National Cooperative Highway Research Program

NCHRP Synthesis 269

Road User and Mitigation Costs in Highway Pavement Projects

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Transportation Research Board
National Research Council

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

NATIONAL ACADEMY PRESS
Washington, D.C. 1999

Subject Areas
Planning and Administration, and Pavement Design, Management, and Peformance, and Maintenance

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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NCHRP SYNTHESIS 269

Project 20-5 FY 1996 (Topic 27-12)
ISSN 0547-5570
ISBN 0-309-06822-3
Library of Congress Catalog Card No.98-67636

Price $24.00

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

and can be ordered through the Internet at:

http://www.nas.edu/trb/index.html

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis report will be of interest to transportation agency planners; design, construction, and maintenance engineers; and administrators, managers, economists, and other decisionmakers involved in programming highway pavement projects. This synthesis describes current practice with regard to road user and mitigation costs in highway pavement projects. Information for the synthesis was collected by surveying U.S. and Canadian transportation agencies and by conducting a literature search of both domestic and foreign publications.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board provides detailed information on the various methods employed by transportation agencies to estimate user costs. The advantages and disadvantages of each are reported. Information on the various components of user costs: time related, vehicle operating, safety, and environmental costs, is also included. In addition, the study reports on the various mitigation strategies available to agencies to reduce user costs. Information is also provided on how user costs and mitigation strategies have been applied to evaluate different alternatives; and how uncertainties, political considerations, and quality control contribute to the decisionmaking process.

To develop this synthesis in a comprehensive manner and to ensure inclusion of signficiant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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ACKNOWLEDGMENTS

David L. Lewis, Hickling Lewis Brod, Inc., Silver Spring, Maryland, collected the data and prepared the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Kazem Attaran, Chief Economist, California Department of Transportation; Andrew V. Bailey, State Maintenance Engineer, Virginia Department of Transportation; Dick Clark, Pavement Management Supervisor, Montana Department of Transportation; Gaylord Cumberledge, New Cumberland, Pennsylvania; John W. Fuller, Professor, University of Iowa; James Walls, Highway Engineer, Federal Highway Administration, Jon M. Williams, Senior Program Officer, Transportation Research Board; and Mark J. Wolfgram, Chief of Program Analysis, Wiscosnin Department of Transportation, Bureau of State Highway Programs.

This study was managed by Stephen F. Maher, P.E., Senior Program Officer, who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in Topic Panel selection and project scope development was provided by Sally D. Liff, Senior Program Officer. Linda S. Mason was responsible for editing and production.

Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-5 staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

ROAD USER AND MITIGATION COSTS IN HIGHWAY PAVEMENT PROJECTS

SUMMARY

Since the Romans first paved public rights-of-way about 2,000 years ago, transportation planning has been driven by the belief that better pavements mean lower transportation costs for roadway users. Good pavement allowed Roman legionnaires to arrive at their destinations with smaller outlays for fuel (food and water) and equipment maintenance, with fewer injuries and, of course, in less time. The motivation for good pavement is not so different today. Good pavements, and good pavement strategies, mean less costly disruptions to the flow of traffic and commerce during road work; lower shipping costs in the movement of goods to market; smaller household outlays on gas, oil, and auto maintenance; faster travel and thus wider access to job opportunities and housing alternatives; fewer travel related accidents; less expenditure to keep pavements in good shape and thus lower taxes for roadway users; and even diluted exposure to the environmental ills of congestion and traffic noise.

Yet despite the foundational importance of user costs, DOTs in only about half the 50 states and the Canadian provinces actually take user costs into account when planning pavement improvements and road work. Just as people often make decisions about what to eat and drink without weighing the basic nutritional value of food alternatives, transportation decisions seek to serve many objectives yet often without regard for basic value in relation to user costs.

The need to consider basic value in pavement programming decisions is growing, however. DOTs today confront swelling demand for improved pavement infrastructure in the face of stiff financial and land-use barriers to bringing the improvements about. As well, states face a rapid rise in the number of opportunities to adopt advanced pavement technologies, such as products with faster hardening and drying attributes, that shorten the disruptive effects of road work. Inevitably, the number and cost of such opportunities outstrips the financial capacity of DOTs to adopt, or even test them all. Measuring the value of alternative pavement related construction and rehabilitation strategies in relation to their implications for user costs can help DOTs make effective and efficient use of the scarce financial, land, and environmental resources at their disposal.

This synthesis reports on the current practice of transportation agencies in analyzing and applying user costs in decisions about pavement programming. The modern definition of user costs incorporates a range of effects attributable to pavement condition and performance, including the economic value that users place on the time spent in travel and in delay during road work; the economic value of travel time variability, reliability, and predictability; vehicle operating costs in all dimensions, including fuel, oil, and maintenance expenses but extending as well to noncash expenses such as tire wear and vehicle depreciation; the economic value of safety, including fatalities, injuries, and property damage; and the economic value of pavement's environmental effects, including dust and noise associated with road work and vehicle emissions associated with traffic at different volumes, flow rates, and speeds.

Methods of measuring the monetary value of each component are reported. Responses to a survey of state and provincial transportation agencies found that methods are mature in relation to travel time, vehicle operating costs, and safety. They are less mature, though reliable for most planning purposes, in relation to travel time reliability and the environment.

Mechanisms to help planners and engineers apply the measurement techniques in estimating project and program related user costs are presented. Tools are available to measure the effects of pavement rehabilitation, repair, and new construction on user costs over the entire life of a facility or network.

Just over half of the survey respondents consider user costs in most pavement construction decisions; slightly less than half consider user costs in pavement maintenance decisions; and just over 60 percent consider user costs in planning mitigation strategies for new construction and pavement maintenance.

Based on the survey responses, expanded consideration of user costs in the choice of pavement materials, methods, and strategies would follow from three developments. The first would be more timely data, particularly on vehicle operating costs and on accident rates associated with different pavement condition and performance levels (at different traffic speed and flow conditions). The second would be data on local and regional variations in user costs. The third development, and perhaps the most consequential, would be improvements in the user-friendliness and teaching ability of computer-assisted user cost estimation tools.

CHAPTER ONE

INTRODUCTION

SYNTHESIS OBJECTIVES

There is a growing recognition that the efficacy of pavement work could be enhanced if information were available on the relationship between the expense of pavement work and the cost savings that accrue to highway users. Interest in user cost data and analysis tools has grown accordingly.

This synthesis seeks to

- Review the state of the art in quantifying and forecasting changes in user cost that arise from new construction projects, maintenance and rehabilitation activities, and strategies designed to mitigate the disruptive effects of road work on user costs;
- Review the availability of support tools, particularly user-friendly computer tools, designed to assist states and provinces in applying user cost analysis; and
- Survey current practice in state DOTs and Canadian provincial governments to determine the extent to which user cost analysis is employed in planning and designing highway projects that mitigate the effects of road work on user costs.

ORGANIZATION OF THE REPORT

Chapter 2 reports on the expanded definition of user costs and describes the methods most commonly used in the United States and Canada in measuring the monetary value of each component of user costs.

Chapter 3 presents the range of mainstream user cost measurement support tools, that is, mechanisms to help planners apply the measurement techniques in estimating project and program related user costs. Some tools are no more than simple but effective manual worksheets, often devised by agencies for their own use. Other tools are computer based, and their most recent versions are equipped with interfaces and default data bases that make them truly accessible and functional in the day-to-day work of planning agencies. The tools tend to differ in the amount of engineering and pavement design detail they are designed to handle. While some are highly project-oriented, others deal with more strategic issues. Only one presently available computer-assisted tool measures the user costs associated with the disruptive effects of alternative road work strategies.

Chapter 4 examines current practice in the treatment of user costs in state DOTs and Canadian provinces, based on the responses to a survey conducted as part of this synthesis project. Among the agencies that do consider user costs in their pavement construction decisions, many use a qualitative approach. Less than a third of the agencies surveyed use manual or computer-assisted user cost estimation tools in selecting pavement materials and methods of construction, maintenance, and road work mitigation. Two case studies are presented to illustrate the state of the art, and the typical style of approach.

Chapter 5 presents the conclusions drawn from information analyzed for the project and discusses institutional barriers to wider adoption of user cost analysis. Appendix A is the survey instrument, Appendix B presents the survey responses, and the responding agencies are listed in Appendix C.

CHAPTER TWO

METHODS FOR MEASURING USER COSTS

The highway transportation network is a major contributor to social and economic development, but it is also costly to expand and maintain. While road construction and maintenance consume a large portion of the budget, the costs borne by the road-using public for vehicle operation and depreciation are even greater. It is important, then, that policies be pursued which, within financial and other constraints, minimize total costs, that is costs for both agency and user.

Agencies accomplish these twin goals, minimizing user costs and agency costs, through strict project/program appraisal, material selection, and timing decisions. Additionally, agencies typically use mitigation strategies to minimize the increased user costs associated with new construction and/or maintenance and repair activities. Such strategies include congestion management strategies to detour traffic during construction periods and nighttime work.

Accomplishing these goals requires careful analysis of user costs and economic effects of different construction and maintenance alternatives. Such comparison requires an understanding of the empirical relationships between the physical and service characteristics of roadways and associated user costs.

The remainder of this chapter examines the state-of-the-art methods for measuring user costs by first defining user costs and then examining each user cost category in turn. The categories, in the order presented, are: time related costs, safety costs, vehicle operating costs, and environmental costs. For each category, the current methods and techniques as well as the major issues concerning measurement are discussed. The section concludes with a discussion of the sources and use of monetary equivalent values in highway investment analysis.

DEFINITION OF USER COSTS

The term "user costs" applies to the wide range of effects of highway use beyond the cost of resources consumed in producing transportation services. The cumulative value of a highway improvement project, program, or policy change includes both the changes in the costs of providing transportation services after the improvement, and the value of other changes the improvement or policy change conveys, including the value of safety improvements, travel time savings, or vehicle emission reductions.

For purposes of this synthesis study, user costs are defined as costs (or cost savings) incurred by highway users and the community at-large as a result of: 1) planned changes in highway capacity and pavement condition; and 2) the effects of road maintenance.

TIME RELATED COSTS

Time is a resource with economic value *(1)*. Thus, time spent traveling in a vehicle has a cost, commonly referred to as an opportunity cost. Opportunity cost is the value associated with opportunities forgone as a result of choice in the presence of scarcity *(2)*, in other words, the value of the other activity that could be conducted instead of traveling.

Highway investment proposals typically derive the major share of their appraised benefits from travel time savings. In a review of a wide range of road improvement project appraisals, the MVA Consultancy Group found that, on average, 80 percent of total benefits stem from the estimated dollar-value of time savings, 51 percent for savings in working time and 29 percent for nonworking time. If no economic value is attached to time savings, most highway improvements cannot be justified in either social or economic terms *(3)*.

Measuring the Value of Working Time

Most research and practice on working travel time proceeds on the assumption that the value of time savings can be predicted from simple assumptions about the nature of the labor market. Economic theory predicts rational employers expand the amount of labor employed so long as the additional contribution to revenue is greater than the additional cost. At the employer's chosen scale of operations, the value of a worker's time as it contributes to revenue is approximately equal to its cost to the employer. The cost consists of wages, fringe benefits, and any other expenses of accommodation or supplies that vary with employees' attendance at work. By extension, these costs are used as a measure of the value to the employer of the additional production an employee contributes when travel time on work trips is reduced.

Accepting this reasoning, measurement of work trip time savings focuses on the calculation of average wage rates, fringe benefits, and allowances for overheads that go underutilized while workers are in transit.

Recent reviews focus on a fundamental challenge to the logic outlined above, namely that the value of working time savings is less, on average, than the wage rate because travel time is not totally unproductive. Fowkes *(4)* found that 29 to 35 percent of car passengers would use time savings for additional leisure rather than productive work, thus implying a lower value of time savings.

Three approaches are generally used to measure the value of working time: macro-choice models, case studies of states costs, and survey techniques.

Macro-Choice Models

This approach observes the reaction of individuals, traveling for work purposes, who face a time trade-off. For example, Gronau *(5)* derived a trip distribution function from interview data, while De Vany *(6)* estimated a marginal value of time as a function of the elasticities of demand for travel when considering time and price. While both studies focus on the valuation of time during air travel, they support a value of working time close to the average wage rate of the traveler.

Case Studies of States Costs

All the resource costs associated with travel during working time are taken into consideration in this approach. An early study by Hensher *(7)* estimated the cost to the employee, the employer, and the community of an employee's business trip. A second analysis by Hensher *(8)* included additional resource costs such as meal allowances, overnight expenses, literature, welfare benefits, and pensions. Both studies support a value of working time in the neighborhood of the wage rate.

Survey Techniques

Survey techniques are employed by Fleisher *(9)* on long-distance trucking operations and by Hagging and McFarland *(10)* on commercial vehicles to determine how work time savings are used. Kamerud *(11)* used the same approach as Hagging and McFarland to derive a combined value of truck and driver time for single-unit and combination trucks. A survey of business travelers by Fowkes et al. *(12)* determined that work time savings converted into leisure time should be valued at only 40 to 57 percent of the gross wage rate. On the other hand, if the work time savings are used for additional work, the value should be slightly above the wage rate.

Measuring the Value of Nonworking Time

Most research regarding the value of nonworking time is based on welfare economics and the concept of compensating variation; a form of consumer surplus. In the context of travel time measurement, this is the amount of compensation required by a traveler to forego a reduction in travel time and still maintain their initial level of utility (benefit). Consumer surplus measures such as the compensating variation are used to reveal consumer preference.

Four approaches are primarily used to measure nonworking time *(13)* namely, discrete choice models, travel demand models, stated willingness-to-pay studies, and speed choice models.

Discrete Choice Models

Discrete choice models, also referred to as the "revealed preference approach," assume that travelers reveal their implicit valuation of time savings (i.e. their willingness-to-pay) through their selection of either modes or routes from among two or more alternatives. The theoretical framework of discrete choice models is random utility theory *(14)* and a common feature of these models is that they estimate the probability of an individual choosing a given mode or route.

Travel Demand Models

In this approach, a traveler's willingness-to-pay for a reduction in travel time is estimated from a modal demand analysis, so long as time is included as an explanatory variable in the demand function. The value of nonworking time is calculated from the estimated coefficients as the ratio of the coefficients for time and out-of-pocket costs.

Stated Willingness-to-Pay Studies

For this approach, travelers are asked how much they are willing to pay for a reduction in travel time. The sometimes called "stated preference" approach follows the work of Lee and Dalvi *(15)*. Additionally, influential studies by Hensher *(16)*, Heggie *(17)* and developments resulting from studies by Hauer and Greenough *(18)* have shaped this approach.

The results of using this approach are found lacking by many due to biases in responses to surveys, but recently, the MVA Consultancy resurrected the technique on the premise that the potential for much larger samples and modern bias-correction techniques yields important advantages relative to discrete choice and demand models *(19)*.

Speed Choice Models

This approach uses speed choice models to measure the value of time in rural or other areas where few transit alternatives (bus, subway, train) are available. For example, Ghosh, Lees, and Seal *(20)* defined a set of optimal speeds for the British roadways by equating the marginal benefits to the marginal costs of speed. The same approach was refined by Jondrow, Bowes, and Levy *(21)* who analyzed separately the private optimum speed and the social optimum speed. More recently, McFarland and Chui *(22)* estimated specific cost curves for individual drivers based on each individual's desired speed in various situations.

Key Concerns

A 1994 study by Hickling Lewis Brod Inc. (HLB), for the National Cooperative Highway Research Program (NCHRP) *(23)*, brought together many experts to scrutinize and critique the primary methods to measure time related costs. The major concerns expressed by the panel in this study also reflect many of the researcher's concerns, discussed in the previous section. Table 1 summarizes these concerns.

TABLE 1

KEY ISSUES CONCERNING THE ESTIMATION OF TIME RELATED COSTS

Link to the Wage Rate	Traditional US methodologies related estimates of the value of time to some measure of wages plus overhead. UK and European practice have recently begun to deemphasize the wage base and to link the value of time to life cycle characteristics of travelers. Researchers are exploring value differences between frequent and infrequent travelers, the effects of culture and ethnicity, and the way in which time constraints (for example, catching a plane or arriving at work on time) related to a users's willingness to pay for reductions in travel time.
Variability	Measuring only changes in average travel times omits important factors in valuing time savings. Measuring changes in travel time variability and understanding how those changes are reflected in long range adjustments to trip making and freight handling is important to understanding the productivity effects of highway improvements. Recent NCHRP studies indicate that highway users value unit reductions in the variability of travel time three to four times more highly than unit reductions in average travel times (see National Cooperative Highway Research Program, *Valuation of Travel Time Savings and Predictability in Congested Conditions for User Cost Estimation*, NCHRP Project 2-18(2), Hickling Lewis Brod Inc., 1998.
Congestion	Understanding congestion involves more than simply comparing the value of time spent in traffic in congested and uncongested situations. Travelers may be willing to pay more to avoid the unreliability of traveling in congested conditions than to travel faster on average. Moreover, although the onset of congestion may disrupt trip schedules, congestion is not universally unproductive and time spent in congested travel can be spent productively as well as unproductively.
Small Time Savings	The current American Association of State Highway and Transportation Officials (AASHTO) Red Book methodology favors valuing small time savings at a lower rate than larger time savings. However, many experts favor valuing small and large time savings equally because no plausible evidence exists that small time savings are valued less than larger time savings. If time is a good like other goods, the marginal utility of travel time savings would tend to decline rather than increase as the amount of time saved increased. Additionally, evidence suggests that people are adept at aggregating small time savings into useable amounts of time.
Discontinuities	Discontinuities between travel time savings and average trip times affect the valuation of paid driver time and may make the wage-based valuation system unreliable. Paid driver time should be valued directly at the additional revenue (or value) employers gain from shorter journeys. This may differ from the pro rata hourly wage rate for the time actually saved, because the saving is less than that needed to complete an additional trip, or to make an additional delivery.
Valuing Business Time	Treating time as a resource that is consumed in travel leads to methods of valuing business time based on measures of the marginal production lost while travel is being undertaken. Thus estimating methodologies include factors for the unproductive issue of office space and other overhead factors as well as nonsalary benefits paid to traveling employees. Some methods also net the value of any work accomplished during travel. This approach assumes that business time spent traveling would otherwise be spent in fully productive work, as measured by the overall average cost of employment. Alternative approaches would seek empirical evidence on either what travelers would be willing to pay to reduce travel time (of various sorts), or what employers would be willing to pay to reduce employee time spent traveling.

