USER BENEFIT ANALYSIS FOR HIGHWAYS

American Association of State Highway and Transportation Officials
The User Benefit Analysis for Highways Manual and accompanying CD-ROM were developed largely to support transportation planners in state, regional, and local governments who evaluate highway investments. The theory and methods for estimating the benefits and costs of highway projects are presented to provide practical tools for practitioners. The CD-ROM contains an electronic copy of this manual in Portable Document Format (PDF). It also contains practical materials and resources for conducting and presenting benefit-cost analyses of highway improvements. These resources include the following:

- **Analytical tools.** An interactive Microsoft Excel “wizard” is provided. This wizard takes the user through a series of dialogs where information about a project is collected and then calculates and presents the results of a benefit-cost analysis in a printable format. A series of Microsoft Excel spreadsheets also are included to help analysts organize data and make calculations to carry out benefit-cost analyses. These spreadsheets are electronic versions of the calculation worksheets in the manual.

- **Presentation materials.** Microsoft PowerPoint slideshows that can be easily customized are provided to help practitioners prepare presentations about the results of benefit-cost analyses of highway projects. The slideshows complement the guidebook and can be used for presentations to decisionmakers, the public, and the media. A library of relevant, royalty-free images for use in presentations and documents is also provided.

- **A resource library.** The CD-ROM contains resources to support practitioners as they evaluate the costs and benefits of highway projects. These resources include a glossary of terms used in the manual, a list of transportation organizations and website links where additional data may be found for benefit-cost analyses, and a list of websites that contain useful electronic maps and geographic information systems data.
PREFACE

This manual and the accompanying CD-ROM are intended to help state and local transportation planning authorities evaluate the user benefits of highway improvements. These products extend, update, and replace AASHTO’s 1977 Redbook (which analyzed both highway and transit improvements) and bring up to date both the theoretical and empirical bases of highway improvement evaluations. The findings of a separate project, sponsored by the Transit Cooperative Research Program (TCRP), are available in TCRP Report 78: Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners.

The enclosed CD-ROM contains an electronic copy of this manual in Portable Document Format (PDF). It also contains (1) a computerized “wizard” that automates benefit-cost analysis for highways, (2) electronic calculation worksheets matching the worksheets in the manual, (3) presentation templates and materials, and (4) reference materials.

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Chapter 1. Overview

PREFACE: WHY USE THIS MANUAL?
Transportation planners and policy makers are charged with the responsibility of identifying and selecting the projects that deserve implementation. Often, there are competing project designs to serve the same purpose. The project-selection process is complicated further, in most cases, by limited budgets and a host of candidate projects that might benefit the community. In these situations, analytic tools are needed to evaluate the relative merits of each candidate project and ultimately provide a means for allocating resources to that set of projects that will maximize the total benefits. The purpose of this manual is to assist in this process by providing the tools necessary to evaluate the costs and benefits related to transportation improvement projects.

General Purpose
While there are many different types of benefits related to transportation improvements, this manual focuses on user benefits, or benefits that are enjoyed by travelers that are directly affected by a transportation improvement. User benefits are determined by travel costs in three distinct areas: travel time costs, operating costs, and accident costs. Taken together, the total of these costs is essentially the price that travelers must pay to travel. When a comparison is made between the costs of traveling and the number of trips taken at each price level, a relationship is determined between the cost of travel and the demand for trips. When all users are aggregated together, the difference between the travel "price" that travelers are required to pay and what they would have been willing to pay is the user benefit affiliated with the trip. Any reduction in travel costs (i.e., trip price), then, will result in a benefit to the traveler. For example, with a cost reduction, users who were already making the trip receive the benefit of making the same trip at a lower cost.

The focus on user benefits is critical, because most of the economic benefits of transportation projects come from the reduction in user costs. When trips in a particular corridor are perceived as costly, perhaps due to long travel times or high accident rates, travelers sacrifice taking some trips in that corridor, and the economic activity associated with those trips is lost. Reducing user costs makes the perceived cost of travel cheaper, and facilitates trip making and the accompanying economic activities. By balancing these accompanying user benefits against project costs, we can determine which projects will provide the optimal level of net benefits to society.

Obviously, a project will also impact people other than direct users of the facility. These effects are referred to as indirect benefits or non-user benefits. Examples of indirect benefits include environmental impacts, effects on urban growth, economic influences, and the distribution of costs and benefits attached with the project. While these issues are important and should be considered in the transportation decision framework, they are outside the scope of this manual.

The framework for estimating user benefits is relatively straightforward. User benefit estimation requires that each project being evaluated be compared against some alternative outcome. The alternative outcome could be a “Base Case” or “No-Build Scenario” that maintains current facility conditions into the future. The alternative
scenario could also be a different improvement project. In either case, to conduct the user benefit analysis, benefit levels are estimated for two different scenarios. The difference in user costs (that is, the combined effect on user benefits due to changes in travel costs, operating costs, and accident costs) is the impact to the users linked to the project. Since an improvement should result in a *reduction* in these costs, the difference in these cost levels is used to determine the total user benefit of the project.

**Complicating Issues**

The preceding discussion provides the simplest overview of determining the user benefits connected to the transportation projects. To summarize, this manual provides the tools needed to estimate benefits from changes in travel time costs, operating costs, and accident costs—the factors that directly affect travelers’ transportation choices.

Naturally, applying these principles to specific project applications is a much more complicated endeavor in the real world. Complicating issues that need to be addressed include:

- How do you measure the benefits of something that does not yet exist, especially when it interacts in a complicated way with other products or services?
- What do you do if some benefits or costs are not susceptible, at all, to measurements? What if the saving or loss of human life potentially is involved?
- What if the benefits and/or costs play out over a period of time? How should these delays be incorporated in the analysis?
- What if there is uncertainty about the measurements?
- What if many projects have positive net benefits, but budgets are limited? Which projects should be selected for implementation?
- How do you compare projects that have different types of benefits? For example, how do you compare the benefits of one project that improves travel time with another project that reduces accidents?

Economists have developed at least partial answer to each of the questions. Much of the challenge in applying benefit-cost analysis in the transportation arena, however, stems from the fact that providing good answers almost always requires specialized information and analysis techniques. This manual provides the analytical tools to help address these questions and allows for the estimation of user benefits for a range of different project types and conditions.

Specific complicating analysis factors are described briefly below. Methods for adapting the user benefit estimation techniques to address these issues are provided in subsequent chapters of this manual.

**Different Project Objectives.** Some projects, such as the addition of lanes to urban or rural highways, have the objective of improving traffic flows. Those that include installing stop signs or traffic signals at rural intersections have the goal of improving safety and saving lives. Still other maintenance projects, whose purpose is to avoid degradation of the facility and prevent increases in vehicle operating costs, repair or remediation costs, and traveler delays. Although the objectives and types of benefits of
these projects are different, they can all be cast in benefit-cost terms and evaluated using the procedures in this manual.

**Different Road Types.** The same improvement type will have different effects on user benefits depending on the type of road being evaluated. A project that widens a lane, for example, is designed to improve travel times and will have a predictable effect on travel behavior. The magnitude of this effect, however, will depend on a variety of different factors, including whether or not the lane widening occurs on a freeway or an urban street. This manual provides guidance on how to measure the impact of specific improvement types across different street and highway types.

**Units of Measure.** The elements of user benefits are quantified using different units of measurement, and must be converted to a common, monetary unit of measurement so that they can be compared with project costs. Travel time, for example, is measured in minutes while operating costs are measured in dollars and accident costs might be reported as the number of accidents. This manual provides the methods for converting each of these benefit components into a common dollar value so they can be aggregated across years, users, and vehicle classes. This conversion also allows for user benefit comparisons across different projects, as the benefits estimated for each project are expressed in common dollar values.

**Data Needs.** The calculation of user benefits requires a significant amount of information on costs that is specific to the facility and project being evaluated. That is, information is needed for each of the user cost components: travel times, operating costs, and accident costs. In addition, cost data are needed for both the Base Case scenario and for the scenario where the project is built. Total costs in each of these categories are often estimated as a function of traffic volumes estimated over the life of a project for each of the project scenarios. This manual provides information on where these data can be found and the level of detail needed to estimate user benefits.

**Incomplete Data.** In practical applications, an analyst is often faced with the problem of missing or incomplete data. For example, the total user benefits associated with a project will be determined in part by the amount of use the facility gets with and without the project being built. This is often determined using traffic volume estimates obtained from a traffic demand model. In some cases, only limited information is available, such as an average annual volume or traffic volumes for a single peak traffic hour or a peak traffic day. This manual shows how this information can be extrapolated to estimate annual traffic volumes, taking into account daily and seasonal fluctuations in travel volumes.

**Discounting Costs and Benefits Over Time.** Methods for expressing all user benefits in a single dollar value that can be compared across different project types are also provided in this manual. The pattern of costs and benefits over a project’s life varies from one project to another, even for alternative projects that are designed to perform the same purpose. For example, improvements projects generally have large capital or investment costs that occur at the start of the project. Operating and maintenance costs are incurred after the construction phase and continue throughout the life of the project. Similarly, benefits of the project accrue to users each year and may increase annually with growth in population and travel demand. This manual shows how these annual variations in multiyear projects can be accommodated so that fair comparisons can be made across
projects with different timing of costs and benefits. The procedure is known as the calculation of _present discounted value_ of costs and benefits. Discounting procedures allow all project values to be converted to a single dollar value in present value terms, which allows for comparisons across projects.

As this suggests, the estimated user benefits of a project will depend on the methods used to discount future costs and benefits. This manual provides a detailed discussion of the appropriate techniques and discount rates to use for transportation projects for converting benefits to present value terms.

*Risk and Uncertainty.* Even with the best data, there will be some uncertainty in the estimates of user benefits. Analysis inputs such as traffic volumes, for example, need to be estimated for each year over the life of the project and even the best estimates will still be subject to error. This manual provides tools for adjusting benefit estimates for risk and uncertainty related to future outcomes.

The remainder of this manual expands on this discussion of user benefit analysis. The first part of the manual expands the discussion of the basic economic concepts underlying the user benefit calculations. Following this is a discussion of how the user benefit analysis should be applied to specific improvement types. Additional detail is provided in the following sections and worksheets accompanying this manual regarding the calculation of travel time costs, operating costs, and accident costs.
INTRODUCTION

This manual presents a comprehensive methodology for evaluating the user benefits from highway improvements. Highway improvements generate user benefits if they reduce the users’ travel time, operating costs, or the user cost of accidents. These user benefits then can be compared with the cost of developing and operating the highway improvement to determine the basic, economic feasibility of the proposed improvement.

In this manual, the broad types of highway improvements considered include:

- Development of new roads.
- Operational improvements to existing roads.
- Safety improvements to existing roadways.
- Highway project-management activities.

The manual updates, extends, and replaces the 1977 AASHTO report, *User Benefit Analysis for Highway and Bus Transit Improvements*, known colloquially as the Red Book. Unlike the earlier Red Book, however, this manual does not provide a methodology for evaluating user benefits from transit improvements. This methodology is now provided in the Transit Cooperative Research Program (TCRP) manual, *Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners*. Where appropriate, however, this manual does identify those portions of the methodology that should be coordinated with transit user benefit analysis.

There is a second, important difference between this manual and its previous edition. The Red Book was written in two parts. One part presented research findings concerning concepts and parameters relevant to user benefit analysis. The second part presented the manual of procedures for implementing user benefit analysis. In contrast, the current manual subsumes the research discussion into the manual itself. The basic methodology is laid out in an initial part of the manual. However, the theoretical and empirical motivation for the other elements of the manual are presented in context, so that the reader can make judgments about the proper procedures and parameters as the need to do so arises.

The emphasis in the manual on user benefits is strictly enforced. The methodology in the manual does not include procedures for evaluating any indirect or induced economic effects of the highway improvement. Hence, the reader will be directed elsewhere for evaluation of such factors as:

- Economic development or employment impacts.
- Environmental impacts.
- Cost impacts on institutions that provide ancillary services to highways, such as the court system, hospitals, public safety agencies, surface water management agencies, etc.

Impacts in each of these areas are deserving of consideration when evaluating highway improvements, but involve complex and specific conditions that do not lend themselves to being characterized usefully in a manual. In addition, in some cases the science for
accounting for these impacts is only now developing or contested, making it difficult for definitive procedures to be offered in a manual.

The omission of these other impacts from the manual does not handicap seriously benefit-cost analysis of highway improvements in the United States, or other, highly developed economies. Although non-user impacts may affect the desirability of proceeding with a given project, such factors less often influence the ranking of similar, alternative projects. In highly developed areas, the user benefit evaluation typically dominates these other impacts because of the high values of time and human life involved. In addition, the environmental and public finance influences of a roadway project are often constrained by other regulations or mitigation policies. User benefit analysis even by itself, therefore, is very helpful in the development of state and local transportation improvement plans which, once developed, can then be subject to more extended or qualitative considerations. Finally, the user benefit analysis provides a framework on which these other, more contentious considerations can be hung. The technical information developed in the course of evaluating user benefits is helpful input to other investigations.

In summary, the methodology presented in this manual addresses a substantial portion—but not all—of the economic evaluation issues that are encountered in evaluating highway projects. Figure 1-1 illustrates the relationship between the user benefit analysis emphasized in the manual and the other areas of investigation that may be pursued. The figure also hints at the kind of technical information or parameters from the user benefit analysis that can be used to assist the ancillary analyses. Items below the dashed line in Figure 1-1 are outside the scope of this manual.
Figure 1-1: Relationship of User Benefit Analysis with Other Analysis Areas

- **Economic Conditions**
  - Costs and Values
  - User Benefit Analysis:
    - Travel Time
    - Operating Costs
    - Accident Costs
  - Basic Economic Feasibility:
    - Accounting of user benefits and operating costs over the project life

- **Travel Demand Forecasts**
  - Traffic Volumes
  - Capital and Operating Costs
  - Facility Physical and Performance Characteristics
  - External Impact Analysis:
    - Net benefits associated with economic development, environmental, and other non-user impacts

- **System and Facility Design Processes**
  - Ambient Environmental Conditions
  - Institutional Arrangements

- **External Impact Analysis**
  - Comprehensive Economic Feasibility:
    - Accounting of user and non-user benefits and costs
THE WORKFLOW STRUCTURE OF THIS MANUAL

This manual has been written with a workflow orientation. That is, it is arranged so that the information needed to evaluate a project is developed in an orderly and natural manner. This is achieved by first organizing the analysis by highway type, project type, and improvement type. Then, for each improvement type, there are analysis modules that lead the reader through procedures specific to the characteristics of the improvement. The aim is to generate information in a modular form that can easily be joined with other information later in the manual. Analysis of project management options and the final, economic analysis step are the two, overarching analyses that bring this modular information together.

