cost per ton by the change in carbon emissions under the different scenarios. Carbon emissions rates for different fuel cycles were taken from reports by CEC, the U.S. Environmental Protection Agency, and DeLuchi et al (1987).

APOGEE RESEARCH (1994)

The report by Apogee Research, prepared for the Conservation Law Foundation, presents the results of case studies of intraurban passenger transportation in Boston, Massachusetts, and Portland, Maine. The report "attempts to develop a framework for comparing transportation costs and to provide specific quantification of the costs of passenger transportation" in the two regions analyzed. The methodology developed by the authors was constructed such that it could be adapted for other case studies.

The study evaluates nine "sub-modes" of transportation: single-occupancy vehicles (SOVs) on expressways, SOVs off expressways, high-occupancy vehicles (HOVs) on expressways, HOVs off expressways, commuter rail, rail transit, bus, bicycle, and walking. It also distinguishes between high, medium, and low population densities, and between on-peak and off-peak travel. Table 5 summarizes the cost categories used in their report.

Their report is divided into four main sections. The first is a comprehensive literature review that provides background information for the analytic framework. The next section describes the methodology used in the case studies, and defines the costs and travel parameters studied. The analytic framework is then applied to estimate the costs in Portland and Boston. Finally, the report presents the results of the case studies and suggests some policy responses.

Apogee Research focuses primarily on developing original estimates for user and governmental costs, and relies on existing estimates for the societal costs. Wherever possible, they try to use data from the relevant agencies to develop their cost estimates. This is supplemented by literature reviews when data were unavailable. The cost estimates derived from these data are primarily the result of relatively simple, yet intuitively reasonable, analysis, rather than the product of more complex and rigorous statistical models. The authors acknowledge this, stating that "while additional research and analysis on particular costs would undoubtedly lead to more refined results, we believe that these case studies provide a good sense of the magnitude of the various costs of transportation" (p. 59).

The policy recommendations provided in the report are common to most analyses: reduce trip length, favor lower cost modes, increase vehicle occupancy, explore single occupancy vehicle pricing, and educate the public on transportation costs.

LEE (1994)

This draft paper examines the debate about the extent to which drivers pay the costs associated with motor vehicle use. Lee uses a "full cost pricing" approach to analyze this issue. "Full cost pricing is a policy strategy based on the idea that the economy would benefit from imposing the discipline on each enterprise that all its costs should be recovered from consumers, i.e., total user revenues should equal total cost for each activity" (p. 1).

Lee is concerned more with theoretical issues than with estimates of costs. After discussing the fundamental economic issues pertaining to full and marginal cost pricing, Lee outlines a strategy for estimating these costs. His focus is not so much on estimating costs as developing an appropriate analytical structure. He discusses which costs should be included in a social costs analysis, why they

TABLE 5 Transportation Cost Categories
Apogee Research 1994

User costs[1]	Governmental costs[2]	Societal costs[3]
Vehicle purchase and debt	Capital investment—land, structures, vehicles	Parking—free private
Gas, oil, tires[4]	Operations and maintenance	Pollution—health care, cost of control, productivity loss, environmental harm
Repairs, parts	Driver education and DMV	Private infrastructure repair—vibration damage, etc.
Auto rentals	Police, judicial system, and fire	Accidents—health insurance, productivity loss, pain and suffering
Auto insurance	Parking—public, tax breaks	Energy—trade effects
Tolls[4]	Energy—security	Noise
Transit fares[4]	Accidents—public assistance	Land loss—urban, crop value, wetlands
Registration, licensing and annual taxes[4]	Pollution—public assistance	Property values and aesthetics
Parking—paid		Induced land-use patterns
Parking—housing cost		
Accidents—private expense		
Travel time		

DMV = Department of Motor Vehicles.

[1] User costs are the costs borne by vehicle owners: the direct ownership and operating costs, such as gas, oil and parts; the indirect costs, such as garage parking and accident risks.

[2] Governmental costs include expenditures that are not explicitly for the purpose of transportation, but which nevertheless are necessitated by vehicle travel.

[3] Societal costs of transportation are those paid by neither the traveler nor the government, but rather are spread across the economy.

[4] These items are, or include, dedicated taxes that fund governmental transportation expenditures and must be deducted from costs in

should be estimated, and important theoretical issues on how they should be calculated. However, Lee does make some estimates of unpaid costs, primarily on the basis of a literature review. Table 6 summarizes his estimates.