SAFETY COSTS

Highway safety is a factor in the planning of roads, an important measure of transportation efficiency and a major public concern. Since safety requires resources, it competes with alternative resource uses. As such, there is some support for increasing highway safety for safety's sake and removing it from general highway planning. Until such a consensus is reached, the rational allocation of highway resources requires that highway safety be measured on a comparable basis with the value of alternative uses of these resources.

Highway use inevitably generates accidents resulting in property damage, fatalities, and injuries. Measuring the cost savings associated with safety improvements involves identifying: 1) losses prevented (reduction in highway incidents) and 2) benefits from reduced exposure to risk. The first category of safety benefits has been recognized in the literature for decades while the second has only come into wide acceptance among economists and planning and regulatory agencies during the past 10 to 15 years *(24)*.

The first component is a fairly direct process involving compilation and analysis of existing data. The second, however, involves the indirect measurement by statistical means of what people pay for safety benefits. Measurement of the consumer surplus associated with what people are willing to pay for safety benefits is more difficult because the "value of life" varies for individuals with respect to both income and risk level.

Measuring Accident Incidence

Measuring accident incidence for the purpose of assigning costs involves obtaining estimates for accident frequency and levels of severity of predicted accidents.

The usual measure of accident frequency is the accident rate, which is defined as the number of accidents (whether total number, or, of a certain type or severity) divided by some measure of exposure (i.e., vehicle miles traveled (VMT)). Accident rates are used to assign risk for different levels of exposure and forms the basis for safety comparisons between different road alternatives *(25–27)*.

The Highway Performance Monitoring System (HPMS) which, according to NCHRP Project 7-12, provides the most comprehensive general rates (*28*), is based on a report by Fee (*29*). Fee pooled accident data from 40 states, creating three general purpose rates. Rates are provided for 9 ranges of AADT (average annual daily traffic) and over 12 highway types. These rates are used to predict accident incidence. The three rates are:

1. Accident rates (accidents/100 million VMT),
2. Injury rates (injuries/100 million VMT), and
3. Fatality rates (fatalities/100 million VMT).

For the development of the Highway Economic Requirements System (HERS) the HPMS rates were revised. The revisions were conducted by: 1) removing outliers in original data; 2) adjusting for ratios of rates that were radically different from known data; 3) changing rates when the pattern across facility type seemed illogical; and 4) scaling of rates so that the overall rates matched recent national accident data.

The data sources used to determine the severity of predicted accidents for the majority of studies are the Fatal Accident Reporting System (FARS) and the National Accident Sampling System (NASS). The NASS makes use of the Maximum Abbreviated Injury Scale (MAIS) to record severity of injury. The MAIS scale ranks injuries on a one-to-five basis by the threat to life entailed and was proposed by the American Association for Automotive Medicine [AAAM] in order to inventory life-threatening injuries. This differentiation does not, however, take into account the cost, disability, or trauma that the injury involves. An injury of MAIS category 1 (least severe) can be, and frequently is, more costly than a higher level injury.

However, the MAIS scale provides disaggregation of the most severe and costly accidents, which are lumped together in category A of the KABCO system, described below, which is employed in FARS. Unfortunately, the severe injury statistics on the MAIS scale are based on a small sample size in NASS yielding, for some levels, an uncertainty range of roughly plus or minus 20 percent (*30*).

The KABCO scale is the injury scheme designed for police coding at the crash scene where K,A,B,C,O are the different levels of classification (K = fatal, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, O = property damage only). This scale, while defined by the American National Standards Institute, has serious limitations because it is based on the medical judgment of the police officer on the scene of the accident.

These rates, as employed in HPMS and HERS, do not take into account numerous other variables that affect highway safety. Other factors to consider include: pavement condition, weather and lighting, traffic congestion, traffic composition, traffic regulations, and driver characteristics (i.e., age, intoxication) (*31*).

Mahalel (*32*) takes issue with the current use of accident rates as estimators of risk for varying levels of exposure and argues that they can lead to erroneous evaluations of safety. His critique centers on the use of linear extrapolations of rates from one level of exposure to another.

Measuring Accident Costs

To measure the cost of these accidents, a number of different approaches have been used. These approaches are loss accounting, human capital costs, and individual's valuation of life and safety.

Loss of Life and Limb

The greatest loss from accidents is the pain and suffering of victims and their families, their emotional trauma and other related consequences. Early attempts to account for these loses centered around "loss accounting," finding measures for lost productivity in the wake of an accidental death or injury. These methods were deemed to be conceptually inadequate as the losses bore no relation to an individual's attitude toward risk or the valuing of his own life. For the most part, this method has been discredited for benefit-cost analysis and highway investment evaluation.

Human Capital Costs

The human capital approach measures the loss of future earnings, or the value of housework, of an accident victim. One variation of this approach discounts future consumption of the deceased while the other variation does not. This approach also has been discredited for benefit-cost analysis but human capital measurements are still widely used to illustrate the magnitude of accident and injury costs *(33,34)*.

Individual's Valuation of Life and Safety

The willingness-to-pay approach, based on the accepted welfare economics principle of deferring to the individual in determining what is best for him/her, has become widely accepted.

The "value of life" discussion is not about what an individual would pay in exchange for giving up his life. In drawing a distinction between loss of identifiable lives of individuals and "statistical deaths," the empirical studies on the subject seek to quantify how much an individual is willing to pay for a reduction in their exposure to risk. Thus, the "value of life" is a colloquial way of saying the "value per statistical death avoided," which is the sum of the amounts that the population at risk is willing to pay to avoid a statistical death.

This approach is based on the individual's willingness to pay for safety enhancements and if it is measured correctly, the benefits resulting from public safety investments can be determined. The difficulty lies in the fact that people do not actually purchase risk reduction, safety is usually an attribute of some composite good that is purchased. Studies using this approach isolate what people pay for risk reduction or, the amount they are compensated in exchange for increased exposure to risk. This approach is accepted by the National Safety Council (*35*), the Office of Management and Budget (*36*), and the Regulation Council of the U.S. Department of Transportation (*37*).

Studies using this approach generally use one of three techniques to obtain usable data. These techniques are: labor market studies, consumer behavior studies, and survey studies.

Labor Market Studies

Labor market studies analyze the wage premiums paid to workers who agree to face different levels of risk in the marketplace. The premiums are then used to infer value-of-life estimates. Typically, the studies isolate the differences in wages due to differing levels of risk. To do this accurately, the other possible causes of wage differences, such as the worker-specific situation (level of education, tenure with employer, occupation), job requirements (skill, education, experience), personal information (age, marital status, sex, race, health problems), and employment conditions (sector activity, job geographic location) must be addressed.

The result of a study is an estimate of the average wage premium paid for a unit increase in risk. In other words, the average willingness-to-pay for a marginal increase in safety or decrease in risk. This estimate is then converted into an implied value of statistical life (*38–40*).

Consumer Behavior Studies

Consumer behavior studies derive values through the association of risk reduction with consumption of a class of products. In such analyses, a measure is provided of individuals' willingness-to-pay for safer products or for safety-enhancing products. For example, Ghosh, Lees, and Seal (*20*) developed a model to determine the optimal travel speed based on data for British highways. They assumed that roadway users will increase travel speed up to the point where the value of the time saved is equal to the increase in costs of vehicle operations and the increase in accident risks. They derived a value for a risk change as equal to the cost to avoid statistical death.

Survey Studies

Survey studies involve asking a series of questions to an individual. The answers help the investigator to determine the value of what he or she will be willing to pay to avoid a given risk. This approach suggests that public safety improvements should reflect the preferences of consumers. For example, people can be asked to rank factors related to death from various diseases according to their importance (*41*).

Key Concerns

Concerns about the measurement of accident costs, displayed in the following table, were articulated by experts convened as part of an NCHRP study (*23*). Many of these concerns were also expressed by the researchers discussed in the previous section. These concerns are summarized in Table 2.

VEHICLE OPERATING COSTS

Vehicle operating costs (VOC) are the most recognized of highway user costs because they typically involve the out-of-pocket expenses associated with owning, operating, and maintaining a vehicle. Five cost components associated with operating a vehicle are fuel consumption, oil consumption, maintenance and repairs, tire wear, and roadway related vehicle depreciation. Each component is a unique function of vehicle class, vehicle speed, grade level, and surface condition. Thus, overall vehicle operating costs vary significantly between different facility types, geographic areas, and traffic patterns. Table 3 is a matrix of roadway factors and the VOC component that is affected.

Measuring VOC involves identifying: 1) quantity of each type of resource consumed in the production of transportation services (resources necessary to drive a vehicle from one point to another); and 2) the unit cost of consumption of the resource, which are marginal costs, taxes, subsidies, and other transfer payments.

The first part is problematic, despite a number of major studies carried out in the last two or three decades. The second part is relatively straightforward and based on readily available data.

Measuring VOC Consumption

The equations used to estimate vehicle consumption have been developed from a number of major studies around the world. Variables such as fuel consumption and travel speeds are easily measured by tests. Other variables, such as tire wear and vehicle maintenance, require tedious and long-term observations under a variety of road conditions. Consequently, the

TABLE 2

KEY ISSUES CONCERNING THE ESTIMATION OF ACCIDENT COSTS

Perceptions	The focus on valuing risk reduction in highway evaluation may be missing important aspects of safety in highway use that are related to peoples' perceptions of the safety of certain highway design features. The public appears willing to pay for many features, wider traffic lanes for example, that cannot be shown to reduce safety risks but that make drivers and passengers "feel" safer. Certain other safety design features, such as pedestrian crossings, may be shown to increase injury risks, but equally make people feel safer.
Value of Life	Many experts have expressed the view that estimates of the "value of life" are fundamentally flawed because people cannot realistically make such assessments. The behavioral studies, such as the market studies that estimate what compensation people will accept for various levels of risk, may lack information about the extent of the risks they are accepting, or they may discount the importance or relevance of the information to which they have access. Additionally, many experts are skeptical that stated preference studies, in which respondents answer questions about their reactions to various hypothetical situations, can produce meaningful information about how the public values risk.
Risk Taking	Values used in estimating safety benefits and costs are drawn from the behavior of people who are taking risks. In as much as people are willing to accept risk in one field are also often willing to take on other risks, the values may reflect the behavior of risk-prone individuals. However, if the majority of highway users and the public are risk averse, the values found in studies of risk takers will understate the benefits from risk reductions.
Injury Reductions	Under current methodologies, the values of reducing injury risk are derived from the values from reducing fatality risk by estimating the "equivalent life years lost" associated with injuries of different severity. Two issues arise from this approach. First, there is no conceptual underpinning for this approach. Second, under current practice, the choice of the discount rate tends to determine the importance of safety benefits in the overall estimate of user costs. For any given "value of life," the value of injury risk reduction will be higher for the lower discount rates since the value of a "remaining life year" will be higher. Since injury accidents are more common than fatality accidents, the effect of the choice of either rate on the overall safety benefit measurement may be large.
Unreported Accidents	Estimates and projections of the level of risk are likely to be too low because of the problem of unreported accidents and misreporting on the severity of injuries. This is thought to be of particular concern in rural areas, where police may arrive on the scene well after the accident, and for accidents in urban areas that involve bicyclists and pedestrians.
Exposure Measures	Predicting safety risks relies on understanding when accidents are likely to happen. Most projections predict risk by relating accident rates to vehicle miles of travel (VMT) or some other traffic volume measure, segmented by highway types. In most cases, user cost estimates are based simply on extrapolating local accident data, but no causal relationships are established between the number of accidents and the driving or highway conditions (other than highway type). Better understanding is necessary to be able to predict how changes, such as greater use of seat belts and introduction of airbags, and other changes in driving habits and vehicle technology will affect the number and severity of accidents.

TABLE 3

ROADWAY FACTORS AFFECTING VEHICLE OPERATING COSTS

Roadway Factor	Vehicle Operating Cost Component				
	Fuel	Oil	Tire Wear	Maintenance and Repair	Depreciation
Vehicle class	x	x	x	x	x
Vehicle speed	x	x	x	x	x
Road grade	x	x	x	x	
Surface type	x	x	x	x	x
Surface condition	x	x	x	x	x
Road curvature	x		x	x	

methods for determining VOC consumption are based on a mixture of survey work, mechanistic modeling, and statistical analysis.

The principal sources for estimating VOC consumption associated with highway travel are listed below. This list should not be confused with user-cost models, which merely apply the principal relationships within their own analytical framework. To this group belong models such as StratBENCOST, the Highway Performance Monitoring System (HPMS) and the Canadian Highway User Benefits Analysis Model

(HUBAM), all of which use the VOC relationships developed by the Texas Research and Development Foundation (TRDF). The principal sources for VOC consumption equations are:

- The American Association of State Highway and Transportation Officials (AASHTO) Red Book,
- The Texas Research and Development Foundation's (TRDF) VOC relationships,
- The World Bank's Highway Design and Maintenance Standards Model (HDM-III),
- The Australian Road Research Board's Road Fuel Consumption Model (ARFCOM),
- The National Association of Australian State Road Authorities' Improved Model for Project Assessment and Costing (NIMPAC),
- The Swedish Road and Traffic Research Institute's Vejstandard och Transportomkostninger (VETO) model, and
- The British Cost Benefit Analysis program (COBA).

Prior to discussing each of these sources in detail, some general concerns can be raised with regard to all VOC relationships. The data used to develop these relationships are based on a number of major studies around the world. Thus, the data embody the effects of the various conditions at the time and location that each of the studies were performed. This brings into question the transferability of these relationships.

The second criticism involves the predictive accuracy of the relationships since VOC relationships depend on many assumptions, for example, selected vehicle representatives, vehicle age distributions, and road class. As a result, predictive accuracy is low. Additionally, many influences on consumption, such as highway conditions, vehicle features and owner characteristics, which might influence consumption do not appear in the equations (*42*).

Analysis of VOC consumption is complicated by the fact that various independent variables describing the vehicle and its utilization, the road conditions, and the economic environment are correlated and not easily separated through statistical analysis. Without knowledge of these factors and their effect on VOC it is difficult to construct causal models for prediction of costs under any conditions.

Another area of concern is vehicle technology. Newer vehicles are more energy-efficient than those used to develop the VOC relationships, bringing into question the predictive accuracy of the equations due to technology advances.

For example, truck tractor engines can be programmed electronically for a specified horsepower, torque, and speed for a given haul. New engine types, heat exchangers, and recycling of exhaust gases are some of the developments that have brought about fuel savings of between 10 and 30 percent (*43*) in recent years. Even mechanistic models of fuel consumption based on engine maps need a major revision for these changes.

AASHTO Red Book

The AASHTO Red Book's (*44*) VOC consumption relationships are largely based on surveys of operating cost data that were synthesized by Winfrey (*45*) and Claffey (*46*). The Red Book provides relationships to calculate VOC consumption on: 1) uniform sections of highway; 2) in transition between sections with different characteristics; and 3) at intersections.

A procedure for updating VOC costs with consumer price indexes is provided in the manual. However, rapid changes in vehicle and tire technology have changed these costs. Additionally, fuel consumption rates on even grades and at uniform speeds are based on vehicles from 1964–1972, i.e. largely before the major inroads on fuel consumption improvements of the 1970s and 1980s. For example, in the Red Book, the mix of 1975 model cars would average 12.4 percent better fuel economy than the 1974 mix due to more efficient emission control, a decline in vehicle weight, and a reduction of average engine size (*47*).

The Red Book bases consumption factors for trucks on industry data, rather than observations under variable road conditions. In addition, regulatory reforms in the U.S. trucking industry, in terms of weights and dimensions, particularly for combination trucks, engine technology, and trucking operations management, affect consumption factors for trucks. Consequently, the truck running costs estimated in the Red Book are not accurate for present day analysis of truck transportation costs.

Texas Research and Development Foundation Relationships

From 1979 to 1982, the Federal Highway Administration (FHWA) contracted with the Texas Research and Development Foundation (TRDF) to investigate the influence of highway design and pavement condition on VOC consumption and other user costs (*48*).

The TRDF researchers participated and had access to data collected for a study in Brazil, which was sponsored by the World Bank and from which eventually the Highway Design and Maintenance Standards model (HDM-III) resulted. Results of the Brazilian study were used to estimate the effect of road roughness on VOC for FHWA.

TRDF collected fuel consumption data in the United States for all vehicle classes by conducting experiments in 1981 and 1982. Additionally, data on truck operating costs were provided by 15 intercity line-haul carriers operating primarily on interstate highways. These data were supplemented by data from the Bureau of Census (*49*) and published vehicle registration data. Operating costs for passenger vehicles were estimated from data compiled for Ullman (*50*) and adjusting Winfrey's data from the AASHTO Red Book. Maintenance and repair costs were also developed from Ullman's data and by adjusting Winfrey's data.