This approach requires that the reader have clearly defined the project to be analyzed. The manual requires, even for sketch analysis, that the features of the project be carefully defined. The nature of the improvement is what influences the user benefit analysis. The manual is not designed to specify ideal projects, although iterative use of it can help refine and improve a project’s specifications.

The reader also is expected to know the base case against which the project’s virtues are being measured. As a practical matter, it is impossible to measure the total user benefits associated with something as complex as an entire highway system. It is possible, however, to measure accurately the impact of a change to that system, whether it be as significant a change as a brand new freeway, or as modest a change as an improvement in an intersection’s signalization timing.

Once the reader brings the project definition to the effort, the manual guides the reader through various categorization and analysis activities.

Highway, Project, and Improvement Types

The manual uses a taxonomy of highway, project, and improvement types to guide the reader to those analytical modules that are relevant for a particular project.

A highway type is the broad, functional class of road to which the improvements will be made. The highway types recognized in the manual are:

- Arterials, collectors and local streets.
- Two-lane highways.
- Multilane highways.
- Limited access freeways.

The highway type influences the improvement types that typically are involved in an improvement of that type of highway. For example, signalization improvements are not typically associated with limited access highways, except for metering of ramp traffic.

A project type is determined by the broad type of service enhancement that the project will be providing:

- Operational enhancements, and
- Safety enhancements.
The project type influences the dimensions of the analysis. Operational enhancements, for example, primarily improve the speed and comfort experienced by the users of the facility. Therefore, analysis of this project type involves considerations of time and operating costs savings. Safety enhancements, on the other hand, primarily affect the accident rate and, consequently, the morbidity, mortality, and property damage common to road usage. Generally, there are different improvement types associated with each of these project types.

Indeed, operational and safety enhancements also, in some cases, have countervailing effects on the analysis. For example, an operational enhancement that speeds up traffic flow may have the effect of increasing the accident rate under some circumstances. Conversely, some safety enhancements, such as signalization and signing, may reduce the effective capacity of a road, and degrade travel times and operating costs. In order to properly incorporate both effects, the analyses must interact accordingly. This is best done by identifying a project’s service enhancement type.

The improvement type defines the project activity at a level that directs the reader to the appropriate analysis module. For operational improvements, the major improvement types are:

- Additional lanes. This is the conventional method of adding capacity, and can take various forms.
- A new road or highway, i.e., the addition of a link in the road network that did not previously exist.
- A new traffic control device or system. Signals, signs, ramp metering and roundabouts can be added to existing roads, or incorporated in new roads to enhance effective capacity.
- Signal control systems. Existing signalization systems can be enhanced to change timing and coordination of traffic flows.
- Intelligent Transportation System (ITS) improvements. These are improvements that allow the road or the user to respond to changing conditions on the road. ITS improvements include such things as variable or incident signage, incident management, and on-board navigation aids.
- Pricing and regulatory policies. Congestion pricing and designation of lanes as high occupancy toll (HOT) or high occupancy vehicle (HOV) lanes are changes in policies that can affect the performance of a road or a corridor.

Within each of these improvement types, there can be several analysis modules to choose from. For example, a roundabout and a signalization system are two, very different types of traffic control devices for optimizing intersection capacity. There are separate analysis modules for each of these. As indicated in Figure 1-2, the modular analysis process yields the parameters for the evaluation of the project.
Figure 1-2: The Workflow Path from Project to Evaluation Parameters

- Economic Conditions
- Project Attributes

Planning Process:
- Identify Highway Type
- Arterial
- 2-Lane Highway
- Multilane Highway
- Limited Access Freeway

Identify Highway Type:
- Improve Operation
- Identify Project/Improvement Type

Select, Use Analysis Module:
- New Road
- Additional Lanes
- Traffic Control
- Signal Control
- ITS System
- Price and Regulatory

Parameters for Evaluation:
- New Corridor Capacity
- New Link Capacity
- Ramp Metering
- Signal Timing
- Incident Mgmt
- Value Pricing

To Evaluation
Project Management Options

There are two, overarching levels of analysis in this manual—i.e., analyses that may apply to a project regardless of its highway, project, or improvement type. The first of these is the analysis of project management options.

Although the engineering specifications of a highway project generally determine its performance potential, the extent to which that potential is realized in the most cost-effective manner depends on how the project is managed. Project management affects the economic feasibility of a project because it influences project cost, the pace at which the improvements become available, and the impact that construction activities have on existing traffic, and so on. In this sense, project management assumptions affect the parameters of the economic feasibility analysis.

Several project management options can be analyzed using this manual:

- Lane rental. Lane rental is a contractor-incentive technique whereby contractors must pay to close lanes while they undertake roadway improvements. Analysis of this option allows planners to determine the tradeoff between speedier completion and higher project cost.

- Performance contracting. A more general technique than lane rental, performance contracting involves providing financial incentives (and, thereby, raising upfront construction costs) for speedier project completion (which, effectively, increases the value of the improvement to users).

- Public-private partnering. Public agencies that are cash-flow constrained can get beneficial projects built by partnering with private entities; thereby augmenting public funds with private funds. Whether or not such partnering makes sense depends upon the economic value of the improvements and the cost of private funds. Partnering also requires that the private partners have a means of collecting revenues from users upon completion, and thus may require modifying the project characteristics to include a tolling policy, or the analysis of value-capture tax policies.

- A+B bidding. This is one of several incentive/disincentive contracting methods that provide contractors with incentives to complete projects on time and on budget. Under A+B bidding, the bid is evaluated based on both the expected capital costs (A) and the number of days (B) the construction period is expected to last.

The project management evaluation step, and its relationship to the analysis modules and the economic analysis are shown in Figure 1-3.

Economic Analysis

The second overarching level of analysis, the economic analysis step, is the final, synthesizing step; it aggregates and processes the data developed in the various, analysis modules. It makes the determination of the extent to which the proposed project is economically feasible. A project is economically feasible if the value of its user benefits exceeds project costs, properly measured and with recognition of the fact that benefits or
costs in the future have a lower present value than benefits or costs nearer in time to the analysis date.

Hence, the goal of the economic analysis is to determine if the present discounted value of user benefits exceeds the present discounted value of project capital and operating costs. Conceptually, this is a simple arithmetic exercise. In order to do this in an orderly manner, however, the following elements of the analysis must be in place:

- Information from the various improvement analysis modules must be in a correct and consistent form for aggregation.
- Appropriate assumptions must be made about the project’s anticipated life, the appropriate discount and inflation rates, and the values to apply to time, human life, operating costs, and other key cost and benefit factors.
- The pattern of benefits and spending over time must be specified. Methods of interpolating or extrapolating available information must be provided if the analysis done in the improvement modules was not performed for every year of the project’s anticipated life.

The economic analysis step provides calculations of benefit-cost measures that are useful both for deciding whether a project should proceed or not, and for ranking the project relative to other, available alternatives. In practice, the benefit-cost indicators generated by using this manual need not be the final word on a project’s feasibility. The results of the economic analysis can be used to refine a project’s design, timing, or management. In addition, as indicated earlier, the user benefit analysis may be incorporated in a more comprehensive evaluation system.

A GUIDE TO THE CHAPTERS OF THE MANUAL
The manual has the following chapters:

Chapter 1 provides an introduction to the manual. It discusses the purpose and scope of the manual, and introduces the workflow orientation of manual. It also provides a glossary of terms and this summary.

Chapter 2 presents the basic concepts and methods used in measuring user benefits. It discusses in detail the requirements of a properly defined project and its base case, and guides the reader through the first steps of the workflow process. The activity in Chapter 2 establishes pointers to the next workflow elements, i.e., the relevant analysis modules and the project management analysis.

Chapter 3 contains the analysis modules for operational improvements. The modules accommodate new roads, as well as traffic controls and signal systems. The reader is guided to this chapter by the project classification adopted in Chapter 2. This section also provides pointers to appropriate portions of Chapters 4, 5, and 6 of the manual.

Chapter 4 contains the analysis modules for safety improvements. The reader is guided to this chapter by the project classification adopted in Chapter 2 and/or the analysis modules in Chapter 3. This section provides pointers to Chapter 3, as appropriate, and Chapters 5 and 6 of the manual.
Chapter 5 provides modules for analyzing the effects of various project management options. The results of this analysis influences the nature of the economic feasibility analysis performed in Chapter 6.

Chapter 6 contains the procedures for performing the final, economic feasibility analysis. The reader is asked to provide key behavioral and financial parameters at this point in the analysis. The reader is also instructed about the motivation and procedures for performing sensitivity analysis.
GLOSSARY OF TERMS

Use of this manual involves careful specification and calculation of economic and engineering relationships as well as some of the most commonly used functional classification for streets and highways. A consistent terminology helps keep these various relationships clear in the reader’s mind.

Much of the terminology used in the past Red Book remains in common, professional use. In the 25 years since the Red Book was last updated, however, new procedures and relationships have been introduced. As a consequence, this glossary is an amalgam of terminology from earlier editions of the Red Book as well as from new research and practice.

Arterial. Signalized streets that serve primarily through traffic and provide access to abutting properties as a secondary function, having signal spacings of 3 km or less.

Average Annual Daily Traffic. The total yearly volume divided by the number of days in the year, commonly abbreviated as AADT. Unless otherwise specified, the terms AADT and ADT (average daily traffic estimated without reference to a year’s traffic) will be used synonymously.

Bus. A self-propelled, rubber-tired road vehicle designed to carry a substantial number of passengers (at least 16, various legal definitions may differ slightly as to minimum capacity), commonly operated on streets and highways. Smaller capacity road transit vehicles, often without full headroom, are termed vans. This manual does not provide procedures for evaluating transit investments, per se. However, the influence of bus transit vehicles on traffic flow and the time- and operating-cost savings associated with bus transit must be accommodated in highway project evaluations.

Capacity. The Highway Capacity Manual (HCM 2000) defines capacity as the maximum number of vehicles that have a reasonable expectation of passing over a given section of a lane or a roadway in one direction (or in both directions for a two-lane or a three-lane highway) during a given time period under prevailing roadway and traffic conditions. In the absence of a time modifier, capacity is an hourly volume.

Capital Cost. The total investment required to prepare a highway improvement for service, including engineering design and supervision, right-of-way acquisition, construction, signals and signs, and landscaping.

Centerline Mile. A measure of highway length that counts each mile of a facility regardless of the number of separate lanes. Contrasts with Lane Mile.

Collector. Surface street providing land access and traffic circulation within residential, commercial, and industrial areas.

Congestion. A traffic condition involving interactions of vehicles that results in reduction in speed below the design speed.

Congestion Pricing. A policy of charging for a vehicle’s impact on other vehicles’ delay.

Design Speed. A speed selected for purposes of design and correlation of those features of a highway, such as curvature, superelevation, and sight distance, on which the safe operation of vehicle depends.
Depreciation, also Economic Depreciation. The gradual loss of productive capacity of a piece of capital equipment. Depreciation occurs both as the result of the passage of time, through obsolescence, and as the result of wear-and-tear from use. The term refers to real or economic depreciation, in contrast to tax or accounting depreciation which is an arbitrary proration of capital expenses over time.

Depreciation Rate. The percentage loss in productive capacity per unit time. Typically expressed as a percent per year.

Discount Rate. A percentage figure representing the opportunity cost of capital for an investment, used for converting periodic costs and benefits for a project to present value or to equivalent annual cost.

Equivalent Annual Cost. A uniform annual cost that is equivalent to all disbursements or costs over the analysis period. The present value of equivalent annual cost equals the present value of all such disbursements.

Expressway. See Freeway.

Fixed Cost. A cost that does not vary with activity level or use, but cannot be avoided without abandonment of the facility. Administrative spending is often a fixed cost.

Free Flow. Traffic flow which is unaffected by upstream or downstream conditions. Free-flow speed is the speed expected under free flow conditions.

Freeway. Freeways and expressways are multilane divided highways having a minimum of two lanes for exclusive use of traffic in each direction and full control of access without traffic interruption.

High Occupancy Vehicle. A vehicle that is operated with high passenger occupancies. Variably defined to include carpool vehicles, vans and transit buses.

High Occupancy Vehicle Lane (HOV lane). A lane that is restricted to use by vehicles with high occupancies.

High Occupancy Toll Lane (HOT lane). A lane that is restricted to use by vehicles that have high occupancies or pay tolls.

Hypercongestion. A traffic condition wherein speed is lower at the given volume than is observed, at the same volume, under other conditions.

Incremental Cost. The net change in dollar costs directly attributable to a given decision or proposal compared with some other alternative, including the existing situation or “do-nothing” alternative. This definition includes any resulting cost reductions (negative costs, or benefits). The only costs that are relevant to a given proposal are incremental future costs, in contrast to sunk costs of the past.

Inflation Rate. The percentage change in the unit value of an element of costs or benefits. Generally expressed as an annual average rate.

K Factor. A factor that that relates peak-hour travel to average annual daily traffic (AADT). K is the percentage of AADT represented by two-way traffic volume in the peak hour. Values for K tend to decrease as traffic volume approaches capacity and some peak-hour travel spreads into adjacent “shoulder” hours.
**Lane Mile.** A measure of highway length that counts each mile of each lane. Contrasts with Centerline Mile.

**Long Run.** A perspective on cost analysis that assumes flexibility in the capacity of a system like a highway system. In the Long Run, all costs are variable.

**Levelized Cost.** See Equivalent Annual Cost.

**Level of Service (LOS).** A qualitative measure of the freedom of a flow of traffic from constraints, interruptions, or other inconveniences, relative to the best possible conditions for a given type of highway facility.

**Maintenance Cost.** A subset of Operating Cost relating to keeping a highway and its appurtenances in serviceable condition.

**Motor Vehicle Running Cost.** The mileage-dependent cost of running automobiles, trucks, and other motor vehicles on the highway, including the cost of fuel, tires, engine oil, maintenance, and the value of vehicle wear-and-tear.

**Multilane Highways.** Roads with four or more lanes, without significant access control features and with low enough adjacent development to permit speed limits of greater than 40 mph and signalization (signals or stop signs) with average spacings of more than one mile.

**Occupancy Rate.** The number of occupants of a vehicle, expressed as persons per vehicle.

**Operating Cost.** The ongoing costs of maintaining and otherwise keeping a road in service. Operating costs include such things as road surface repair, traffic control and lighting expenses, snow removal, cleaning of debris from shoulders, maintenance and replacement of landscaping, restriping, on-going toll collection costs, etc.

