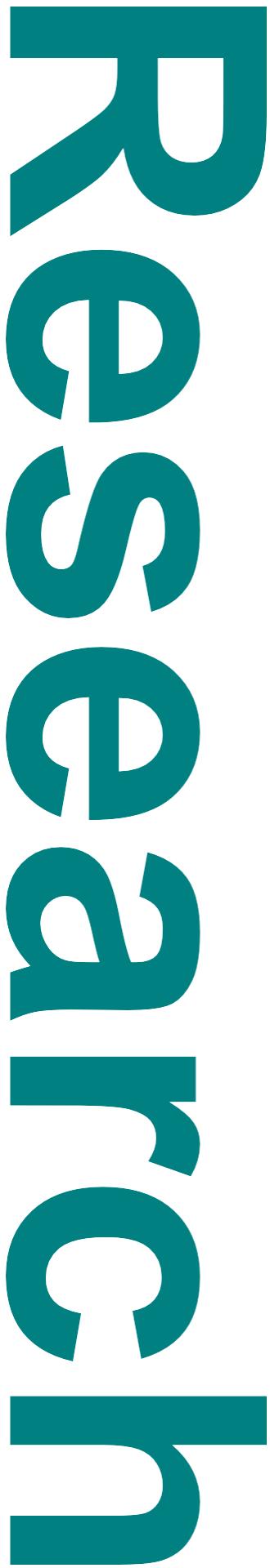
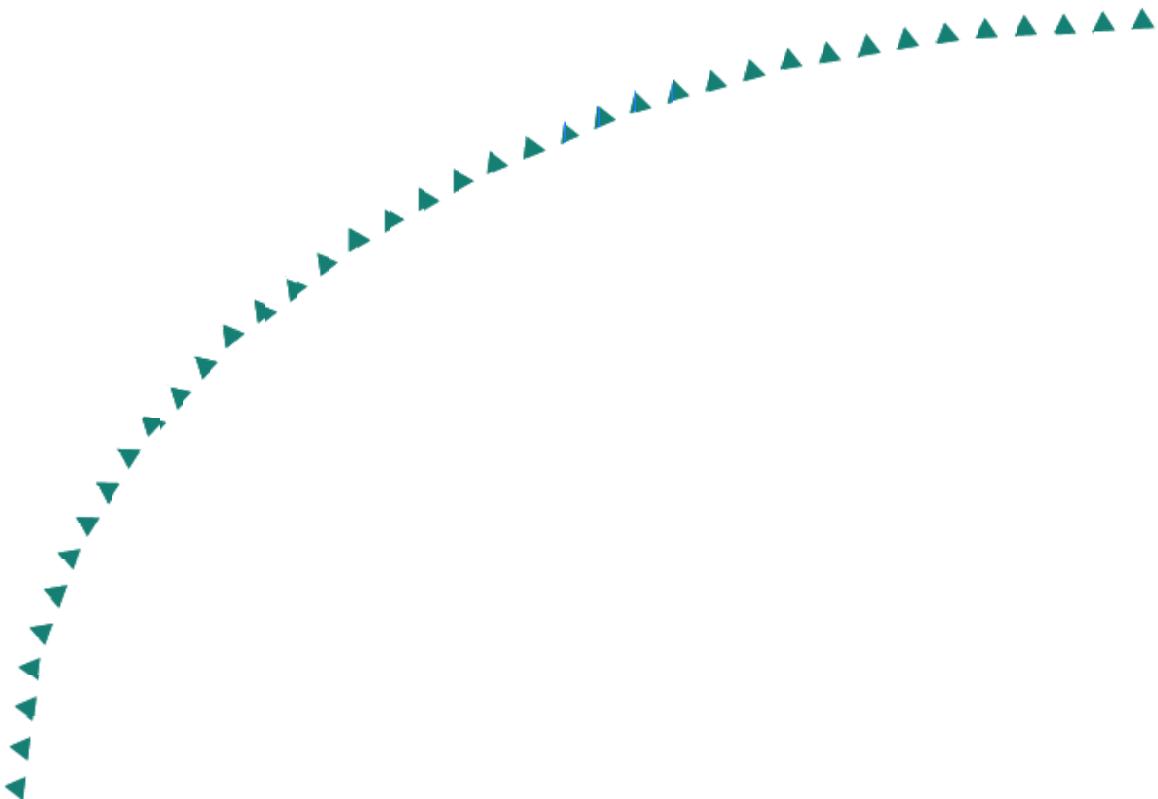


2003-19

Final Report

The Per-mile Costs of Operating Automobiles and Trucks



Technical Report Documentation Page

1. Report No. MN/RC 2003-19	2.	3. Recipients Accession No.	
4. Title and Subtitle THE PER-MILE COSTS OF OPERATING AUTOMOBILES AND TRUCKS		5. Report Date June 2003	
		6.	
7. Author(s) Gary Barnes, Peter Langworthy		8. Performing Organization Report No.	
9. Performing Organization Name and Address University of Minnesota Humphrey Institute of Public Affairs State and Local Policy Program 301 19th Avenue South Minneapolis, MN 55455		10. Project/Task/Work Unit No.	
		11. Contract (C) or Grant (G) No. (c) 74708 (w) 149	
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Office of Research Services 395 John Ireland Boulevard St. Paul, MN 55155		13. Type of Report and Period Covered Final Report 2002 to 2003	
		14. Sponsoring Agency Code	
15. Supplementary Notes http://www.lrrb.gen.mn.us/PDF/200319.pdf			
16. Abstract (Limit: 200 words) This report provides a spreadsheet model for calculating the costs of operating cars and trucks. This cost will be used in the planning of highway projects. One challenge faced by the researchers is the fact that highway projects alter the vehicle operations costs.			
The researchers used innovative methods to determine the travel cost estimates based on usage, while excluding the fixed costs of vehicle ownership. The research also offers methods to adjust the costs for different driving conditions, like smooth or rough roads. The report also suggests methods to determine what the cost of operating a personal vehicle or truck will be in the future.			
17. Document Analysis/Descriptors Operating costs Automobiles Trucks Fixed costs Variable costs		18. Availability Statement Personal vehicles Commercial vehicles Highway Improvements Benefit Cost Ratio No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 46	22. Price

THE PER-MILE COSTS OF OPERATING AUTOMOBILES AND TRUCKS

Final Report

Gary Barnes
Peter Langworthy

State and Local Policy Program
Humphrey Institute of Public Affairs
University of Minnesota
Minneapolis, MN 55455

June 2003

Published by:
Minnesota Department of Transportation
Office of Research Services
395 John Ireland Boulevard
St. Paul, MN 55155

This report represents the results of research conducted by the authors and does not necessarily represent the view or the policy of the Minnesota Department of Transportation and/or the Center for Transportation Studies. This report does not contain a standard or specified technique.

The authors and the Minnesota Department of Transportation and/or Center for Transportation Studies do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to this report.

ACKNOWLEDGEMENTS

This study was funded by the Minnesota Department of Transportation (Mn/DOT). The authors wish to thank Mn/DOT, project technical liaison Rabinder Bains, and technical advisory panel members Deanna Belden and Ed Idzorek for their insights into the research methodology and findings, and their comments on the drafts of the final report. The authors also wish to acknowledge the assistance of other individuals from around the United States during our efforts to better understand the costs of operating trucks.

This research and report are based on earlier work by David Anderson, formerly of the Department of Applied Economics at the University of Minnesota. His efforts were of considerable help to us in understanding the basics of automobile operating costs, and in becoming aware of the many subtleties of this problem. The material in Appendix B was largely written by him.

TABLE OF CONTENTS

<u>1</u> INTRODUCTION	1
<u>2</u> THE COSTS OF OPERATING PERSONAL VEHICLES	5
2.1 OPERATING COSTS BY MODEL	5
2.1.1 FUEL COSTS	6
2.1.2 MAINTENANCE (NON-TIRE)	6
2.1.3 TIRES	7
2.1.4 REPAIRS	7
2.1.5 DEPRECIATION	8
2.2 THE PERSONAL VEHICLE FLEET	10
2.3 ADJUSTMENT FACTORS	11
<u>3</u> THE COSTS OF OPERATING TRUCKS	15
3.1 SUMMARY OF DATA SOURCES	16
3.2 18-WHEEL TRUCK OPERATING COSTS	17
3.2.1 FUEL	17
3.2.2 REPAIR AND MAINTENANCE	18
3.2.3 TIRES	18
3.2.4 DEPRECIATION	18
3.3 ADJUSTMENT FACTORS	19
<u>4</u> SUMMARY OF COSTS	21
4.1 SUMMARY OF METHODOLOGY	21
4.2 SUMMARY OF COSTS	22
4.3 COMPARISON TO OTHER COST ESTIMATES	23
<u>REFERENCES</u>	25
<u>APPENDIX A: USING AND UPDATING THE SPREADSHEET</u>	A-1
<u>APPENDIX B: BACKGROUND ON VEHICLE OPERATING COSTS</u>	B-2

LIST OF TABLES

Table 2.1: Marginal depreciation per 5,000 miles (dollars)	9
Table 2.2: Effect of pavement roughness on operating costs	12
Table 3.1: Truck literature cost summary (cents per mile)	17
Table 3.2: Truck costs by type.....	19
Table 4.1: Use of adjustment factors	22
Table 4.2: Baseline costs (cents per mile)	22
Table 4.3: City driving conditions (cents per mile)	23
Table 4.4: Extremely poor pavement quality (cents per mile).....	23
Table 4.5: Comparison of baseline costs to other sources (cents per mile).....	23
Table 4.6: Comparison of total and variable costs (cents per mile).....	24

EXECUTIVE SUMMARY

This report describes a methodology and spreadsheet model for calculating the variable costs of operating cars and trucks, for use in benefit-cost analysis of highway projects. This research was undertaken because Minnesota Department of Transportation (Mn/DOT) analysts felt that existing guidance on this topic was not explained adequately to allow them to understand if they were using it appropriately. A particular concern in this regard was that much of the material was quite dated, and it was not clear how to properly update the costs to the present and future times. A second problem was that it was not always clear how the numbers should be adjusted to account for varying conditions.