Tire wear and vehicle depreciation were estimated anew rather than adjusting or updating Winfrey's data. Tire wear was estimated with a model that predicts the forces at the tire-pavement interface due to road geometry and vehicle operating mode (*51*). Travel related depreciation was estimated with Daniels' (*52*) method, which considers depreciation of vehicles in the highest 3 percent category of annual mileage to be totally assignable to use rather than to mix mileage and age depreciation. The age and accumulated mileage of vehicles were compiled from the 1977 census, and the number of registrations were obtained from 1945 to 1977 census statistics.

While the TRDF relationships are partly based on operating characteristics of newer vehicles, the VOC relationships developed by TRDF do not fully account for the effects of changing vehicle technologies.

The TRDF relationships regarding the predictive accuracy of fuel consumption for trucks larger than 2-S2 has also been altered by technology. For example, the 2-S2 unit, from which fuel consumption rates were extrapolated for larger trucks, had nine forward gears. Newer engines have more gears, which affects fuel consumption at different speeds.

In a comparison with truck industry cost data, Bein (*53*) found TRDF's VOC relationships, as used in HUBAM, could not handle truck combinations with more than five axles. He found fuel and tire consumption were greatly over-predicted, and maintenance and depreciation were under-predicted.

The TRDF used aggregate data to update the relationships in 1980 and this could not be presented as a function of road conditions, with the exception of fuel consumption, which was measured in controlled experiments. The functional dependencies on road conditions are assumed from the earlier U.S. studies and from preliminary results of the Brazil study, particularly for road roughness.

HDM-III

The World Bank developed the HDM-III from data collected in a large-scale survey of road users conducted in Brazil between 1975 and 1984. The research represents one of the largest efforts to date to develop a model capturing the relationships between costs of construction, maintenance, and utilization of roads. The model is based on the premise that operating costs and vehicle speeds are related to highway construction and maintenance standards through the effect of road geometry and pavement surface quality.

HDM-III employs idealized aggregate uphill and downhill road segments for predicting fuel consumption, which is based on the World Bank's finding that fuel consumption can be estimated by using a constant nominal engine speed instead of actual engine speed. Additionally, an energy-efficiency factor allows the user to incorporate changes in vehicle technology. The differences between experimental and real-life driving conditions are accounted for by another factor.

The HDM-III model is only relevant to studying rural road infrastructure design and planning issues. Although formulated for developing countries, the VOC sub-model is practical and can be used to appraise those North American roads that do not experience significant congestion. The VOC consumption adjustments for surface condition are imprecise since levels of roughness in North America are low compared to the Brazilian database.

ARFCOM Model

The Australian ARFCOM model is capable of estimating the fuel consumption due to speed changes induced by curvature, grade, or traffic control devices and due to the extra power required to overcome grade and cornering resistance. Only limited vehicle parameters are required such as vehicle mass, maximum engine power or engine capacity, number of wheels, tire type, frontal area, and aerodynamic drag coefficients.

The user can select from three models, each differs with regard to the use of vehicle speed data and the level of aggregation (*54*). The three models are:

- The instantaneous form requires second-by-second speed, grade, and curvature data and is suitable for use in micro-level traffic simulation programs;
- The four-mode elemental form requires initial and final acceleration and deceleration speeds, cruise speed, idle time, and average grade and curvature data and is suitable for use in detailed analytical type models applicable to short road sections; and
- The most aggregate form, a running speed model, requires either running speed and idle time, or just average travel speed and is suitable for use in macro level models applicable to long road sections or road networks.

ARFCOM calculates fuel consumption by estimating the power that must be produced by the engine. This is similar to the way the automotive industry's engine map-based simulation models estimate truck performance. Both types of models use engine speed as one of the principal variables. However, the engine-fuel relationship in ARFCOM is modeled in a way to facilitate road management applications rather than vehicle performance evaluation.

Assuming that the efficiency of the engine at converting fuel to power is nearly constant, and allowing a drop in the efficiency at high power levels, the model considers the following forces:

- The internal friction within the engine, approximated by the square function of engine speed between idle and maximum load governed speed;
- Rolling resistance as a function of road, tire, and vehicle dependent parameters and vehicle speed;
- Air resistance with an allowance for constant wind speed and direction; and
- Inertial and accessory power losses.

There are few criticisms of the ARFCOM model with respect to the VOC consumption relationships. Bein (*44*) found that ARFCOM is suitable for both rural and urban traffic and transport management applications in different planning cases. Its user-selectable level of aggregation makes it appropriate to use with any vehicle speed prediction method, from a simulation of urban driving to aggregate speed prediction modeling.

A comparison between ARFCOM estimates and fuel consumption observed in heavy Canadian trucks used in intercity service (*58*) demonstrated that ARFCOM is a truly mechanistic model that can be easily calibrated and adapted to the following new conditions:

- Different country and climate,

- Different vehicle technology and weight regulations, and
- Extrapolation to larger trucks than Australian vehicles used in the development of ARFCOM.

Bein found that the features of ARFCOM and validations completed to date place ARFCOM far ahead of its competitors (*44*).

NIMPAC

NIMPAC is a detailed computer program used by the Australian Road Research Board to estimate VOC consumption on rural and urban roads (*56*). The relationships in NIMPAC were developed between 1968 and 1973 from an assortment of domestic and overseas studies. Some 20 parameters mainly related to unit costs, such as fuel and tire prices, are specified for each type of vehicle in order to estimate VOC. These parameters are updated regularly on a national basis to allow for changes in prices.

The VOC submodel in NIMPAC estimates fuel, oil, tire wear, repairs and maintenance, and depreciation. Where appropriate, interest is also included (for example when increased speeds lead to better utilization of commercial vehicles, and consequently reduce the size of a commercial fleet). Seven vehicle types are considered: cars and station wagons; two-axle four-tire trucks including vans; two-axle six-tire trucks; three-axle straight trucks with two pairs of dual wheels; four-axle articulated trucks; five-axle articulated trucks; and road trains with two three-axle trailers.

Both the rural and urban VOC methodologies rely heavily on functional relationships developed in the early 1970s. Additionally, research conducted by NAASRA in 1985 (*57*) found that NIMPAC overestimated VOC consumption for large trucks. This is due to the improved performance of trucks over the last decade, which is not reflected in the VOC relationships.

The relationships were developed between 1968 and 1973, based on the available evidence. Researchers find many of the equations in the model are difficult to substantiate (*44*).

VETO Model

The VETO model of highway vehicle transportation costs was developed by the Swedish Road and Traffic Research Institute (VTI) (*58*). VETO is a purely mechanistic model. The physical basis of the relationships allows greater freedom than other models in evaluating transportation costs as a function of various properties of the road surface, different road alignment, speed limit, vehicle types, and driving behavior.

The following component costs are calculated by VETO:

- Fuel consumption,
- Tire wear,
- Repair cost comprising brake wear, roughness-dependent repair, and other repair,
- Distance and time related vehicle depreciation, and
- Interest charges for vehicle and cargo.

Calculations are performed in three stages: 1) all dynamic forces acting on the vehicle are computed as a function of longitudinal roughness; 2) consumption and wear rates are determined from the force effects; and 3) unit costs are applied to the consumption rates to calculate component and total costs.

In the VETO model the capital cost of a vehicle is not influenced by the type of road surface.

COBA Model

Ministry of Transport is responsible for multimodal transportation in England. The development of roadways and trunk roads in the 1950s and 1960s produced a formal procedure called COBA for the economic appraisal of interurban road schemes. The procedure gave the Department a rational method of allocating the available funds to achieve the best return for the money. Based on experience gained through its applications, the method evolved to its present version, COBA-9 (*60*). An extension of the current appraisal methodology to urban trunk road schemes is the main thrust of ongoing work that is expected to produce COBA-13 (*60*).

COBA considers the total discounted user costs on a road network over a 30-year period (*61*). Recognizing that traffic forecasts for such a long period are subject to uncertainty, the program contains high and low projections of traffic, fuel prices, and economic growth.

COBA operates with four representative vehicle types: car, light van, diesel truck, and bus. VOC consumption is calculated for: fuel, oil, tires, maintenance, and depreciation. The effects of grade and curvature of the road alignment enter VOC indirectly through their effects on traffic flow and vehicle speeds.

All mileage related resources are included in VOC as well as vehicle capital savings, which are related to time. Resource costing, i.e. costs net of indirect taxation representing transfers between sectors of society, is used by COBA, except for fuel. The costs are updated periodically to account for changes in prices, taxation policy, vehicle technology, operating speeds and utilization, and fleet representatives.

The reasoning behind the special treatment of fuel costs is that resources and expenditures diverted from fuel will go to produce or be spent on goods that are taxed by the government at a higher rate to compensate for fuel tax saved through road investments (*62,63*). Thus a fraction equal to the percentage level of indirect taxation throughout the economy is added back to the resource cost of fuel. It is computed as the ratio of expenditure taxes minus subsidies to gross domestic product. This indirect taxation changes over time and it is monitored for updating the VOC formulas.

The marginal resource costs of oil and tires are assumed to be independent of speed. They are treated as fixed costs per kilometer although it is recognized that tire costs vary with a number of other factors, which include speed changes, braking, cornering, and road surface (*64*).

Measuring VOC Costs

The unit costs of VOC consumption are marginal costs, net of taxes, subsidies and other transfer payments. These costs are readily available from a number of data sources, such as:

1994 Statistical Abstract of the U.S., U.S. Department of Commerce, Washington, D.C. (1994).
1995 Statistical Abstract of the U.S., U.S. Department of Commerce, Washington, D.C. (1995).
Transportation Statistics Annual Report 1994, Bureau of Transportation Statistics, U.S. Department of Transportation, Washington, D.C. (1994).

Concerns about measuring VOC, displayed in the following table, were articulated by a panel of experts convened as part of an NCHRP study (*23*). Many of these concerns were also expressed by the researchers discussed above. Table 4 summarizes these concerns.

TABLE 4

KEY ISSUES CONCERNING THE ESTIMATION OF VEHICLE OPERATING COSTS

Simulation	Many experts believe that economic models must be developed to provide a means of projecting driver choices and driver behavior into future periods when basic economic conditions are expected to be different. Such modeling improvements would improve the accuracy of vehicle operating cost estimation and reduce the uncertaintly associated with it. Other areas that would benefit from more advanced models are: fleet or vehicle choice; travel demands, including freight logistics choices; route choice and speed choice; fleet management and vehicle scrapping policy; and vehicle maintenance policy.
Pavement Condition	Models must reflect pavement condition and their effect on vehicle operating cost. Current relationships may not accurately reflect the true interaction between pavement and vehicle performance. New relationships may need to be estimated and included in user-cost estimating methodologies.)

ENVIRONMENTAL COSTS

Environmental costs are gaining increasing acceptance as an important component in the economic evaluation of transportation and infrastructure projects. The principal environmental impacts of vehicles can be broadly classified into two categories: vehicle exhaust emissions and vehicle-generated noise. Vehicle exhaust emissions include nitrogen oxides, carbon monoxide, hydrocarbons, volatile organic compounds, and particulates. These emissions cause wide-ranging effects on humans, material, and vegetation. Vehicle generated traffic noise has a cost to society in terms of effects on people living along highways or arterial roads.

Sections of recent federal legislation, such as the Clean Air Act Amendments of 1990, as well as the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, are designed to directly account for the environmental impacts of proposed transportation investments. Heightened public and private awareness of environmental concerns, therefore, requires that transportation planners and policy makers include the monetary costs associated with highway traffic pollution when evaluating highway projects.

Estimating the cost to society involves: 1) calculating the production of emissions, 2) determining the transport of pollutants, 3) estimating the dose-responses of victims, and 4) assigning a suitable monetary value to the damages, based on willingness-to-pay concepts, for each pollutant type.

The above steps represent the sequence of how pollutants are generated and dispersed in the atmosphere causing damage to humans, vegetation, and materials. For instance, air pollutants are produced at a source and then released into the atmosphere. They are carried by movement of atmosphere to surrounding areas. The existence of some of these pollutants in the atmosphere causes damage to humans, vegetation, and materials. The extent of resulting damages depends on the sensitivity of each victim to exposure to the pollutant. Such sensitivity represents the relationship between expected damages and a given level of pollution, and is given by the dose-response function of the victim. And finally, once the damages are estimated based on dose-response relationships of affected groups, the appropriate monetary values are assigned.

There is considerable uncertainty involved in the first two steps of the sequence, i.e., measuring the production and transport of pollutants or noise. Many simplifying assumptions are usually made with respect to local topography, distant weather patterns, and upper atmospheric interactions.

Equally as difficult and uncertain are the final two steps of the sequence, which assign dollar values to expected damages. This involves valuing nontraded goods (in particular, health and visibility losses and nuisance due to noise). This valuation exercise is regarded as a troublesome area by environmental economists, and there are no prescriptive measures for valuing a human life, a healthy day, or a value of eyesight.

Measuring Environmental Effects

A number of air pollution models have been developed to stimulate the production of emissions and transport of pollutants. These air pollution models measure the amount of polluting emissions arising from traffic and changes in air quality, and are based on technical relationships between vehicle technology, driving conditions, and site conditions where pollution is released. Two of the primary models used to measure the production of pollutants and their transport are Mobile4 and Caline3.

Mobile4

This model, developed by the Environmental Protection Agency (EPA), measures the level of emission from any flow of highway traffic. Estimates of hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (Nox) are produced for up to eight vehicle types in two regions (low and high altitudes). Emissions depend on various conditions, such as ambient temperatures (minimum and maximum daily), average travel speed, operating modes, fuel volatility (evaporation rate of the fuel), and mileage accrual rates.

Caline3

Caline3, developed by California Department of Transportation (Caltrans) is a screening model that predicts air pollutant concentrations at receptors along a highway. Caline3 treats the traffic as a line source of pollution, with a known emission factor. Thus, it must be used in conjunction with other models that predict emission rates depending on vehicle, traffic, fuel, highway, meteorology, and other factors.

Caline3 predicts concentrations under constant meteorological conditions (for example, wind speed and direction). Moreover, Caline3 predicts concentrations within 10 km of the highway (the maximum distance of a source from a receptor), and discounts the effects of the fast-settling emissions, discounting the concentration of other polluting effects of emissions such as soil lead or nonpoint water pollution through run-off.

The factors affecting the concentration of pollutants at receptors are: wind speed, wind direction, atmospheric stability class (the Pasquill stability class, a number between 1 and 6 that represents atmospheric conditions at the receptor before taking account of the effects of traffic), settling velocity (the rate at which a particle falls with respect to its immediate surroundings), deposition velocity (the rate at which a pollutant can be absorbed or assimilated by a surface), surface roughness, averaging time (the period over which receptor averages emissions in recording data), ambient concentration of pollutants (parts per million), and mixing height (height of the air volume that mixes with vehicle emissions).

Environmental assessments of air quality issues are based on a "worst case" scenario: concentrations of pollutants are estimated for meteorological and other conditions, under which pollutant concentrations would be expected to be highest. If the result meets air quality standards, then no remedial action is required. If the result does not meet air quality requirements, then plans to reduce worst case concentrations are examined. This means the models produce estimates for a single wind direction or a single traffic flow level. Putting air quality in a format comparable with user cost estimates requires measuring expected pollutant concentrations by taking into account the variability in traffic, meteorology, and highway construction features.

Additionally, the environmental models are issue-specific. Thus, while emissions models provide measures of pollutants for different traffic flows and mixes, separate models are needed to reflect the effects on air quality, surface water runoff, soil and groundwater contamination, and noise.

Lastly, the conversion of pollution levels to social costs that are directly additive to highway user costs requires estimates of health risk associated with exposure rates for various pollutants and these risks are generally not known. Thus, the current models provide only general assistance to the task of incorporating environmental effects into highway user cost estimates.

Caline3 does not consider noise costs. Research sponsored by NCHRP has developed procedures for estimating traffic noise based on flow, highway characteristics, and vehicle mix. The procedures measure hourly noise levels in decibels. Work in other modes, notably aviation, has led to the development of methodologies to measure the cost of noise nuisance, taking account of the effect of noise pollution in lowering property values and the annoyance and interruption effects on daily and nighttime activities.

Measuring Environmental Costs

Measuring the extent of damages (dose-response) and assigning monetary values to them requires value judgments on the part of decisionmakers, and continues to be a particularly troublesome area with a wide range of both theoretical and empirical issues still unresolved. Almost all research studies attempting to quantify and monetize environmental damages carry caveats to the effect that the numbers must be used with considerable caution.

Despite widespread agreement that environmental impacts are significant, there is no widely accepted method for evaluating and applying the economic costs of environmental effects in traditional user cost analyses. A limited database of experimental data is part of the reason (*65*). Research relating to environmental costs only gained prominence in the last 20 years. Adding to the lack of data is the complexity of environmental effects. The negative effects of pollution depend not only on the quantity of pollution produced, but on the types of pollutants emitted and the conditions into which the pollution is released.

Measuring the Dose-Response Relationships

The formulation of dose-response functions is rooted in epidemiological research and the measurement of dose-response relationship is an essential step in assessing changes in health risks with changes in levels of pollution. Such a measurement requires a systematic framework that relates pollutant concentrations, exposure duration, and dosimetry factors to calculate the risk to an exposed population. Examples of dose-response relationships include the effect of pollution on health, vegetation, and physical depreciation of material assets.

Mendelsohn (*66*) derived used dose-response functions for pollutants such as sulfur dioxide, sulfate, nitrogen dioxide, oxidants, nitrates, and particulates. These dose-response functions link levels of pollutants to human health risks, as well as risks of vegetation and material damages. These functions are applicable to a wide variety of settings and are based on studies by Waddell (*67*), the National Academy of Sciences (*68*), and Lave and Seskin (*69*).