**Operating Speed.** The highest, overall safe speed at which a driver can travel on a given highway under favorable weather conditions and under prevailing traffic conditions. (Most HCM 2000 tables and charts give operating speed, but average running speed is more desirable for estimating road user travel time and costs.)

**Out-of-Pocket Cost.** The incremental cash costs associated with travel.

**Ownership Cost.** The cost associated with owning, in contrast to operating, a vehicle. Leasing costs, depreciation, insurance premia, and registration fees are examples of ownership costs.

**Passenger Car.** A motor vehicle with seating capacity up to nine persons, including for capacity and economy study purposes taxicabs, station wagons, and the two-axle, four-tired pickups, panels, and light trucks.

**Passenger Car Equivalent (PCE).** The ratio of a vehicle’s influence on a traffic stream to that of a typical passenger automobile. Expressing traffic volumes in terms of PCEs permits analysis of mixed traffic streams.

**Peak Period.** The hours of the day during which traffic volumes are heaviest on a highway. The length of the Peak Period is variably defined, but by definition, the Peak Period incorporates the Peak Hour. **Contrasts** with Shoulder Period and Off-Peak Period.
**Perceived Cost.** The subset of costs that are perceived by the user, and to which the user reacts. User costs can exceed perceived user costs.

**Preservation.** A road improvement activity involving significant renovation of the existing roadway without adding to the road’s effective capacity.

**Project.** Any relatively independent component of a proposed highway improvement. By this definition, independent links of a large improvement proposal can be evaluated separately. For a given transportation improvement, all individual contracts or work orders such as grading and draining, pavement, signs, and landscaping can be considered as a single project. Where alternative construction improvements are being considered, separate projects can be defined. However, highly interdependent sections of a highway improvement (such as a bridge and its approach roads) ordinarily should be considered as one project for economy study purposes.

**Project Management.** Activities relating to the manner in which a project of given specifications is implemented. Staging, financing, ownership and operation authority are examples of aspects of Project Management.

**Present Value (PV).** Also termed "Present Worth," it is the present amount that is equivalent to specified amounts of money or time in different time periods, at a given discount rate. Two related considerations underlie the need for computing PV: (1) the fact that money has a time value of capital cost, due to its productiveness and scarcity (see the definition of discount rate), and (2) the need in an economy study for comparing or summing outlays or savings of money or time in different time periods.

**Project Alternatives** are any variations to the basic project plan that (1) involve significantly different costs, (2) result in significantly different levels of service or demand, or (3) incorporate different route locations or other distinctive design features.

**Public-Private Partnerships.** Legal relationships among public and private entities established for the purpose of jointly providing design, build or operating services (or some combination).

**Ramp.** A short segment of roadway serving as a connection between two traffic facilities; usually services flow in one direction only.

**Rehabilitation.** Rebuilding or restoring an existing facility that is under disrepair or not up to standards.

**Residual or Salvage Value.** The value of an investment or capital outlay remaining at the end of the study period.

**Roundabout.** An intersection design that accommodates two or more intersecting roads and permits vehicles to pass through the intersection without signalization or stopping.

**Running Speed.** The speed over a specified section of highway, being the distance divided by the running time (the time the vehicle is in motion). Average running speed is the same as average speed if there are no stops; otherwise it is higher. For the purposes of this manual, the terms average midblock speed or intersection approach speed are used to denote average running speed in analyzing signalized arterials.
Short Run. A perspective on cost analysis that takes as given the capacity of a system like the highway system. Only the utilization of the fixed facility is variable in the Short Run. Contrasts with Long-Run.

Shoulder Period. The hours of the day which are not the Peak Period, but are adjacent to it in time. Variably defined. Contrasts with Peak Period and Off-Peak Period.

Sketch Planning. Sketch planning is a method for developing general estimates of user costs and benefits when more detailed data are not available. For example, sketch planning might rely on annual traffic volumes and simple demand relationships to estimate user benefits when peak hour data and detailed traffic model output are not available. The spreadsheet tool SPASM has been developed for sketch planning analysis.

Social Surplus. Social surplus is analogous to consumer surplus and reflects the total benefit to society resulting from a highway improvement. It is the sum of the individual consumer surplus measures for all persons that will be affected by the project.

Speed. Average Speed (or average overall traffic speed). The summation of distances traveled by all vehicles or a specified class of vehicles over a given section of highway during a specified period of time, divided by the summation of overall travel times.

Study Period (or Analysis Period). The time period over which the stream of benefits and costs is to be evaluated. The final year of construction is designated year 0 (zero), and subsequent years are designated year 1, year 2, etc. Projects involving staged construction that extends over more than four or five years should either be divided into separate projects for the separable stages, or use the final year of construction for the first major stage as year 0, with prior capital outlays being discounted to their present value in year 0.

Taxicab. A passenger automobile that is operated by a professional driver. To account an improvement’s benefit to taxicab traffic, the value of operator and passenger time need to be considered.

Transit Vehicle Operating Cost. The cost incurred for operating a bus on a highway facility. Such operating costs include (a) the cost of the drivers' wages and fringe benefits; (b) the cost of vehicle operation, including tires, fuel and lubricants; (c) the cost of bus maintenance, including labor and parts; (d) costs of insurance, and managerial and administrative labor; and (e) the costs of vehicle rental or depreciation.

Travel Time. The time spent by users traversing a roadway or road network. Conventionally, travel time is expressed in minutes.

Truck. A heavy vehicle engaged primarily in the transport of goods and materials or in the delivery of services other than public transportation.

Two-Lane Highways. Roads with two lanes, speed limits generally greater than 40 mph in both directions, and average signal spacing more than one mile. They may have varying degrees of access control.

User Benefits. The advantages, privileges, or cost reductions that accrue to highway drivers or owners and/or to highway transit users through the use of one highway facility as compared with the use of another. Benefits are generally measured in terms of a decrease in user costs.
**User Cost.** The costs of travel that are borne by individual users. Highway user costs are the sum of motor vehicle running cost, the value of travel time, and traffic accident cost. Bus transit user costs on a particular highway segment are the fares, the value of travel time, and traffic accident costs.

**User Fee or User Charge.** A fee charged users for their use of a highway. A Toll is a way of implementing a User Charge.

**Value of Time.** The opportunity value attributed to one hour of a user’s time. This value is different for different types of users and/or trip purposes. It is conventionally expressed in dollars per hour.

**Value Pricing.** The practice of charging for access to a lane or facility in return for shorter or more reliable travel times. Congestion Pricing is a form of value pricing.

**Variable Cost.** A cost is variable if it changes with the activity level, such as the number of vehicles, speed, occupancy, etc. Contrasts with the term Fixed Cost.

**Variable Pricing.** A policy of charging different prices for use of a road at different times or under different conditions. Congestion Pricing is a form of Variable Pricing.

**Volume, or Traffic Volume.** The number of vehicles that use a highway lane or facility. Typically expressed in vehicles or PCEs per hour.

**Volume-Capacity Ratio.** The ratio of traffic volume to road capacity. Both volume and capacity are expressed in PCE terms.

**Volume-Delay Function.** A mathematical equation that expresses the relationship among traffic volumes, capacity, and the time required to travel one mile. Different volume-delay functions are attributed to different types of roads.
Chapter 2. Concepts and Basic Methodologies

User benefit analysis of highways is a straightforward analytical process. Most of the complexity arises with implementing these concepts in a practical application, not with the underlying concepts. Nevertheless, implementation of any project is easier with a good understanding of the concepts and basic methodologies, and their theoretical rationale.

This chapter introduces the basic concepts and methodologies. For users eager to begin a simple application, it also contains a section called the QuickGuide. The QuickGuide also serves as a way to orient the user to the basic steps of more complicated applications.

A CD-ROM analysis tool has also been developed with this manual to assist users in the user benefit calculations.

BASIC CONCEPTS

The basic aim of user benefit analysis is to balance consideration of user benefits against costs that must be incurred to deliver those benefits to users. Fundamentally, therefore, user benefit analysis for highways is an application of benefit-cost analysis. Most of the basic concepts and methodologies of user benefit analysis, therefore, are simply specialized adaptations of benefit-cost concepts and methods.

Regardless of the specifics of a particular project, or the precise methodologies used in the evaluation, certain basic concepts pervade highway user benefit analysis.

The Economic Basis of Highway User Benefit Analysis

User benefit analysis is fundamentally an economic analysis process, rather than an engineering issue. Engineering expertise is necessary to design remedies to traffic problems. But the availability of an engineering solution is not, by itself, sufficient to justify taking action. The improvement project must be justified economically, because it will use resources that have value in other pursuits in the economy.

The dilemma of evaluating which projects deserve implementation is neither new nor confined to the public sector, let alone the transportation sector. Even Benjamin Franklin employed what he called “prudential algebra” to organize his thinking about the pros and cons of alternative business opportunities. But early thinkers had only the most rudimentary understanding of how to implement benefit-cost analysis and they were stymied by how to make decisions when some people were made better off, and some worse off, by a decision.

In the 1930s, two economists offered the useful prescription that a project was worth doing if its benefits exceeded its costs, and the winners could (at least conceptually) compensate the losers (Kaldor 1939) (Hicks 1940). This principle, called the Kaldor-Hicks principle after its authors, has evolved over time into the formal field of benefit-cost analysis. Benefit-cost analysis is very simple, in principle—simply estimate the costs and estimate the benefits of each candidate project. Those projects for which benefits exceed costs, in the Kaldor-Hicks sense, are worth doing, and those that do not, are not.
Conceptual simplicity quickly gives way to technical complexity; however, when one attempts to practice cost-benefit analysis in the real world consider these scenarios:

- How do you measure the benefits of something that doesn’t yet exist, especially when it is a project that interacts in a complex way with other parts of the road network?
- What if the benefits and/or costs play out over a period of time? How should these delays be incorporated in the analysis?
- What if there is uncertainty about the measurements or risk in bringing the project successfully to fruition?
- What if many projects have positive net benefits, but budgets are limited? Which projects should be selected for implementation?
- What if a project has negative net benefits, but is particularly effective at helping a targeted or protected class of user (such as the poor)?

Economists have developed answers to most of these questions. Much of the challenge in applying benefit-cost analysis in the transportation arena, however, arises from the fact that providing good answers in almost all cases requires specialized information and analysis techniques.

**A QUICKGUIDE TO USER BENEFIT ANALYSIS**

Before getting into the details of user benefit analysis, it is worthwhile to provide a quick overview of user benefit analysis. Hopefully, this *QuickGuide* will help orient the analyst to the various, analytical steps that need to be performed, and find the resources to do so. This *QuickGuide* is not intended to be a substitute for reading certain portions of the manual in detail, but may help to clarify what unfortunately is, in practice, a very complex and laborious computation process.

**The Basic Steps of the Process**

There are eleven basic steps in user benefit analysis. The *QuickGuide* Table summarizes these steps, with references to the places in the manual where the analyst can get more information. The analytical concepts underlying these eleven steps are discussed in general terms in the remainder of this chapter.
QuickGuide Table to the Basic Steps of User Benefit Analysis

<table>
<thead>
<tr>
<th>Step</th>
<th>The Types of Information Needed</th>
<th>Go Here for More Information</th>
</tr>
</thead>
</table>
| 1    | Define the **Project Alternative** and the **Base Case** | 1. The network elements affected  
   2. Engineering characteristics  
   3. Project build-out schedule  
   4. Project capital cost schedule  
   5. Project operating cost schedule | Chapter 2 (this chapter) |
| 2    | Determine the level of detail required | 1. Vehicle classes to be studied  
   2. Types of benefits and costs  
   3. Hourly/daily/seasonal detail  
   4. Link vs. corridor perspective  
   5. Periods to model explicitly | Chapter 3  
Chapter 4 |
| 3    | Develop basic user cost factors | 1. Value(s) of time  
   2. Vehicle occupancy rate(s)  
   3. Vehicle unit operating costs  
   4. Accident rate and cost parameters | Chapter 3  
Chapter 4  
Chapter 5 |
| 4    | Select economic factors | 1. Discount rate  
   2. Analysis period  
   3. Evaluation date  
   4. Inflation rate(s)  
   5. Value of life, morbidity | Chapter 5  
Chapter 6 |
| 5    | Obtain traffic performance data (for **Project Alternative** and **Base Case**) for explicitly-modeled periods | 1. Volumes, speeds/travel times, occupancy, before and after improvement  
   2. Usually requires travel demand and traffic assignment model(s) | Not covered in this manual  
See **Highway Capacity Manual** for guidance. |
| 6    | Measure user costs (for **Project Alternative** and **Base Case**) for affected link(s) or corridor(s) | 1. Hourly/daily/seasonal traffic volumes  
   2. Link/corridor travel time costs  
   3. Vehicle operating costs  
   4. Intersection delay costs  
   5. Accident costs  
   6. Factors in Steps 3 and 4 | Chapter 3  
Chapter 4  
Chapter 5 |
| 7    | Calculate user benefits | 1. Data from Step 5  
   2. User benefit formula | Chapter 5 |
| 8    | Extrapolate/interpolate benefits to all project years (unless all time periods are explicitly modeled) | 1. Traffic growth rate factors  
   2. Volume-delay function factors  
   3. Peak-spreading assumptions | Chapter 6 |
| 9    | Estimate terminal value | 1. Assumptions about facility life  
   2. Assumptions about salvage opportunities | Chapter 6 |
| 10   | Determine present value of benefits, costs | 1. Data from Steps 1, 4, 7, and 8  
   2. Analysis of project management alternatives | Chapter 6 |
| 11   | Make project selection decision | 1. Data from Step 9  
   2. Data from other project alternatives  
   3. Budget constraint conditions | Chapter 6 |
Step 1: Defining the Project Alternative and the Base Case
The first step in the process is to define the Project Alternative and the Base Case against which the project improvements are to be measured. As detailed elsewhere in this chapter, this first step is a crucial one because it identifies clearly exactly what improvement to the road system is being evaluated. Analysts must think carefully about what portion of the total road system is being affected by the project, because they will need to perform calculations on all of the affected road system links or corridors.