The underlying problem that we are addressing is that highway projects change the conditions under which people drive, and thus change the amount of expense that they incur. The two most significant examples of this are time savings and crash reductions, which are the primary justifications for most highway improvements. However, the cost of actually operating the vehicle in terms of fuel, repairs, and other costs, are not insignificant, and also may change depending on how the project impacts conditions. For example, a bypass around a town may add some miles to the trip, but reduce the cost per mile by reducing the number of stops and starts.

Our concern in this report is the marginal cost of driving a vehicle one additional mile. That is, we focus on costs that increase when a vehicle is driven more, such as fuel use and tire wear, and ignore costs, such as insurance and finance costs, that are incurred regardless of how much the vehicle is driven. The specific costs that we address are:

- Fuel consumption
- Routine maintenance
- Tires
- Repairs
- Some depreciation

The methodological challenge in this undertaking was that most information on the costs of operating vehicles has been developed for different purposes than ours. For example, information on the operating costs of cars is widely available from consumer guides, but this tends to look at full ownership costs, rather than the marginal costs incurred by actually driving the vehicle. Also, these cost estimates typically only consider the first four or five years of the

vehicle's life (when repair costs are relatively low), rather than the full life cycle operating costs. Similarly, information on trucking costs tends to focus on the full cost of taking a load from point A to point B, which includes many costs that are fixed and would be incurred whether the trip was taken or not.

There are several important innovations in this research:

- Distinguishing clearly between fixed and variable costs
- Considering full life-cycle costs
- Integrating methods to adjust costs for different driving conditions
- Providing explicit guidance on how to adjust the costs in the future

We develop operating costs for personal vehicles (autos, pickups, SUVs, vans) primarily from consumer guides. We develop a fleet average cost based on Minnesota vehicle sales, given operating costs of specific models. We also develop factors for adjusting the costs based on stop-start conditions, and on pavement roughness.

Operating costs for large commercial trucks are based on a review of a number of sources of trucking costs. We use costs that are in the middle of the range of the sources we examined, and check these numbers against other sources. We also include adjustment factors for driving conditions.

We conclude that in a "baseline" case of highway driving on smooth pavement, with a gasoline price of \$1.50 per gallon, that personal vehicles average 17.1 cents per mile to operate, and trucks average 43.4 cents per mile. City driving conditions, involving frequent stops and starts, increase this cost by 3.9 cents per mile for personal vehicles and 9.5 cents for trucks. Extremely rough pavement increases the baseline cost by 2.7 cents for personal vehicles and 5.5 cents for trucks.

1 INTRODUCTION

When work is done on highways, or when new highways are built, one of the possible impacts is that the people who make trips on those highways might spend more or less money to operate their vehicles. This could happen during construction, either because detours increase the distance that must be traveled to complete a trip, or because slowdowns cause vehicles to be operated at less-than-optimal speeds. Costs could also change after the project is over, again because either the length or the operating conditions, especially speed, might have changed for certain trips. For example, a bypass around a town will generally increase the distance that must be driven, but improve conditions by avoiding stops and starts.

The analysis of whether and how highways projects ought to be done is based on the benefits gained and costs incurred under various scenarios. Many of the most significant benefits, and a few of the costs, accrue to highway users. Two of the biggest benefits of most highway projects are reductions in travel time and in crashes. A third major impact on highway users is the cost of operating their vehicles for trips through the affected area. There are four major components of this cost: fuel, routine maintenance (including tires, oil, and other routine work), unanticipated repairs, and depreciation in the value of the vehicle.

The purpose of this report is to describe methods for determining these vehicle-operating costs under different conditions, and to explain how to use and update a spreadsheet program that we have developed for calculating total operating costs for a project given counts of different types of vehicles, and project characteristics. This is done in the following order:

- Chapter 2 develops estimates of automobile operating costs
- Chapter 3 does the same for trucks
- Chapter 4 summarizes the methodologies and results
- Appendix A describes how to use and update the spreadsheet program
- Appendix B describes some other studies and ideas about vehicle operating costs.

While researchers and analysts have been aware of this issue for some time, no definitive methodology for estimating these costs seems to exist. There are likely two reasons for this. First, compared to the values of travel time and crashes, operating costs are relatively small in magnitude, and thus have commanded less attention from researchers and policy analysts. Second, the costs of operating vehicles depend inseparably on characteristics of the vehicles themselves. Cars, for example, gained considerably in fuel efficiency between 1975 and 1985, but have held steady since. And cars today are more reliable than those of 20 years ago. This impacts

operating costs both in reduced repair bills, and also in that cars do not depreciate as quickly, since they can reasonably be expected to last 150,000 miles or more.

The overall impact of these and other changes to cars is that it is difficult to develop estimates of operating costs that will remain valid for any length of time, especially the long time spans often considered in highway project analyses. Indeed, one of the major motivations for this project was that the estimates that Mn/DOT analysts were using were relatively old, and adjusted only for inflation (as were all the available alternatives). The desire behind this project was that methods could be developed for estimating costs based directly on current information about vehicle characteristics; and that this information could be easily updated in the future, ensuring that cost estimates would remain current.

Existing methods for calculating vehicle-operating costs tend to suffer from one or more of several problems that we address in this research:

- Inflexibility: Operating costs depend on conditions; much cost guidance recognizes this point but does not systematically address it by explaining how to adjust the numbers.
- Too complex: Sometimes when adjustment tools are included, they require more information than is typically available, or more than the typical analyst has time to deal with.
- Fixed in time: The components of operating costs change in price at different rates, and in general not at the rate of overall inflation. No guidance that we are aware of addresses explicitly how to update cost estimates in future years.
- Confusion of fixed and variable costs: Many costs of owning vehicles are incurred regardless of how much they are driven. But highway project cost studies should include only the costs that vary with distance driven. Much cost guidance seems confused about the difference between the two.
- Life-cycle costs: Some costs, such as repairs, increase as vehicles age. Most cost guidance does not address this issue.

Our philosophy here is that vehicle operating costs are significant enough, and variable enough, to warrant an explicit calculation tool, but they are sufficiently small that the tool should be fairly easy to use and require only limited information. We wish to develop a baseline cost that can be reasonably customized to local conditions, and a small number of adjustment factors that can be used to account for important project-specific variations.

The information that this report will add will be estimates of the cost of driving a mile in various types of vehicles, under various highway conditions. An important point to note here is that, unlike most sources of information about operating costs, we are not estimating total costs

and dividing by some assumed mileage. This is a standard practice in consumer-based guides, which are rightfully concerned with the *total* cost of operating the vehicle, including costs such as insurance and age-based depreciation that do not depend directly on how much the car is driven. For our purposes here, however, we are concerned only with the *marginal* resource consumption that can be attributed to mileage changes resulting from a highway project. The cost of a driver's insurance will not change if he drives a few extra miles; the amount of gas he uses will.

Given our estimates of the cost of a marginal mile of driving under different conditions, the analyst can then use this information to calculate the total cost of the trips being made under the current conditions, and the total costs of the trips during and after the project. This will help with addressing issues of the overall value of the project, as well as questions of construction timing and staging. Equally significantly, this report will include information on how the cost estimates were determined, and how they can be updated in the future. In this report we assume that our cost estimates will be used for certain "normal" types of situations; more unusual situations, such as prolonged and extreme congestion, or extremely poor pavement quality, may require some customization of our results.

2 THE COSTS OF OPERATING PERSONAL VEHICLES

The cost of operating an automobile or light truck is strongly dependent on the characteristics of the specific model. As an obvious example, big pickups consume considerably more fuel than do subcompact cars; but other costs vary widely as well. As analysts will generally not know the specific models of car and light truck that will use a given highway, we develop an “average” operating cost based on model counts in the existing fleet.

For each model, we break operating costs into five major components: fuel, maintenance (excluding tires), tires, unscheduled repairs, and depreciation. We have information by model for the first four of these, and by classes of models for the last. We first develop a baseline cost per mile of operating each model based on “highway” conditions. We then multiply this by model counts to arrive at a baseline per mile cost for the fleet as a whole. Finally we develop adjustment factors to use for accounting for future price changes, and other specific conditions that might be of interest, in particular pavement roughness and “city” versus “highway” driving conditions.

Although there is consensus that gradients and curves also affect operating costs, we do not address these here, for two reasons. First, they are unlikely to be significant factors for most highway projects in Minnesota. Second, there is apparently no simple way to account for these factors short of describing every hill and curve on the project in question; a degree of detail and effort, which is unlikely to be worthwhile given normal Minnesota conditions.

2.1 Operating Costs by Model

Determining operating costs for cars and light trucks is a process of working simultaneously with the very specific and the very vague. For example, we know the expected gas mileage of every model type, and can reasonably assume, with a few exceptions, that this will remain largely unchanged at least in the near future. On the other hand, it is hard to know even within 20% what gas prices will be one year from now, let alone farther in the future. And some car-buying guides have very detailed estimates of repair and maintenance costs, but only for the first five years. After that there is seemingly no information at all, which is problematic since the average vehicle age is now more than eight years, and these costs rise with age.

In this section we address each of five major costs, fuel, maintenance, tires, repairs, and depreciation in turn, explaining how we arrive at estimates for each of them.

2.1.1 Fuel Costs

There are two issues in calculating fuel costs: the expected consumption of fuel by a given model, and the price of fuel. We address these separately, so that analysts can modify assumptions about fuel mileage and prices as these factors evolve over time.