Lave (*70*) of Carnegie Mellon University, and Seskin of Resources for the Future reviewed various studies that quantify the relationship between air pollution and both morbidity and mortality, and concluded that although there is a quantifiable association between air pollution and both mortality and morbidity, the results must be viewed with considerable caution. Factors such as income or social status, the ethnic origins of a population, general occupation, personal habits, and sampling errors are likely to affect the association between air pollution and mortality rates. These factors are not typically considered, however, in quantifying the relationship between air pollution and health damages.

According to Schwing, dose-response functions suffer from a variety of pitfalls (*71*) and the reliability of dose-response estimates, according to Mendelsohn (*66*), is low. Additionally, actual dose-experiments are performed at abnormally high dosage levels, only for acute exposures, and frequently upon small populations. Except for experiments with mild exposures, none of the experiments is performed directly on humans. The studies of natural exposure to humans suffer from data limitations and an inability to remove unwanted sources of variation. In addition to these limitations, the timing of human responses to air pollution exposures is also poorly understood, contributing to uncertainty in measurements. A new source of pollution may not cause any immediate health losses because the damage may only occur after a few years of exposure, or because the symptoms are only apparent several years later. All these factors contribute to considerable uncertainty in dose-response relationships.

Measuring the Monetary Values of Damages

Once the increased risks to humans, material, and vegetation as a result of pollution are measured, the next step of the process is to assign dollar values to the damages. During the last 15 years, environmental economists have made advances in the development of techniques for assigning monetary values to environmental damages. These techniques fall into two categories: *indirect*, which intend to infer from actual choices, such as choosing where to live and the value people place on environmental goods; and *direct* questioning approaches, which ask people to make trade-offs between the environment and other goods in a survey context. The two methods generally used are: the Contingent Valuation Method; and the Hedonic Price Method.

Contingent Valuation Method (CVM)

The CVM falls within the category of direct methods and attempts to measure the willingness-to-pay for an environmental benefit, and/or the willingness-to-accept compensation to tolerate a cost. This is measured by a process of "asking" through a direct questionnaire/survey, or experimental techniques in which subjects respond to various stimuli in "laboratory" conditions. Respondents give their personal valuation of what they would be willing-to-pay or willing-to-accept if a market existed for the good (improved air quality and low noise neighborhood). A contingent market is taken to include not just the good itself, but also the institutional context in which it is provided, and the way in which it is financed.

Hedonic Price Method

This method falls within the category of indirect methods and is based on the assumption that different locations have varied environmental attributes, which result in differences in property values, all else being equal. Identification of property price differentials due to differences in pollution levels (air or noise pollution) are made by means of a multiple regression in which data are taken from either a small number of properties over a period of years or from a large number of diverse properties at a point in time (cross-section). In practice, most studies are cross-sectional studies, since controlling for other influences over time is much more difficult.

There are a number of concerns with these two methods. Mendelsohn (*66*) believes survey respondents, in the CVM, may purposely mislead (if they think it will help them). Also, because the survey questions are hypothetical, the answers may deviate from observed behavior. Additionally, property value studies, conducted as part of the hedonic price method, are hampered by aggregated data, primitive hedonic equations and poor air quality measurements. Furthermore, both survey and property value-based studies assume that people are aware of the harmful consequences of individual pollutants, which is unlikely.

Concerns about the estimation of environmental effects and costs, displayed in the following table, were articulated by a panel of experts convened as part of an NCHRP study (*23*). Many of these concerns were also expressed by the researchers discussed in the previous section. Table 5 summarizes these concerns.

TABLE 5
KEY ISSUES CONCERNING THE ESTIMATION OF ENVIRONMENTAL COSTS

Measurement	The importance of the economic effects of pollution coupled with the lack of adequate data call for a cost estimating methodology that allows planners to include environmental costs without grossly misrepresenting the importance of those costs.
Valuation	Given the wide range of environmental conditions in the United States and the varying degree of exposure to highway pollution from mobile sources, estimating appropriate environmental user costs relies on an approach that addresses the considerable uncertainty that exists in each step of the evaluation process.

USER COST VALUES AND SOURCES

The best values for use in highway investment analyses are local values, reflecting local market conditions. For example, since the value of work time is highly correlated to the prevailing wage rate (this is discussed previously in the section titled Time Related Costs), differences between localities translate into different values of working time. Such differences impact all user costs and not just the value of working time.

Capturing such local differences is important in highway investment analysis, since user costs reflect society's willingness-to-pay to reduce the costs of highway travel and thus directly reflect the values and priorities of local constituents. While local values are the most desirable, they are not always readily available or easily measured. In such cases, default national values are acceptable and they are available from a variety of sources.

The following references provide sources for national default data for user cost values:

1995 Statistical Abstract of the U.S., U.S. Department of Commerce, Washington, D.C. (1995). (Vehicle Operating Costs).

Transportation Statistics Annual Report 1996, Bureau of Transportation Statistics, U.S. Department of Transportation, Washington, D.C. (1996). (Vehicle Operating Costs).

Highway Statistics 1993, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. (1993). (Vehicle Operating Costs).

Socio-Economic Attributes and Impacts of Travel Reliability: A Stated Preference Approach, Small, K.A., *et al.*, California PATH Research Report, UCB-ITS-PRR-95-36, University of California, Irvine, California (November 1995). (Value of Time).

The Cost of Highway Crashes, Miller, Ted, John Viner, Nancy Pindus, *et al.*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. (1991). (Safety).

The Highway Economic Requirements System Technical Report, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. (July 1991). (All User Costs).

Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors, U.S. Department of Transportation, Washington, D.C. (June 1982). (Vehicle Operating Costs).

Monetary Values of Air Pollution Emissions in Various U.S. Cities, Wang, M. and D. Santini, Transportation Research Board Paper No. 951046, 74th Annual Meeting, Washington, D.C. (January 1995). (Air Pollution Emission Costs).

Characteristics of Urban Transportation Systems, Federal Transit Administration, U.S. Department of Transportation, Washington, D.C. (1992). (Vehicle Operating Costs).

National Transportation Statistics 1996, Bureau of Transportation Statistics, U.S. Department of Transportation, Washington, D.C. (1996). (Vehicle Operating Costs).

Nationwide Personal Transportation Survey, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. (1997). (All User Costs).

CHAPTER THREE

TOOLS FOR STATE AND PROVINCIAL GOVERNMENTS

It is generally recognized that either life-cycle or benefit-cost analyses of maintenance and repair activities that include agency and user costs result in a more efficient allocation of resources (*72*). However, this was not always the case. During the 1960s and 1970s, routine maintenance and repair activities were not included in any methodological framework and decisions on maintenance expenditures were made on the grounds that maintenance is necessary to preserve infrastructure assets (*73*).

In the United States during the 1970s, three factors began to change this situation: 1) the growing realization of the role of maintenance in road preservation; 2) the widespread implementation of maintenance management systems in state DOTs; and 3) the successful integration of maintenance in an economic decision support framework by international lending agencies such as the World Bank (*74*).

While incorporating user costs into maintenance and repair decisions is a relatively new phenomenon, incorporation into project/program analysis has a more lengthy history. With respect to highways, basic concepts of engineering economy were formulated more than 100 years ago and began to be applied in studies of highway improvements in the 1920s (*74*). In the early 1970s, Winfrey (*47,75*) compiled, quantified, and organized these concepts and principles into a methodological framework that included not only construction and maintenance costs but also user costs.

Since this time, major research efforts have clarified, augmented, and expanded our understanding of the interaction between highway construction and maintenance activities, highway performance, and user costs. Such improvements are necessary to broaden understanding and public support of decisionmaking. An important byproduct of these efforts is the array of tools developed to assist decisionmakers. Tools aid a planner's understanding of user costs and facilitate their incorporation into decisionmaking. Additionally, they provide a simple and efficient means of transferring technology and information.

In this chapter, the analysis tools available for state and provincial governments are reviewed and current research efforts and their findings are discussed. Special attention is paid to the effect the research may have on existing analysis tools.

ANALYSIS TOOLS

Much of the user cost research conducted since 1970, discussed in the previous chapter, led to the development of new models incorporating the results of the research. The following list provides some of the major models developed to date that incorporate user costs. For each model a brief description, a table displaying its major features, and a discussion of the model's limitations is provided. The models are:

- The Australian Road Research Board's Road Fuel Consumption Model (ARFCOM);
- The Ministry of Transport's (England) Cost Benefit Analysis program (COBA);
- The World Bank's Highway Design and Maintenance Standards Model (HDM-III and HDM-PC);
- The Texas Transportation Institute's Highway Economic Evaluation Model (HEEM-III)
- Jack Faucett Associates' Highway Economic Requirements System (HERS);
- The Federal Highway Administration's (FHWA) Highway Investment Analysis Package (HIAP);
- FHWA Revised Highway Investment Analysis Package (HIAP-Revised);
- FHWA Highway Performance and Monitoring System (HPMS);
- The Texas Transportation Institute's Microcomputer Evaluation of Highway User Benefits Model (MicroBENCOST);
- The National Association of Australian State Road Authorities' Improved Model for Project Assessment and Costing (NIMPAC);
- The American Association of State Highway and Transportation Officials (AASHTO) Red Book; and
- Hickling Lewis Brod's Strategic Highway Planning Model (StratBENCOST).

None of the models listed above covers the entire range of user costs because all were developed with specific applications in mind and omit certain aspects of highway user cost that are not relevant or not critical to those applications. The models fall in two broad categories: models for investment appraisal, and models for planning or scheduling. The appraisal models permit fairly detailed comparisons of features among competing alternatives. They compute comparative measures of worth (i.e., net present value and rate of return). The planning models are broader in approach and tend to show the effects of different highway policies, i.e., more or less maintenance, higher or lower investment, and so on, by simultaneously computing the policy's effect on user costs.

In each case, the coverage and detail required by the methodology fits the model's design application. The World Bank's HDM-III, for example, focuses on optimizing maintenance strategies for developing countries and thus pays a great deal of attention to trade-offs between pavement roughness and vehicle operations, but gives relatively little attention to congestion or safety. The FHWA's HPMS model, used for estimating the impacts of different funding and maintenance policies in the United States includes equations for estimating effects of pavement condition, safety, and congestion, but does not estimate pollution or other environmental intrusions of highway programs, as these are largely project-specific.

ARFCOM

The ARFCOM model, developed by the Australian Road Research Board, is designed for analysis of both rural and urban traffic management improvements. The model is capable of estimating fuel consumption due to speed changes induced by curvature, grade, or traffic control devices and due to the extra power required to overcome grade and cornering resistance.

Model Name	*ARFCOM*
Agency	Australian Road Research Board
Developer(s)	Australian Road Research Board
System	Personnel Computer
Primary Purpose	Traffic Management System Analysis
Relationship Basics	Mechanistic
Level of Aggregation	Simulation, Project and Network
Vehicle Operations	Uniform Speed, Curves, Speed Changes and Idling
Typical Vehicles	Default, User Specified, Modem Truck
Road Variables	Gradient, Curvature, Super-Elevation, Roughness, Pavement Type, Texture, Snow, Water and Ice, Wind and Temperature and Absolute Elevation
Vehicle Operating Costs	Fuel
Value of Time/ Productivity	No
Accident Costs	No
Environmental Costs	No, pollutant emissions from oil-based fuels are calculated instead.
Other	

While the model calculates fuel consumption accurately, the other major user cost categories are omitted. Because project/program analysis requires all user costs to be considered, the failure to account for three user cost categories and only one-fifth of VOC is a significant limitation.

COBA-9

In England the procedures for comparing highway alternatives were originally presented in two manuals (*76,77*). These procedures were later incorporated into a mainframe computer program that is currently in its ninth version, called COBA-9.

The program is used to analyze complicated road networks, consisting of numerous links (highway sections) and nodes (intersections, interchanges, etc.). COBA uses a "fixed matrix" traffic allocation procedure, meaning that total trips between nodes is the same for the before-improvement and after-improvement situations. Some traffic may choose different routes in the improvement case but the number of trips between origin and destination nodes is fixed in each year of the analysis period. User cost savings are calculated directly as the savings per trip for alternative routes consisting of traveling along certain links and through certain nodes.

Model Name	*COBA-9*
Developer(s)	Reynolds and Dawson
System	Mainframe Computer
Primary Purpose	Network Investment Analysis
Relationship Basics	Statistical
Level of Aggregation	Project and Network
Vehicle Operations	Uniform Speed
Typical Vehicles	Default
Road Variables	Gradient and Curvature
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance Depreciation, Overhead and Fleet Stock
Value of Time/ Productivity	Yes
Accident Costs	No
Environmental Costs	No
Other	

The primary limitation of the model is that pavement condition and its effect on VOC or vehicle speed is not considered. Additionally, two user cost categories, accident costs and environmental costs, are omitted, limiting the applicability of the model.

HDM-III and HDM-PC

The highway design and maintenance standards study, initiated by the World Bank in 1969 and carried out in collaboration with leading research institutions and road agencies in several countries, provides empirical quantification of the trade-offs between the costs of road construction and maintenance and vehicle operations. These empirical relationships were incorporated in the Highway Design and Maintenance Standards Model (HDM).

The third version of the model, HDM-III, released in 1987 by the World Bank, is designed to meet the needs of the highway community, particularly in developing countries, for evaluating policies, standards, and programs of road construction and maintenance. The original mainframe version of the model was adapted to the personal computer environment and released as HDM-PC version 2.0, which includes the core HDM-III model and a constrained version of the Expenditure Budgeting Model (EBM).

Model Name:	*HDM-III/HDM-PC*
Agency	World Bank
Developer(s)	Mainframe: Watanatada, Harral, Paterson, Dhareshwar, Bhandari and Tsunokawa Personal Computer: Fossberg, Bhandari and Tharakan
System	Mainframe and Personal Computer
Primary Purpose	Maintenance and Scheduling Analysis
Relationship Basics	Statistical and Mechanistic
Level of Aggregation	Project and Network
Vehicle Operations	Uniform Speed and Curves
Typical Vehicles	Default, User Specified and Modem Truck
Road Variables	Gradient, Curvature, Super-Elevation, Roughness, Pavement Type and Absolute Elevation

Model Name:	*HDM-III/HDM-PC*
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance, Depreciation, Interest and Overhead
Value of Time/ Productivity	Yes
Accident Costs	No
Environmental Costs	No
Other	

The limitations of the HDM models (HDM-III and HDM-PC) are that the relationships used in the model were developed in and for developing countries and there are serious concerns about their transferability to developed countries. Additionally, the model does not include speed-volume relationships (speed does not decline as traffic volumes increase over time) nor does it estimate the effect on travel time of volume/capacity constraints. The model also does not include safety or environmental costs. While the model may be limited in these respects, the costs of construction related traffic delays, congestion, accidents, and environmental pollution can be entered in the model exogenously (estimates are made with other models).

HEEM

The Highway Economic Evaluation Model (HEEM), released in 1976, was developed by the Texas Transportation Institute (TTI); its latest version, HEEM-III was released in 1990. HEEM-III analyzes capacity improvements or new lane miles in a defined corridor. It allows for staging over time and optimization of the construction year as well as the expansion year.

Model Name:	*HEEM-III*
Developer(s)	Memmott and Buffington
System	Mainframe Computer
Primary Purpose	Project Analysis
Relationship Basics	Statistical
Level of Aggregation	Project
Vehicle Operations	Uniform Speed, Curves, Speed Changes and Idling
Typical Vehicles	Default
Road Variables	Gradient, Curvature, Roughness, Pavement Type and Texture
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance and Depreciation
Value of Time/ Productivity	Yes
Accident Costs	Yes
Environmental Costs	No
Other	Additional delay due to queuing at turn lanes is calculated.

The HEEM-III model is limited in that the speed-flow relationships are based on the *1985 Highway Capacity Manual* and do not reflect peak period congestion. Additionally, the VOC relationships are based on a 1982 study by Zaniewski et al. (*48*) and are dated. Environmental costs are not considered; no budgetary or investment analysis is performed. Each project and alternative must be analyzed independently. Any budgetary constraints or incremental analysis for mutually exclusive projects must be done outside the program.

HERS

The Highway Economic Requirements System (HERS) is designed to provide an additional economic dimension to the national-level HPMSs analytical capabilities. The HERS model simulates improvement selection decisions based on the relative benefit-cost merits of alternative improvement options. HERS uses the description of the current state of the highway system contained in the HPMS databases as the basis of all analyses.

Model Name:	*HERS*
Developer(s)	Jack Faucett Associates
System	Mainframe
Primary Purpose	Network Analysis for Budgeting
Relationship Basics	Statistical
Level of Aggregation	Project and Network
Vehicle Operations	Uniform Speed, Curves and Speed Changes
Typical Vehicles	Default, User Specified and Modern Truck
Road Variables	Gradient, Curvature, Roughness, Pavement Type, Texture and Temperature
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance and Depreciation
Value of Time/ Productivity	Yes
Accident Costs	Yes
Environmental Costs	No
Other	

The model is limited by the failure to link pavement condition, which is estimated by the model, with the VOC calculations. Additionally, environmental costs are not calculated.

HIAP

The Highway Investment Analysis Package (HIAP) was developed by the Federal Highway Administration in 1979. This mainframe computer benefit-cost analysis model is capable of analyzing several mutually exclusive project alternatives at the same time and has a sophisticated investment analysis package that allows for maximization with a budget constraint.

HIAP uses a consumer surplus approach to calculate benefits when evaluating changes in traffic demand. The model has the capability to analyze multiple corridor routes in the same analysis and uses linear interpolation for years in which benefits are not calculated. Non-user impacts such as emissions and changes in noise levels are calculated.