Step 2: Determine Level of Detail Needed
The second step is to determine the level of analytical detail that is required. This will vary significantly from one type of project to another. In some cases, a project involves making a simple improvement to a facility that has a very homogenous traffic stream (all passenger cars, for example), in a corridor that has very little daily or seasonal variation in traffic, low accident rates, etc. In such a case, detailed analysis by vehicle class, hour of the day, season, etc. is not required. But for many projects, the analyst will face a mix of traffic (with different values of time), and sharp diurnal, seasonal, or other variations in traffic volumes and composition. The number of calculations that must be made, of course, increases exponentially with the number of dimensions of detail that must be accommodated. The analyst is well-advised to start first with simple representations of the Project Alternative and Base Case, and only add complexity if it aids measurably in the project feasibility analysis.

Step 3: Develop Basic User Cost Factors
The third step is to develop basic user cost factors, such as the value of time and vehicle occupancy rates (to use in evaluating travel time savings), and vehicle operating cost parameters to evaluate operational savings. The value of time is related to the wage rate prevailing among the users of the facility, and the vehicle operating costs relate to the type of the vehicles involved. Accident rates can vary considerably depending upon the engineering characteristics of the Project Alternative and the Base Case. This manual provides detailed guidance on how to evaluate accident costs, but for projects with limited safety-improvement elements, it may be possible to ignore this element. Similarly, vehicle operating cost savings can sometimes be ignored in a first-pass analysis of a project because they tend to be minor relative to savings in travel time.

Step 4: Select Economic Factors
In the fourth step, the analyst must select economic factors or parameters, such as the discount rate, the analysis period, evaluation date, inflation rates, and the value of life and injury (morbidity) to be used in accident analysis. These are general parameters that should be used consistently within and across a portfolio of candidate projects. The discount rate incorporates the time value of money. This is generally the same for most of a road authority’s projects evaluated at a given time, unless there are differential risks involved in the various projects. The analysis period is simply the timespan that embraces all of the data that is to be considered (which may be longer than the project life, because it may include planning efforts, etc.). The evaluation date is the timeframe to which all of the calculations are to be brought; it is common practice to bring all project calculations to the present-day terms for comparability.
Step 5: Obtain Traffic Data
The fifth step, obtaining traffic performance data, is usually the most time-consuming part of project evaluation. It is in this step that the analyst must provide the traffic volume, speed/travel time, and other performance measurements for all of the affected road segments or corridors of both the Project Alternative and the Base Case. For road authorities that have well-developed network representations and travel demand modeling suites, the effort required to produce detailed information is much less than in the case where an analyst is making estimates by hand. Even with sophisticated models, however, considerable time, effort, and expense is involved in developing traffic performance data for even simple projects. This is especially true if the pattern of traffic is such that diurnal, seasonal and annual variation in these parameters anticipated over the life of the project. In most cases, analysts tend to perform detailed calculations explicitly only for a few project years, and interpolate and extrapolate to obtain traffic performance information for other years.

Step 6: Determine User Costs
Using the traffic performance data in the sixth step, the analyst develops user cost data. As shown in the QuickGuide Table, above, the user costs include travel delay costs, vehicle operation costs, and operation costs associated with specific projects. The cost factors themselves are developed in Step 3 and are combined in this step with specific information on the project alternative being analyzed. This is a relatively simple process once the traffic volumes, link travel time, intersection delay, operating cost and other factors are determined by, or derived from, the traffic performance data.

Step 7: Calculate User Benefits
This information is then used in the seventh step to calculate user benefits. That is, information from Step 5 is used to calculate the potential benefits of the project in terms of reductions in travel time costs, vehicle operation costs, and accident costs incurred by users of the project facility. The same, basic formula is used to make these calculations in virtually all project types. In this manual it is called the User Benefit Formula.

Step 8: Expand Benefits to All Project Years
It is common to not have access to detailed traffic simulations available for every time period. Consequently, it usually is necessary to extrapolate either the traffic performance data, or to extrapolate/interpolate the user benefits calculated in selected years to other years of the project’s life. Such extrapolation/interpolation exercises are performed in the eighth step of the typical project analysis. This manual, for the first time, provides guidance on direct extrapolation of benefits for projects whose primary effect is to increase roadway capacity. Unfortunately, for project with benefits that evolve in a complex way over time, however, the analysis will have no choice but to perform multiple travel demand and traffic assignment simulations. The analyst must be prepared for this eventuality and always obtain the most detailed data that is feasibly available.

Step 9: Estimate Terminal Value
The ninth step of the analysis is to determine the terminal value of the facility at the end of the project life period used in the analysis. This is simply a characterization of what
continuing net value (if any) the project provides at the end of its life, either through continued operation or through demolition and salvage. Since the terminal value (by definition) is something that is realized far in the future, it is often ignored in user benefit calculations because it is so heavily discounted in the present value arithmetic. In shorter lived, or large projects, however, the terminal value calculation can be important.

Step 10: Determine Present Value of Costs and Benefits
The purpose of the tenth step is to perform the present valuation of the stream of user benefits and capital and operating costs of the facility so as to reduce this complex stream to a single, tractable number. Typically the measure sought is net present value of benefits (i.e., benefits net of costs), and benefit-cost ratios.

Step 11: Make Project Selection Decision
Once Steps 1–10 have been completed, the analysts will have all the information needed on user benefits and project costs to evaluate the merits of different project alternatives. All that remains is the eleventh and final step, to make project selection decisions. These decisions are influenced by whether the agency faces budget constraints, regional allocation constraints, and other restrictions on the project selection process.

The Base Case vs. the Project Alternative
As the QuickGuide indicates, the first concept of user benefit analysis to master is the notion of the frame of reference of the analysis. Specifically, all benefit-cost analysis is conducted by comparing two situations: the situation without the project in place, and the situation with the project in place. The situation without the project is typically called the base case and the situation with the project is typically called the project alternative or the project scenario. If there are many project alternatives that are to be compared, they all must be compared, first, to the same base case. Pairwise comparisons of alternatives only establishes the relative, not absolute, viability of a project alternative.

The reason that user benefit analysis focuses on comparing two situations is, of course, a practical one: the new project cannot lay claim to all of the travel benefits that users already enjoy or will continue to enjoy even if the project is never implemented. The new project can only take credit for improvements to travel conditions, relative to the base case conditions.

As a practical matter, this comparative frame of reference for user benefit analysis also makes user benefit analysis feasible. It is much easier to model and measure changes from base case conditions than it is to model a project’s effects in a vacuum.

Defining the Base Case and the Project Alternative
The base case and the project alternative have to be clearly specified. One does not want to attribute to the project benefits that arise because of inconsistent definitions of the base case and the project. This is a very common problem in highway benefit-cost analysis. It is worth emphasizing the definition and use of the base case and the project alternative.

The Base Case
The base case should be an accurate characterization of what the world will be like if nothing is done to affect the future state of roadway system. This does not mean simply a
characterization of today’s conditions. On the contrary, constructing the relevant base case requires projection into the future of the conditions that will prevail under the base case scenario as well. In addition, it does not mean that there will be no improvements to the existing roadway system. The base case incorporates whatever improvements that will be in place beyond the project that is the subject of the analysis. The base case conditions need to be projected as far into the future as the project alternative is expected to have its effect; this way, when the two are compared, the analysis does not omit important streams of costs or benefits.

The Project Alternative

Careful definition of the project alternative is equally important. The project alternative is measured by the set of conditions that will prevail if the project is implemented. As in the base case, these conditions must be projected into the future, for as long as the project is expected to have effect.

Importantly, the project alternative must be defined in such a way that it includes all of the features and impacts that the project under evaluation is expected to engender. Depending upon which aspect of the activity is being evaluated, the project alternative can be broadly or narrowly defined.

By way of example, consider the case where a new lane is being built as a toll lane. There are two possible ways to define the project alternative in this case. The first way is to consider the act of building the new lane and tolling it as part of the same project. In this case, therefore, the project alternative would be measured against the base case of a world without the lane or the toll policy in place.

The second way to define the project is a pure, tolling policy evaluation. In this case, it is not the construction of the lane that is being evaluated, but rather the decision to add tolls to the new lane. The key presumption of this project setting is that the lane itself would be built anyway, and is, thus, part of the base case. The only policy question is whether or not to finance it with tolls. In this case, where only the toll policy is at issue, the project alternative is measured against a different base case—i.e., one where a new lane is in place, but is not tolled.

The definition of the project alternative and the appropriate base case, therefore, requires careful consideration of the policy decision that is actually being contemplated. In the example above, it would be inappropriate to characterize the project alternative as a tolling policy evaluation if the viability or existence of the new lane itself depended upon the toll finance scheme. In such a case, the tolling policy and the decision to build the lane are inextricably entwined, and should be treated as part of one project alternative.

Multiple Project Alternatives: The Concept of Mutual Exclusivity

In the real world, highway budgets are constrained, and highway commissions and other decision makers must allocate scarce budgets amongst many project alternatives. These alternatives may or may not be in the same corridor, but they compete for scarce budget funds.

For user benefit analysis to be helpful in selecting among or ranking alternative projects, the project alternatives must be defined in such a way that they are mutually exclusive. In
benefit-cost analysis of transportation projects, the term mutually exclusive refers to projects having benefits that are independent of other projects being constructed. This is often the case, but in other situations, candidate projects may overlap in the locus and type of some of the benefits they provide. There may also be cost synergies (negative or positive) among candidate projects. When projects are not mutually exclusive, building a set of interrelated projects may be more or less beneficial than building the projects individually. For example, two projects that are not cost effective on their own may be very beneficial when combined.

When project alternatives are not mutually exclusive, the analyst has two choices. The analyst can redefine the “project” to be the portfolio of interrelated projects. Alternatively, the analyst could consider reconfiguring the project alternative so it is mutually exclusive of other projects. This latter alternative is only acceptable, of course, only if it makes conceptual sense to disaggregate the portfolio of projects.

**Benefits and Costs**

It is easy to get confused when trying to decide what constitutes a benefit and what constitutes a cost in highway user benefit analysis. It can be particularly confusing when the analysis is cast, as it is here, as a change in conditions between a base case and an alternative.

In this manual, the term benefit is defined as an increase in well-being or a decrease in the use of real resources. Therefore, a project can generate a benefit if it increases the sense of well being of users or non-users, or if it decreases the cost borne by society in providing transportation services. We will operationalize measurement of benefits later in this chapter; what is important here, however, is the point that benefits result from changes in conditions, and that both changes in well being and changes in costs can generate changes in benefits. Adding to the confusion, a positive increase in costs is sometimes referred to as a disbenefit.

The term cost, therefore, has to be used carefully in this manual so as to not confuse reductions in certain expenses needed to (which will be part of the accounting of user benefits) and the additional resource costs or expenditures bring the project to fruition (which we will be characterizing as project costs). Although arithmetically costs are negative benefits, and benefits are negative costs, it is important to distinguish among benefits and costs consistently in this manner, or the proper calculation of benefit-cost ratios cannot be performed.

Elements typically considered user benefits are:

- Savings in travel time.
- Savings in the out-of-pocket and other operating expenses of users.
- Reductions in injury, morbidity, and mortality.
- Increases in consumer surplus (defined below).
Elements typically considered costs are:

- The project costs associated with developing the project.
- The cost of operating and maintaining the project.
- User travel delay incurred during project construction.
- Financing costs that must be borne to assemble the financing for the project. These are often incorporated in project costs.

Another distinction that is frequently made is between project and user costs. The term project cost refers generally to the cost of developing and operating the project. The term user cost refers to costs borne or perceived by the user, reductions in which can directly generate user benefits.

Finally, it is worth emphasizing that benefits and costs are generic terms, and that measures of these can be either positive or negative in sign.

**Project Performance Over Time: The Concept of Present Value and the Discount Rate**

Most transportation projects provide benefits and impose costs over an extended period of time. For as long as the project is operational, it is providing transportation services. Therefore, some benefits (and costs) will be associated with it throughout its life. If travel time is saved or lost because of the operational characteristics of the facility, the value of that time savings that persists over each year of its expected duration must be calculated. Similarly, the development and operating costs associated with the improvements play out over an extended period of time. Though the bulk of the capital, or development cost usually occurs at the front end of the implementation process, operating costs and maintenance costs occur over the life of the project.

The process of telescoping the stream of benefits and costs over time into an equivalent single figure in today’s dollars is the process of present valuation or calculation of the present discounted value of benefits and costs. Present valuation is not simply a matter of adding up each year’s benefits net of costs in a simple, arithmetic fashion. An adjustment needs to be made for society’s perception of what a dollar is worth when it is received or spent in the future, as opposed to today.

The reason is that present value calculations are important is that society always has the option of using the funds for the transportation project on something else instead. In economics parlance, the project costs have opportunity costs representing the value of what could have been obtained instead.

Financial markets provide insight into the size of these opportunity costs. Financial markets are willing to give us positive interest rates on money that we set aside today. A dollar invested even in a riskless manner (through an insured bank savings account or a government security, for example) returns more than one dollar later. Consequently, a dollar received today is worth more now than it would be if received later because you always have the option of investing it and turning it into more than one dollar later.

The implication of this is that future benefits and costs should be discounted relative to benefits and costs experienced today. The rate, per year, that future benefits and costs
should be discounted to present value is the *discount rate*. The discount rate should be selected so that it represents the forgone economic opportunities of the funds involved in the project. This leads to a few simple guiding principles for choosing discount rates when doing project evaluations. Further details about discount rate selection are presented later in the manual.

Discount Rates When Risk Is Not an Issue
When there is no risk or uncertainty about the stream of future benefits and costs, and the social rate of time preference is the same as the private rate (explained below), transportation projects should be discounted using the riskless interest rates that prevail in private financial markets. The reason is that public projects are taking resources away from private projects, and they should be permitted to do so only if they offer a commensurate return. A good choice for the discount rate, thus, is the riskless rate of return that financial markets are currently offering over the same horizon as a cost or benefit element. One thousand dollars in user benefits received 10 years from now, for example, would be discounted using the current yield on the 10-year Treasury bond. If that yield is, say seven percent per annum, then the discounting calculation is:

\[
\text{Present Value} = \frac{1,000}{(1 + 0.07)^{10}} = 508
\]

\[
\text{Net Present Value} = \left( \frac{B_0 - C_0}{1 + r} \right) + \left( \frac{B_1 - C_1}{(1 + r)^2} \right) + \ldots + \left( \frac{B_T - C_T}{(1 + r)^T} \right) = \sum_{t=1}^{T} \left( \frac{B_t - C_t}{(1 + r)^t} \right)
\]

where \( B_t \) is the nominal value of benefits in year \( t \), \( C_t \) is the nominal value of costs in year \( t \), \( T \) is the life of the project in years, and \( r \) is the nominal discount rate.