For fuel mileage, we use the standard fuel economy data generated by the Environmental Protection Agency, which offers estimated mileage per gallon for both city and highway driving conditions. For our purposes here, we copied this data from the same (printed) source that we used for repair and maintenance costs. However, it is also available online, for a much wider variety of car models than we dealt with.

Historical retail fuel prices are also available online. For Minnesota, historical (weekly) prices are only available back to 2000. There are longer time series available for the Midwest as a whole (starting in 1992) and the U.S. (starting in 1990). Minnesota prices closely match U.S. prices. There is no long-term “trend” in these prices in the normal sense of a somewhat steady change. Prices hovered around a single level for several years, then increased sharply to a new level, around which they have hovered since.

Because there is no clear trend or pattern to fuel prices, probably the best number to use is whatever the current price is, unless the analyst has some other forecast of future prices for the period under consideration. Fuel costs are further modified based on the balance between highway and city driving conditions. Full “city” conditions lead to about 35% more fuel usage on average. Extreme congestion will lead to levels even higher than this, and this option is part of our spreadsheet. Available evidence indicates that pavement roughness does not significantly impact fuel usage, so this adjustment factor does not play a role here.

2.1.2 Maintenance (Non-Tire)

The business of the company IntelliChoice® is developing estimates of the five-year lifecycle costs of cars and light trucks, for the information of consumers choosing which model to buy. Their annual publications (1) *The Complete Car Cost Guide* and (2) *The Complete Small Truck Cost Guide* are commonly available in library reference sections and can be purchased directly from the company. They contain detailed cost information for all the common models.

The costs of maintenance are estimated based on the manufacturers’ recommended maintenance schedule. The costs of the various forms of maintenance are based on industry-standard service times, national labor-rate averages, and manufacturers’ suggested list price for parts. They note that this is probably an upper bound for maintenance costs; it will be less

expensive than this for many people. They assume that cars are driven 14,000 miles per year. A major portion of the maintenance costs is the replacement of tires, which we break out separately in the next section.

To generate per-mile maintenance cost estimates we subtract the tire replacement cost from the total five-year maintenance cost. The remainder is divided by 70,000 (the five-year assumed mileage) to get a baseline per-mile cost. We assume that this routine maintenance cost will continue for the life of the vehicle.

We make three adjustments to this baseline cost. The first adjustment would be a 3% annual price increase, based on consumer price indices (CPI) for the U.S. for the last 20 years. This would impact estimates done in future years. The second is a multiplier for pavement roughness, which creates the need for replacement of parts ahead of the “normal” maintenance assumptions. The derivation of the pavement roughness multiplier is described in section 2.3. The final adjustment is for driving conditions. Frequent stops and starts, in addition to using more fuel, will cause increased wear to other parts of the car as well. We apply an adjustment factor as described in section 2.3.

2.1.3 *Tires*

Tire costs are also taken from (1,2) IntelliChoice®. These costs are based on a 45,000-mile cycle. Tire costs have not had any inflation for the last 20 years according to the CPI. Thus we recommend no inflation factor, although we include the option in the spreadsheet. Also, we assume that city vs. highway conditions will not impact tire wear. We do, however, include pavement roughness here as bad pavement may create the need for early tire replacement. Thus the per-mile cost for tires is the total, divided by 45,000, multiplied by the pavement roughness factor described in a subsequent section.

2.1.4 *Repairs*

The estimated costs of repairs also come from (1,2) IntelliChoice®, and are based on the cost of a five-year, zero-deductible repair-service contract for each model of car. They note that these will generally offer a very good proxy for expected repair costs since the companies offering these contracts must price the high enough to cover expected costs, but low enough to remain competitive.

For most models, the cost of repairs in the fifth year is estimated to be 50% or more of the five-year total. This is the range from about 60,000 to 70,000 miles when parts might be expected to begin failing, and warranties begin expiring. For this model, we assume for simplicity

that for all models, 50% of the five-year repair costs will occur in the first four years, and 50% in the fifth year. We assume that the costs incurred in the fifth year will then be incurred in all subsequent years.

Thus for repairs, as will also be the case for depreciation, the per-mile cost will depend on the age of the vehicle. To account for this, we use the distribution of the vehicle fleet by age, and assume for simplicity that all individual models follow the overall distribution. This distribution comes from (3) *Ward's Automotive Yearbook*, page 285. Overall in 2000, 25% of cars and 31% of pickups/SUVs were less than five years old. However, it seems likely that new vehicles are driven more than older ones. In particular, about 50% of registered cars are more than eight years old, some substantially more.

Our issue with estimating marginal repair costs is not the average age of all vehicles, but the average age of the vehicles that are actually on the road at a given time. This is almost certainly more weighted toward newer cars. We assume that 33% of mileage is driven by vehicles less than 5 years old. So to get an overall baseline model repair cost we multiply the lower rate for newer cars by 0.33 and the higher rate for older cars by 0.67, and sum the two.

A higher percentage of pickups than cars are less than five years old. This is because pickup sales have increased considerably in the last few years, skewing the age distribution toward the new. However, the difference is not that big, and it does not have much impact on overall costs, so we ignore this complication.

Finally, repair costs are multiplied by three adjustment factors: a 3% annual inflation rate, a pavement roughness multiplier, and a city/highway driving condition multiplier, in the same manner as described in the maintenance section.

2.1.5 *Depreciation*

Much vehicle depreciation is due to the simple passage of time, but some fraction is dependent on the number of miles that the vehicle has been driven. Most estimates of depreciation are too high for our purposes because they are total depreciation (including age-based) divided by some assumed mileage. Here we are not interested in total depreciation, but only in the reduction in value that can be attributed directly to additional mileage being driven.

We were able to isolate the marginal per-mile depreciation by using standard tables from the (4) *N.A.D.A. Official Used Car Guide*, Midwest Edition (March 2003). The purpose of these books is to value used cars with various features. Their approach is to offer a base value for a given model and year, and then adjust this value given the specific features of the car, such as

automatic transmission, sunroof, and so on. One of the characteristics for which they offer specific adjustment factors is the car's mileage.

Their method is to start from a standard mileage for a given model year, then adjust the value up or down based on deviations from this standard mileage. For example, a car with 5,000 fewer miles than the standard might be worth \$200 more. They give price adjustments for 5,000-mile intervals. Each model is placed into one of four different classes, with different depreciation rates. The classes correspond to different original values of the cars; economy cars are Class I, while luxury cars are Class IV. Presumably more expensive cars also depreciate at a faster rate.

There are two complications. First, the marginal bonus or penalty for non-standard mileage is larger for older cars than for newer ones, likely reflecting the idea that additional miles matter more as a car gets closer to the end of its expected useful life. To account for this, we use a different depreciation rate for cars more than four years old, as we did when estimating repair costs. Second, the bonus for low mileage is smaller than the penalty for high mileage, and also varies depending on the total deviation from the standard value. To derive a representative average from this, we take a rough average of the marginal price difference for 5,000 and 10,000 miles over and under the average. Thus we use the following table as representative of the marginal depreciation cost of 5,000 miles:

Table 2.1: Marginal depreciation per 5,000 miles (dollars)

Class	Age of car: < 5 years old	5 years and over
I	150	275
II	200	350
III	275	475
IV	325	575

We divide the above numbers by 5,000 to get a per-mile depreciation cost for each of the four classes of vehicles. We then assign each model to the appropriate class to get the cost for that model. Then the “less than 5 years old” cost is multiplied by the fraction of Vehicle Miles Traveled (VMT) that is driven by newer vehicles (explained in the section on repair costs), and the “5 years and older” cost by the fraction of VMT driven by older vehicles.

There are two adjustment factors assumed for depreciation. We recommend no inflation factor, although we include the option in the spreadsheet, as auto prices appear from CPI results to have been steady for several years. The pavement roughness and stop-start conditions multipliers are applied in the same way as for maintenance and repairs.

2.2 The Personal Vehicle Fleet

In an ideal world, it would be possible to get an actual enumeration of the models of cars and light truck that are currently registered in Minnesota, for purposes of developing an “average” per-mile cost for the fleet. However, this was not feasible given the computer system currently in use at the Department of Motor Vehicles. This would probably be the single most beneficial upgrade to this cost estimation program in the future, if this information becomes more easily available.

In the absence of this ideal data set, we developed a proxy for the Minnesota fleet based on the following procedure. The annual motor industry publication (3)*Ward's Automotive Yearbook* provides a wide range of summary-level data regarding the auto industry. Among these is a table that gives registrations by model for the U.S. as a whole, and another that gives registrations by make for each state. We used the second table to estimate the percent of the Minnesota fleet from each major brand, such as Chrysler, Plymouth, etc. We then used the U.S. data to estimate the percent within each brand to assign to each model. For example, if Chrysler is 10% of the registrations in Minnesota, we use that as the baseline, regardless of its size relative to the U.S. market. We then use the U.S. market numbers to assign Chrysler's 10% share to its various models, since model-level registration data is only available at a national level.

Given this procedure, we derived a proxy for each car model as a fraction of the total car fleet, and each pickup/SUV model as a fraction of that fleet. We did this separately because high recent sales of pickups mean that our fractions based on recent sales data would assign too much weight to pickups relative to their importance in the entire existing fleet. Thus we use the fractions for cars, multiplied by the per-model costs, to get an average total cost for cars; and the fractions for pickups to get an average total cost for pickups. Finally, the two averages are averaged, based on the fraction of cars in the entire existing (U.S.) fleet. Currently 58% of the fleet is cars. We assume for simplicity that this ratio will continue in the future as it does not impact the overall average much, however, this parameter can be edited by the spreadsheet user. Better information about this ratio in Minnesota would be useful as we feel that there are probably relatively more pickups/SUVs here than the national average, especially given that pickups/SUVs have about 60% of recent sales in Minnesota, but only about 50% in the U.S. overall.