Model Name:	*HIAP*
Developer(s)	Federal Highway Administration
System	Mainframe Computer
Primary Purpose	Project and Network Analysis for Budgeting

Model Name:	*HIAP*
Relationship Basics	Statistical
Level of Aggregation	Project and Network
Vehicle Operations	Uniform Speed, Curves and Speed Changes
Typical Vehicles	Default, User Specified, Modern Truck
Road Variables	Gradient, Curvature, Roughness, Pavement Type and Texture
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance and Depreciation
Value of Time/ Productivity	Yes
Accident Costs	Yes
Environmental Costs	Yes
Other	The model calculates induced demand. The model is capable of calculating accidents at railroad grade crossings.

The model is limited by its design since it analyzes different alternatives in a large system of highways with budgetary constraints, rather than specific projects. Some users find the data requirements difficult to adapt to individual project evaluations (*28*). Additionally, the relationships on which the model is based were developed in the 1970s and do not account for vehicle technology.

HIAP—Revised

The HIAP model was revised by Berg. The original speed-volume relationships were revised using the *1985 Highway Capacity Manual* (*78*), while the VOC relationships were updated with more recent cost data.

Model Name	*HIAP—Revised*
System	Mainframe
Primary Purpose	Project and Network Analysis for Budgeting
Relationship Basics	Statistical
Level of Aggregation	Project and Network
Vehicle Operations	Uniform Speed, Curves and Speed Changes
Typical Vehicles	Default, User Specified and Modern Truck
Road Variables	Gradient, Curvature, Roughness, Pavement Type and Texture
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance and Depreciation
Value of Time/ Productivity	Yes
Accident Costs	Yes
Environmental Costs	Yes
Other Costs	The model calculates induced demand. The model is capable of calculating accidents at railroad grade crossings.

While the revisions to HIAP rectified many of the limitations with the original version, the *1985 Highway Capacity Manual's* speed-flow relationships still are imperfect with regard to peak period congestion. Additionally, some users still find the revised model too complex for evaluating individual projects (*23*). Notwithstanding, NCHRP Project 7-12 found it to be "best mainframe computer program currently available" (*28*).

HPMS

The Highway Performance Monitoring System (HPMS) computer model, developed by the Federal Highway Administration, is designed to provide Congress and others with timely and accurate information on the public highway system. This information covers the condition of the existing system, anticipated needs for a given level of performance, as well as the impacts if future funding does not cover those needs.

The HPMS model is similar to the original HIAP model in terms of the procedures used for calculating the benefits of highway alternatives. Unlike HIAP, HPMS is not designed for analyzing individual projects in a network but rather for evaluating highway performance and needs in the United States or for a specific state using the HPMS data samples.

Model Name	*HPMS*
Developer(s)	Federal Highway Administration
System	Mainframe
Primary Purpose	Network Analysis for Budgeting
Relationship Basics	Statistical
Level of Aggregation	Network
Vehicle Operations	Uniform Speed, Curves and Speed Changes
Typical Vehicles	Default and User Specified
Road Variables	Gradient, Curvature, Roughness, Pavement Type and Texture
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance and Depreciation
Value of Time/ Productivity	Yes
Accident Costs	Yes
Environmental Costs	Yes
Other	

As with HIAP, HPMS analyzes different alternatives in a large system of highways, rather than specific projects. Also, the model's VOC relationships were developed in the 1970s and do not account for advances in vehicle technology.

MicroBENCOST

MicroBENCOST, developed by the Texas Transportation Institute in 1993, is designed to conduct benefit-cost analysis on a personal computer. The model estimates user benefits and costs, stemming from improvements, and calculates several economic measures for decisionmakers to use in their planning decisions. The software is designed to cover a broad spectrum of projects, including added capacity projects, new location or bypass projects, pavement rehabilitation projects, intersection/interchange projects, bridge rehabilitation and replacement projects, railroad crossing improvements, safety projects, and high-occupancy vehicle lane (HOV) projects.

Model Name	*MicroBENCOST*
Developer(s)	Texas Transportation Institute
System	Personal Computer
Primary Purpose	Project Analysis
Relationship Basics	Statistical
Level of Aggregation	Project
Vehicle Operations	Uniform Speed, Curves, Speed Changes and Idling
Typical Vehicles	Default
Road Variables	Gradient, Curvature and Roughness
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance and Depreciation
Value of Time/ Productivity	Yes
Accident Costs	Yes
Environmental Costs	No, but pollutant emissions are calculated.
Other	The model calculates induced demand. Adjustment factors for travel time costs are calculated based on discomfort due to congestion.

The primary limitation of the model is that the VOC relationships are based on a study by Zaniewski et al. (*48*), which does not account for current vehicle technology.

NIMPAC

The National Association of Australian State Road Authorities developed NIMPAC, which is designed to estimate VOC on rural and urban roads.

Model Name	*NIMPAC*
Developer(s)	National Association of Australian State Road Authorities
System	Personal Computer
Primary Purpose	VOC estimation
Relationship Basics	Statistical
Level of Aggregation	Project and Network
Vehicle Operations	Uniform Speed, Curves, Speed Changes and Idling
Typical Vehicles	Default and Modern Truck
Road Variables	Gradient, Curvature, Roughness and Pavement Type
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance, Depreciation and Interest
Value of Time/ Productivity	No
Accident Costs	No
Environmental Costs	No
Other	

The model is limited in that three of four user cost categories are not considered, significantly limiting the model's applicability for investment analysis.

Red Book

For over 30 years, the American Association of Highway and Transportation Officials (AASHTO) has promoted the use of benefit-cost analysis for comparing highway alternatives through the publication of manuals. Named for their red covers, the first of these manuals was published in 1952 and the latest version was published in 1977.

The Red Book includes extensive procedures to calculate highway user benefits. The Red Book provides a comprehensive methodology to calculate benefits for a wide variety of highway and transit improvements.

Model Name	*Red Book*
Developer(s)	American Association of State Highway and Transportation Officials
System	Manual
Primary Purpose	Project Analysis
Relationship Basics	Statistical
Level of Aggregation	Project
Vehicle Operations	Uniform Speed and Curves
Typical Vehicles	Default, User Specified
Road Variables	Gradient, Curvature and Roughness
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance and Depreciation
Value of Time/ Productivity	Yes
Accident Costs	Yes
Environmental Costs	No
Other	

The applicability of the model is limited because of its time-consuming nature. Additionally, pavement condition is not linked to VOC or vehicle speed calculations and the VOC relationships do not account for current vehicle technology.

StratBENCOST

StratBENCOST was developed by Hickling Lewis Brod Inc. to assimilate highway user costs and benefit-cost analysis into a broad-based highway investment evaluation tool for planners. This model serves as a tool to be used at the early stages of strategic planning, when there is limited data, complementing MicroBENCOST (developed by TTI) which is intended for more detailed project level evaluation and optimization.

StratBENCOST conducts comprehensive statistical simulations in order to provide the probability range for the net present value associated with each project. The simulations reflect uncertainty in each and every factor entering into the net present value (NPV) calculus, including demand.

StratBENCOST thus provides important insight for planners and decisionmakers in honing their benchmark and reprioritized project rankings. Two projects, each displaying an equal NPV, do not offer equal promise if one exhibits a materially greater risk of low return. This can occur when traffic forecasts underpinning one project are less certain than another.

In any "portfolio" there is a place for riskier investments; the important thing is to be aware of them and to choose them judiciously. StratBENCOST provides the management information needed to make such decisions wisely and collectively.

Model Name	*StratBENCOST*
Developer(s)	Hickling Lewis Brod Inc.
System	Personal Computer
Primary Purpose	Project and Network Analysis
Relationship Basics	Statistical
Level of Aggregation	Project and Network
Vehicle Operations	Uniform Speed, Curves and Speed Changes
Typical Vehicles	Default
Road Variables	Gradient and Roughness
Vehicle Operating Costs	Fuel, Oil, Tires, Maintenance and Depreciation
Value of Time/ Productivity	Yes
Accident Costs	Yes
Environmental Costs	Yes
Other	The model calculates induced demand. Risk analysis is used to account for the inherent uncertainty surrounding the user cost relationships.

The primary limitation of the model is that the VOC relationships are based on a 1982 study by Zaniewski et al. (*48*) which does not account for current vehicle technology.

CURRENT RESEARCH EFFORTS

Research in this area is ongoing and it is likely that new tools will be developed building upon those discussed here. For example, Ben-Akiva and Gopinath (*79*) recently developed a unique approach to highway alternative analysis. The authors integrated an infrastructure-performance-deterioration model and a user-cost model to predict the performance of infrastructure facilities such as roads and highways and their corresponding effect on highway user costs. Performance is measured by using traditional, identifiable variables, such as infrastructure characteristics (i.e. construction quality) and, usage of facility. Tests of the model found the methodology to be applicable to any deteriorating facility and bolsters the authors contention that use of a dual deterioration and user cost model provides a more adequate analysis for pavement managers and planners (*79*).

Another effort to incorporate user costs into a comprehensive investment decision-support tool is exemplified by Uddin and George's USER model (*80*). The model includes user costs into a life-cycle analysis of pavement maintenance. To test the model, the authors compared USER and the World Bank's HDM model in an examination of two maintenance and rehabilitation strategies. The two models compared favorably except when pavements are in good condition (the HDM model overestimates VOC). The test results indicate that USER is an effective program to quantify the cost-effectiveness, user costs, and benefits of improved and timely maintenance and rehabilitation programs.

Numerous other research efforts are underway to explicitly address the role of user costs in decisionmaking methodologies. One of these initiatives, sponsored by the Strategic Highway Research Program (SHRP) seeks to identify cost-effective materials and procedures, with regard to minimizing user delay costs during maintenance periods (*81*).

Additional research in this area by Davis and Van Dine (*82*) led to the development of a probabilistic linear programming model for the Connecticut Department of Transportation to optimize maintenance and reconstruction activities. Each mile of roadway in the system can be assessed with respect to minimizing user costs. The model generates the best treatment option among several available options and the optimal timing of the activity. Additionally, the model allows for the incorporation of budget constraints and allowable expenditure ranges for each maintenance activity.

Research in other areas, such as work zone configurations is also expanding our understanding of user costs. An investigation of speed profiles through work zones by Benekohal et al. (*83*) determined the speed reduction experienced as a result of different work zone configurations. This information facilitates the calculation of vehicle delay costs and the optimal work zone configuration. A related study by Cassidy and Han (*84*) investigated speed reductions due to lane closures on two-lane highways.

Such research into the dynamics and effects of work zones has resulted in the development of a number of models to predict the additional user costs (time and vehicle operations) associated with lane closures. These models are the Queue and User Cost Evaluation at Work Zones (QUEWZ) model (*85*), the DELAY model (*86*), the FREWAY model (*87*) and the FREQ10PC model (*88*).

For example, given the characteristics of the work zone (i.e., configuration, schedules), the characteristics of traffic at the work zone (i.e., volume, percent trucks), and the emissions characteristics of vehicles in the area, the QUEWZ model is capable of providing the excess emission values for two vehicle types and three pollutant types. QUEWZ is used to compare work zone construction and traffic management strategies specifically in terms of air pollution, with the results used to develop construction strategies to minimize air pollution (*89*).

Research in these areas has and will continue to have significant benefits for highway users. Congestion created by highway construction and maintenance activities imposes substantial costs on highway users, in the form of travel delays and increased levels of pollution. Strategies and technical solutions to mitigate these adverse conditions must be evaluated, with the costs of the strategy weighed against its benefits. Tools developed as part of these research efforts have an important role to play in this process.

CHAPTER FOUR

REVIEW OF CURRENT PRACTICE

The upper bound of theoretical knowledge is established in the literature review and the current practice is established through a survey of 52 state DOTs and 13 Canadian agencies, with 36 agencies responding, that examines the extent to which user costs and mitigation strategies are used in decisionmaking. The chapter concludes with two case studies highlighting two agency's applications of user costs in decisionmaking.

SURVEY RESULTS

The survey examines state and provincial level use of user costs in the highway investment decisionmaking process. Questions relate to the use of user costs and mitigation strategies in decisionmaking and the way in which they affect the design, construction, and maintenance and rehabilitation facets of highway projects and programs.

The survey was distributed to U.S. and Canadian transportation agencies. A total of 36 agencies in the United States and Canada responded to the first mailing of the survey. A second survey was conducted to include an additional 12 agencies, providing a sample of 48 respondents in total. The analysis presented in the next section reviews the results of Round 1 survey only, however, the findings in Round 1 do not change significantly in Round 2. Full details of the survey and both Round 1 and Round 2 responses are provided in Appendix B. Not everyone who responded to the survey completed all the questions.

User Costs

The results of the first two survey questions (Figures 1–4) indicate that user costs are used, either quantitatively or qualitatively, by 18 of 32 agencies responding with respect to most new construction projects and programs. Additionally, they are used by 14 of 32 agencies responding with respect to most new maintenance and rehabilitation projects and programs.

As expected, when asked the same question with regard to major construction projects and programs, 25 of 34 agencies indicated that user costs are considered either quantitatively or qualitatively. For major new maintenance and rehabilitation projects and programs, 24 of 33 agencies indicated that user costs are considered either quantitatively or qualitatively. But, the order of responses changes when considering major projects and programs. Now, "Qualitatively" is the most frequent response, followed by "Quantitatively" and "Not at all."

This result indicates that when faced with larger, more capital intensive investments, agencies undertake more detailed analyses that include user costs. Conversely, smaller

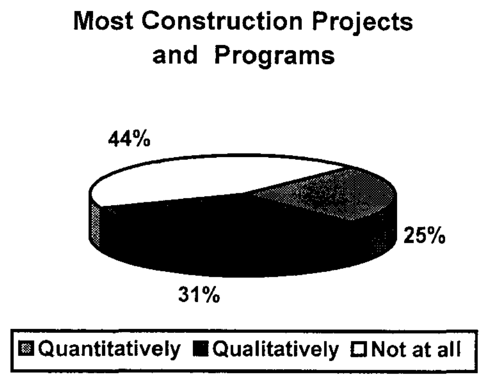

FIGURE 1 Results of Question 1A. Are user costs considered, either quantitatively or qualitatively, in the design phase of most new construction projects and programs?

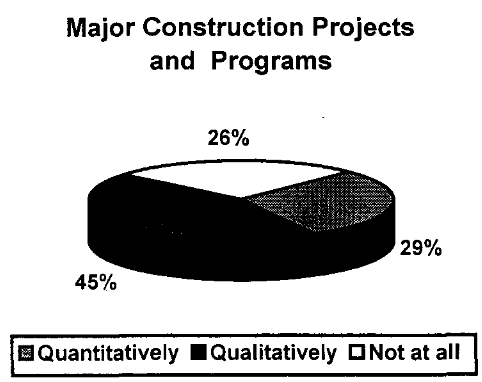

FIGURE 2 Results of Question 1B. Are user costs considered, either quantitatively or qualitatively, in the design phase of major new construction projects and programs?

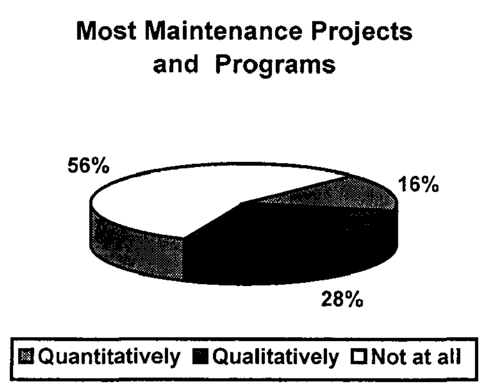

FIGURE 3 Results of Question 2A. Are user costs considered, either quantitatively or qualitatively, in the design phase of most maintenance and rehabilitation projects and programs?

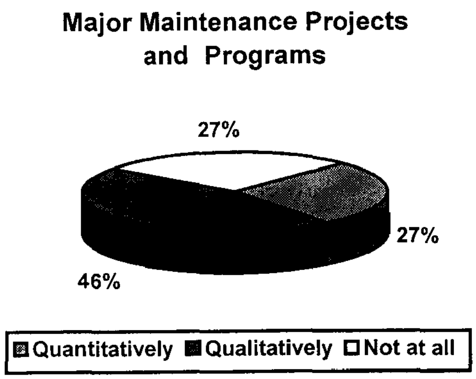

FIGURE 4 Results of Question 2B. Are user costs considered, either quantitatively or qualitatively, in the design phase of major maintenance and rehabilitation projects and programs?

projects and maintenance and repair activities are not routinely subjected to the same level of scrutiny. For some agencies this might be an unofficial policy, probably arising from limited planning resources. In other states, this is a policy. For example, Pennsylvania has a proscribed dollar threshold, below which user costs are not considered. While many of the agencies did not indicate any threshold on the survey, the responses tend to indicate that major investments receive greater scrutiny.

The results of the first two survey questions provide evidence of the extent to which user costs are considered by agencies. Equally important is the depth to which user costs are considered by agencies. For example, does an agency have a formal procedure for considering user costs or determining which user costs to consider? Survey questions 5 and 7 address these questions.

Of the 36 agencies responding to question 5, only 2 do not consider user costs. Almost half the agencies, 14, indicate that the agency has a formal procedure for considering user costs, while 5 indicate that they consider user costs quantitatively but not formally (Figure 5). A little over a third of the agencies, 13, indicate that they perform minimal analysis with user costs, which may include some numerical calculations but the role of user costs in the decisionmaking process is strictly qualitative/subjective.

While the majority of agencies (94.2 percent) consider user costs, there is considerable variation in the categories of user costs considered. Not surprisingly, 23 of 24 agencies responding consider time/delay costs but only 14 consider vehicle operating costs and even fewer consider environmental costs (see Appendix B, question 7). Washington State DOT on the other hand, considers any user cost category that is appropriate to a given project.