Discount Rates When Risk Is an Issue
When there is some risk that benefits or costs may not actually transpire as predicted, and the decision-makers are risk-averse, then the net present value should be lower than that obtained when one is certain of the outcome. The best way to accommodate risk in cost-benefit analysis is to try to estimate benefits and costs on what is called a *certainty-equivalent basis* by imagining inclusion of the costs of insurance policies and other protections against risk into the projections of the project costs. An alternative, rough and ready way to account for risk is to use a higher discount rate, \( g > r \), obtained perhaps by looking at the rates of return required by investors in similarly risky enterprises. This method is only useful when the pattern of risk affects all benefit and cost streams similarly, however.

Social vs. Private Discount Rates
If private market considerations dominate financial markets, and private markets care only about the consumption prospects of current generation of market participants, some economists argue that society may not be adequately valuing the future. Specifically, the economist Kenneth Arrow and others have argued that the social rate of time preference should be lower than the private market rate of time preference (i.e., the private market discount rates are higher than the one that should be used in public projects) (Arrow
Many transportation projects involve high, upfront costs, with benefits that play out only over long periods of time. If the social rate of time preference, \( s \), is lower than the private rate, \( r \), then projects discounted at \( s \) will have net present values that are higher than if they were discounted at \( r \) and thus be more likely to be undertaken.

Economists have debated whether very low discount rates should be used on public projects despite considerations like the social underinvestment hypothesis (Feldstein 1988). One reason for the debate is that through the operation of futures markets and by virtue of bequest behavior, the consumption prospects of future generations are adequately considered in present-day, private decision making. As a practical matter, no one has been able to demonstrate how low the social discount rate should be. For these reasons, the social discount rate notion is not widely accepted. Because lower discount rates tend to make marginal transportation projects look better, the social discount rate notion tends only to be brought out when a marginal project is at issue.

Discount Rates: A Place to Start

All of these complexities aside, a good rule of thumb is as follows:

- If the analyst has measured all costs and benefits in constant (inflation-removed) dollars, use a discount rate of 3 percent.
- If the analyst has measured all costs and benefits in nominal (i.e., inflation-included) dollars, use a discount rate equal to 3 percent plus the annual, future inflation rate that was used in the analysis. At the time this manual was written (2002), the consensus for future inflation was 2.5 percent, so the discount rate would be \( 3.0 + 2.5 = 5.5 \) percent. Again, if risk or uncertainty is a consideration, either add a risk premium to this amount or do sensitivity analysis on the key, uncertain factors.

BASIC METHODOLOGIES

The basic concepts discussed earlier need to be implemented in measurement methodologies that provide actual numbers that can be used in benefit-cost analysis. Later on in this manual, very specific methodologies are presented that are applicable to specific project circumstances. Some basic techniques, however, are common to all methodologies.

User Benefit Measurement

The benefits of a transportation improvement redound to either users or non-users. That is, they are enjoyed either by those who use highway facilities or those who are engaged in activities affected by the highway activity. In the parlance of this manual, the term user benefits is reserved for benefits that accrue to users of the highway system. These user benefits arise on the improved road segment; the effect of the improvement may propagate to other road segments in the highway network, and to the users of those segments as well. Of course, as we are using the term benefits, it can either be a positive or negative quantity. As pointed out earlier, a negative benefit is the same as a cost in the benefit-cost framework.

Non-users will also have benefits (positive or negative) imposed upon them by highway improvements. These are referred to alternatively as non-user benefits, indirect benefits,
or *societal benefits*. The noise of an adjacent roadway, for example, may impose a cost on homes or shops along the roadway. Similarly, the cost of dealing with accidents on the road may fall to the local police or highway patrol, and impose a burden on taxpayers.

The focus of this manual is on *user benefits* and this manual does not address non-user benefits. Nevertheless, the analysts may wish to include estimates of non-user benefits in a more comprehensive benefit-cost calculation. Estimates of these societal impacts are also often required as part of project permitting, EIS, and NEPA compliance.

The most commonly analyzed non-user benefits are environmental impacts associated with highway projects. The U.S. Environmental Protection Agency (EPA) has developed the MOBILE and PART5 models for estimating emissions rates by vehicle type for specific pollutants such as SOX, NOX, and carbon monoxide. More information on these models is available on the EPA website [http://www.epa.gov/otaq/models.htm](http://www.epa.gov/otaq/models.htm). Per-unit impact estimates by vehicle types are also presented in *Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners* (“*the Transit Manual,*” TCRP Report 78).

Other non-user benefits that often are of interest for a comprehensive benefit-cost analysis of highway projects include noise impacts, land use impacts, and economic-development impacts. The Transit Manual provides an overview of how these costs and benefits can be estimated and incorporated into a benefit-cost analysis, with cost estimates provided by vehicle type for some of the most common indirect cost categories. For a comprehensive treatment of non-user benefits related to transportation, see Delucci (1997).1


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1 Other references that address how non-user benefits can be measured and incorporated into evaluations of highway projects include Small and Kazimi (1995) and Lee (1994, 1995, 1997). FHWA’s Highway Cost Allocation Study (HCAS) also provides guidance for incorporating non-user benefits and NCHRP Report 403 *Guidance for Estimating the Indirect Effects of Proposed Transportation Projects* provides information on which types of non-user benefits might need to be addressed for compliance with CEQ and NEPA regulations. This study reviews the literature and various agency reports and also analyzes completed EIS reports and case law relating to compliance. Finally, both TCRP Report 39 *The Costs of Sprawl Revisited* (1998) and NCHRP Project 8-32(3) *Land Use Impacts of Transportation: A Guidebook* (1998) are references covering the treatment of land use and development impacts of transportation projects.
The remainder of this chapter is devoted solely to the measurement of user benefits for different types of operational improvements.

Basic Measurement Techniques
The measurement of user benefits might seem to be hopelessly complex. We need to measure, after all, the extent to which the user feels better off with the improvement. Such perceptions of well-being clearly are subjective, and measurement of them seems a great challenge.

Fortunately, economists have demonstrated that people express how much well-being they get out of something by demonstrating a willingness-to-pay for it. All the analyst need do, therefore, is to characterize users’ aggregate willingness to pay for highway services at various quantities of those services, and he/she is on his/her way to developing a quantitative metric of the level of well-being.

The willingness-to-pay relationship for, say, trips between A and B is a schedule of the aggregate quantity of those trips that the users would be willing to make at various levels of cost per trip. (Economists call the willingness-to-pay relationship the demand relationship or the demand curve.) The difference between what users (in the aggregate) would have been willing to pay, and what they are actually asked to pay, is captured by the consumer as surplus well-being, and accordingly is called consumer surplus. A more detailed discussion of consumer surplus and the impact of induced demand on benefit calculations is presented in Chapter 6.

Calculating User Benefits on a Directly Affected Road Segment
When a transportation improvement reduces the users’ cost of a trip between A and B on a particular road segment, the willingness to pay remains the same, but since users’ perceived cost of travel is less, consumer surplus will increase. Users who were already making the trip get to make the trip at lower cost, and new users (those for whom the willingness to pay was less than the old cost of the trip) are induced to travel.

This leads to a simple way to calculate the benefits of the improvement: simply subtract the consumer surplus without the improvement from the consumer surplus with the improvement. To do so, we need to know only two things:

- The willingness-to-pay (demand) relationship that is involved, and
- The effect of the improvement on the users’ perception of his/her cost of travel.

As it happens, we don’t even have to know terribly much about the willingness-to-pay relationship to implement this procedure. All we need to know is the effect on additional travel of a change in travel costs. A simple example is illustrated in Table 2-1, which corresponds to the graph shown in Figure 2-1. Table 2-1 depicts the schedule of willingness to pay at various trip levels, and calculates the consumer surplus without the project improvement (when the cost per trip is 15 cents per trip), and with the project (which reduces the cost per trip to 10 cents per trip). This calculation is shown for each price with and without the project and is calculated by taking the area above the cost line and below the demand curve. Note that for the existing trips in the table, all we need to know to calculate the change in consumer surplus is the difference in the cost without and with the improvement (i.e., 15.0 – 10.0 = 5.0 cents per trip). We do not need to know the
entirety of the demand curve, only the reduction in unit costs per trip, and the number of trips in the base case.

To calculate changes in consumer surplus for new trips, however, we need to know how many additional users there will be with the improvement. Hence, we need to know how elastic the response of demand is to the travel cost reduction associated with the improvement. Economists speak of the elasticity of travel demand relationships numerically as the percent change in the quantity of travel that results from a one percent change in the perceived unit cost of travel.

The proper measurement of elasticity of demand with respect to travel cost is one of the key informational needs of transportation project selection methodologies. Modern techniques for measuring demand elasticities are very accurate, but information-intensive.

Table 2-1: Stylized Calculation of User Benefits Resulting from a Reduction in Trip Cost

<table>
<thead>
<tr>
<th>Trip Number</th>
<th>Willingness to Pay (Cents per Trip)</th>
<th>Incremental Consumer Surplus Without the Project (Cost/Trip = 15)</th>
<th>Incremental Consumer Surplus with the Project (Cost/Trip = 10)</th>
<th>Incremental User Benefit (Difference in Consumer Surplus)</th>
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</tr>
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<td>7.5</td>
<td>5.0</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>1.5</td>
<td>6.5</td>
<td>5.0</td>
</tr>
<tr>
<td>11</td>
<td>15</td>
<td>0.5</td>
<td>5.5</td>
<td>5.0</td>
</tr>
<tr>
<td>12</td>
<td>14</td>
<td>0.0</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>0.0</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
<td>0.0</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>15</td>
<td>11</td>
<td>0.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>16</td>
<td>10</td>
<td>0.0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>17</td>
<td>9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>All Trips</td>
<td></td>
<td>60.5</td>
<td>128.0</td>
<td>67.5</td>
</tr>
</tbody>
</table>
Figure 2-1 renders this table and the benefit calculations in a graphical form. Algebraically, the calculation of user benefits, $B$, for one period for this simple example of a directly affected link is

**Equation 2-1: User Benefits**

$$B = (U_0 - U_1) \frac{(V_0 + V_1)}{2} = \Delta U \frac{(V_0 + V_1)}{2}$$

where:
- $U_0 = \text{user cost without the improvement}$
- $U_1 = \text{user cost with the improvement}$
- $V_0 = \text{trip volume without the improvement}$
- $V_1 = \text{trip volume with the improvement}$

Applying Equation 2-1 to the data in Table 2-1, we get the same result as shown in the All Trips row of Table 2-1:

$$B = (15 - 10) \frac{(11 + 16)}{2} = 67.5$$

Note that this is also the area of the shaded portion of Figure 2-1, which is derived from the same data.

The calculation of user benefits gets a bit more complicated if the effects of the project are so large that they appreciably affect the income of the user; in that case, the income effect shifts the demand curve, and the price effect of the project improvement is intertwined with the fact that the users now feel better off. Separating the income effect
impacts of the project itself requires knowing how much the demand relationship shifts in response to changes in income (that is, it requires knowledge of the \textit{elasticity of demand with respect to income}). But separating these two effects is relatively straightforward, and can be implemented with the information from good transportation demand models.

For simplicity, Equation 2-1 uses a linear approximation of the demand function. In practice, this is a worthwhile tradeoff. Between the two user costs, the true demand curve will not exhibit much curvature, so the amount by which the linear approximation overestimates benefits will be small. More important, the analyst never really knows the true demand function. All he/she has are two point estimates from a travel model, and drawing a straight line between those two points is a perfectly reasonable approach.

\textit{Calculating Benefits on an Indirectly Affected Road Segment}

A similar complexity arises when a road segment is indirectly affected by an improvement elsewhere in the road network. In situations where a project will indirectly affect other segments, the benefit-cost analysis should be conducted at the corridor level in order to incorporate all of the transportation costs and benefits associated with the project. The indirectly affected segment sees a \textit{shift} in the willingness-to-pay (demand) relationship. For example, if improvements cause traffic to shift to the improved segment, other, indirectly affected segments may see a backward shift in demand on the indirectly-affected segment(s). That is, the quantity of travel demanded on the indirectly-affected segments is less at every user cost. This issue of induced demand, or changes in demand across segments, is discussed in more detail in Chapter 6.

The impact of this shift in demand is illustrated in Figure 2-2. Note that the quantity of trips demanded on this link is lower at any given user cost. Although it appears that there are complex changes in consumer surplus that need to be rendered, in fact these changes are just analogues of the changes that are measured on the directly affected segment. Thus, the same equation is applied to calculations on the indirectly affected segments as to directly affected segments.
In this example, where demand has shifted inward by four trips and the user cost per trip has been reduced by one cent, it would appear that consumer surplus has, on net, been reduced. However, since this is an indirectly affected link, the consumer surplus lost because of the inward shift of the demand curve (at a user cost of 15 cents—the uppermost shaded area) is already accounted for in the slope of the demand curve for the directly affected link. The only change that must be accounted for on the indirectly affected link is the one that results from the reduced user cost (because of less congestion), given the reduced demand (the lowermost shaded area).

Note that if there had been no reduction in user costs associated with the shift in demand for travel on the indirectly affected segment, there would have been no user benefit calculation impact, even though there was a change in the volume of traffic.

Applying Equation 2-1 to every affected link properly accounts for all changes in consumer surplus.

The Components of User Benefits
The user benefit discussion shows why it is necessary to estimate user costs. Changes in user costs are a primary element in user benefit analysis.

Before discussing the basic elements of user cost measurement, it is important to discuss the debate around perceived versus total user costs. The user costs portrayed in the analysis of willingness-to-pay analysis are perceived user costs, of course, because they are the costs that mediate user behavior. Although users mediate their behavior in response to their perceptions of costs, it is possible that other cost elements, though ultimately borne by users, do not affect users’ travel decisions. If this is the case, then the user benefit analysis methodology in Equation 2-1 will not capture any benefits that accrue due to reduced ownership costs.
Some analysts, for example, believe that the costs of vehicle ownership are not an element of the costs perceived by users when they make their travel decisions. In this manual, however, the contrary assumption is made. The reason is that the context of project selection is the *long run*. Long run changes in travel behavior must incorporate consideration of whether or not to own a vehicle, how long to own it, etc. If this were not the case, then it would be difficult to explain the ownership and use of vehicles, since their specific purpose is to help produce travel services. In this manual, therefore, the use of the term perceived user costs is suppressed in most instances, and the terms user costs and total user costs are employed without reference to this debate.

We now turn our attention to the elements of user costs.