2.3 Adjustment Factors

Finally, we develop two adjustment factors based on possible variations in roadway conditions. The first is based on pavement roughness, which will affect maintenance, tire, repair, and depreciation costs. Pavement roughness is typically measured by either Present Serviceability Rating (PSR), or International Roughness Index (IRI). (Some documents refer to Present Serviceability Index, or PSI, which is the same thing as PSR.) The second has to do with starting and stopping conditions, which could be summarized as “city” versus “highway” conditions. City conditions lead to measurably higher fuel consumption, and there is some consensus that maintenance and repair costs will be higher as well. Assigning a value to driving conditions will require some judgment on the part of the analyst.

While in the past there was some consensus that rough roads were associated with higher fuel consumption, it seems that the studies on which that conclusion was based were done in developing countries with much worse roads than the U.S. The consensus now is that there is no measurable difference in fuel consumption on paved roads of different roughness. Fuel consumption is higher on gravel roads, but these are unlikely to be the subject of a benefit-cost analysis, even as part of a detour route.

Impacts of pavement roughness on other operating costs were estimated by Texas Research and Development Foundation (1982). While this is the most detailed available source, the impacts of roughness on operating costs seem unrealistically large, especially for smoother pavement levels. It could be that these factors were mostly extrapolated from impacts observed at much higher roughness levels, or it could be that cars were much more prone to roughness-induced failures in the 1970s when the data were collected. Evidence for the latter theory is that the impacts that they estimate for large commercial trucks are much smaller than those for cars.

Evidence cited in (5) Walls and Smith (1998), from a New Zealand study, indicates that overall costs will only vary by a cent per mile or less within the range of pavement roughness typically observed in the U.S. This document, however, notes an upcoming comprehensive study on pavement quality and operating costs. This study, (11) Papagiannakis and Delwar (2001), concludes that a unit increase in IRI (in m/km) will lead to a \$200 per year increase in maintenance and repair costs. The range in IRI between the smoothest and roughest pavement likely to be encountered on a major U.S. highway is perhaps 2 m/km, implying \$400 in extra costs. Assuming 12,000 miles a year, this implies an extra cost of 3.3 cents per mile, which would amount to a 60% increase of maintenance and repair costs from the baseline level.

Given all this, we base our adjustment factors on the Texas study, but limit the range of pavement roughness that we use, and use simplified truck adjustment factors for all vehicles. We take as a baseline that a PSI of 3.5 or better (IRI of about 80 inches/mile or 1.2 m/km) will have no impact on operating costs. We then adjust for three levels of rougher pavement as in Table 2.2. The adjustments that we use imply an extra cost of about 1 cent per mile between the smoothest and roughest pavement in maintenance and repair costs. However, because we also assume an impact on depreciation costs through reduced vehicle life, the total cost is about 2.5 cents per mile. This is in line with (6) Papagiannakis and Delwar. From their findings a 1.5 increase in IRI, as we have in our range, would be \$300 extra costs per year; at 12,000 miles per year this is 2.5 cents per mile.

Table 2.2: Effect of pavement roughness on operating costs

PSI	IRI (inches/mile)	IRI (m/km or mm/m)	Adjustment multiplier
2.0 and worse	170	2.7	1.25
2.5	140	2.2	1.15
3.0	105	1.7	1.05
3.5 and better	80	1.2	1.00

We assume that pavement roughness will affect maintenance, tire, repair, and depreciation costs. There is consensus in the literature for the first three of these.

There is no consensus in the literature that pavement roughness affects depreciation; however we include it here based more on casual experience than formal evidence. Experience suggests that a car that is driven almost exclusively on smooth highways will last more miles than one that is driven mostly on rough pavement. Since per-mile depreciation is reflecting the loss in “life expectancy” of the vehicle as it is driven more, factors that reduce the ultimate number of miles that the car can be driven must by implication be increasing the rate at which the car depreciates.

“City” as opposed to “highway” driving conditions involves a greater number of starts and stops, and time spent idling. This clearly affects fuel use, as reflected in the dual fuel mileage estimates produced by EPA for vehicle models. We include an option to specify that a project includes “city” driving conditions, which will have the effect that fuel consumption will be set to the EPA city level. We also include a “congestion” option, which sets fuel consumption at an even higher level, as suggested in (7)ECONorthwest, Associates et al. (2002).

There is some evidence that stop-start conditions affect other costs as well, although here the impact is less clear. Brakes obviously will wear faster in city conditions, but tires and other parts will probably wear less due to the lower speeds. (1,2) IntelliChoice, in a discussion of how often to change oil, notes that while manufacturers might recommend long intervals, they (the manufacturers) are also assuming generally highway driving, and consider city driving to be “extreme” conditions requiring more frequent oil replacement.

As a compromise, we assume that tire wear does not depend on start-stop conditions, but that other maintenance and repair costs will be affected. However, the impact should not be as large as the impact on fuel use. Some of the increased fuel use comes from the time that the car spends sitting still; this should not impact wear on other parts. We use a stop-start adjustment that is half as big as the adjustment for fuel use, and we cap it at the city level. That is, extreme congestion, while it further increases fuel consumption, should not increase wear on parts compared to ordinary city conditions. Overall, the maximum adjustment for this factor is about 70% for fuel use (for severe congestion) and about 17% for other costs.

We also assume that stop-start conditions will affect depreciation costs in the same way as they affect repair and maintenance. While this is not reflected in N.A.D.A. price guidance, this is in part because there is no way for the buyer to know the conditions under which the car has been driven. In terms of real loss of “life expectancy” though, it seems intuitive that a car driven in city conditions will not last as long as one that is driven mostly on the highway. And as with pavement roughness, a reduced vehicle life is equivalent to higher per-mile depreciation.

3 THE COSTS OF OPERATING TRUCKS

Our methodology for determining truck-operating costs differs substantially from that for passenger vehicles because there are very different types of information available. When looking at cars, there are many third party sources that estimate operating costs and resale values of different models, as a service to potential buyers. No similar service exists for trucks. This is probably because buyers of trucks are more knowledgeable about their purchases, and hence have less use for such services. Since they are using trucks for a specific purpose, they tend to buy the same type of truck over and over, and hence have a good understanding of costs and resale values.

The result of this lack of third party cost estimates is that we must develop estimates of truck costs more from research sources, which will in general be aimed at purposes slightly different than ours. That is, they may include some fixed costs, or some costs that may vary with the number of trips but not with the number of miles driven. Thus our methodology for truck costs is primarily focused on analyzing several estimates of these costs, reconciling the differences between them, and deriving a “consensus” estimate that corresponds to the specific costs that we are interested in here.

While there are obviously many different sizes and types of trucks, we estimate a single composite value to account for all of them. This was done for two reasons. First, analysts will typically not have detailed counts of different types of trucks. Second, and more importantly, we could not establish robust estimates of the costs of operating different types of trucks. The available sources tend to focus either on long-haul tractor-trailer combination trucks, or on “all” commercial trucks; there does not seem to be much information on how types of trucks differ from each other.

The lack of information on the costs of different truck types is especially problematic given that we are interested in a specific type of cost, namely operating the truck on a highway under varying start-stop and pavement roughness conditions. However, available estimates of operating costs tend to focus on the “typical” environment for a truck type, which may be very different from this. For example, trucks used in construction and for deliveries operate mostly in extreme conditions; on a highway they may cost less, but no one has had reason to figure this out. And ultimately we don’t have that much precision available on the costs of combination trucks, which are the type that we know the most about. So to be conservative, we derive a consensus operating cost and assume that this cost applies to all truck types.

3.1 Summary of Data Sources

We reviewed a number of sources of semi-truck operating costs. The most significant of these are listed below:

- (8) *Benchmarking the Fleet*; Ronald D. Roth, The Private Carrier, October 1993. In this article, Roth used data from annual financial reports submitted by major general freight carriers to the Interstate Commerce Commission. The article addresses line-haul costs only. The primary purpose of the report is to help companies that have their own trucking fleets to compare their costs against for-hire trucking operations. The author acknowledges that the cost information as summarized in the report is to a significant degree subject to how given trucking companies chose to report their costs.
- (9) *The Effect of Size and Weight Limits on Truck Costs*; Jack Faucett Associates, for the US Department of Transportation, revised October 1991. This report was one of a number of technical reports as part of the US Department of Transportation's Truck Size and Weight and User Fee Policy Analysis Study. It lists and briefly summarizes a number of previous studies that looked at trucking costs-per-mile. Using these sources and others, the authors developed estimates of cost per vehicle-mile as a function of vehicle configuration and operating gross vehicle weight (GVW) ratings.
- (10) *Truck Costs for Owner/Operators*; Mark D. Berwick, Upper Great Plains Transportation Institute (North Dakota State University), September 1997. In this paper, the author designed a spreadsheet simulation model which projects trucking costs for different truck configurations, trailer types, and trip movements. Cost assumptions within the model were derived prior truck costing studies and interviews with various trucking experts.
- (11) *Fruit and Vegetable Truck Fleet Cost Report No. 08*, US Department of Agriculture AMS Market News Service, August 1996 (included in "Cost-per-Mile" information packet prepared by the American Trucking Association). Cost information was based upon annual reports to the Interstate Commerce Commission from 48 long distance haulers of perishable agricultural products and solid refrigerated products.
- (12) *External Costs of Truck and Rail Freight Transportation*; David J. Forkenbrock, Public Policy Center, University of Iowa, 1998. The primary purpose of this book is to examine the full social costs associated with freight movement, including "external costs" (those which are not reflected in market-driven prices) such as environmental and congestion impacts. The author summarizes "private" trucking costs (conventional costs reflected in prices) as derived from operating and financial data compiled by the American Trucking Associations (ATA). The private costs are the base upon which external costs are added to estimate full societal costs. While the focus of the book is on external costs, the summary of private costs was of significant interest for our purposes.
- (13) *Operating Costs of Trucks In Canada – 2001*, Trimac Logistics, Ltd., for Transport Canada, Economic Analysis Directorate. The purpose of this study is to determine 2001 trucking costs for each of the provincial and territorial regions in Canada and to develop US-based trucker comparisons. This is the 20th annual edition of the report series, which began in 1972. It provides estimates for ten categories of semi-trucks plus smaller two-axel delivery trucks. It uses a computer model to

develop cost estimates. The information used to set up and utilize this model was derived from a number of sources including: quotes from suppliers of equipment, tires, and fuel; consultation with experts in the field; review of relevant published literature; others.