The responses to these questions provide a picture of the breadth and depth to which user costs are considered by state agencies. Whether this picture has changed in recent years can only be determined by comparing these results to those of previous surveys. There are two surveys, conducted in the last few years, that provide a basis for comparison.

A 1985 survey by Peterson (*90*) concentrated on the use of life-cycle costing in selecting pavement alternatives at the agency level. Peterson's survey of 49 North American agencies found that construction, replacement, and maintenance costs were the most frequently used cost elements, while less than one-fifth, 10 agencies, considered user costs.

In 1992 Chien-Hung and Schonfield (*91*) surveyed 47 organizations regarding state and local highway maintenance practices specifically asking if highway maintenance planning formally considers user costs (yes, no, or sometimes). The authors found that only 13 agencies (8 of which were state agencies), stated that they formally considered user costs. Ten agencies (9 of which were state agencies), remarked that user costs were sometimes used in their analysis. More than half indicated that user costs were never formally included in their maintenance planning process.

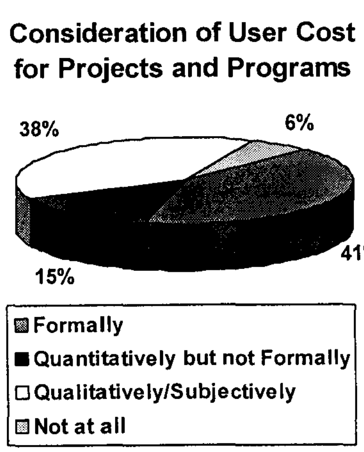

FIGURE 5 Results of Question 5. In project/program design and planning do you consider user costs?

Mitigation Strategies

The same information provided by the survey respondents with regard to user costs is also provided for mitigation strategies. Mitigating the effects of highway construction and maintenance activities is an important function for many agencies. Developing efficient mitigation strategies requires that the additional costs associated with a strategy be compared to its benefits. For example, using a more expensive quick-hardening pavement might minimize traffic disruptions but the additional costs of the material may outweigh the benefits from reduced delays. Questions 3 and 4 address the extent to which agencies consider user costs in developing such strategies and the responses are summarized in Figures 6–9.

In mitigating the temporary user costs associated with most construction projects and programs, user costs are considered quantitatively or qualitatively by 20 of 32 agencies responding. For most maintenance projects and programs, user costs are considered quantitatively or qualitatively by 19 of 31 agencies responding.

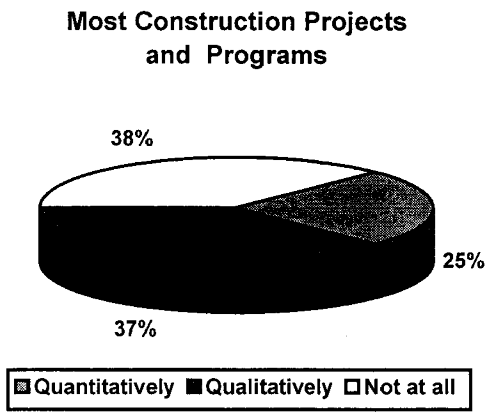

FIGURE 6 Response to Question 3A. Is the mitigation of temporary user costs considered, either quantitatively or qualitatively, in the planning of road work for most new construction projects and programs?

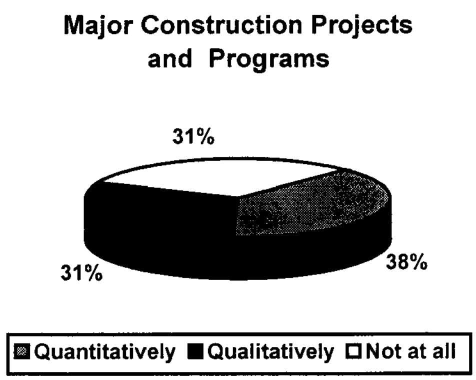

FIGURE 7 Results of Question 3B. Is the mitigation of temporary user costs considered, either quantitatively or qualitatively, in the planning of road work for major new construction projects and programs?

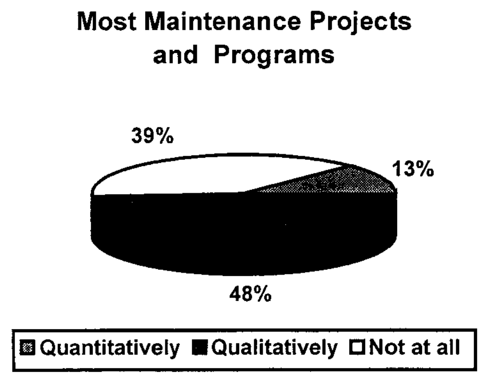

FIGURE 8 Response of Question 4A. Is the mitigation of temporary user costs considered, either quantitatively or qualitatively, in the planning of road work for most maintenance and rehabilitation projects and programs?

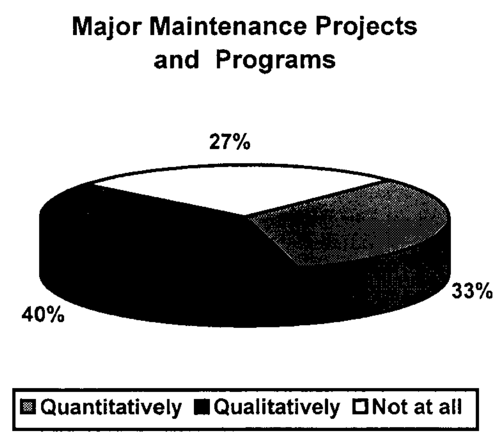

FIGURE 9 Response to Question 4B. Is the mitigation of temporary user costs considered either quantitatively or qualitatively, in the planning of road work for major maintenance and reahabilitation projects and programs?

As with questions 1 and 2, there is a difference between major and most projects and programs. The majority of agencies, 20 of 29 responding, indicate that user costs are quantitatively or qualitatively considered when designing mitigation strategies for major construction projects and programs, while 22 of 30 consider user costs for major maintenance projects and programs.

The difference between major and most projects and programs is attributable to the desire of agencies to mitigate disruptions associated with large projects. Major projects and programs have larger and longer-lasting disruptions, which the public has every right to expect to be mitigated.

Despite the fact that agencies are more likely to consider user costs for major projects and programs, agencies indicate that they are sensitive to highway users and seek to minimize any inconveniences associated with construction and maintenance activities.

As with the first two questions, questions 3 and 4 serve to establish the extent to which user costs are considered in designing mitigation strategies. But, the depth to which they are considered is also important. Questions 6, 8, and 10 define that depth.

Of the 33 agencies responding to question 6, only 6 agencies do not consider user costs (Figure 10). The most frequent response, by 16 of 33 agencies, was that user costs are considered qualitatively/subjectively.

Of the agencies considering user costs to develop mitigation strategies, by far the most frequently employed user cost is time/delay. In fact, 100 percent of agencies use time/delay costs when designing mitigation strategies. Other user costs are considered by some agencies but do not have nearly the widespread use as time/delay (complete data are provided in Appendix B, question 8).

Mitigation strategies are not exclusive to work zone design, as the responses to question 10 indicate. Many different strategies are used to minimize disruptions to highway users. More than 70 percent of all agencies use nighttime, off-peak work and/or fast-hardening materials to minimize disruptions.

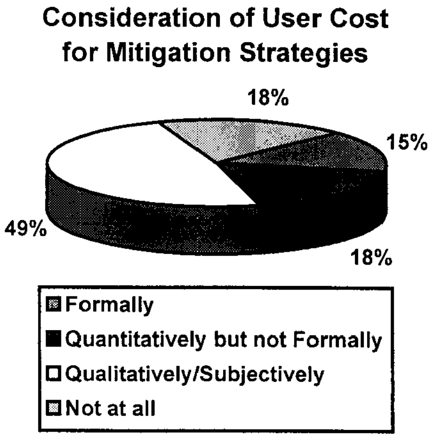

FIGURE 10 Response to Question 6. In seeking to mitigate the temporary user costs of road work through strategies such as night work and the use of costlier but more rapid hardening materials, do you consider user costs?

Additionally, other strategies such as lane reductions, lane closures, oversized crews, and special equipment are also popular with agencies.

SUMMARY OF FINDINGS

Building on the findings in the previous chapter, this section assesses the inclusion of user costs and mitigation strategies in the decisionmaking process by transportation officials and planners. It also evaluates the way in which these costs affect the design, construction, maintenance, and rehabilitation facets of highway projects and programs. The role of user costs and mitigation strategies in decisionmaking among respondents can be summarized by the following points:

- Fifty-six percent of agencies consider user costs for most new construction projects and programs;
- Seventy-four percent of agencies consider user costs for major new construction projects and programs;
- Fifty-six percent of agencies do not consider user costs for most maintenance and rehabilitation projects and programs;
- Seventy-three percent of agencies consider user costs for major maintenance and rehabilitation projects and programs;
- Sixty-two percent of agencies consider user costs when designing mitigation strategies for most new construction projects and programs;
- Sixty-nine percent of agencies consider user costs when designing mitigation strategies for major new construction projects and programs;
- Sixty-one perdent of agencies consider user costs when designing mitigation strategies for most maintenance and rehabilitation projects and programs;
- Seventy-three percent of agencies consider user costs when designing mitigation strategies for major maintenance and rehabilitation projects and programs;
- Forty-one percent of agencies have formal procedures for considering user costs with respect to project and program decisionmaking;
- Fifty-six percent of agencies consider user costs formally or quantitatively with respect to project and program decision making; and
- Sixty-seven percent of agencies do not consider user costs or do so only qualitatively/subjectively when developing mitigation strategies.

A number of additional observations can be made based on the findings of this synthesis. First of all, the extent to which user costs are employed in agencies is growing. This is based on a comparison between these results and those of a 1992 study by Chien-Hung and Schonfield.

Second, the majority of states do not consider user costs when designing mitigation strategies. This is evidenced by the results of question 6. But, contradicting this response is the response to question 10. An overwhelming majority of states indicated that they employ some type of mitigation strategies such as nighttime work, off-peak work or fast-hardening materials. This contradiction indicates that agencies realize mitigation strategies are beneficial and necessary but do not analyze the strategies in any quantitative way. The risk agencies run by not considering user costs in their decision to employ one or more of these strategies is that the costs of the strategy may outweigh the benefits. For example, newer costlier materials, designed to speed up application time and minimize traffic disruptions, may cost more than the benefits derived from reduced traffic delays.

The third conclusion drawn from this synthesis is that significant research carried out over the last couple of years is not being employed by agencies. Evidence of this gap is provided by the scarcity of agencies considering user costs in evaluations of new construction projects and programs. A number of software programs are available for precisely this purpose, yet fewer than a quarter of the agencies quantitatively consider user costs. Two possible reasons could account for low use of these models. First, most of the models were developed for one specific purpose and only a few are applicable to a broad spectrum of projects. Second, the vast number of inputs required and the inaccessibility of most user cost data seems to be a significant impediment to improving evaluation practices.

The final conclusion that can be drawn from this synthesis is that a technology gap exists. A technology gap is defined as a lack of infrastructure, either human, capital, or technological, that prevents current information from being absorbed and implemented.

CASE STUDIES

Based on the survey results, two case studies were selected to contrast and explain how two states faced with different geographic, economic, and demographic characteristics employ user cost concepts and tools in their decisionmaking process. The case studies are based on internal or published reports. One case study considers a sophisticated approach employed by a large urban center while the other focuses on a more informal approach typical of most states characterized by sparsely populated rural areas.

The state-of-the-art study, provided by the Wisconsin Department of Transportation, demonstrates how an agency can employ user costs to create incentives/disincentives to compel contractors to complete work ahead of schedule. The more typical application of user cost tools, provided by the New Mexico State Highway and Transportation Department, demonstrates a more informal approach to how user costs can be incorporated into all facets of decisionmaking for new construction and maintenance and repair activities.

State-of-the-Art Applications of User Cost Tools

The Wisconsin Department of Transportation (WisDOT), has two programs, the incentive/disincentive (I/D) program and the interim liquidated damages (ILD) program, to minimize the disruptions associated with highway construction and maintenance activities. These programs insert provisions in construction contracts to compensate contractors for completing critical work on or ahead of schedule, or assesses a deduction for work not completed on time. The programs are only used on critical projects where traffic inconvenience and delay must be kept to a minimum and access must be restored as soon as possible.

Both programs have two common features:

- They provide for a specified contract date for completion of critical work and opening the highway to traffic.
- They recover some or all road user costs due to detours and delays if the roadway is not opened on the specified date.

The unique elements of an I/D program are:

- It is used when the work necessary to open a highway to traffic cannot be completed with normal production rates.
- It provides significant financial motivation to complete critical work on a highly accelerated schedule.
- It includes less tangible elements, such as disruption to adjacent business and negative impacts to other road/streets, since nearby roads and streets may experience undesirable congestion and delays caused by diverted traffic.

The unique elements of an ILD are:

- It is used when the work necessary to open a highway can be completed with reasonably normal production rates.
- It is used more frequently than I/D on projects where it is necessary to open a highway to traffic on a specific date.

The Incentive/Disincentive Program

The I/D program is intended to motivate contractors to complete the work faster than normal. The program is limited to projects where construction severely disrupts highway traffic, significantly increases road user costs or has a significant impact on adjacent business.

In determining which projects are candidates for an I/D provision, the increased travel distance due to detours, user delays, or retail business losses must be identified. The project selection criteria include:

1. User costs related to detours or delays caused by congestion/capacity problems exceed 20 percent of the project construction cost, but are a minimum of $100,000.
2. Motorists' delay time waiting in line is 10 minutes greater than normal operation and occurs more than three times during construction.
3. Projects where access to retail business will be restricted or inconvenienced because of reconstruction and as a result, significant business losses can be expected to occur.

Projects meeting these criteria are analyzed by the district staff to determine whether a shortening of the construction time can be accomplished and whether the I/D provision will achieve the desired result.

The next step in the process is to calculate the dollar amount of the I/D provision. Calculating the appropriate amount is critical for early completion of a portion of the project or all of the project. To be effective, the dollar amount must be sufficient to benefit the contractor and encourage interest in an accelerated work schedule. If the incentive payment is not sufficient to cover the contractor's cost for the extra work, then it is unlikely the I/D provision will produce the intended result. The I/D amount is calculated by using detour costs, road user delay costs, or impacts on business. Note that these costs are calculated on a per day basis. WisDOT procedure 11-60-5 provides information and examples to determine road user costs associated with a detour (procedure 11-60-5 is also used to calculate ILD).

WisDOT uses a delay model to calculate queue lengths, time to dissipate, and delay costs within a work zone. WisDOT advises that the model be used when considering an I/D provision. Since the dollar amount calculated by the model can be quite large, WisDOT recommends the results be factored by 10 percent for rural projects and 15 percent for urban projects to determine a practical I/D amount.

A sample application of the WisDOT queue model is displayed in the following tables. The inputs for the model are provided in Table 6 and the outputs of the model are provided in Table 7 and Table 8.

When the detour costs and/or road user delay costs are not substantial and an I/D provision is being considered due to potential business losses, the dollar amount is subjectively determined in cooperation with the community.

The Interim Liquidated Damages Program

Selecting when to use the ILD provision is based on the same criteria presented for the I/D provision, with the exception that the provision is used when the work necessary to open the highway can be completed with reasonably normal production rates.

TABLE 6

INPUTS FOR WISDOT'S QUEWZ 85 v. 1.0 MODEL

Number	Variable Description	Value
1	Problem title	Wed / Thr 7 am
2	The major highway or freeway name	I-94
3	Free flow speed	65.0
4	Level of service D/E speed	40.0
5	Speed in mph at capacity after queue formation	30.0
6	Work zone strategy	Crossover
7	Start of work zone traffic control setup	1
8	End of work zone traffic control setup	24
9	Start of actual work	1
10	End of actual work	24
11	Percent of 1981 dollars used to estimate current worth	132.0%
12	Total number of inbound lanes	2
13	Total number open inbound lanes during work	1
14	Total number of outbound lanes	2
15	Total number open outbound lanes during work	1
16	Percent of inbound trucks	22.0%
17	Percent of outbound trucks	22.0%
18	The length in miles from beginning of taper to end of work zone	12.0
19	Maximum flow per inbound lane before work activity	2,000
20	Maximum flow per outbound lane before work activity	2,000
21	LOS DE breakpoint volume per inbound lane before work activity	1,650
22	LOS DE breakpoint volume per outbound lane before work activity	1,650
23	The capacity per lane of the inbound work zone	1,400
24	The capacity per lane of the outbound work zone	1,400

Source: Chapter 19: Plans, Specifications, & Estimates, Section 15: Special Provisions, Subject 18: Incentive/Disincentive, Procedure 19-15-18, *Facilities Development Manual*, Department of Transportation, State of Wisconsin.