**Travel Time Savings**

An important aspect of transportation activity (in contrast to most other goods and services in the economy) is that users commit their own *time* to the production of transportation services. Consequently, the user cost of travel includes not only expenses like gasoline or transit fares, etc., but also the value of the time spent traveling. This makes the *value of time* a crucial factor in cost-benefit analysis in transportation. Specifically, the user cost of a particular trip includes an assessment of the amount of time the user spends traveling times the *value* of that time.

The value that users assign to their travel time will depend upon the opportunity cost of that time, and the consumption opportunities that the user associates with traveling on highways. The *opportunity cost* perspective suggests that the value of travel time should bear some relationship to the after-tax wage of the traveler, since that is an alternative use of time—especially in a commute travel context. Even in a leisure context, the value of time is likely linked in some way to the hourly wage rate because work is a meaningful alternative to leisure as well. Finally, in a commercial setting involving truck drivers or other hired labor (where the value of the time of hired labor is involved) the wage rate is even more obviously important, since that is the explicit cost of the labor.

The *consumption* perspective implies that the value of time will be affected by level of pleasure or pain that the user associates with travel. From this perspective, sightseeing, on-board music systems, portable telephones, the companionship of others in the vehicle, etc. should influence the value that users associate with their time spent traveling.

Considering these factors, it makes sense that the value that users associate with their travel time will depend upon the context of the travel, and the characteristics of the traveler (especially the wage rate) and, perhaps, the vehicle involved. Economists have spent considerable time examining the behavior of travelers, and the trade-offs that they appear to make between travel time and cash. In so doing, the value of time can be measured or inferred. These studies, so called *revealed preference* studies, confirm that the wage rate is, indeed, an important determinant of absolute and relative time values, but that the variation in values is greater than can be explained by variations in wage rates alone.

The variation that is observed in time studies gives the analyst the latitude to use time values estimated from local studies if they fall within normal ranges. It is imperative, however, that the analyst use time values in a consistent manner and make sure that the
decision to proceed with a project does not depend on unusual assumptions about the value of time. One of the first empirical tasks in a highway user benefit evaluation process is to assemble a table of values of time, by its various types of travel and/or user categories. These values allow the conversion of quantities of time to dollar-valued time.

In this manual, a value of time module presents the recommended values of time to assign to various types of time savings. That module differentiates among the values of time of automobile, truck and (bus) transit users, and differentiates between automobile drivers and passengers. Then, if the improvement affects, say, the use of carpools, or the amount of truck traffic, the analysis can more accurately incorporate the impact of these shifts among user types on the benefit calculation.

In practice, it is often the case that a complete and accurate tableau of time values is not available, or the analyst does not have the resources to model the travel behavior at the necessary level of detail. In such cases, it is possible to use only a few values of time in the detailed analysis, but then use sensitivity analysis to systematically explore how dependent the results are on the particular time value selected. In general, if the project remains feasible (or infeasible) irrespective of the time value used, then the analyst can be more confident of the feasibility analysis.

Conventionally, travel time is measured in minutes, and the value of time is measured in dollars per hour. For example, at a travel time value of ten dollars per hour, and a speed of 30 miles per hour, travel time contributes about 33 cents per person-mile to the user cost of travel. If average vehicle occupancy were, say, 1.3 persons per vehicle, this would translate into approximately 43 cents per vehicle-mile. Obviously, at higher values of time and vehicle occupancies, this component of user cost is proportionately higher, and at higher speeds, it is proportionately lower.

**Operating and Ownership Cost Savings**
The second, significant component of user cost is the cost of operating the vehicle. This is the composite of the costs associated with owning and operating the vehicle over the road segments involved in the project analysis. Specifically, operating and ownership costs involve the following cost elements:

- **Operating Costs.** These include fuel and oil, maintenance, and prorated tire wear-and-tear.

- **Ownership Costs.** These include insurance, license and registration fees and taxes, economic depreciation, and finance charges. In special cases, they also include the inventory cost of the cargo on the vehicle.

In simple settings, these costs can be presented in an average form, prorated over vehicle miles traveled. Operating costs can be calculated on a per vehicle-mile basis. Similarly, ownership costs can be calculated on an annualized basis, and then prorated over vehicle-miles traveled.

Advice about measuring these user cost elements is provided in the operating cost module later in this manual.
Accident Cost Savings

The final, broad category of user costs is accident costs. These are costs borne by the users in the course of using the facility that arise as a result of bearing the costs they impose on themselves or others, or others impose on them, of accidents on the highway. Information on estimating accident costs is provided later in this manual in a special module on this topic. It is worth emphasizing in this basic concepts chapter, however, how accident costs should be treated relative to accident insurance costs.

The ownership of accident insurance policies protects the user from some of the financial burden of accidents. Hypothetically, accident insurance premia, by some completely prescient method, could be charged differentially by road, time of day, and other dimensions of the specific risk of the roadway being used. Then, the users’ costs associated with accidents would be captured in the insurance premium. So, if a road were improved, and the accident rate reduced, one could imagine the insurance premium levied for use of this road declining exactly by the value of the reduced accident risk. In this hypothetical case, the effect of accident costs would be fully covered in the properly calculated operating cost measures, if the accident insurance policy covered all costs of accidents to the user. Hence, the inclusion of such on-the-fly insurance premia in the user cost calculation would incorporate fully the perceived costs associated with accidents.

Insurance companies are experimenting with charging for insurance by the mile, by facility. Hence, this perspective on accident insurance costs may be more than a helpful way to conceptualize accident costs. In present reality, however, the administration of insurance premia is much less precise than in this hypothetical case. The user does perceive a higher cost of using more accident-prone facilities, both because not all of the user’s costs of accidents are covered by insurance policies, and also because the user is concerned about the risk of being re-rated by the insurance company after an accident. Re-rating would raise the users’ insurance premium payments. This perception of the risk of raised insurance premium payments is part of the perceived cost of using a road. But the extent to which the user accurately perceives differences in this risk from one facility or circumstance to another certainly is questionable.

In keeping with the user benefit focus of this manual, accident costs are modeled as part of the perceived user cost of highways. Consequently, changes in accident costs should be incorporated into the analysis through changes in user cost components. At this time, the best way to do so is to measure changes in accident risk and assign those changes as part of the changes in user costs of travel. From this perspective, insurance premia per vehicle mile should remain in the operating cost calculation, but there generally would be no change in these premia modeled in response to a project’s effect on a facility or corridor. The effect of a project on accident costs is modeled as an explicit change in the accident cost component of the change in user costs. To combine these cost components without double counting, it is recommended that accident costs be calculated net of insurance reimbursements. More details are provided in the Accident Costs Module in Chapter 5.

If insurance premium payments evolve to become much more sensitive to local conditions, and are charged on-the-fly, it may become more appropriate to focus the incorporation of accident costs through changes in the premium payments.
The User Benefit Formulae

The basic user benefit calculation presented earlier can now be made more detailed to recognize the three, major sources of user benefits: the savings in travel time, operating cost, and accident costs, and the consumer surplus that such savings generates. The user benefit calculation also incorporates induced traffic demand by incorporating traffic volumes with and without the project.

Before elaborating on the basic formula, however, it is important to note that real-world projects have more that one class of users or vehicles. These classes of users may arise because of different values of time, different modes of use of the road, or because the improvement impacts them in a different way.

In addition, the user benefits will vary with the hour of the travel day being modeled, the project year, and the segment or corridor affected by the project improvement. As will be made clear later in this manual, the proliferation of the number of user classes, facility segments, project years and travel times makes the accurate measurement of user benefits something that must be done using an organized accounting and display of all of the calculations. Our purpose here, however, is to emphasize that the basic computational element of user benefit analysis is very simple, as in the equation below, an expansion of Equation 2-1.

\[
B_{cht} = \Delta U_{cht} \left( \frac{V_{cht,0} + V_{cht,1}}{2} \right) L = \left( \Delta H_{cht} + \Delta OC_{cht} + \Delta AC_{cht} \right) \left( \frac{V_{cht,0} + V_{cht,1}}{2} \right) L_s
\]

where:

- \( B_{cht} \) = user benefit to vehicle or user class \( c \), at travel hour \( h \), on link \( s \), in project year, \( t \)
- \( \Delta U \) = change in per - VMT user cost
- \( \Delta H = H_0 - H_1 = \text{change in per} - \text{VMT (or per - user) value of travel time} \) (without minus with)
- \( \Delta OC = \Delta OC_0 - \Delta OC_1 = \text{change in per} - \text{VMT (or per - user) operating costs} \) (without minus with)
- \( \Delta AC = \Delta AC_0 - \Delta AC_1 = \text{change in per} - \text{VMT (or per - user) unreimbursed accident costs} \) (without minus with)
- \( V_0 \) = vehicles (or users) of class \( c \) in hour \( h \) without the improvement
- \( V_1 \) = vehicles (or users) of class \( c \) in hour \( h \) with the improvement
- \( L \) = the segment or corridor length, in miles

This formula is a basic building block of user benefit analysis. In the remainder of this manual, therefore, it is simply referred to as the User Benefit Formula. The User Benefit Formula is applicable to all user benefit calculations that involve changes in perceived user cost, and which play out over the length of a highway or corridor’s various segments. It is general enough to be applied to analysis that is done by corridor, by road segment, by vehicle class or by user class.
Not all project impacts are of a format that can exploit the User Benefit Formula directly. The benefits of signalization, for example, depend on the number and features of the signals and intersection volumes, rather than the length of the facility. In the case of these types of improvements, the savings increment is *per installed improvement*, rather than by the miles of highway or corridor affected. The change in user cost simply has to be measured accordingly, and the proper measure of user or traffic volume applied.

To implement the User Benefit Formula, the various components that make up the change in user costs must be calculated. The basic procedures that support the User Benefit Formula are as follows below.

*Calculating the Value of Time Savings*

Changes in the value of time savings can arise either through a change in the amount of time spent traveling with the improvement, or through a change in the unit value applied to changes in travel time. The former is the most common case, but if projects cause users with certain values of time to redirect their trips, the appropriate unit value of time to apply to certain travel may change as well. In most cases, however, changes in travel time arise through changes in speed.

Once any change in speed is calculated from engineering information, the value of time savings resulting from these changes in speed can be calculated. (Later portions of this manual discuss the measurement of changes in speed.) It is assumed for the purposes of the basic analysis formulae that all vehicles on the segment are traveling at the same speed. On a multilane facility, of course, traffic will tend to travel at different speeds in the various lanes. Usually speeds are higher in the lanes nearest the highway centerline. In some circumstances, it may be worthwhile to perform the calculations at a *lane* level. Typically, however, because only a *change* in speed results in user benefits, a calculation at this level of detail is not necessary.

The value of the time savings that result from higher speeds will depend upon the unit value of time that users apply to the time savings, and the mix of those user types on the facility. A vehicle of class $c$ with an associated value of time per person per hour of $M_c$ and a vehicle occupancy of $O_c$ will see a reduction in the value of the time spent traversing the segment, per mile, as in Equation 2-2.

**Equation 2-2: Change in Travel Time Costs**

$$\Delta H_c = 100 M_c O_c \left( \frac{1}{S_0} - \frac{1}{S_i} \right)$$

where:

- $\Delta H_c$ = the value of travel time savings enjoyed by user class, $c$ (in cents per vehicle-mile)
- $M_c$ = the unit value of time for user class, $c$ (in dollars per hour)
- $O_c$ = the occupancy rate of vehicles of user class, $c$
- $S_0, S_i$ = speeds without and with the improvement (in miles per hour)
There is one $\Delta H_c$, of course, for every vehicle class. In economic parlance, this is the unit saving in travel time because it is expressed on a per unit (vehicle) basis. It is convenient to calculate unit cost changes first, and calculate user benefit totals later. The quantity $\Delta H_c$ is the first component of total user cost changes in the basic, User Benefit Formula.

**Calculating the Value of Operating Cost Savings**

The impact of the project on the users’ operating costs is the second element of user costs in the User Benefit Formula. Many operating costs are mileage (distance) related and therefore accrue to all the network segments. This is accommodated in the manual by aggregating user benefits across the various segments of the network with and without the project being built. Consequently, this effect need not be incorporated in the User Benefit Formula, since it is accommodated in through the benefit aggregation across segments.

There are, however, certain costs that are hourly and thus depend upon speed along a given segment. In most cases, such changes in operating costs derive from changes in the density and “stop and go” nature of traffic, or changes in the road surface that result from the project. These changes in operating costs may change non-monotonically with speed. For example, fuel consumption per mile improves up to certain speeds, and degrades thereafter. Speed changes also cause trucks carrying valuable cargo to experience different *inventory costs* than they otherwise would because goods in transit must be financed, may spoil, etc. Changes can also occur if the project causes different types of vehicles to traverse the segment(s) being analyzed.

In general, therefore, there is no common function that captures all of these effects, but it is important to recognize the link between vehicle speed and vehicle operating costs. Equation 2-3 is a placeholder for the specific relationship between operating cost and speeds.

**Equation 2-3: Change in Operating Costs**

$$\Delta OC_c = f(\Delta S)$$

where:

- $\Delta OC_c =$ change in operating costs (in cents per vehicle mile)
- $f(\Delta S) =$ a function relating changes in operating costs to changes in speed

The Operating Cost Module presented later in this manual provides information that can be used to measure the change in operating cost.

**Calculating the Value of Accident Cost Savings**

The third category of user cost savings that contributes to user benefits is changes in accident costs. Because this manual is only interested in user benefit analysis, the only accident costs of interest are those that directly or indirectly redound upon users. Some accident costs redound upon non-users, or the population in general. The cost of courts and police, for example, are typically not paid directly by the user, but rather are paid out of the type of funds that finance general government. These costs are relevant, but confound the calculation of user benefits if they are included in the calculations being illustrated here.
Accident costs generally have four elements:

- Injury, morbidity and mortality of the user;
- Injury, morbidity, and mortality of those other than the user who must be compensated;
- Damage to the property of the user; and
- Damage to the property of others.

As indicated earlier in this manual, the most accurate rendering of the change in the user cost of accidents is obtained from accident rate and value information, rather than changes in insurance premia or other indirect measures.

On the assumption that injury to the user and injury to other parties have like values, from the user’s perspective, accident costs can be calculated using statistics on accident rates by incident type and the unit value of each type of incident. In general terms, therefore, the change in accident costs perceived by vehicle class \(c\) as a result of the improvement depend on the expected change in each type of accident incident times the expected value of those incidents. The arithmetic of this perspective is as given in Equation 2-4.