COHEN (1994)

The goal of this study is to "update and extend the analysis of the external costs of highway operations that was reported in appendix E of the final report on the 1982 Federal Highway Cost Allocation Study" (p. 1). The present report actually is an interim report. It summarizes the literature on estimating external costs, assesses recent efforts to develop national estimates of these costs, and recommends procedures that should be used to develop cost models and estimate the monetary value of external costs.

When the final report is completed, it will contain three primary elements. First, it will provide estimates of the external costs due to congestion delay, highway crashes, noise, and air pollution. Second, the report will include a simple computer model to reproduce these results in future analyses. Third, it will include a detailed discussion of institutional barriers, equity implications, and political consideration that affect marginal cost pricing and other methods to charge highway users for external costs.

For the most part, the literature review in the interim report refers to studies that we have reviewed here. And, because this is an interim report, there are no actual cost estimates for us to report. However, it appears that the authors are in the process of developing a useful framework for making original estimates of these costs. Recent unpublished manuscripts from this project indicate that they are using external cost estimation methods similar to those summarized in Delucchi et al (1996).

TABLE 6 Estimates of Highway Costs not Recovered from Users: 1991
Lee 1994

Cost group	Cost item	$ billion
Highway capital	Land (interest)	74.7
	Construction, capital expenditures	42.5
	Construction, interest	26.3
	Land acquisition and clearance	n.e.
	Relocation of prior uses and residents	n.e.
	Neighborhood disruption	n.e.
	Removal of wetlands, aquifer recharge	n.e.
	Uncontrolled construction noise, dust, runoff	n.e.
	Heat island effect	n.e.
Highway maintenance	Pavement, right-of-way, and structures	20.4
Administration	Administration and research	6.9
	Traffic police	7.8
Parking	Commuting	52.9
	Shopping, recreation, services	14.9
	Environmental degradation	n.e.
Vehicle ownership	Disposal of scrapped or abandoned vehicles	0.7
Vehicle operation	Pollution from tires	3.0
	Pollution from used oil and lubricants	0.5
	Pollution from toxic materials	0.0
Fuel and oil	Strategic petroleum reserve	4.4
	Tax subsidies to production	9.0
Accidental loss	Government compensation for natural disaster	n.e.
	Public medical costs	8.5
	Uncompensated losses	5.9
Pollution	Air	43.4
	Water	10.9
	Noise and vibration	6.4
	Noise barriers	5.1
Social overhead	Local fuel tax exemptions	4.3
	Federal gasohol exemption	1.2
	Federal corporate income tax	3.4
	State government sales taxes	13.2
	Local government property taxes	16.0
	Total cost	*382.1*
	Current user revenues	*52.1*
	Profit (loss)	*(330.0)*

n.e. = not estimated.

LITMAN (1996)

The purpose of Litman's analysis is to establish a foundation for analyzing transportation costs. After estimating the costs for the United States in 1994, primarily through an extensive literature review, he discusses the implications of these costs with respect to efficiency, equity, land use, stakeholder perspectives, and future policy options.

Litman classifies transportation costs into three dichotomies, as shown in table 7: internal (users) or external (social) costs, market or nonmarket costs, and fixed or variable costs. He estimates these costs for 11 different modes of transportation. In order to estimate the costs, Litman conducted a literature review, and from this information, generates his "best guess" at the true cost.

TABLE 7 Motor Vehicle Transportation Costs
Litman 1996

		Variable	Fixed
Internal	*Market*	Fuel Short-term parking Vehicle maintenance (part)	Vehicle purchase Vehicle registration Insurance payments Long-term parking facilities Vehicle maintenance (part)
	Nonmarket	User time and stress User accident risk	
External	*Market*	Road maintenance Traffic law enforcement Insurance disbursements	Road construction "Free" or subsidized parking Traffic planning Street lighting
	Nonmarket	Congestion delays Environmental impacts Uncompensated accident risk	Land-use impacts Social inequity

His estimates of costs for motor vehicles are summarized in table 8. In 1994, internal costs were about $1.6 trillion, and accounted for about two-thirds of the total costs. External costs amounted to about $0.8 trillion.