- (14) *Partners in Business (Chapter 13—Cost of Operation)*; Volvo Trucks (internet base-report/information), 2003. This document is produced by Volvo Trucks as a guide to help individual owner-operators understand their economic considerations and maximize profits. While it is generated by an equipment supplier, it is reportedly considered within the industry to be a legitimate and useful source of business and cost information pertaining to trucking operations.
- (15) *Major Motor Carrier Index (compilation of data for 2001 and Quarter 1 of 2001)*; Bureau of Transportation Statistics (BTS), US Department of Transportation. This information is a summary of data compiled from financial and operating statistics required to be submitted by Class I carriers to BTS. The index information reviewed for our study did not break down trucking costs by category, but was of interest to provide context for our distance-dependant costs.

3.2 18-Wheel Truck Operating Costs

These documents had differing data sources, methods, and assumptions behind their cost information. Our goal was to come up with figures that would reasonably and broadly reconcile with the information available in the sources identified above. Table 3.1 shows the costs taken from the key sources described above, both total and for specific categories of interest. In all cases except Volvo, the total costs include some amount related to driver wages and indirect costs. The dates in the “source” column are the years on which the analyses are based, not the year the report was published. The subsequent sections describe how we determined “consensus” values for purposes of this report.

Table 3.1: Truck literature cost summary (cents per mile)

Source	Total costs	Fuel	Maint./Repair	Tires
Roth, 1992	121	17.3	12.0	2.5
Faucett, 1988	109	21.6	10.9	3.5
Berwick, 1996	104	19.0	10.0	4.0
USDA, 1995	108	19.1	15.5	2.8
Trimac, 2001	174	24.4	10.5	3.5
Volvo, 2000	64	6 mpg	7.1	2.1

3.2.1 Fuel

The sources of information identified above had fuel costs ranging from 17.3 cents per mile (8)(Roth) to 21.6 cents per mile (9)(Faucett Associates). Assuming nominal fuel costs at \$1.25, this range translates to a range of approximately 7.2 miles per gallon to 5.8 miles per

gallon. The Volvo guidance document (14) assumes an average of 6 miles per gallon. Conversations with trucking sources indicate that a big combination truck would get about 6.5 to 7 miles per gallon, and smaller delivery trucks about 9. Based on these facts, we assume 7 miles per gallon as the input for our model.

Historical diesel prices can be found on the internet. As with gas prices, we recommend that the analyst simply use the current price for purposes of cost estimation, unless specific credible forecasts are available.

3.2.2 Repair and Maintenance

In the literature we surveyed, scheduled maintenance and unscheduled repair are typically included together. Based upon information from the (15)Bureau of Transportation Statistics and (10)Berwick, it is likely that the actual rate of inflation for maintenance costs has been significantly less than the CPI over the past ten to fifteen years, and these prices might have even declined over this time. The literature shows a range of 7.1 to 15.5 cents per mile; excluding those two outliers, the range is 10 to 12.

(16) Zaniewski, et al. provide information which is not useful in absolute terms as it is more than 20 years old, but which indicates that large truck maintenance costs are about 3 times that of a mid-sized car. As car maintenance and repair costs in our model turn out to be about 3.5 cents per mile, we use an estimate of 10.5 cents per mile for truck costs. This is also consistent with the central estimates from the published sources.

Although these costs appear to have inflated very little in the last 10 years, we assume that in the future they will inflate at the rate assumed for automobile maintenance costs, or 3% per year. The stable prices in the past appear to have been at least in part a result of deregulation and increasing competition in the industry; an impact, which will likely not continue in the future.

3.2.3 Tires

The literature cited here shows a range of 2.1 to 4.0 cents per mile for tire costs. We use 3.5 cents as a conservative midrange estimate. Again, this is about 3 times the cost per mile for tires for passenger vehicles.

3.2.4 Depreciation

Mileage-based depreciation is not broken out as a separate category in the published literature. As with automobiles, the interest seems to be in overall depreciation, assuming a certain annual mileage. The head of a local trucking company gave estimates of the values of

trucks of a given age with differing mileage, which implied that the marginal impact of mileage independent of vehicle age is about 5 cents per mile. This is in the same range as the mileage-based depreciation for cars. This is probably reasonable since although trucks cost much more they also last much longer. Another confirmation comes from the (17) 1977 AASHTO user benefit analysis manual, which estimates auto depreciation at 3.32 cents per mile, a 2-axle truck at 3.5 cents, and a 5-axle semi at 3.0 cents. These numbers are in 1977 dollars and are describing vehicles with a generally shorter life span than is the case now, so the numbers themselves are not useful. However, the point that all these different vehicles depreciate at about the same per-mile rate confirms what we have found in our analysis.

Based on these sources, we use a depreciation rate that is derived from the rate for the most expensive cars. That is, we use the class 4 depreciation schedule, assuming that 70% of mileage is driven by trucks less than 5 years old, and 30% by trucks 5 years old and more. Newer trucks are driven 100,000 miles per year or more, and older trucks at a much reduced rate. Overall these assumptions lead to a depreciation rate of 8 cents per mile.

3.3 Adjustment Factors

The figures in the previous section are for standard five axle “van” semi-trucks assuming over-the-road interstate driving conditions. Vans make up the largest percentage of semi-trucks, and information we reviewed indicated that, relative to the purposes of this project, there is not a large difference in per-mile operating costs for the various semi-truck types. We take these trucks as being representative of trucks that would be affected by a typical highway construction project, both because they are the most common type, and because their costs are a midpoint between the other two major truck types that we considered, as seen in Table 3.2.

Table 3.2: Truck costs by type

	Semi-truck	Straight truck-pick-up/delivery van	Straight truck-industrial/construction
Fuel milage	6.5-7.0 mpg	8-9 mpg	5
Maint/repair costs	10-15 cents/mile	8-10 cents/mile	156-25 cents/mile

We adjust these baseline truck costs by the same two factors as was done for cars: stop-start conditions and pavement roughness. We assume, for lack of better information, that stop-start conditions will impact trucks in the same way that they impact pickups/SUVs, which amounts to about a 31% increase in fuel, and 15% in maintenance and repair costs (excluding

tires). We assume that pavement roughness will affect truck costs in the same way as car costs, as outlined in section 2.3. This is an increase of 5% for a PSI of 3.0, 15% for a PSI of 2.5, and 25% for a PSI of 2.0 and worse, applied to all costs except fuel.

4 SUMMARY OF COSTS

In this section we summarize the methodologies and the how the adjustment factors influence different cost components. We also describe what operating costs turn out to be under a few different situations, given the methodologies described above, and compare these costs to other published sources.

4.1 Summary of Methodology

For automobile operating costs we estimate values for each of five cost components, for each of about 100 car, pickup, van, and SUV models. We multiply the values for the cost components by the fraction of the overall fleet that each model comprises, to get a weighted average for each of the five costs. We do this for two separate categories, cars and other, including pickups, vans, and SUVs. We then multiply this fleet average for each of the five cost components and two vehicle categories by several adjustment factors to get a project-specific cost for cars and other vehicles. We then multiply these two costs by the fraction of the total fleet that are cars, and other vehicles respectively to get an overall average.

The baseline per-mile values for the five cost categories are estimated in the following ways (adjustment factors are discussed later):

- Fuel: EPA fuel economy ratings, converted to gallons per mile, multiplied by the gas price.
- Maintenance: Intellichoice estimated five-year maintenance costs, excluding tires, divided by the assumed 70,000 miles. This per-mile cost is assumed to continue for the life of the vehicle.
- Tires: Intellichoice estimated tire replacement cost, divided by the assumed 45,000-mile tire life.
- Repair: Intellichoice estimated five-year repair costs. They indicate that generally half of these costs occur in the fifth year. We calculate a per-mile cost for the first four years as half of the total divided by 56,000, and for the fifth year as half of the total divided by 14,000. We assume the fifth year cost continues for the life of the vehicle. We assume, based on registration patterns, that 1/3 of all mileage is driven by cars less than five years old. So we multiply the new-car repair cost by 1/3 and the old-car cost by 2/3 to get a weighted average for the life of a vehicle.

- Depreciation: N.A.D.A. gives adjustment factors for used car prices based on mileage above and below the assumed average for a car of a given age. Other depreciation is assumed to be based on the age of the vehicle rather than mileage. Adjustment factors are given in four categories, mostly determined by the initial value of the vehicle. The implied per-mile depreciation rate is higher for vehicles more than four years old. We create a weighted average using the same method as for repair costs.

Adjustment factors are applied to some of these costs, in order to account for stop-start conditions, unusual pavement roughness, and the possibility of price changes over time. The following table summarizes which adjustments apply to which costs.