**Equation 2-4: Change in Accident Costs**

\[
\Delta AC_c = v_i \Delta I + v_m \Delta D + v_p \Delta P
\]

where:

- \(\Delta AC_c\) = change in accident costs for vehicle class \(c\) (in cents per vehicle mile)
- \(v_i\) = perceived cost associated with each injury accident (in cents)
- \(v_m\) = perceived cost associated with each fatal accident (in cents)
- \(v_p\) = perceived cost associated with each property damage incident (in cents)
- \(\Delta I\) = change in the number of injury accidents per vehicle-mile
- \(\Delta D\) = change in the number of fatal accidents per vehicle-mile
- \(\Delta P\) = change in the number of property damage incidents per vehicle-mile

The Accident Cost Module presented later in this manual provides information that can be used to make Equation 2-4 operational.

Implementation of the User Benefit Formula in a project context requires linking the characteristics of the facility, with and without the improvement, to the elements of the User Benefit Formula. Figure 2-2 shows a stylized representation of these linkages. The remainder of this manual provides much of the information that the analyst can use to operationalize the User Benefit Formula in this manner.
Project Cost Measurement

The final, basic component of a benefit-cost analysis is the estimate of the project cost. This manual is not a project costing manual. Nevertheless, it is important for a user benefit manual to incorporate discussion of project cost to ensure that the collection and measurement of project cost data proceeds consistently with the collection and measurement of user benefit data.

In addition, the purpose of measuring user benefits is to evaluate the economic feasibility of highway projects. Feasibility involves balancing of benefits against costs. Although user benefits may be only a subset of the total benefits of a project, they are typically important enough to use alone in preliminary feasibility analyses.

The project cost is an aggregate cost figure against which the aggregate, present value of all user benefits can be compared for the purpose of evaluating the preliminary economic feasibility of highway projects. Although, as we have seen, there are user costs embedded in benefit calculations themselves, project costs are those costs borne by the highway authority/provider and which consume its investment budget. It is important for later considerations of project ranking that this concept of project cost be properly implemented.
The project cost has two elements: capital or investment cost, and operating or ongoing cost. The former term is generally reserved for the costs associated with developing the facility, and the latter for the costs associated with keeping the facility operating over time, once completed. The latter is frequently referred to as operating and maintenance or O&M cost, to emphasize the maintenance cost components. Similar engineering activities, of course, can contribute to either cost category. When a road is being developed, the paving activity contributes to initial capital or development cost; when the road is being operated, the periodic repaving activities are part of the operating cost. Finally, the construction and maintenance phases of projects will create additional user costs through increased travel times during the construction period. These costs are not counted as part of the project costs but should be included in the user benefit calculations. Additional detail on how user costs associated with construction periods should be incorporated into the benefit-cost calculations is provided in Chapter 5.

The fundamental difference between capital and operating costs is the treatment of these costs in benefit-cost arithmetic. In particular, operating costs occur frequently over the life of the facility, whereas capital costs generally occur only at some early point(s) in the development timeline. In both cases, present valuation techniques must be used to determine the project cost figure to be used in the benefit-cost decision. Project costs are very idiosyncratic to an individual project, and typically are developed by the project’s consulting engineers or highway authority staff.

Another important distinction is that when calculating benefit-cost ratios for the purpose of allocating constrained capital budgets, capital costs go into the denominator of the ratio and operating costs go into the numerator. Again, this is done for the purpose of allocating capital budgets across projects and as a consequence only capital costs are counted as costs. This is a common situation with many agencies where project budgets primarily reflect the capital costs associated with projects and have operation and maintenance costs included as separate budget items and are often paid for through user fees such as tolls and gas tax revenues. Chapter 6 provides additional guidance on the construction of benefit-cost ratios.

Salvage and Terminal Value

Another important factor is the treatment of the salvage value of a highway facility. As a practical matter, it is difficult to know what will happen to a road 30, 40 or 50 years hence. Consequently, highway projects are usually given finite lives for the purpose of planning and benefit-cost analyses. For consistency, some economists recommend calculating a salvage value at the end of the project’s life. This is the market value of all of the rights-of-way, structures, and other remaining assets, net of demolition costs. It is a negative cost, in the sense that any remaining market value is an offset to earlier project spending. (Of course, in the benefit calculations, any further benefits would also be eliminated by demolition; this diminution of benefits must be properly accounted for in the benefit calculation.) Sometimes the long-term benefits of a facility are modeled with terminal values, representing the present value from the end of the life of the facility to “infinity” of any residual benefits of the facility instead of, or in addition to, the salvage value.
Table 2-2 illustrates the generic types of activities that make up each category, and how they might (hypothetically) play out over a project’s life. Note that right-of-way acquisition costs, which, in this example, were occasioned prior to the evaluation date, are compounded forward in the present value calculation. This is appropriate in a situation in which those rights-of-way have current market value and could be sold for other purposes instead of being used for the project. An alternative to compounding is to obtain an independent, current appraisal of the value of rights-of-way.

Table 2-2: Hypothetical Project Costs for Selected Years and Activities

<table>
<thead>
<tr>
<th>Calendar Year</th>
<th>Project Year</th>
<th>Example Activity</th>
<th>Excess Inflation/Year</th>
<th>Capital</th>
<th>Operating</th>
<th>Total Present Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>-20</td>
<td>ROW acquisition</td>
<td>0%</td>
<td>$ 10.0</td>
<td>$ 26.5</td>
<td>$ 26.5</td>
</tr>
<tr>
<td>1991</td>
<td>-9</td>
<td>ROW acquisition</td>
<td>0%</td>
<td>$ 2.0</td>
<td>$ 3.1</td>
<td>$ 3.1</td>
</tr>
<tr>
<td>2000</td>
<td>0</td>
<td>Evaluation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>1</td>
<td>Demolition and grading</td>
<td>0%</td>
<td>$ 22.0</td>
<td>$ 21.0</td>
<td>$ 21.0</td>
</tr>
<tr>
<td>2002</td>
<td>2</td>
<td>Building of structures</td>
<td>2%</td>
<td>$120.0</td>
<td>$ 113.1</td>
<td>$ 113.1</td>
</tr>
<tr>
<td>2003</td>
<td>3</td>
<td>Building of structures</td>
<td>2%</td>
<td>$ 40.0</td>
<td>$ 36.6</td>
<td>$ 36.6</td>
</tr>
<tr>
<td>2004</td>
<td>4</td>
<td>Paving, signalization</td>
<td>0%</td>
<td>$ 10.0</td>
<td>$ 8.2</td>
<td>$ 8.2</td>
</tr>
<tr>
<td>2005</td>
<td>5</td>
<td>Facility Opens</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>15</td>
<td>Surface maintenance</td>
<td>1%</td>
<td>$ 2.0</td>
<td>$ 1.1</td>
<td>$ 1.1</td>
</tr>
<tr>
<td>2020</td>
<td>20</td>
<td>Surface maintenance</td>
<td>1%</td>
<td>$ 2.0</td>
<td>$ 0.9</td>
<td>$ 0.9</td>
</tr>
<tr>
<td>2030</td>
<td>30</td>
<td>Rehabilitation</td>
<td>2%</td>
<td>$ 10.0</td>
<td>$ 4.1</td>
<td>$ 4.1</td>
</tr>
<tr>
<td>2040</td>
<td>40</td>
<td>Surface maintenance</td>
<td>1%</td>
<td>$ 2.0</td>
<td>$ 0.4</td>
<td>$ 0.4</td>
</tr>
<tr>
<td>2050</td>
<td>50</td>
<td>Surface maintenance</td>
<td>1%</td>
<td>$ 2.0</td>
<td>$ 0.3</td>
<td>$ 0.3</td>
</tr>
<tr>
<td>2051</td>
<td>51</td>
<td>Salvage valuation</td>
<td>0%</td>
<td>$(12.0)</td>
<td>$(1.0)</td>
<td>$(1.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Present Value of Project Cost</strong></td>
</tr>
</tbody>
</table>

Note: The present value calculation uses an assumed discount rate of five percent per year. Excess inflation factor adjusts for cost increases above the general inflation rate.

**Performing Benefit-Cost Analysis and Project Selection**

Benefit-cost analysis is used to reach decisions based on the proper balancing of benefit and cost considerations. The proper use of benefit and cost information depends upon the decision context.

Efficient investing in highway projects is fundamentally a search for projects with positive net benefits. If the discount rate is properly chosen—and user benefits are the only necessary perspective—projects with positive net benefits are worth building. In economic parlance, such projects are said to be economically feasible. Whether such projects actually will be built depends upon considerations of budget constraints and financial feasibility.
Key Dimensions of Benefit-Cost Analysis

There are several, key dimension that affect the benefit-cost evaluation. At the outset of the study, the analyst should make some decisions about these issues before proceeding to developing more extensive information on the project.

- **Evaluation year.** This is the year in which the evaluation occurs. All costs forward of this date must be discounted and all non-sunk costs incurred prior to this year must be compounded by the appropriate discount rate.

- **Calendar vs. project year.** It is important to distinguish between the calendar year and the project year. Project years are measured relative to the date of project evaluation forward and backward in time.

- **Units of measurement.** As this manual makes clear later, some types of improvements are best analyzed on a road-segment basis, while others are best analyzed on a corridor basis. Similarly, some are best analyzed focusing on users as vehicles, while others are best analyzed focusing on individuals, rather than vehicles. Finally, in some circumstances, segment volumes are the most convenient unit of measurement of volume data; in other cases, corridor volumes or O-D pair volumes are more appropriate. Often data availability drives this decision as much as conceptual considerations. If vehicle occupancy and direct user travel data are not available, for example, vehicle volumes will have to be used.

The only requirement is consistent use of traffic volume measures and the associated user cost measurers (or consistent conversions between alternate measures). The analyst needs to be careful that per-vehicle-based user costs are used with vehicle measured volumes, and that per-trip-based user costs are used with trip-measured volumes, etc. The same units need not be used throughout the analysis, but will have to be segregated by measurement type to ensure proper aggregation.

- **User class definitions.** Throughout this manual it is accepted that there are multiple classes of users, and that these users may differ by type of vehicle, value of time, or other behavioral features of interest. One of the first decisions the analyst must make is the definition of user classes, and to plan for their disparate treatment. As a practical matter, most highway analysis involves measurement of vehicular flows, because these flows determine the performance of the facilities. Therefore, if the analyst wishes to perform some of the analysis on a per passenger-mile or per passenger-trip basis, occupancy rate data that converts from one measure to the other is necessary.

- **Vehicle class definitions.** Even if vehicle classes are not contiguous with user classes, the analyst must decide at the outset the extent to which the analysis is going to be sensitive to traffic mix. This is because the engineering performance of highway facilities can vary with vehicle type, as can the travel time experienced by the user classes occupying those vehicles. In some settings, where truck traffic is low and grades and sharp curves are not important, the analyst can often ignore the traffic mix and treat all traffic volumes as if they are passenger
In other cases, it is important to be more explicit, and to establish passenger car equivalents (PCE) of various types of vehicles.

### Table 2-3: Passenger Car Equivalents at Typical Operating Weights by Vehicle Configuration and Facility Class (Battelle, 1998)

<table>
<thead>
<tr>
<th>Functional Class</th>
<th>Auto</th>
<th>Single-Unit Truck</th>
<th>5-Axle Semi Truck</th>
<th>6-Axle Double Truck</th>
<th>Triple Trailer Truck</th>
<th>Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural Interstate</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Rural Other Principal Arterial</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Rural Minor Arterial</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Rural Major Collector</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Rural Minor Collector</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Rural Local Road</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Urban Interstate</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Urban Other Freeway</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Urban Other Principal Arterial</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Urban Minor Arterial</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Urban Collector</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Urban Local Street</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Uphill (any functional class)</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Uphill (maximum weight)</td>
<td>1</td>
<td>55</td>
<td>15</td>
<td>16</td>
<td>29</td>
<td>5</td>
</tr>
</tbody>
</table>

- **Treatment of inflation.** It is convenient to think of future costs and benefits in current (evaluation year) dollars. However, costs and benefits have a history or prospect of inflating, in unit cost terms, some at a rate greater or less than other goods and services in the economy. Any such excess inflation factors the analyst proposes will need to be developed and justified.

- **Modeling grain.** A key dimension of user benefit and benefit-cost analysis for highways is the “grain” of the analysis. Project can affect the highway system’s performance differently at different times of the day, months of the year, for different classes of users or vehicles, and for various years into the future. If the analyst chooses to model all of these dimensions in full detail, the research effort can be very daunting. On the other hand, if the analyst chooses to not do so, various expansion factors or rules of thumb will be needed to expand the selective studies to the entire operating context of the project. These factors (some of which are provided later in this manual) are at best an approximation of what detailed analysis would yield.

It is always best to make these decisions early in the project evaluation process. Otherwise, the travel demand and other analyses may end up generating data incompatible with the needs of the feasibility calculations.

**The Role of Budget Constraints**

The analyst also needs to know the decision context in which the user benefit analysis is going to be used. The reason is that benefit-cost analysis results have different implications for project investment decisions depending upon the decision context. The most important, practical decision context is the budgetary situation of the agency or firm.
developing the highway project proposals. Some projects—even if clearly economically feasible—are not worth the effort to analyze if they are unlikely to be selected in a properly implemented, project selection exercise. This exercise differs importantly under unconstrained, vs. constrained, budgetary circumstances.

If budgets for building roadways were not constrained, all economically feasible road projects should be considered for implementation. That is, all projects with positive net benefits—benefits in excess of costs—should be built. To do otherwise would be economically wasteful, and injurious to the economy, by definition. Road projects do not have to be balanced against other, non-road projects, by the way. This is done automatically by the choice of the appropriate discount rate used to measure the opportunity cost of funds used in road projects.

For a variety of reasons, the budgets of highway departments are constrained in practice. That is, there may be more economically feasible projects than can be developed from the department’s budget. The budget may rely, for example, on certain tax or user fee sources that are poorly configured or arbitrary. If these constraints impose a serious limitation on the number of economically feasible projects that may be built, of course, removal of these constraints should be seriously considered. Nevertheless, as a practical matter, highway development budgets are often constrained by such considerations, and benefit-cost analysis has to be accommodated to it.

Constrained Budgets: The Use of Benefit-Cost Ratios

The calculation of benefit-cost ratios facilitates project selection under circumstances of constrained budgets. The project selection process under these circumstances proceeds as follows:

- Calculate benefit-cost ratios for all economically feasible projects. It is important that the denominator of this ratio, the project cost, has been defined so that it represents the budgetary cost to the highway agency and not user costs that are influenced by the project. It is also important that the projects are independent, or non-mutually exclusive—that is, they do not affect the feasibility of one another.