In Litman's analysis, the value of user time alone accounts for over 20% of the total cost of the average automobile used during peak times in urban areas. As a basis for deriving the costs, Litman uses a 1992 value of time schedule for British Columbia because it is "current and comprehensive." That study assumes that the value of the personal vehicle driver's time is 50% of the current average wage, which Litman assumes to be $12 per hour. He calculates total costs assuming average speeds of 30 mph (urban peak), 35 mph (urban off-peak), and 40 mph (rural), and an hourly cost premium of 16.5% in congestion.

In Litman's analysis, land-use impacts and parking costs are the largest external costs associated with an average car. On the basis of a review of the literature, Litman assumes that the average automobile off-street parking cost is around $3 per day.

TABLE 8 Motor Vehicle Costs in the United States: 1994
Litman 1996
(Billions of 1994 dollars)

	Internal costs	External costs	Total costs
Urban peak	327	281	607
Urban off-peak	653	313	966
Rural	589	184	773
Total	*1,569*	*778*	*2,347*

According to Litman, "a primary conclusion of this research is that a major portion of transportation costs are external, fixed, or non-market . . . This underpricing leads to transportation patterns that are economically inefficient and inequitable . . ." (p. vi).

LEVINSON ET AL (1996)[6]

Goals and Methodology

The goal of this report is to compare the costs of intercity passenger travel by air, automobile, and high-speed rail in the California Corridor (i.e., between San Francisco and Los Angeles). The policy question they address is whether the full costs of developing a high-speed rail line are comparable to the costs of expanding the air or highway transportation systems. To accomplish this, they develop long- and short-run average and marginal cost functions for each of the three modes of travel. Our discussion of this report will be limited to their analysis of the highway costs.

[6]In this review, we refer to the pair of 1996 papers by Levinson et al (1996a and 1996b) as Levinson et al (1996). The later paper, 1996b, is a condensed journal article that summarizes the more detailed research report, 1996a.

TABLE 9 Long-Run Full Costs of the Highway System
Levinson et al 1996
(Dollars per vehicle-kilometer)

Cost category	Short-run costs: Marginal	Short-run costs: Average	Long-run costs: Marginal	Long-run costs: Average
Infrastructure costs				
Construction and maintenance	0.0055	0.0008	0.0180	0.0174
External costs				
Accidents	0.0350	0.0310	0.0350	0.0310
Congestion	0.0330	0.0680	0.0330	0.0068
Noise	0.0090	0.0060	0.0090	0.0060
Pollution	0.0046	0.0046	0.0046	0.0046
Total external costs	*0.0816*	*0.1096*	*0.0816*	*0.0484*
User costs				
Fixed + variable	0.0490	0.1300	0.0490	0.1300
Time	0.5000	0.5000	0.1500	0.1500
Total user costs	*0.5490*	*0.6300*	*0.1990*	*0.2800*
Total costs[1]	*0.2861*	*0.3292*	*0.2986*	*0.3458*

[1] This table is reproduced directly from Levinson et al without changes. Note that the total for the short-run costs do not add up properly.

They identify three types of costs associated with automobile use: infrastructure costs, user costs, and social (or external) costs.[7] For the most part, Levinson et al develop their own econometric models to estimate these costs. Each of these is discussed in more detail below. A summary of their estimates of the long-run full costs of the highway system is provided in table 9.

Infrastructure Costs

Infrastructure costs include the capital costs of infrastructure construction and debt servicing, and operations and maintenance costs. Levinson et al develop an econometric model that predicts total expenditures as a function of the price of inputs (interest rates, wage rates, and material costs), outputs (miles traveled per passenger vehicle, single unit truck, and combination truck), and network variables (the length of the network and the average width of the links). The data used for the model come from a variety of sources, such as FHWA data on maintenance and operating costs, and Gillen et al (1994) data on capital stock, among others. Costs are allocated among the different vehicle classes on the basis of an engineering analysis of the amount of damage caused by each vehicle type.

User Costs

Levinson et al estimate the cost of gas, oil, maintenance, tires, and depreciation for an intermediate-size automobile, the most popular vehicle type in 1995. (They omit insurance costs, license and registration fees, and taxes on the grounds that they are transfers.) For most of their estimates, they use data from the American Automobile Association (AAA). However, to estimate depreciation, they regress the posted price (not the actual transaction price) in an Internet classified ad for Ford Taurus and Honda Accord against the age of the vehicle and the distance traveled multiplied by the vehicle age. From this, they estimate depreciation costs of $1,351 per year and 2.3¢ per vehicle-mile of travel, which, assuming 10,000 miles per year, translates to an annual depreciation of about $1,581, as compared with the AAA estimate of $2,883 in 1993. To estimate the cost of user time, the authors assume that travel time costs $10 per hour and vehicles travel at 100 km per hour.