Table 4.1: Use of adjustment factors

Cost Category	Stop-start conditions	Pavement roughness	Price changes
Fuel	Full increase	no	yes
Maintenance	Partial increase	yes	yes
Tires	no	yes	no
Repair	Partial increase	yes	yes
Depreciation	Partial increase	yes	no

For maintenance, repair, and depreciation, worsening stop-start conditions will increase costs, but to a smaller extent than the increase associated with fuel consumption.

4.2 Summary of Costs

Table 4.2 shows baseline per-mile costs in 2003 cents for our three vehicle types for a baseline scenario of highway conditions, smooth pavement, and fuel prices of \$1.50 per gallon.

Table 4.2: Baseline costs (cents per mile)

Cost Category	Automobile	Pickup/van/SUV	Commercial Truck
Total	15.3	19.5	43.4
Fuel	5.0	7.8	21.4
Maintenance/Repair	3.2	3.7	10.5
Tires	0.9	1.0	3.5
Depreciation	6.2	7.0	8.0

Table 4.3 shows per-mile costs given city rather than highway conditions, with other assumptions the same. This fairly sizeable impact is even greater when “congested” conditions are assumed.

Table 4.3: City driving conditions (cents per mile)

Cost Category	Automobile	Pickup/van/SUV	Commercial Truck
Total	19.1	23.6	52.9
Fuel	7.0	10.1	28.0
Maintenance/Repair	3.8	4.3	12.1
Tires	0.9	1.0	3.5
Depreciation	7.4	8.1	9.2

Table 4.4 shows per-mile costs given extremely rough pavement (PSI = 2), again with other assumptions the same as the baseline.

Table 4.4: Extremely poor pavement quality (cents per mile)

Cost Category	Automobile	Pickup/van/SUV	Commercial Truck
Total	17.9	22.5	48.9
Fuel	5.0	7.8	21.4
Maintenance/Repair	4.0	4.7	13.1
Tires	1.1	1.2	4.4
Depreciation	7.8	8.8	10.0

4.3 Comparison to Other Cost Estimates

Our passenger vehicle cost estimates are comparable to those in other published sources, as shown in Table 4.5. We assume a mix of highway and city conditions, and a mix of the two smoothest pavement roughness levels. We assume a fuel price of \$1.25 per gallon, which is the average for the last 10 years, to make our fuel cost derivation more comparable with theirs. We also take 0.5 cents per mile from their fuel estimates and put it in with repair and maintenance to make the categories comparable with ours.

Table 4.5: Comparison of baseline costs to other sources (cents per mile)

Cost Category	This study car only	FHWA “Red Book” medium size car	Qin, et al.(18)
Total	16.5	14.8	23.8
Fuel	5.0	5.4	4.5
Tires	0.9	1.7	1.0
Repair/Maint/Oil	3.7	4.0	4.8
Depreciation	7.0	4.2	13.5

The estimates in (18) Qin, et al. differ substantially from ours only in the depreciation line, which in their case apparently includes age-based as well as mileage-based depreciation. The

only other major difference is that our repair and maintenance costs are lower. The annual Intellichoice reports from which we derived our maintenance and repair estimates show a substantial drop in scheduled maintenance costs between 1999 and 2000. The 2000 report offers no explanation of why this adjustment was made; presumably it had to do with improved reliability and warranties and longer maintenance cycles. So if the other operating cost sources were basing their estimates on a similar source, then perhaps their maintenance estimates are reflecting earlier, higher estimates of these costs.

One final issue is the size of the variable cost estimates for large commercial trucks. We address this in Table 4.6, which shows a comparison of variable and total costs for cars and trucks. The total cost per mile for cars is taken from FHWA, and is a routinely used number. The total per mile for trucks is a composite average taken from the variety of sources described in Chapter 3 of this report. We assume that the truck driver costs \$30/hour in wages and indirect costs, and that the truck travels a mile in one minute. All of these numbers are approximate, as the point of this is to demonstrate the general comparability of costs.

Table 4.6: Comparison of total and variable costs (cents per mile)

Cost Category	Automobiles	Trucks
Total per mile	45	180
Driver costs	N.A.	50
Total vehicle cost per mile	45	130
Variable cost per mile	15	43
Variable as % of total	33%	33%

The essential point here is that while truck variable costs may seem low compared to total costs, they are actually a higher fraction of the total than automobile variable costs, once driver costs are taken out.

REFERENCES

1. IntelliChoice, I. (2002). "The Complete Car Cost Guide."
2. IntelliChoice, I. (2002). "The Complete Small Truck Cost Guide."
3. Ward's Reports, I. (2001). "Ward's automotive yearbook." Detroit
4. N.A.D.A. (2003). "Official Used Car Guide."
5. Walls, J. I., and Smith, M. R. (1998). "Life-Cycle Cost Analysis in Pavement Design - Interim Technical Bulletin." Federal Highway Administration.
6. Papagiannakis, A. T., and Delwar, M. (1999). "Methodology to Improve Pavement Investment Decisions." For National Cooperative Highway Research Program.
7. ECONorthwest, Associates, K., and Parsons, B. Q. D. (2002). "Development of an Update to the 1977 AASHTO Redbook: User Benefit Analysis for Highways." National Cooperative Highway Research Program.
8. Roth, R. D. (1993). "Benchmarking the Fleet." Private Carrier.
9. Jack Faucett Associates. (1991). "The Effect of Size and Weight Limits on Truck Costs." US Department of Transportation.
10. Berwick, M. D. (1997). "Truck Costs for Owner/Operators." Upper Great Plains Transportation Institute, North Dakota State University.
11. AMS Market News Service. (1996). "Fruit and Vegetable Truck Fleet Cost Report No. 08." US Department of Agriculture.
12. Forkenbrock, D. J. (1998). External Costs of Truck and Rail Freight Transportation, Public Policy Center, University of Iowa.
13. Trimac Logistics Ltd. (2001). "Operating Costs of Trucks In Canada - 2001." Transport Canada, Economic Analysis Directorate.
14. Volvo Trucks. (2003). "Partners in Business."
15. Bureau of Transportation Statistics. (2001). "Major Motor Carrier Index." US Department of Transportation.
16. Zaniewski, J. P., et al. (1982). "Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors." Texas Research and Development Foundation, Federal Highway Administration, Austin, Texas.
17. AASHTO. (1977). "A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements." American Association of State Highway and Transportation Officials.
18. Qin, J., Weissmann, J., Euritt M., and Martello, M., "Evaluating the Full Costs of Urban Passenger Transportation," *Transportation Research Record 1518*, 1996.

APPENDIX A

USING AND UPDATING THE SPREADSHEET

The ultimate objective of this research was the development of a spreadsheet that analysts can use to estimate vehicle-operating costs for specific projects. The estimates of vehicle operating costs per mile are based on the research described in the previous chapters. The spreadsheet assists in the calculation of per-mile costs for a given project by automating the application of fuel prices and other variable adjustment factors.

While the spreadsheet contains a number of separate pages, the user will typically only be interested in the “user input” page. This is where the user will enter project cost parameters, and the results in terms of average and total costs will be shown on this page. The first section of this chapter describes how to use this page of the spreadsheet. The worksheet also contains several pages of raw data and intermediate calculations. There may be reasons the user would want to modify these underlying formulas; the final section of this chapter describes how to do this.

Typically the analyst will want to compare a number of alternative project scenarios. In particular, the proposed project will usually be compared with the status quo, but it may also be compared with alternative designs or schedules. To facilitate these types of comparisons, the user input page is organized so that the inputs are entered into columns; each of the four available columns describes a different scenario. The multiple columns could also be used for situations where different parts of the project have different characteristics. For example, different phases of the project might involve detours of different lengths, or driving conditions in terms of congestion might depend on the time of day.

The first column of the page gives the names of the various input and output rows. Attached to each name is a comment that describes what it is; left clicking on the name cell will display the comment.

The page “Methodologies” contains links to Word documents that are extracts from this final report, describing in detail the methodologies for specific cost elements.

Editing Cost Parameters

There are four types of information. They describe driving conditions, pavement roughness, fuel prices, and cost inflation. User inputs are shown in green type on the “User Input and Results” page.

The description of driving conditions reflects the idea that costs such as fuel and some maintenance and repair costs will be higher in a situation with frequent stops and starts than on a

free-flow highway. The input is set up so that there are three levels of driving conditions: highway, city, and severe congestion. Highway represents generally free-flow conditions, including some infrequent stops. City represents conditions of frequent starts and stops but with generally smooth-flowing traffic in between. The congestion option is included here to represent conditions that are considerably worse than ordinary city conditions; these sorts of conditions can easily arise during construction due to lane closures and so on.

The data is entered as the proportion of the total project that falls in each of the three levels. For example, a 12-mile project with 9 miles of highway and 3 miles of city conditions, would be entered as 0.25 in city, 0.75 in highway, and zero in congestion. There is an error cell built in so that if the total does not add to one, the cell will indicate this.

The entry for pavement roughness works the same way, in which the proportion of the project that falls in each roughness level is entered. Here, there are a sequence of pavement roughness levels that correspond to the widely used Present Serviceability Index (PSI). The levels included here range from 2.0 to 3.5, which represents the range likely to be relevant in Minnesota; conditions worse than 2.0 rarely if ever occur, and better than 3.5 has no impact on costs. Comments attached to these cells convert PSI into IRI if that is the information that is available.

There are two fuel cost parameters. Gasoline prices impact costs for autos and pickups/SUVs, while diesel prices affect costs for large commercial trucks. As these costs don't appear to follow any useful trend, we recommend that the analyst simply use the current price, unless a specific credible forecast is available.

Finally, there are four cost adjustment parameters. The inflation rates for repair and maintenance will affect the size of these costs in years after 2003. This rate has been about 3% for several years. In the spreadsheet the analyst should enter 1.03^n , where n is the current year minus 2003.