TABLE 7

INBOUND WORK ZONE COSTS

Inbound			Total Lanes: 2		Work Zone Lanes: 1		
Time		Hourly	Capacity	Approach	Work Zone	Queue	User
From	To	Volume	Inbound	Speed	Speed	Length	Cost
0	1	450	4,000	61.6			
1	2	481	1,400	61.4	54.6	0.0	30
2	3	529	1,400	61.0	53.5	0.0	41
3	4	539	1,400	60.9	53.3	0.0	43
4	5	703	1,400	59.7	49.8	0.0	112
5	6	819	1,400	58.8	47.3	0.0	202
6	7	1,110	1,400	56.6	41.0	0.0	699
7	8	1,407	1,400	54.3	29.9	0.0	3,027
8	9	1,582	1,400	53.0	26.1	0.3	5,481
9	10	1,732	1,400	51.9	22.9	1.2	9,969
10	11	1,785	1,400	51.5	21.8	2.3	14,497
11	12	1,586	1,400	53.0	26.0	3.3	14,726
12	13	1,240	1,400	55.6	30.0	3.3	12,814
13	14	963	1,400	57.7	30.0	2.3	9,166
14	15	750	1,400	59.3	34.5	0.8	2,452
15	16	586	1,400	60.6	52.3	0.0	58
16	17	390	1,400	62.0	56.6	0.0	15
17	18	223	1,400	63.3	60.2	0.0	4
18	19	132	1,400	64.0	62.2	0.0	1
19	20	73	1,400	64.4	63.4	0.0	0
20	21	80	1,400	64.4	63.3	0.0	1
21	22	56	1,400	64.6	63.8	0.0	0
22	23	63	1,400	64.5	63.6	0.0	0
23	24	99	1,400	64.3	62.9	0.0	1

The sum of inbound work zone costs is $73,428

Source; Chapter 19; Plans, Specifications, & Estimates, Section 15; Special Provisions, Subject 18; Incentive/Disincentive, Procedure 19-15-18, *Facilities Development Manual*, Department of Transportation, State of Wisconsin.

TABLE 8

OUTBOUND WORK ZONE COSTS

Inbound			Total Lanes: 2		Work Zone Lanes: 1		
Time		Hourly Volume	Capacity Inbound	Approach Speed	Work Zone Speed	Queue Length	User Cost
From	To						
0	1	566	4,000	60.7			
1	2	671	1,400	59.9	50.5	0.0	94
2	3	725	1,400	59.5	49.3	0.0	126
3	4	824	1,400	58.8	47.2	0.0	207
4	5	836	1,400	58.7	46.9	0.0	219
5	6	867	1,400	58.4	46.2	0.0	252
6	7	1,001	1,400	57.4	43.3	0.0	452
7	8	1,110	1,400	56.6	41.0	0.0	699
8	9	1,281	1,400	55.3	38.6	0.0	1,160
9	10	1,656	1,400	52.5	24.5	0.4	6,631
10	11	1,753	1,400	51.7	22.4	1.4	11,101
11	12	1,683	1,400	52.3	23.9	2.4	13,359
12	13	1,216	1,400	55.8	30.0	2.6	10,635
13	14	808	1,400	58.9	30.0	1.3	5,824
14	15	518	1,400	61.1	50.6	0.2	148
15	16	410	1,400	61.9	56.1	0.0	18
16	17	327	1,400	62.5	57.9	0.0	9
17	18	234	1,400	63.2	59.9	0.0	4
18	19	150	1,400	63.9	61.8	0.0	2
19	20	126	1,400	64.0	62.3	0.0	1
20	21	154	1,400	63.8	61.7	0.0	2
21	22	153	1,400	63.8	61.7	0.0	2
22	23	236	1,400	63.2	59.9	0.0	4
23	24	313	1,400	62.6	58.2	0.0	8

The sum of the outbound work zone costs is $50,957.

Source: Chapter 19; Plans, Specifications, & Estimates, Section 15; Special Provisions, Subject 18; Incentive/Disincentive Procedure 19-15-18, *Facilities Development Manual*, Department of Transportation, State of Wisconsin.

Calculating an appropriate ILD amount is just as critical as with the I/D provision. ILD amounts are based on road user costs, using an average cost per mile approach. This approach provides a more uniform statewide measure than is possible using an incremental cost approach, which requires consideration of several influences on operating cost, including type of highway, vertical and horizontal geometry, traffic mix, and congestion.

The average cost approach uses the operating costs for passenger cars as reported annually by the FHWA. Similar truck costs are derived from the 1977 AASHTO *Manual on User Benefit Analysis of Highway and Bus-Transit Improvements*. The costs are updated and converted to average cost using the reports mentioned above and the Wisconsin consumer price index.

Calculating the amount of ILD to apply to a project is accomplished with a formula in which the variables are known project-specific values. The formula is:

Road User Cost = ADT * Increased Distance * Cost per Mile

where

ADT = current average daily traffic (ADT) on the project highway or the volume of traffic expected to be inconvenienced, such as in areas with seasonal variances;

Increase Distance = additional length of travel attributable to the detour; and

Cost per Mile = cost per mile of travel.

Two sample cost per mile of travel calculations are provided in Tables 9 and 10.

Road user costs determined by using the above formula could be excessive when compared to the contract amount and thus be impractical. For that reason, minimum and maximum limits on ILD were established. They are displayed in Table 11.

The actual result of the user cost computation is rounded to the nearest hundred dollars, except where it falls outside the chart. If the computed road user costs exceed the maximum amount shown in the chart, the chart maximum is applied. If the computed road user costs are less than the chart minimum, and ILD provision is not applied to the contract.

Two sample ILD calculations are provided in Tables 12 and 13.

Typical Application of User Cost Tools

The New Mexico State Highway and Transportation Department incorporates user costs into the decisionmaking process for both new construction and maintenance activities. On high-volume roads, user delay and operating cost are found to

TABLE 9

SAMPLE CALCULATION TO DETERMINE AVERAGE PASSENGER CAR OPERATING COST (Cents per Mile)

Car Size	Cost, Depreciation, Maintenance, Gas, Oil, Insurance and Taxes	Wisconsin Fleet (%)	Total
Large	25.8	32.0	8.26
Intermediate	23.0	42.0	9.66
Compact	20.6	12.0	2.47
Sub-Compact	18.1	10.0	1.81
Van	32.4	4.0	1.3
Average		100.0	23.49

Source: Cost of Owning and Operating Automobiles and Vans 1982-FHWA and Bureau of System Planning.

TABLE 10

SAMPLE CALCULATION TO DETERMINE AVERAGE TRUCK OPERATING COST (Cents per Mile)

Truck Size	Cost, Depreciation, Maintenance, Gas, Oil, Insurance and Taxes
SU	55.9
3-S2	65.8

Source: The costs were derived from Tables B-1, 2 and 3 in the 1977 AASHTO *Manual on User Benefit Analysis of Highway and Bus-Transit Improvements* and were updated to 1982 average cost using 1.2117 (1975) and 2.006 (1982) price deflator factors from the Bureau of Policy Planning and Analysis.

TABLE 11

APPLICABLE INTERIM LIQUIDATED DAMAGES

Cost of Improvement (Million $)	Minimum ($)	Maximum ($)
0 to 1	1,000	2,500
1 to 3	1,000	3,500
Greater than 3	1,000	5,000

Source: Chapter 11; Design, Section 60; Detours, Subject 5: Interim Liquidated Damages, Procedure 11-60-5, *Facilities Development Manual*, Department of Transportation, State of Wisconsin.

play an equal role with construction costs in determining what design to use. The user costs on high-volume roads are calculated in the Department's life-cycle analysis process to determine the method and materials to be used. For medium- to low-volume roads, user costs are found to play a minimal role.

The procedures for calculating user delay costs in the New Mexico case are informal and less systematic and sophisticated than in Wisconsin. This approach however, is more typical (and appropriate given the nature of transportation and infrastructure in the region). The procedures employed in New Mexico do not rely heavily on technology to provide a

TABLE 12

SAMPLE CALCULATION 1 TO DETERMINE INTERIM LIQUIDATED DAMAGES

Input Descriptions	Input Values
Contract Cost	2,540,000
Length (miles)	7.97
Detour (miles)	9.68
Difference (miles)	1.7
Car Traffic (%)	89.2
SU Truck Traffic (%)	4.2
3-S2 Truck Traffic (%)	6.6
On Detour Cars	5,162
On Detour Trucks	625
Car Cost per Mile	23.5
SU Truck Cost per Mile	55.9
3-S2 Truck Cost per Mile	65.8

Vehicle Operating Costs ($)

Cars 2,062 = 5,162 * (23.5/100) * 1.7
Trucks 658 = 625 * [55.9 * (4.2/10.8)] + [65.8 * (6.6/10.8)] * 1.7
Total 2,720

Results: The interim liquidated damages are set to $2,700 (2,720 rounded to the nearest hundred), since this amount falls within the range of values specified for the contract amount.

TABLE 13

SAMPLE CALCULATION 2 TO DETERMINE INTERIM LIQUIDATED DAMAGES

Input Descriptions	Input Values
Contract Cost ($):	1,100,000
Length (miles):	4.26
Detour (miles):	7.65
Difference (miles):	3.4
Car Traffic (%):	89.2
SU Truck Traffic (%):	4.2
3-S2 Truck Traffic (%):	6.6
On Detour Cars:	5,368
On Detour Trucks:	649
Car Cost per Mile:	23.5
SU Truck Cost per Mile:	55.9
3-S2 Truck Cost per Mile:	65.8
Vehicle Operating Costs ($)	
Cars 4,289 = 5,368 * (23.5/100) * 3.4	
Trucks 1,367 = 649 * [55.9 * (4.2/10.8)] + [65.8 * (6.6/10.8)] * 3.4	
Total 5,656	
Results: Since $5,656 exceeds the maximum allowable interim liquidated damages for the contract amount, the maximum amount of $3,500 would apply.	

TABLE 14

NEW MEXICO PROCEDURE FOR CALCULATING USER DELAY COSTS ($ per Minute)

Inputs	Descriptions
One or More Lanes Closed in One Direction of Traffic:	
ADT	Average Daily Traffic
% Auto	Percent Automobile Traffic
% Truck	Percent Truck Traffic
Est. Auto Cost	Cost per Hour of Automobile Time, Including Drivers Time
Est. Truck Cost	Cost per Hour of Truck Time, Including Drivers Time
User Delay Costs:	
Auto	[% Auto * (ADT/2) * Est. Auto Cost]/60
Truck	[% Truck * (ADT/2) * Est. Truck Cost]/60
Crossover One or More Lanes Closed in Each Direction of Traffic:	
ADT	Average Daily Traffic
% Auto	Percent Automobile Traffic
% Truck	Percent Truck Traffic
Est. Auto Cost	Cost per Hour of Automobile Time, Including Drivers Time
Est. Truck Cost	Cost per Hour of Truck Time, Including Drivers Time
User Delay Costs:	
Auto	[% Auto * ADT * Est. Auto Cost]/60
Truck	[% Truck * ADT * Est. Truck Cost]/60

comprehensive procedure for inclusion of user costs in decisionmaking. Rather, the procedures are based on data entry forms containing the appropriate equations. All the calculations are made manually.

The procedure used in New Mexico is a life-cycle cost analysis based on present worth and a 30-year life. The parameters used in the analysis are derived internally and are based on current, future, and past experience on costs, rehabilitation methods, maintenance, traffic, and availability of materials. The factors considered in the analysis depend on the specific characteristics of the project. Analyses are performed at the Department's Central Materials Laboratory, which is also responsible for collecting costs, materials and historical data. All project locations are field reviewed and local district personnel are interviewed to determine additional problems or complexities. The technical foundation of the New Mexico approach is based on formulas presented in Table 14. The department recently obtained a computer program named "Darwin 2.0," from AASHTO, which contains a module for life-cycle cost analysis. The Department intends to automate some of the procedures in the future.

A Note on Current Practice in Relation to Mitigation

By far the weakest area of user cost analysis is in the assessment of alternative road work mitigation strategies. The disruptive effects of road work apply to all dimensions of user cost. Although the tool known as MicroBENCOST includes a module designed to permit such analysis, it has yet to enjoy widespread application in state or provincial DOTs for this purpose. StratBENCOST also facilitates mitigation analysis, but not as a specific module.

The Arizona Department of Transportation, through the Arizona Transportation Research Center, has experimented with StratBENCOST as a means of examining the cost-effectiveness of new pavement materials and construction and repair procedures. Since advanced, faster drying paving materials are more expensive than existing materials, Arizona DOT wished to determine whether their use was justified by the reduction in user costs resulting from reduced worksite disruption. Although these experiments confirm the feasibility of formal user cost analysis tools in mitigation planning, most agencies apply user cost logic informally at present.

CHAPTER FIVE

CONCLUSIONS

A consensus in the economic literature reflects the belief that user cost analysis should play a central role in highway budgeting and project prioritization. Although the centrality of user costs in budgeting and prioritization is still not widely accepted in transportation planning agencies, the importance and measurement of user costs does have growing currency in that milieu. In particular, user costs are seen as an important measure of highway system performance. Indeed, since user costs associated with travel time and delay are related to average roadway speed, and given that average speed–together with accident rates—have long been central to transportation planning, virtually all transportation planning agencies can be said to consider user costs to some extent.

Many agencies have grown to recognize that speed and safety are *partial* and *indirect* as a basis for budgeting and priority setting in relation to user costs. They are *partial* in the sense that highway user costs also include vehicle operating and maintenance expenses, environmental effects, and variability in roadway speed. Highway users incur the cost of speed variability in the form of unreliable and unpredictable roadway conditions. Such conditions cause productivity losses for shippers and manufacturers, as when just-in-time deliveries are late, for example. Unreliable conditions prompt compensating behavior by auto users that cost employers money (i.e., leaving extra early for meetings) and that disrupt family life (i.e., leaving extra early to get to work on time). Research findings indicate that highway users are willing to pay three to four times more for greater reliability than faster travel time.

The measurement of speed and safety provides only an *indirect* index of user costs in the sense that each yields, at best, a rough signal of the value of highway improvements. Whereas the measurement of value requires the assessment of market prices and users' willingness to pay, conventional planning methodologies consider speed and safety in physical units only.

Awareness of the importance of user costs and of the incompleteness of physical measures of speed and safety as a basis for performance measurement has grown substantially in transportation agencies. A majority of agencies today consider user costs in planning, budgeting, and prioritization in a qualitative fashion and a growing minority of states routinely do so quantitatively. Of the 50 agencies responding to a survey conducted for this study, an estimated 29 percent indicate that they assess user cost impacts quantitatively in considering major construction projects; 27 percent for major rehabilitation and maintenance projects; and an estimated 38 percent and 33 percent do so in planning roadwork mitigation strategies for major construction and maintenance projects, respectively. While the number of states that address user costs quantitatively for *most or all* projects is smaller (25 percent do so for most construction projects and 16 percent for most maintenance projects), the survey findings suggest that the proportion of agencies that endeavor to measure user cost impacts in the budgeting and prioritization of projects has grown over the last 10 years.

The growing demand for user cost information has led to a growing demand for user cost analysis tools. The availability of computer models that ease the computational burden of user cost analysis has grown accordingly since 1977 when the American Association State Highway and Transportation Officials (AASHTO) published its Red Book. The Red Book is a guide to the quantitative assessment of user costs. While groundbreaking in many respects, the Red Book employs manual methods and quantitative rule-of-thumb relationships. As a tool, the Red Book is time-consuming in application and dated in relation to the data and relationships it employs.

Recognizing the Red Book's shortcomings, and seeking to combine user-friendly computer technology with the Red Book concept of a widely available and transferable analysis framework, the National Cooperative Highway Research Program (acting on behalf of AASHTO) has developed two major desktop computer tools, one for the assessment of projects and programs at a strategic level (StratBENCOST) and one for the assessment of projects in advanced levels of design (MicroBENCOST). The strategic model enables planners to compare the cost-benefit balance of projects at the conceptual stage of the planning process. This facilitates multi-year resource allocation between urban and rural needs and among the needs of different subregions and metropolitan areas. The more specific model facilitates the cost-benefit comparison of project design and scoping options, providing planners with a means of searching out design solutions that maximize the economic merit of individual project investments. Other user-friendly user cost analysis tools are also available.

A number of common concerns help explain why only a minority of agencies make routine use of quantitative user cost methodologies in support of budgeting and prioritization. Some officials are concerned about the data employed in certain models, noting that it is either out-of-date or reflective of national averages rather than specific local circumstances. This is particularly the case in relation to accident rates, economic valuations of time and delay and environmental costs. Notwithstanding this common concern, analysis indicates that the timeliness of existing user cost data bases will not compromise the utility of available tools for most agency applications. Moreover, certain models, such as StratBENCOST, permit the substitution of local values for default values where local user cost information is available. While the development of more locally oriented user cost data would encourage more agencies to take advantage of this flexibility, analysis indicates that the degree of error introduced when using existing data and default values is unlikely to sway the conclusions to be drawn for budgeting and prioritization purposes.

Although the lack of currency in certain user cost data is partly responsible for the low rate at which agencies are adopting user cost analysis and analysis tools, it is the perceptions of elected officials and the general public that represent the fundamental barrier. The issue of perception has two dimensions. First, elected officials and the general public do not comfortably equate the concept of user cost with the range of economic and social purposes they view as the principal objectives of transportation improvements. Such objectives are typically expressed in broad qualitative terms, such as "advancing economic development," "improving mobility," "enhancing accessibility," "reducing congestion," "shaping desirable land-use patterns," "improving environmental conditions," "fostering tourism," and "reducing accidents." Many decisionmakers perceive the conventionally defined range of user costs as, at best, a sub-set of the relevant range of effects to be considered in major decisions. To be sure, the consensus in economics supports the theoretical proposition that accounting for user costs also captures all other value-adding economic effects of transportation improvements. This theory proves that adding the estimated value of "regional industrial development" or "tourism income" to user cost reductions constitutes double-counting since such effects are but the downstream impacts of user cost reductions. Attempts to convince elected officials and members of the public that user costs represent a sound index of all such downstream effects rarely succeeds, however.