[7] Note that Levinson et al (1996) use a different definition of social costs than we do in our own analyses (Delucchi et al 1996). In their report, they limit the definition of social costs to negative externalities, or external costs.

External Costs

Levinson et al identify four external costs, which they also refer to as social costs: accidents, congestion, noise, and air pollution. Their estimates for each of these costs are based on simple models and an analysis of existing work.

Accidents. Their estimate of accident costs is developed by combining an accident rate model by Sullivan and Hsu (1988) with the work of the Urban Institute (1991). The accident cost is obtained by determining the value of life, property, and injury per accident, and multiplying this by an equation that represents accident rates. They estimate that a crash on a rural interstate costs about $120,000 (in 1995 dollars), and a crash on an urban interstate costs about $70,000. The disparity is largely attributable to the higher death rate associated with accidents on rural highways due to the higher speed of travel.

Congestion. Assuming a modest average traffic flow of 1,500 vehicles per hour per lane, a $10 per hour value of time, and 1.5 passengers per vehicle, the authors estimate that the average congestion costs are $0.005 per passenger-kilometer of travel. This is based on a simple analysis of the relationship between traffic volumes and time delay.

Noise. For noise costs, they develop a simple analytical framework and use the results of previous research to derive their estimates. Essentially, this involved translating noise production rates into economic damages using total residential property damage costs per linear-kilometer of roadway.

Air pollution. The authors identify four types of air pollution (photochemical smog, acid deposition, ozone depletion, and global warming), which generate three types of damages (health effects, material and vegetation effects, and global effects). Their estimate of the total cost of air pollution is derived by combining the results of a number of other studies.

Costs Excluded from the Analysis

Levinson et al (1996) do not include U.S. defense expenditures in the Middle East or the costs of parking in their analysis. They dispute the notion that a significant share of U.S. defense expenditures are directly related to the transportation sector. They exclude parking on the grounds that it is a local cost that is unlikely to be avoided by switching intercity travel modes.

DELUCCHI ET AL (1996)

In a series of 20 reports, Delucchi et al (1996) estimate the annualized social cost of motor vehicle use, as:

- 1990 to 1991 periodic or "operating" costs, such as fuel, vehicle maintenance, highway maintenance, salaries of police officers, travel time, noise, injuries from accidents, and disease from air pollution;
  plus
- the 1990 to 1991 value of all capital, such as highways, parking lots, and residential garages (items that provide a stream of services), converted (annualized) into an equivalent stream of annual costs over the life of the capital.

This annualization approach essentially is an investment analysis, or project evaluation.

They classify and estimate costs in six general categories: personal nonmonetary costs, motor vehicle goods and services priced in the private sector, motor vehicle goods and services bundled in the private sector, motor vehicle goods and service provided by government, monetary externalities, and nonmonetary externalities.

Personal Nonmonetary Costs

In Delucchi et al, personal nonmonetary costs are those unpriced costs of motor vehicle use that a person imposes on him or herself as a result of the decision to travel. The largest personal costs of motor vehicle use are personal travel time in uncongested conditions and the risk of getting into an accident that involves nobody else. Delucchi et al perform detailed analyses of travel time costs in this category.

Motor Vehicle Goods and Services Priced in the Private Sector

The economic cost of motor vehicle goods and services supplied in private markets is the area under the private supply curve: the dollar value of the resources that a private market allocates to supplying vehicles, fuel, parts, insurance, and so on. To estimate this area, Delucchi et al subtract producer surplus (revenue in excess of economic cost) and taxes and fees (mainly noncost transfers) from total price-times-quantity revenues. The cost items in this category include those in the "transportation" accounts of the Gross National Product (GNP), and several others. For several of these costs, Delucchi et al use the same primary data and methods used in GNP accounting.

Motor Vehicle Goods and Services Bundled in the Private Sector

Some very large costs of motor vehicle use are not explicitly priced separately. Foremost among these are the cost of free nonresidential parking, the cost of home garages, and the cost of local roads provided by private developers. However, all of these costs are included in the price of "packages," such as homes and goods, that are explicitly priced.[8] Delucchi et al use a variety of primary data sources to estimate national parking and garage costs in detail.