A more thorough upgrade several years in the future would include replacing the baseline cost information originally taken from the Intellichoice cost guides, and the sales information from Wards. This could probably be done in a matter of a few hours. A reduced version of this might be to pick 10 or so major sellers, check the new cost information for those against the figures in the spreadsheet, and simply enter new parameters in the maintenance and repair cost adjustment that reflect the average increase for that sample of vehicles. We use the 2002 book to

predict 2003 costs, since the book is forecasting future ownership costs, so updates should use the book from year n to represent costs for year n+1.

There are also lines available to input cost adjustment parameters for tires and depreciation. Currently we recommend that these be set to 1, since the evidence indicates that these costs have not changed much for a number of years. However, if different information becomes available, these costs could be adjusted. As with maintenance, an aggregate cost adjustment should be entered, not an annual inflation rate.

A full or partial upgrade for tire costs would be taken from Intellichoice, the same as maintenance and repair costs, with the same time commitments. An upgrade for depreciation would be simpler, since these numbers are simply a series of tables in the front of the N.A.D.A. guides; the analyst would simply need to replace the tables at the bottom of the user input page, with the new tables.

The interpretation of all of these inputs is fairly straightforward. The primary complication that could arise lies more in defining the project, in that parameters might not be uniform over an entire project and so it may be necessary to break the project into uniform components. Some possible examples of this might include:

- The driving conditions and pavement quality of detour routes change over the course of a project
- Driving conditions are congested at some times of day but free-flowing at others (or there is seasonal variation)

To some extent it should be possible to get around most of these issues within the context of a single scenario by hand-calculating an “average” level of the parameter in question. However, in other cases it may be interesting to understand exactly what the impacts of the variations are; in these cases a single project can be broken into several separate components with each described explicitly as a different scenario.

Modifying the Spreadsheet

The spreadsheet is set up so that all the basic parameters that a user might want to modify can be edited directly on the user input page. Beyond this, modifications to the spreadsheet would involve changing the actual structure of the formulas from which the costs are calculated. This might be desirable, for example, if the user wanted to calculate a particular cost using a different method. We assume that anyone trying to do this will already have a solid grasp of the technical

aspects of working with spreadsheets, and the ability to interpret and appropriately modify the formulas. Thus this section focuses on describing the basic flow of information.

The general strategy for the spreadsheet is to calculate baseline information about each of the five cost categories for cars, pickups/SUVs, and large commercial trucks. Then scenario-specific parameters such as fuel prices and operating conditions are applied to this baseline cost information to create costs for each of the five elements and each of the three vehicle types.

The fraction of the total fleet that each model comprises is calculated in the sheet “Vehicle Counts.” Fractions are calculated separately for cars and for pickups/SUVs/vans. The sheet “Cost Data and Calculations” contains the raw cost data by cost category for all the vehicle models. It also contains intermediate calculations, which convert these raw data into costs per mile, and then weight these costs by the fraction of each model in the fleet, to arrive at aggregate baseline costs by category for cars and pickups/SUVs/vans. These aggregate baseline costs are shown in the top two rows of the sheet. The one exception is fuel costs, which are shown as gallons per mile; they are converted into costs on the main user page because the fuel price is scenario-dependent.

The page “User Input and Results” is the only one that the user would typically want to see. The top part of the page contains user inputs and results for four scenarios. Normally the user would only work in this part of the page, unless there were reasons to modify some of the baseline costs and parameters. The bottom part of the page contains other inputs, which do not vary by scenario, such as baseline commercial truck costs, and some intermediate calculations. Any calculations that are scenario-dependent are done on this page. Of the baseline costs that do not vary by scenario, some come from the “Cost Data and Calculations” page, and some are at the bottom of this page. All parameters that influence the costs in any way are entered on this page.

The first column of this page where row headings are shown contains comments, which explain what that row is. For results, this comments describes briefly the methodology by which that cost is calculated. For user inputs and parameters, it describes what the input or parameter is, and the recommended entry.

APPENDIX B

BACKGROUND ON VEHICLE OPERATING COSTS

This appendix is divided into three parts. The first discusses studies of aggregate costs of travel. These studies include analyses of the full social costs of travel and studies of aggregate vehicle costs. While these studies do not generally provide detailed analyses of vehicle operating costs, they do identify major categories of costs, provide alternative methods of calculating costs, and make use of important data sources. The second section examines studies of vehicle operating costs and discusses some of the limitations of these studies. There appears to be no one study of vehicle operating costs that is widely considered to be definitive. Limitations include studying only a few types of vehicles, making simplifying assumptions about vehicle life, and examining major cost categories in isolation. In addition, many studies focus on determining the average annual cost of operating a vehicle, and do not focus on calculating marginal costs in ways that are useful for performing cost/benefit analyses. The third section describes four programs that calculate vehicle operating costs: Modecost, STEAM, SCALDS, and MicroBENCOST. In general these programs do not provide very detailed information on how to calculate vehicle-operating costs. Instead they provide default values for a few categories of VOC. Another problem is that the programs are not generally easy to update.

While our examination of the literature is not exhaustive, there appears to be a great deal of consistency in the studies we examined. Overall our conclusion is that shortcomings exist in available studies of VOC that we feel we can mitigate. Specifically, we attempt to improve upon these studies by:

- determining values of VOC specifically for Minnesota,
- constructing a method to update these values of VOC, and
- accounting for some of the interrelationships between different categories of vehicle operating cost.

Studies of Aggregate Travel Costs

There have been a number of broad studies of the full costs of vehicle travel in recent years. They include Miller and Moffet (1993), Litman (1994), Delucchi (1996), and Anderson and McCullough (2000). These studies are not particularly helpful to us, because they do not analyze vehicle-operating costs in great detail. There are two major reasons for this. First, these studies generally focus on external, and to a lesser extent, governmental, costs. *Governmental costs* are costs borne by any level of government; expenditures on road construction or the highway patrol would be examples. *External costs* are those costs that are not borne by the person who causes them. Examples include air and noise pollution. *Internal costs* are borne by the

person who causes them—vehicle-operating costs are a component of internal costs. This focus on governmental and external costs occurs despite the fact that almost all studies of the costs of transportation have found that internal costs are significantly larger than external costs. The interest is probably due to the fact that they create a disproportionate share of political and economic problems. The second reason studies of full costs are not very helpful to us is that variable vehicle operating costs make up a relatively small share of total internal costs. Anderson and McCullough, for example, estimate that variable vehicle operating costs made up 12% of all internal costs in 1998, and 20% of variable internal costs).

While we have not found any studies of the full costs of travel that analyze vehicle operating costs in a great deal of detail, examining these studies has allowed us to identify three main ways that these vehicle operating costs are calculated. They can be calculated based on (i) data on Gross Domestic Product (GDP) and on VMT, (ii) consumer expenditure surveys, demographic data, and data on VMT, and (iii) direct data on operating cost per mile. Consider how each of these methods might be used to calculate the costs of fuel, for example. Using the first method, one might determine the cost based on total value of sales of motor fuels at retail stations. Using the second method, one would use a survey of consumers to determine how much the average consumer spent on motor fuels, and then determine total costs based on the total number of consumers. Using the third method, one could determine costs by estimating fuel mileage the price of fuel. While we expect to use all three methods in various parts of this study we expect the first and third to be most helpful. The first method is useful because GDP data is usually detailed and accurate. The third method is almost always needed when we want information on the costs of different types of vehicles.

The Bureau of Labor Statistics (BLS) is a primary source for information on consumer expenditures. Their consumer expenditure surveys (see, for example, BLS (2000)) contain data on the average expenditures of people in different demographic categories. They do not keep state-level data, but they do have data on the Twin Cities Metropolitan Statistical Area and on the Midwest. Demographic categories include age, income, household size, and the number of vehicles owned by the household. Of special interest to us, the survey contains the following data on expenditure types:

- Vehicle purchases
- Gasoline and motor oil
- Vehicle finance charges
- Maintenance and repairs

- Vehicle insurance
- Vehicle rental, leases, licenses, other charges

The Bureau of Economic Analysis (BEA) assembles data on the GDP of the United States. See, for example BEA (2000). It maintains data on (i) consumer purchases (*e.g.*, purchases of motor vehicles and parts; gasoline and oil; and other transportation services); (ii) public and private investment; and (iii) the output of the transportation industry. The BEA data is quite accurate, and it is assembled quarterly, but their main tables only contain five categories related to the variable costs of user-operated transportation. These are

- Tires, tubes, accessories, and other parts
- Repair, greasing, washing, parking, storage, rental, and leasing
- Gasoline and oil
- Bridge, tunnel, ferry, and road tolls
- Insurance

Studies by Han and Fang (1998) and Fang et al., (1998) make use of national income accounting data to provide more details on the aggregate costs of transportation. Han and Fang (1998) contains data *on transportation final demand* (which is the value of all goods and services delivered to final users for transportation purposes). Transportation final demand is between 10.5 and 11.1 percent of GDP for the years from 1991 to 1996. Han and Fang (1998) also contains data on the value added by the transportation industry (*i.e.*, they assemble data on the value of transportation services minus the costs of producing those services).

Fang et al., (1998) contains data on transportation satellite accounts (TSAs). TSAs extend the United States input-output accounts to allow for more detailed analysis of economic activity involving transportation. The TSAs show the value of different types of transportation services are used by various industries (the mining or construction industries, for example) and they show the value of other industries' inputs that are used by transportation industries.

Studies of Vehicle Operating Cost

The depreciation cost of vehicle operation is typically split into subcategories, namely the costs of scheduled maintenance, those of unscheduled repairs, and the natural devaluation in a vehicle due to its condition and age. The latter is, naturally, related to the former two: condition is likely a proxy for the subjective probability of future breakdowns, hence future unscheduled repairs; age, similarly, is important in calculating depreciation at least in part because it proxies for the likelihood of needed scheduled repairs and maintenance.