A second common and fundamental concern among decisionmakers is the belief that user cost analysis has certain built-in biases. Suspected biases include urban over rural investments; high-volume over low-volume road improvements; capacity over maintenance projects; and improvements that benefit higher income over lower income individuals. Many decisionmakers also question the value judgment implied in the ranking of non-safety above safety projects on the basis of user cost analysis. Although certain "biases" do indeed exist, economists would call them "appropriate policy signals." This is because economic research finds transportation to be a very weak instrument of wealth redistribution and job creation and a strong instrument of economic growth through user cost reductions and related downstream benefits. This runs counter to the common belief among elected officials that transportation is as much an instrument of wealth redistribution and social policy (including job creation) as it is an instrument of economic productivity and growth. Thus, resistance to user cost analysis reflects a fundamental disagreement about the appropriate objectives of transportation policy.

Both singly and in combination, the concerns among elected officials and the general public outlined above inhibit the transportation planners who serve them from introducing user costs as a central element in planning, budgeting, and prioritization.

The more widespread adoption of user cost analysis and analysis tools requires continued efforts to update national databases, to create databases of local variation from national averages, and to make software tools easier and more flexible in application.

More fundamentally, however, user cost information and analysis tools need to be better directed to the policy and political realities facing transportation planners. Some tools, such as StratBENCOST, are already sensitive to this requirement. They permit economic "sub-optimization" of user costs within prespecified sub-budgets for low-volume roads, rural areas and safety. A greater awareness of such approaches needs to be fostered along with the development of other approaches.

Finally, any progress in translating user cost estimates into downstream implications for economic development, tourism, and other common transportation objectives would go far to enhance the acceptability of user cost analysis and analysis tools in mainstream decisionmaking.

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APPENDIX A

Survey Instrument

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Project 20-5, Synthesis Topic 27-12
Road User and Mitigation Costs in Highway Improvement Projects

QUESTIONNAIRE

General Information

Name: ______________ Title: ______________
Agency: ______________
City: ______________ State/Province: ______________
Zip/Postal Code: ______________
Phone Number: ______________ Fax Number: ______________
Email Address: ______________

May we contact you for follow-up questions? [ ] Yes [ ] No

PART 1: USER COSTS

Instructions: For each question, please provide an appropriate response(s), from the perspective of your agency.

1. Are user costs considered, either quantitatively or qualitatively, in the design phase of new construction projects and programs?

   A) Most Projects/Programs: (check one of the following)
      Quantitatively ______
      Qualitatively ______
      Not at all ______
   B) Major Projects/Programs Only: (check one of the following)
      Quantitatively ______
      Qualitatively ______
      Not at all ______

Comments: ______________

2. Are user costs considered, either quantitatively or qualitatively, in the design phase of maintenance and rehabilitation projects and programs?

   A) Most Projects/Programs: (check one of the following)
      Quantitatively ______
      Qualitatively ______
      Not at all ______

B) Major Projects/Programs Only: (check one of the following)
Quantitatively _______
Qualitatively _______
Not at all _______

Comments: ____

3. Is the mitigation of temporary user costs considered, either quantitatively or qualitatively, in the planning of road work for new construction projects and programs?

A) Most Projects/Programs: (check one of the following)
Quantitatively _______
Qualitatively _______
Not at all _______

B) Major Projects/Programs Only: (check one of the following)
Quantitatively _______
Qualitatively _______
Not at all _______

Comments: ____

4. Is the mitigation of temporary user costs considered, either quantitatively or qualitatively, in the planning of road work for maintenance and rehabilitation projects and programs?

A) Most Projects/Programs: (check one of the following)
Quantitatively _______
Qualitatively _______
Not at all _______

B) Major Projects/Programs Only: (check one of the following)
Quantitatively _______
Qualitatively _______
Not at all _______

Comments: ____

5. In project/program design and planning do you consider user costs: (circle one)

A) As part of a formal costing methodology such as life-cycle cost analysis, benefit-cost analysis or cost minimization
B) Quantitatively but not as part of a formal cost methodology
C) Qualitatively/subjectively
D) Not at All

Comments: ____

6. In seeking to mitigate the temporary user costs of road work through strategies such as night work and the use of costlier but more rapid hardening materials, do you consider user costs: (circle one)

   A) As part of a formal costing methodology such as life-cycle cost analysis, benefit-cost analysis or cost minimization
   B) Quantitatively but not as part of a cost methodology
   C) Qualitatively/subjectively
   D) Not at All

Comments: ____

7. Are separate dimensions of user cost considered in the design phase of new construction and maintenance and rehabilitation projects and programs? (circle yes or no)

   Yes No

If Yes, (circle one or more)

   A) Speed Effects
   B) Time/Delay
   C) Safety Effects
   D) Vehicle Operating Costs
   E) Environmental Effects on Noise
   F) Environmental Effects on Air Quality
   G) Environmental Effects on Water Quality
   H) Environmental Effects on Land Management and Preservation (i.e., wetlands)
   I) Other: (please specify)

Comments: ____

8. Are separate dimensions of user cost considered in the development of strategies such as night work and the use of costlier but more rapid hardening materials, to mitigate the temporary user costs of road work? (circle yes or no)

   Yes No

If Yes, (circle one or more)

   A) Speed Effects
   B) Time/Delay

C) Safety Effects
D) Vehicle Operating Costs
E) Environmental Effects on Noise
F) Environmental Effects on Air Quality
G) Environmental Effects on Water Quality
H) Environmental Effects on Land Management and Preservation (i.e., wetlands)
I) Other: (please specify)

____
____
____

Comments: ____________________

9. If you quantify user costs, do you use standard monetary values for any of the components below? (circle yes or no)

Yes No

Please specify where appropriate:

Time/Delay:
- Cost per hour of vehicle time ($/hour) __________
- Cost per hour of truck time ($/hour) __________
- Cost per hour of bus/transit time ($/hour) __________

Vehicle Operating Costs:
- Cost of fuel ($/gallon) __________
- Cost of oil ($/quart) __________
- Cost of a tire ($/tire) __________
- Cost of maintenance and repair (average annual cost) __________
- Cost of a vehicle ($/vehicle) __________

Safety Effects:
- Cost of a Fatal Accident ($/accident) __________
- Cost of a Injury Only Accident ($/accident) __________
- Cost of a Property Damage Only Accident (PDO) ($/accident) __________

Environmental Effects:
- Cost of carbon monoxide emissions ($/lb.) __________
- Cost of nitrous oxide emissions ($/lb.) __________
- Cost of volatile organic compound emissions ($/lb.) __________
- Cost of hydro carbon emissions ($/lb.) __________
- Cost of noise ($/decibel) __________

Other:

____
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____
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Comments: ____

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PART 2: MITIGATION STRATEGIES

Instructions: For each question, please circle the appropriate response(s).

10. In implementing projects/programs and mitigating delay and other negative effects on existing users do you consider one or more of the following strategies?

    A) Night Time Work
    B) Off-Peak Work
    C) Lane Reduction but Not Complete Closure
    D) Periodic Lane Closure
    E) Oversized Crews to Speed up Work
    F) Fast Hardening Materials
    G) Special Equipment to Speed up Work
    H) Other (please indicate)

Comments: ____

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APPENDIX B

Summary of Survey Responses

PART 1: USER COSTS

	Round 2	Round 1
Agencies Responding to Survey:	48	36

1. Are user costs considered, either quantitatively or qualitatively, in the design phase of new construction projects and programs?

A) Most Projects/Programs: (check one of the following)

	Round 2		Round 1	
Quantitatively	13	28.9%	8	25.0%
Qualitatively	14	31.1%	10	31.3%
Not at all	18	40.0%	14	43.8%
Total Responses	45	100.0%	32	100.0%

B) Major Projects/Programs Only: (check one of the following)

	Round 2		Round 1	
Quantitatively	15	33.3%	10	29.4%
Qualitatively	18	40.0%	15	44.1%
Not at all	12	26.7%	9	26.5%
Total Responses	45	100.0%	34	100.0%

2. Are user costs considered, either quantitatively or qualitatively, in the design phase of maintenance and rehabilition projects and programs?

A) Most Projects/Programs: (check one of the following)

	Round 2		Round 1	
Quantitatively	9	20.0%	5	15.6%
Qualitatively	16	35.6%	9	28.1%
Not at all	20	44.4%	18	56.3%
Total Responses	45	100.0%	32	100.0%

B) Major Projects/Programs Only: (check one of the following)

	Round 2		Round 1	
Quantitatively	12	27.9%	9	27.3%
Qualitatively	20	46.5%	15	45.5%
Not at all	11	25.6%	9	27.3%
Total Responses	43	100.0%	33	100.0%

3. Is the mitigation of temporary user costs considered, either quantitatively or qualitatively, in the planning of road work for new construction projects and programs?

A) Most Projects/Programs: (check one of the following)

	Round 2		Round 1	
Quantitatively	11	25.6%	8	25.0%
Qualitatively	18	41.9%	12	37.5%
Not at all	14	32.6%	12	37.5%
Total Responses	43	100.0%	33	100.0%

B) Major Projects/Programs Only: (check one of the following)

	Round 2		Round 1	
Quantitatively	15	36.6%	11	37.9%
Qualitatively	15	36.6%	9	31.0%
Not at all	11	26.8%	9	31.0%
Total Responses	41	100.0%	29	100.0%

4. Is the mitigation of temporary user costs considered, either quantitatively or qualitatively, in the planning of road work for maintenance and rehabilitaiton projects and programs?

A) Most Projects/Programs: (check one of the following)

	Round 2		Round 1	
Quantitatively	8	18.2%	4	12.9%
Qualitatively	21	47.7%	15	48.4%
Not at all	15	34.1%	12	38.7%
Total Responses	44	100.0%	31	100.0%

B) Major Projects/Programs Only: (check one of the following)

	Round 2		Round 1	
Quantitatively	14	33.3%	10	33.3%
Qualitatively	18	42.9%	12	40.0%
Not at all	10	23.8%	8	26.7%
Total Responses	42	100.0%	30	100.0%

5. In project/program design and planning do you consider user costs:

A) Formally	21	43.8%	14	41.2%
B) Quantitatively but not formally	7	14.6%	5	14.7%
C) Qualitatively/subjectively	16	33.3%	13	38.2%
D) Not at all	4	8.3%	2	5.9%
Total Responses	48	100.0%	34	100.0%

6. In seeking to mitigate the temporary user costs of road work through strategies such as night work and the use of costlier but more rapid hardening materials, do you consider user costs: (circle one)

	Round 2		Round 1	
A) Formally	9	19.1%	5	15.2%
B) Quantitatively but not formally	10	21.3%	6	18.2%
C) Qualitatively/subjectively	21	44.7%	16	48.5%
D) Not at all	7	14.9%	6	18.2%
Total Responses	47	100.0%	33	100.0%

7. Are separate dimensions of user cost considered in the design phase of new construction and maintenance and rehabilitation projects and program?

	Round 2		Round 1	
Yes	33	66.0%	24	66.7%
No	17	34.0%	12	33.3%
Total Responses	50	100.0%	36	100.0%

If yes, circle one or more

A) Speed Effects	17	51.5%	10	41.7%
B) Time/Delay	32	97.0%	23	95.8%
C) Safety Effects	24	72.7%	15	62.5%
D) Vehicle Operating Costs	20	60.6%	14	58.3%
E) Environmental Effects on Noise	9	27.3%	6	25.0%
F) Environmental Effects on Air	9	27.3%	5	20.8%
G) Environmental Effects on Water	7	21.2%	2	8.3%
H) Environmental Effects on Land	8	24.2%	3	12.5%
I) Other (please specify)	2	6.1%	1	4.2%

8. Are separate dimensions of user cost considered in the development of stategies such as night work and the use of costlier but more rapid hardening materials, to mitigate the temporary user costs of road work? (circle yes or no)

	Round 2		Round 1	
Yes	27	54.0%	18	50.0%
No	23	46.0%	18	50.0%
Total Responses	50	100.0%	36	100.0%

If yes, circle one or more

A) Speed Effects	10	37.0%	5	27.8%
B) Time/Delay	25	92.6%	18	100.0%
C) Safety Effects	16	59.3%	8	44.4%
D) Vehicle Operating Costs	12	44.4%	8	44.4%
E) Environmental Effects on Noise	5	18.5%	4	22.2%
F) Environmental Effects on Air	5	18.5%	3	16.7%
G) Environmental Effects on Water	4	14.8%	2	11.1%
H) Environmental Effects on Land	3	11.1%	1	5.6%
I) Other (please specify)	2	7.4%	0	0.0%

9. If you quantify user costs, do you use standard monetary values for any of the components below? (circle yes or no)

	Round 2		Round 1	
Yes	15	30.0%	8	22.2%
No	35	70.0%	28	77.8%
Total Responses	50	100.0%	36	100.0%

Please specify where appropriate

	Round 2			Round 1		
Cost per hour of vehicle time ($/hr)	12	24.0%	US$9.26	7	19.4%	US$11.36
Cost per hour of truck time ($/hr)	9	18.0%	US$22.40	5	13.9%	US$30.40
Cost per hour of bus time ($/hr)	2	4.0	US$30.50	2	5.6%	US$30.50
Cost of fuel ($/gallon)	3	6.0%	US$1.14	1	2.8%	US$1.13
Cost of oil ($/quart)	2	4.0%	US$2.47	1	2.8%	US$3.22
Cost of a tire ($/tire)	1	2.0%	US$61.50	1	2.8%	US$61.50
Cost of M&R (avg. cost)	1	2.0%	US$70.00	1	2.8%	US$70.00
Cost of a vehicle ($/vehicle)	1	2.0%	US$10,355	1	2.8%	US$9,000
Cost of a Fatal Accident ($ M)	8	16.0%	US$1.380	3	8.3%	US$0.283
Cost of an Injury Only Accident ($ T)	8	16.0%	US$48.775	2	5.6%	US$40.529
Cost of a PDO Accident ($ T)	8	16.0%	US$4.338	1	2.8%	US$2.500
Cost of CO Emissions ($/lb)	0	0.0%	US$0	0	0.0	US$0.00
Cost of NOX Emissions ($/lb)	0	0.0%	US$0	0	0.0	US$0.00
Cost of VOC Emissions ($/lb)	0	0.0%	US$0	0	0.0	US$0.00
Cost of HC Emissions ($/lb)	0	0.0%	US$0	0	0.0	US$0.00
Cost of Noise ($/decibel)	1	2.0%	US$3,400	0	0.0	US$0.00
Other	0	0.0%	US$0	0	0.0	US$0.00

PART 2: MITIGATION STRATEGIES

10. In implementing projects/programs and mitigating delay and other negative effects on existing users do you consider one or more of the following strategies?

	Round 2		Round 1	
A) Night Time Work	38	76.0%	26	72.2%
B) Off-Peak Work	39	78.0%	27	75.0%
C) Lane Reduction but Closure	37	74.0%	24	66.7%
D) Periodic Lane Closure	33	66.0%	22	61.1%
E) Oversized Crews to Speed	20	40.0%	14	38.9%
F) Fast Hardening Materials	35	70.0%	26	72.2%
G) Special Equipment	18	36.0%	12	33.3%
H) Other (please indicate)	5	10.0%	3	8.3%

APPENDIX C

Agencies Responding

NUMBER	AGENCY	STATE
1	Nebraska Department of Roads (NDOR)	Nebraska
2	New Mexico State Highway and Transportation Department	New Mexico
3	Wisconsin Department of Transportation	Wisconsin
4	California Department of Transportation	California
5	Virginia Department of Transportation	Virginia
6	Nevada Department of Transportation	Nevada
7	Texas Department of Transportation	Texas
8	Hawaii DOT Highway Testing Lab	Hawaii
9	South Carolina DOT, Preconstruction Department	South Carolina
10	Puerto Rico Highway and Transportation Authority	Puerto Rico
11	Transportation Planning Office	Tennessee
12	Massachusetts Highway Department	Massachusetts
13	Connecticut Department of Transportation	Connecticut
14	Utah Department of Transportation	Utah
15	Indiana Department of Transportation	Indiana
16	Maryland DOT, State Highway Administration	Maryland
17	SHA—Office of Highway Design	Maryland
18	State Highway Administration	Maryland
19	Rhode Island Department of Transportation	Rhode Island
20	Pennsylvania Department of Transportation	Pennsylvania
21	Ohio Department of Transportation	Ohio
22	Florida Department of Transportation	Florida
23	Mississippi Department of Transportation	Mississippi
24	Georgia Department of Transportation	Georgia
25	Maine Department of Transportation	Maine
26	Arkansas State Highway and Transportation Department	Arkansas
27	Illinois DOT—Bureau of Design and Environment	Illinois
28	North Carolina DOT, Pavement Management Unit	North Carolina
29	Washington State Department of Transportation	Washington
30	Michigan Department of Transportation	Michigan
31	Maryland State Highway Administration	Maryland
32	Arizona Department of Transportation	Arizona
33	Vermont Agency of Transportation	Vermont
34	Montana Department of Transportation	Montana
35	New York State Department of Transportation	New York
36	Vermont Agency of Transportation	Vermont
37	New Jersey Department of Transportation	New Jersey
38	New Hampshire Department of Transportation	New Hampshire
39	West Virginia Department of Transportation	West Virginia
40	Iowa Department of Transportation	Iowa
41	Louisiana Transportation Research Center	Louisiana
42	Minnesota Department of Transportation	Minnesota

NUMBER	AGENCY	PROVINCE
1	New Brunswick Department of Transportation	New Brunswick
2	Quebec Department of Transportation	Quebec
3	Transportation System Planning and Development	Manitoba
4	Prince Edward Island Department of Transportation and Public	Prince Edward Island
5	Ontario Ministry of Transportation	Ontario
6	Ministry of Transportation and Highways	British Columbia

Lewis, David L. 1949-

Road user and mitigation
costs in highway pavement

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