Motor Vehicle Goods and Services Provided by the Public Sector

Government provides a wide range of infrastructure and services in support of motor vehicle use. The most costly item is the highway infrastructure. Delucchi et al analyze survey data from FHWA, the Bureau of the Census, the Department of Energy, the Department of Justice, and other government departments to estimate these infrastructure and service costs. They note that, whereas all government expenditures on highways and the highway patrol are a cost of motor vehicle use, only a portion of total government expenditures on local police, fire, corrections, jails, and so on is a cost of motor vehicle use.

Monetary Externalities

Some costs of motor vehicle use are valued monetarily yet are unpriced from the perspective of the responsible motor vehicle user, and hence are external costs. Examples of these are accident costs that are paid for by those *not* responsible for the accident, and congestion that displaces monetarily compensated work. Delucchi et al estimate that the largest monetary externalities are those resulting from travel delay.

Nonmonetary Externalities

Delucchi et al follow Baumol and Oates (1988) and define a nonmonetary externality as a cost or benefit imposed on person A by person B but not accounted for by person B. Environmental pollution, traffic delay, and uncompensated pain and suffering due to accidents are common examples of externalities.

Environmental costs include those related to air pollution, global warming, water pollution, and noise due to motor vehicles. Delucchi et al use damage functions to estimate air pollution and noise costs. They find that by far the largest environmental externality is the cost of particulate air pollution.

The authors' estimates of the total social costs in each of the six cost categories are summarized in table 10.

STUDIES OF THE SOCIAL COSTS OF MOTOR VEHICLE USE IN EUROPE

Although this paper focuses on U.S. studies, there are a number of good studies of the social costs of motor vehicle use in Europe. Quinet (1997) provides the most comprehensive and up-to-date summary of European studies of the external cost of traffic noise. In Quinet, the range of noise cost estimates is between 0.02% and 2.0% of Gross Domestic Product (GDP); the range of local pollution costs, between 0.03% and 1.0% of GDP; and the range of accident costs, between 1.1% and 2.6% of GDP.

Verhoef (1994) also summarizes many estimates of the external cost of noise (0.02% to 0.2% of GDP), air pollution (0.1% to 1.0% of GDP), and accidents (0.5% to 2.5% of GDP) attributable to road traffic, and Kageson (1992) and Ecoplan (1992) summarize estimates of the damage cost of air pollution caused by the transport sector (0.01% to 1.0% of GDP). These ranges indicate that

[8] Delucchi et al note that this bundling is not necessarily inefficient: in principle, a producer will bundle a cost, and not price it separately, if the administrative, operational, and customer (or employee) cost of collecting a separate price exceed the benefits.

TABLE 10 Summary of the Costs of Motor Vehicle Use: 1990–91
Delucchi et al 1996

Category	Low (billion 1991$)	High (billion 1991$)	Low (percent)	High (percent)
1. Personal nonmonetary costs of motor vehicle use	$584	$861	30	26
2. Motor vehicle goods and services priced in the private sector (estimated net of producer surplus, taxes, fees)	$761	$918	40	28
3. Motor vehicle goods and services bundled in the private sector	$131	$279	7	8
4. Motor vehicle infrastructure and services provided by the public sector	$122	$201	6	6
5. Monetary externalities of motor vehicle use	$55	$144	3	4
6. Non-monetary externalities of motor vehicle use	$267	$885	14	27
Grand total social costs of highway transportation	*$1,920*	*$3,289*	*100*	*100*
Subtotal: monetary cost only (2+3+4+5)	*$1,069*	*$1,543*		

European estimates of air pollution and accident costs are somewhat lower than recent detailed U.S. estimates (e.g., Delucchi et al 1996).

Several recent, detailed studies are not included in the reviews by Quinet (1997), Verhoef (1994), or Kageson (1992). Eyre et al (1997) estimate the effects of fuel and location on the damage cost of transport emissions. Bickel and Friedrich (1995; 1996) use a damage function approach to estimate the external costs of accidents, air pollution, noise, land use, and "dissociation effects" (e.g., roads as barriers or dividers in communities) of passenger vehicles, freight trucks, passenger rail, and freight rail in Germany in 1990. Otterström (1995) uses a detailed damage function approach, similar to the method of Delucchi et al (1996, Report #9), to estimate the external cost of the effect of traffic emissions on health, crops, materials, forests, and global warming in Finland in 1990. Maddison et al (1996; summarized in Maddison 1996) use a variety of methods to estimate the marginal external costs of global warming, air pollution, noise, congestion, road damage, and accidents attributable to road transport in the United Kingdom in 1993. Mayeres et al (1996) develop marginal cost functions, again similar to those of Delucchi et al (1996, Report #9), to estimate the marginal external cost of congestion, accidents, air pollution, and noise attributable to cars, buses, trams, metro rail, and trucks in the urban area of Brussels in the year 2005.