To some degree, therefore, including depreciation will introduce some double counting of VOC, if one is separately calculating the impact of scheduled maintenance and the expectation of unscheduled repairs. Typically, however, the effects of depreciation, repairs, and maintenance are evaluated in isolation. In Qin et al., (1996) depreciation is given as a flat \$0.1345 per mile, with a caveat about the assumed vehicle type and a note that changes in assumptions would have changed the estimate. Costs of scheduled maintenance and unscheduled repairs are given at \$0.0233 per mile and \$0.0196 per mile, respectively. These numbers are based on owners' manual recommendations for full-sized automobiles and from estimates of total repair costs. Whether the scheduled maintenance is conducted promptly, how bad things have to be before one conducts unscheduled repairs, and similar issues will presumably affect a vehicle's condition and thus the depreciation (and each other—postponed unscheduled repairs might cause one to burn oil and need more frequent oil changes, for example).

As with depreciation, repair, and maintenance, other variable vehicle operating costs are typically studied in isolation. Fuel and tire expenses are presumably connected to speed, road gradient, curvature, roughness, and so forth. Thus, the indirect effect of gradient on fuel is likely to affect oil expenses, which may in turn affect speed. These issues are discussed in detail in Thoresen and Roper (1996), but their study is confined to a meta-analysis of different models.

Some simulation studies attempt to look at changes in full costs by estimating direct and indirect effects of changes in an input; see, e.g., De Borger and Wouters. Because their interest is not chiefly in VOC but in pricing of public transit, their VOC model is restricted to studying the effects of congestion and average speed.

Industry sources and websites typically provide simplified rules of thumb for estimating VOC. The website www.intellichoice.com estimates automobile VOC as \$0.45 per mile, by assuming that vehicles achieve the fuel economy in the EPA's highway estimates, that maintenance is completed on schedule at suggested retail prices on parts (it's unclear whether labor costs are also included), and that repair costs match the expectations for the first 70,000 miles or 5 years of the vehicle's life. This may be useful as a guideline when making initial purchase decisions, but the figures should be adjusted to account for (i) passenger cars are regularly kept for more than 150,000 miles and (ii) vehicle owners will not always maintain their vehicles optimally.

The US Department of Transportation estimates operating costs as 44.8 cents per mile for a mid-sized automobile in 1997, based on a 4-year, 60,000-mile cycle. Maintenance is estimated at 2.8 cents per mile, which is sharply lower than the maintenance and repair estimates in other

sources. Moreover, no adjustment is made for road roughness, curvature, or grade, or whether the miles are chiefly urban or rural.

Two other sources of information on users' costs are the Motor Vehicle Manufacturers Association (MVMA) and the Federal Highway Administration (FHWA). Both sources provide estimates of VOC for different types of vehicles. Based on international data, MVMA estimates the operating cost to be \$0.436 per mile for an intermediate size car in 1991. The corresponding FHWA estimate is \$0.334 per mile. These estimates depend upon assumptions about the average life and annual mileage of vehicles. The differences between these two sources are due to differences in depreciation rates and finance charges. The reports by the FHWA are published regularly and may be useful for updating cost data in future years.

The costs of truck operation present special problems. The Transportation Research Board (1996) calculated the marginal social cost of freight traffic. Marginal social cost is defined to be the increase in the full social costs of transporting one more unit of freight at a certain time and along a certain segment of road. Because of heterogeneity in the costs, they relied on case studies. Vehicle operating costs are a large share of marginal social cost (between 78% and 98% of total costs in the cases analyzed). The purpose of the work was to address problems of inefficiency related to freight transportation. The authors argue that the marginal cost approach is the correct approach for evaluating the efficiency of transportation systems.

The Battelle Team (1995) analyzed the question of the impact of size and weight policy on truck costs. They examined the costs to drivers, the costs of vehicle depreciation and interest, fuel costs, the costs of tires, repair and servicing costs, and indirect and overhead costs. They estimated these costs for different types of trucks. Trimac Consulting Services LTD (1988) studied the operating costs of trucks in Canada. The purpose of their study was to provide an understanding of the factors that influence truck-operating costs. As part of this work they analyzed the influence of regional factors on costs. They calculated operating costs for a number of case studies.

The American Truckers Association (1997) estimates VOC as roughly \$1.923 per mile. However, more than 10% of that estimate (19.7 cents) is attributed to a category described only as "miscellaneous." Insurance, tax, and license costs are 12.4 cents, making the miscellaneous category an even larger portion of the total. The ATA does not break down costs in to maintenance costs and repair costs, instead reporting on outside maintenance, non-driver wages and benefits, and equipment rental and purchased transportation; these categories presumably

include the cost of in-house and outside mechanics and hence repairs, along with those of renting working vehicles because too much of one's own fleet is being repaired.

Programs to Analyze Vehicle Operating Costs

A few software applications have been developed for performing cost-benefit analyses of transportation alternatives. Qin et al., (1996a) reviews the literature on major studies of the full costs of transportation. They conclude that all studies have an important limitation: they present national averages that might not be accurate for particular situations. User costs depend on location, weather conditions, time of day, fuel price, and other factors. Qin et al., (1996b) describes a computer based model, MODECOST, that was created to take into account these cost variations. The paper conducts a case study to illustrate the use of MODECOST. Euritt, et al. (1996) explain how to use MODECOST for evaluating and comparing the full social costs of different modes of transportation.

DeCorla-Souza and Hunt (1998) describe another software application, STEAM. Their study explains how STEAM was used to perform a cost-benefit analysis for two alternative projects in a major travel corridor. The analysis evaluated the effects the projects had on the costs of different travel modes. A software application has also been developed for the 1997 Federal Highway Cost Allocation (see FHWA (1997)). This study examined the major external costs of highway travel in the U.S., developed total cost estimates for the U.S., and identified the types of vehicles that were responsible for the various costs. The FHWA's software allows users to determine how costs should be allocated across vehicles in a variety of situations. STEAM includes two categories of vehicle operating costs: the cost per gallon of fuel and "non-fuel highway user cost." The model includes baseline values for both categories. The non-fuel costs are four cents per mile for autos and ten cents per mile for trucks. The cost of fuel consumption depends on the cost of fuel and on speed, which affects the rate of fuel consumption. Baseline rates are provided for autos and trucks in five-mile-per-hour increments.

Another program designed to aid in transportation-related cost-benefit analyses is MicroBENCOST. The program provides access to a wide range of transportation cost data, and does not focus narrowly on vehicle operating costs. It divides operating costs into five categories: fuel, oil, tires, depreciation, and repair and maintenance. Default cost values are provided for four types of passenger vehicles (small and medium autos, pickups, and buses) and seven types of trucks.

References

American Automobile Manufacturers Association, *Facts and Figures '93*, Washington DC, 1993.

Anderson, D. and McCullough, G., *The Full Cost of Transportation In the Twin Cities Region*, The Center of Transportation Studies, University of Minnesota, Minneapolis, MN, 2000.

Apogee Research, *The Costs of Transportation: Final Report*, Conservation Law Foundation (Boston), 1994.

Calfee, J. and Winston, C., "The Value of Automobile Travel Time: Implications for Congestion Policy," *Journal of Public Economics*, July 1998.

Canadian Automobile Association, *1992-1993 Car Costs*, Canadian Automobiles Association (Ottawa), Brochure, 1993.

Federal Highway Administration, *The Costs of Owning and Operating Automobiles and Vans 1984*, Office of Highway Planning, U.S. Department of Transportation (1984).

Federal Highway Administration, *1997 Federal Highway Cost Allocation Study--Final Report*, U.S. Department of Transportation, 1997.

DeCorla-Souza, P. and Hunt, J., *Use of STEAM in Evaluating Transportation Alternatives*, Federal Highway Administration, U.S. Department of Transportation, 1998.

Delucchi, M., et al., "The Annualized Social Costs of Motor-Vehicle use in the US Based on 1990-1991 Data," University of California, Institute for Transportation Studies, Davis, CA, 1996.

Euritt, M., Qin, J., Smith, K., Martello, M., and Weissmann, J., *Full-Cost Analysis of Urban Passenger Transportation*, Research Report 1356-1, Center for Transportation Research, The University of Texas at Austin, 1996.

Human Resource Development Canada, *Occupational Injuries and their Cost in Canada*, Government of Canada, Ottawa, Ontario, 1998.

Litman, Todd, *Transportation Cost Analysis: Techniques, Estimates and Implications*, Victoria Transport Policy Institute, 1995.

Miller P. and Moffet J., *The Price of Mobility: Uncovering the Hidden Costs of Transportation*, Natural Resources Defense Council, San Francisco, CA, October 1993.

Qin, J., Weissmann, J., Euritt M., and Martello, M., "Evaluating the Full Costs of Urban Passenger Transportation," *Transportation Research Record 1518*, 1996a.

Qin, J., Martello, M., Weissmann, J., and Euritt, M., *Application of Full-Cost of Urban Passenger Transportation, Case Study: San Antonio Northeast (IH-35) Corridor*, Research Report 1256-6, Center for Transportation Research, The University of Texas as Austin, 1996b.

Quinet, E. "Full Social Cost of Transportation in Europe," in the *Full Costs and Benefits of Transportation*, D. Greene, D. Jones, and M. Delucchi editors, 1997.

Small, Kenneth, *Urban Transportation Economics*, Hardwood, Chur, 1992.

Transportation Research Board, *Paying Our Way: Estimating Marginal Costs of Freight Transportation*, Transportation Research Board Special Report 246, 1996.

Trimac Consulting Services LTD, *Operating Costs of Trucks in Canada 1988*, 1988.