SUMMARY AND CONCLUSION

Our Rating of the Level of Detail

A review of the study summaries, in tables 1 to 10, indicates that in most cost categories, there is a very wide range of estimates. These ranges result from differences in every conceivable facet of the analysis: scope, accounting system, analytical methods, assumptions, and data sources. Because of this, it is not possible to give a simple summary of the *overall* quality of each analysis, or of the sources of discrepancies between analyses. However, it is possible and we hope useful to evaluate the studies according to one partial indicator of quality: the level of analytical detail.

Tables 11a to 11d identify some of the major cost categories included in these studies. For each cost category, we give a rating of A through F, which is our assessment of the level of analytical detail underlying each estimate in the studies reviewed. These ratings are explained in more detail in table 12. We emphasize that they are not necessarily assessments of the *overall* quality, because there is more to quality than detail, and a review and analysis of sound and pertinent literature is preferable to a poorly done detailed, original analysis. Nevertheless, it is useful for policymakers to know who has done a detailed original analysis, and who has done a combination of literature review and detailed analysis, and who has simply cited the work of others.

TABLE 11a Summary of Social Cost Items and Level of Detail in the Studies Reviewed[1]

Author	Keeler and Small (1975)	FHWA (1982)	Kanafani (1983)	Fuller et al (1983)
Geographic region	San Francisco	USA	USA	USA
Year(s) of estimates	1972–73	1981	Varies	1976–79
Primary purpose or objective	Efficient resource use; compare travel modes	Cost allocation	Compare estimates for different countries	Cost allocation
Cost categories[2]				
Accidents	B	F	C	A1/B
Air pollution	A1/B	B	C	A1/B
Congestion/time	A1	B		A1/B
Energy dependence[3]				
Equity				
Global warming/climate change				
Military expenditures				
Noise pollution	A1/B	B	C	A1
Parking	C			
Pavement damage to vehicles		E		
Roadway construction	A1/A2			
Roadway maintenance	A1/A2	A2		
Highway services[4]	A1	C		
Strategic petroleum reserve				
Urban sprawl/land use				
Vehicle ownership and operation		F		
Vibration damage to buildings				
Water pollution		F		

FHWA = Federal Highway Administration.

[1] The ratings A through F are defined in table 12.

[2] This list of cost categories is not meant to be all-inclusive. Instead, it represents some of the costs that are commonly estimated in these studies. The category definitions in this table necessarily are generic, because each study uses its own specific definitions. It is possible that some of the studies include other costs that are not identified in this table.

[3] Energy dependence may include such costs as macroeconomic effects of monopsony power, threats of supply disruption, trade effects, and petroleum subsidies.

[4] Highway services include such costs as police services, fire protection services, the judicial system, and paramedics.

Of course, there is a fair bit of judgment in our assessment here. What one person might consider a combination of literature review and detailed analysis of primary data (our "B" rating), another might consider a detailed analysis of the literature (our "C" rating). Although we tried to assess the studies consistently and evenhandedly, we recommend that readers consult the original studies to fully understand their level of detail as well as their overall quality.

Table 11 shows that the range in the level of detail is quite broad. For example, most of the estimates of MacKenzie et al (1992)—one of the most widely cited analyses—are based on a straightforward literature review. Miller and Moffet (1993) provide a significantly more detailed discussion of the issues, but still derive most of their estimates from the literature. Litman (1994) conducts a rather extensive literature review, and uses this as a basis for generating his "best guess" of the costs. By contrast, Levinson et al (1996) derive their estimates of the marginal and average costs from econometric models, and Delucchi et al (1996) primarily use original data analysis for their figures.

Conclusion

This review, and the ratings in tables 11a to 11d, indicate that many of the current estimates are based on literature reviews rather than detailed analysis. Of course, this in itself is not *necessarily* bad. The real problems are: 1) many of the reviews rely on outdated, superficial, nongeneralizable, or otherwise inappropriate studies; and 2) many of the cost-accounting systems are not fully articulated, or else are a mix of economic and equity crite-

TABLE 11b Summary of Social Cost Items and Level of Detail in the Studies Reviewed[1]

Author	MacKenzie et al (1992)	Ketcham and Komanoff (1992)	Hanson (1992)	Behrens et al (1992)
Geographic region	USA	USA	Madison, WI	USA
Year(s) of estimates	1989	1990	1983	Varies
Primary purpose or objective	Equity; efficient resource use	Efficient resource use	Equity; efficient resource use	Estimate external costs; compare alternative fuels
Cost categories[2]				
Accidents	D	D	D	
Air pollution	C	D, C	C	C
Congestion/time	C	D		
Energy dependence[3]			D	C
Equity				
Global warming/climate change	C	D		F
Military expenditures	D	D		C
Noise pollution	D	D		
Parking	D			
Pavement damage to vehicles		D		
Roadway construction	A2	D	A2	
Roadway maintenance	A2	D	A2	
Highway services[4]	D/E	D	A2	
Strategic petroleum reserve	D	D		C
Urban sprawl/land use			B	
Vehicle ownership and operation	D	D		
Vibration damage to buildings	E	D		
Water pollution			D	

TABLE 11c Summary of Social Cost Items and Level of Detail in the Studies Reviewed[1]

Author	Miller and Moffett (1993)	KPMG (1993)	CEC (1994)	Apogee (1994)	Lee (1994)
Geographic region	USA	British Columbia	California	Boston; Maine	USA
Year of estimates	1990	1990	Varies	1993	1991
Primary purpose or objective	Efficient resource use; compare travel modes	Efficient resource use; compare travel modes	Efficient resource use	Efficient resource use; compare travel modes	Efficient pricing and resource use
Cost categories[2]					
Accidents	B/C	A1/B	B	B	C
Air Pollution	B	B	B	B	C
Congestion/time	C	A1/B	A1/B	B/D	F
Energy dependence[3]	C		C	D	
Equity	F				
Global warming/climate change	C	B	D		
Military expenditures	C				
Noise pollution	C	A1/A2		D	C
Parking	C	A1/A2		A1	B
Pavement damage to vehicles					
Roadway construction	A2	A2		A2	A2
Roadway maintenance	A2	A2	A2	A2	A2
Highway services[4]	D	A2/E	D	A2	C
Strategic petroleum reserve	C				B/C
Urban sprawl/land use	F	E			F
Vehicle ownership and operation	D	B		A1/B	C
Vibration damage to buildings	D				
Water pollution	B	D	B/C		C

See the notes in table 11a.

TABLE 11d Summary of Social Cost Items and Level of Detail in the Studies Reviewed[1]

Author	Cohen (1994)[5]	Litman (1996)	Levinson et al (1996)
Geographic region	**USA**	**USA**	**California**
Year(s) of estimates	**1990**	**1990**	**1995–96**
Primary purpose or objective	**Cost allocation**	**Equity; efficient resource use and pricing; compare travel modes**	**Compare travel modes**
Cost categories[2]			
Accidents	F (A1/B)	B/C	A1/B
Air pollution	F (A1/B)	C	B
Congestion/time	F (A1)	B	B
Energy dependence[3]		C	
Equity		E	
Global warming/climate change			
Military expenditures			F
Noise pollution	F (A1)	C	B
Parking		B/C	F
Pavement damage to vehicles			
Roadway construction		C	A1/A2
Roadway maintenance		C	A1/A2
Highway services[4]		C	
Strategic petroleum reserve			
Urban sprawl/land use		E	
Vehicle ownership and operation		C	B
Vibration damage to buildings			
Water pollution		C	

See the notes in table 11a.

[5] Cohen (1994) is an interim report; the ratings in parentheses refer to expected level of detail of the final estimates when the research is completed.

ria. Thus, with a few exceptions, the recent literature on national social costs in the United States, taken at face value, is of limited use.

There is, however, a good deal of excellent work focusing on particular costs or localities, and it is to these, rather than generic summaries, that analysts and policymakers should turn. For example, there now are at least three detailed, original, and conceptually sound analyses of air pollution costs in the United States (Delucchi et al 1996, Report #9; Krupnick et al 1997; Small and Kazimi 1995, for Los Angeles), and several good European analyses (see discussion above). These analyses supersede previous work. Similarly, the noise cost estimates of Delucchi et al (1996, Report #14) supersede the older and heretofore widely cited estimates of Fuller et al (1983). The recent volume edited by Greene et al (1997) summarizes state-of-the-art estimates of accident costs, congestion costs, travel time costs, air pollution costs, and parking costs. As analysts continue to develop detailed marginal social cost models and sound cost-benefit evaluation tools, policymakers will begin to have more reliable cost information to consider in the complex task of making transportation policy.

TABLE 12 The Level of Detail Rating System

A1: ESTIMATE BASED ON DETAILED ANALYSIS OF PRIMARY DATA

This designation was used if the author performed a detailed, original analysis based mainly on primary data, or developed detailed cost models, such as damage-function models of the cost of air pollution. Primary data include, but are not limited to: original censuses and surveys of population, employment and wages, government expenditures, manufacturing, production and consumption of goods and services, travel, energy use, and crime; financial statistics collected by government agencies, such as the Internal Revenue Service and state motor vehicle departments; measured environmental data, such as of ambient air quality and visibility; surveys and inventories of physical infrastructure, such as housing stock and roads; and the results of empirical statistical analyses, such as epidemiological analyses of air pollution and health.

A2: ESTIMATE BASED ON STRAIGHTFORWARD ANALYSIS OF PRIMARY DATA

This designation was used if the author made relatively straightforward use of primary (or "raw") data published (typically) by a government agency. An example of this that appears in many studies is the use of Federal Highway Administration data (e.g., FHWA 1990) to estimate highway construction and maintenance costs. (See above for other examples of primary data).

Difference between A1 and A2 ratings: A1 work is more detailed and extensive than A2 work.

B: ESTIMATE BASED ON A COMBINATION OF ORIGINAL DATA ANALYSIS AND LITERATURE REVIEW

This designation was used if the author took published estimates and then adjusted them by changing some of the variables used to derive the estimates, or if the author combined published results from various sources to develop his own estimate. For example, in the FHWA Cost Allocation Study (FHWA 1982), the authors estimate the costs of air pollution by combining vehicle pollutant emissions rates published by the U.S. Environmental Protection Agency with an estimate of air pollution damage cost rates for each pollutant.

Difference between A2 and B ratings: A2 work is based mainly on primary data, such as from government surveys or data series or physical measurements; whereas B work is more dependent on the secondary literature. However, the calculations in B work can be more extensive than those in A2 work, which can involve direct use of relevant primary data.

C: ESTIMATE BASED ON A REVIEW AND ANALYSIS OF THE LITERATURE

This designation was used if estimates were based on a review and analysis of literature, with perhaps some simple calculations. Some studies, such as Kanafani (1983), simply provide tables listing the results of other studies. Other studies, such as Behrens et al (1992) and Litman (1996), conduct a literature review and then make their own estimate on the basis of the review.

Difference between B and C ratings: B work involves some primary data (e.g., data from government surveys, from physical measurements, or primary economic analyses), whereas C work by and large does not; correspondingly, B work requires more calculation than C work.

D: ESTIMATE IS A SIMPLE EXTRAPOLATION, ADJUSTMENT, OR CITATION FROM ANOTHER STUDY

This designation was used if the author did some simple manipulation or update of a previously published result. For example, in estimating congestion costs, Ketcham and Komanoff (1992) adjusted FHWA's (1982) congestion factors to reflect 1990 data. Similarly, MacKenzie et al (1992) cite the results of a study by the Urban Institute (1991). They adjust the constant dollar year to 1989, but make no significant adjustment to the published estimate.

Difference between C and D ratings: C work involves more sources and analysis than D work.

E: ESTIMATE IS BASED MAINLY ON SUPPOSITION OR JUDGMENT

This designation was used for estimates or simple, illustrative calculations based ultimately on supposition or judgment. For example, Ketcham and Komanoff's (1992) found no reliable estimates of vibration damage to buildings, and so used their judgment to develop their own.

Difference between D and E ratings: D work cites a substantive analysis or estimate of the cost under consideration; E work is based on judgment without reference to any direct estimate of the cost or its major components.

F: COST ITEM IS DISCUSSED, BUT NOT ESTIMATED

This designation was used for those costs that the authors acknowledge as important, but do not attempt to quantify. For example, Lee (1994) discusses, but does not estimate, the costs of vehicle use. Miller and Moffet (1993) provide estimates for most costs, but do not estimate others due to insufficient data.

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