- Rank projects in descending order of benefit-cost ratios. Note that this ranking is done independently of the size of the net benefits of the respective projects. It just uses the ratio of benefits to cost to rank projects.

- Select projects for construction until the budget is exhausted. This is the project selection criterion under conditions of a constrained budget.

Selecting projects in this manner guarantees that net benefits generated by the fixed budget are maximized.

When using benefit-cost ratios to allocate constrained capital budgets, it is important that the denominator of the benefit-cost ratio contain only the present value of project capital costs. The present value of agency operating expenditures associated with maintaining and preserving the asset once it is acquired goes into the numerator, reducing user benefits. This ensures the most benefit from the expenditure of the constrained capital budget.
Project Interdependence: Handling Mutual Exclusivity

A complicating factor in selecting among candidate projects is that the projects are often not independent. That is, the feasibility of Project A may depend upon whether or not Project B has been implemented.

The most obvious example of this situation is when there are several engineering solutions to the same transportation problem on the same road segment or corridor. The building of one project, therefore, obviates and mutually excludes building the others. In this simple setting, where projects are exactly mutually exclusive, and budgets are unconstrained, net benefits are maximized by doing the following:

- Group mutually exclusive projects. This isolates projects that are, in essence, candidates for solving the same transportation problem.
- Select the project from each group that maximizes net benefits. Following the principles outlined above, this assures that net benefits are maximized.

In practice, however, projects may be partially mutually exclusive; that is, the net benefits of building two projects may exceed (or be somewhat less than) the total of their individual net benefits. In addition, there may be constrained budgets. Implementing efficient project selection in a setting of partial project interdependence and constrained budgets can be complicated. There may be many different combinations of projects that need to be considered and, thus, multiple versions of the candidate project list to compare. The goal, however, remains the same—to maximize total net benefits that can be enjoyed from the given budget. The analyst simply needs to be sure that all relevant combinations of projects are considered, and that project interdependence has been measured accurately.

The details of the evaluation of project feasibility are presented later in this manual. The details include such things as the selection of the proper discount rate, and the proper treatment of inflation and risk. By knowing the context in which the feasibility analysis is being conducted, the analyst can make better decisions about the level of evaluation effort to conduct.

Maintenance Projects

This manual discusses the estimation of user benefits primarily in the context of capital improvement projects. In many cases, however, transportation agencies are concerned with determining the benefits associated with maintenance projects for existing facilities. Maintenance projects have a few minor differences from capital projects in that they tend to be budgeted separately and are directed at maintaining service levels of an existing facility (as opposed to constructing new facilities or expanding existing projects.) In this sense, maintenance projects are a means for extending the project life (and therefore project budgets) for capital improvements. The better maintained a facility is, the longer life it will have.

The evaluation of maintenance projects follows the same general framework presented in this manual for capital improvements. The benefits of a maintenance project are evaluated by examining the impact maintenance will have on user costs for a particular facility. Maintenance will potentially impact each of the user cost elements:
• **Travel Time Costs.** Properly maintained roads and highways will facilitate smooth traffic flows, as traffic will not be slowed by rough pavement or other wear hazards.

• **Operating Costs.** Poorly maintained roads will increase operating costs as wear on vehicles due to rough roads will increase.

• **Accident Costs.** Accident costs also increase when the level of maintenance decreases. Potholes and other rough road conditions resulting from low maintenance levels increase the likelihood of crashes.

The benefits of a maintenance project, then, are estimated by determining how the project affects each of the user cost elements. Since the cost elements are the same as those associated with capital projects, the benefits of maintenance projects can be estimated using the User Benefit Formula.

An additional benefit of maintenance projects is the impact they have on the life of a facility. Without proper maintenance, the life of any given capital project will be reduced as conditions deteriorate to the point where the entire facility needs to be replaced with a new capital project. In this sense, maintenance projects extend capital budgets as they extend the lives of capital projects. As a consequence, maintenance projects will have two related effects on user benefits:

• **User Cost Reduction.** With maintenance, costs in each of the user cost categories will be reduced throughout the remaining life of the project.

• **Project Life Extension.** Facility life will be extended with proper maintenance, thereby allowing user benefits to accrue over a longer period.

The analysis tools presented in this manual can be used to address both these aspects of maintenance projects. The following chapters present methods for estimating user benefits for a range of project types. While the discussion focuses on capital projects, the methods presented are also applicable for estimating the user benefits of maintenance projects. Chapter 6 presents methods for discounting estimates of annual user benefits for comparison across projects, and allows for comparison of benefits between projects with different expected life spans.
Chapter 3. Evaluating Operational Improvements

In this chapter, the general approach to evaluating operational improvements is presented. Operational improvements can affect travel time, vehicle operating cost and accident costs. It is through measurement of these induced changes that the basic elements of user benefits for operational improvements are calculated.

As discussed in the introductory chapters, the focus of this manual is on the calculation of user benefits associated with operational improvements. Since operational improvements often involve substantial changes in capacity and traffic volumes, non-user benefits may also be of interest to the analyst. In particular, costs and benefits relating to emissions, noise, land use, and economic development impacts resulting from the proposed project may need to be incorporated into the a more comprehensive benefit-cost analysis. Chapter 2 provides information on analysis tools and information sources for addressing these types of non-user costs and benefits.

ADDITIONAL LANES

Adding one or more lanes to an existing facility is a common type of highway improvement project. It is also a type of improvement that demonstrates many of the issues of evaluation of operational improvements in general, and it is a good example of the genre of improvements that affects the capacity of a facility. This is an important genre of projects, because they are more easily addressed with expansion factors, rules of thumb, and other shortcuts to sketch planning analysis.

The primary effect of adding lanes is to add additional capacity to one or more road segments in a highway network. Consequently, the primary benefits from additional lanes derive from changes in travel time, changes in operating cost and changes in accident costs in the highway network. In economic parlance, these benefits arise from the reduction in total user cost, i.e., the total of travel time, operating and accident costs.

Because a change in capacity on one part of the network may affect traffic flows elsewhere on the network, the most accurate rendering of the effects of additional lanes is obtained by modeling the entire network. The procedures in this chapter present the evaluation procedures for an improved segment and for indirectly-affected segments. In a full-scale project evaluation, these procedures must be replicated on all of the significantly-affected segments, and aggregated properly to the project level. The aggregation procedure is presented later in Chapter 6 of this manual.

The Basic Elements of Additional Lane Analysis

Analyzing the benefits of additional lanes fits easily into the general framework of the User Benefit Formula and the associated measurement recommendations. The benefits of additional capacity derive both from travel-time savings and accident costs to persons and operating cost savings to operators of vehicles. Consequently, both person and vehicle activity must be assembled to evaluate new lane capacity. Since different vehicle classes have different operating costs, and different persons may apply different values to their time savings, data on the composition of the vehicles and attributes of the users must be obtained.
Ultimately, the savings must be aggregated also over all hours of the day and all days of the year, and for representative analysis years over the project life. However, it is helpful to put aside the discussion of aggregation until later, and focus instead on the analysis of one hourly period. As elsewhere in this manual, it is assumed that the hourly period that is most easily modeled (and most important to model) in most cases is the peak hour of the day.

Calculating Speeds

The key effect of an additional lane is on the capacity of the facility and the resultant speed improvement on the facility. The first step in implementing the User Benefit Formula, therefore, is to calculate the speeds without and with the improvement. The calculation of the change in speeds that occurs because of additional lane capacity is probably the single most important calculation in the evaluation of improvements of this type. The traffic mix and other factors do not typically change significantly with the simple addition of lane capacity. Hence, accurate calculation of speed changes determines significantly the usefulness of the benefit calculations.

The HCM 2000 provides many tools and procedures to assist in the calculation of segment speeds. These procedures permit detailed consideration of segment features, including the effects of road geometry and weaving on the capacity and speed of a highway segment. Speed can be calculated for local streets and roads, highways and freeways using the HCM 2000. The most accurate rendering of the effects of additional lanes on speed, therefore, is through the use of the HCM 2000 calculation procedures.

Table 3-1 presents references to the relevant worksheets of HCM 2000 that can be used to calculate segment speeds on various types of roadway segments. In some cases, the addition of new lanes involves only changing a parameter (number of lanes) on a single, HCM 2000 worksheet. In other cases, the addition of new lanes changes the type of worksheet that is relevant for calculating speeds. For example, adding lanes to a two-lane highway requires that the “without-improvement” analysis be done using the two-lane highway segment worksheet, and the “with-improvement” analysis be done using the multilane highway worksheet.

<table>
<thead>
<tr>
<th>Roadway Segment Type</th>
<th>HCM 2000 Worksheets</th>
<th>Output of HCM 2000 Worksheets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Street</td>
<td>Urban Street Worksheet (Ch. 15)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Two-Lane Highway</td>
<td>Directional Two-Lane Highway Segment Worksheet (Ch. 20)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Multilane Highway</td>
<td>Multilane Highways Worksheet (Ch. 21)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Freeway</td>
<td>Basic Freeway Segments Worksheet (Ch. 23)</td>
<td>S, segment speed</td>
</tr>
</tbody>
</table>

For certain types of road segments, only these detailed calculations offered by the HCM 2000 procedures can provide even a sketch-planning estimate of impacts of improvements on speed. In the context of simple additional lane projects, however, the
effect of the additional capacity on travel speeds and times can be approximated quickly using the information from the volume-delay relationship.

**Volume-Delay Relationships: the Economics Perspective**

The centrality of the volume-delay relationship in highway capacity analysis has led to extensive research into these relationships. The *HCM 2000* provides extensive information on speed-flow relationships that can be used to calculate the predicted speed on a facility of virtually any configuration and geometry.

In the project evaluation sphere, the emphasis has been on volume-delay relationships—the inverse function to the speed-flow relationship—since the emphasis in project feasibility is on measuring travel time, rather than speed or level of service. Network modeling programs also take this perspective, because the travel time or *impedance* of a path in the network influences traffic assignment to that path.

The detailed procedures in *HCM 2000* for calculating speeds from flows on various facilities can be used to estimate travel time savings that result from a project’s effect on the engineering characteristics of the facility. The *HCM 2000* procedures, however, do not lend themselves easily to the kind of manipulation that economists wish to do to develop rules of thumb and other types of sketch planning assistance.

Of particular interest is the mathematical shape of the relationships because the mathematical shape determines their usefulness in many settings. There have been many efforts to develop mathematical functions that match the observed behavior of highway speeds in the face of increasing volumes. In addition, developers of computer programs to allocate traffic to complex highway networks have needed to find functions that allow the computation of equilibrium network loadings to occur in a stable manner. The range of characterizations of the volume-delay relationships is illustrated by the two most popular forms of this relationship: the so-called *Bureau of Public Roads* (BPR) formulations, and the *conical congestion function* (conicals) formulations.

The BPR formulation is of the general form of Equation 3.1. It is a simple algebraic form that is easy to remember and work with. By selecting the proper combination of freeflow travel time and the two other parameters, $a$ and $b$, it can replicate most observed patterns of delay.

**Equation 3-1: BPR Volume-Delay Function**

$$t(V) = t_0 \left(1 + a \left(\frac{V}{C}\right)^b\right)$$

where:
- $t(V)$ = travel time at traffic volume $V$, in minutes per mile
- $t_0$ = the freeflow travel time, in minutes per mile
- $V/C$ = the volume-capacity ratio
- $a, b$ = parameters ($a, b > 0$)

In contrast to the BPR formulation, the conical congestion functions have a more complex mathematical form, as shown in Equation 3-2. The travel delays calculated using conicals can approximate those from BPR formulations very closely. The advantage of the conicals is that for developers and users of large network models, their
behavior at very large $V/C$ ratios is more nearly linear, which aids the equilibration of network models.

**Equation 3-2: Conical Volume Delay Function**

$$t\left(\frac{V}{C}\right) = 2 + \sqrt{a^2(1 - (V/C))^2 + \left(\frac{2a - 1}{2a - 2}\right)^2} - a(1 - (V/C)) - \frac{2a - 1}{2a - 2}$$

where:

$$a = \text{a parameter } (a > 1)$$

From an economic evaluation perspective, the conical representation adds very little. For analysis and sketch planning purposes, economists need a volume-delay relationship that can be parameterized to match actual data reasonably well and which can be manipulated easily to determine interesting economic quantities.

The BPR function, despite its disadvantages in other quarters, is the best choice for characterizing volume-delay relationships in the project feasibility arena because of its simpler mathematical form. The flexibility of its functional form permits a BPR-equivalent of most other volume delay relationships to be estimated. Therefore, analysts charged with performing highway project feasibility analysis should familiarize themselves with the BPR form. If their planning software does not use this form, it is helpful to generate BPR approximations for sketch planning and other feasibility analysis purposes.

**Sketch Planning Estimates of the Effects of New Lanes on Speeds**

Using the underlying mathematics of the BPR-type volume-delay relationships, regular relationships can be established between the speed without the improvement, and the speed with the improvement in place.

The nature of the relationships depend, of course, on the assumptions made about the shape of the volume delay function. Table 3-2 illustrates the type of assumptions that might be made about BPR-type volume-delay relationships for different types of facilities and urban vs. rural/suburban settings.
Table 3-2: Typical BPR Function Parameters in Volume-Delay Analysis

<table>
<thead>
<tr>
<th>BPR Parameters</th>
<th>Freeway</th>
<th>Expressway</th>
<th>Collector</th>
<th>Arterial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>0.1</td>
<td>0.1</td>
<td>0.075</td>
<td>0.05</td>
</tr>
<tr>
<td>b</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Freeflow Speed (mph)</td>
<td>55</td>
<td>45</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Rural/Suburban</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>0.1</td>
<td>0.1</td>
<td>0.075</td>
<td>0.05</td>
</tr>
<tr>
<td>b</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Freeflow Speed (mph)</td>
<td>65</td>
<td>55</td>
<td>40</td>
<td>45</td>
</tr>
</tbody>
</table>

Using these parameters, Figure 3-1 through Figure 3-4 can be used to approximate the change in speed resulting from an additional lane. The analyst needs to supply the speed without the improvement, and the amount of additional capacity that the lane additions represent on the affected road segment. The figures accommodate a 33 percent increase in capacity (e.g., increasing from three lanes to four), a 50 percent increase in capacity (e.g., increasing from two lanes to three), and a 100 percent increase in capacity (e.g., increasing from one lane to two lanes).

These figures are only rough approximations for sketch planning purposes. In real world circumstances, the effective capacity of a new lane depends significantly on the amount of weaving, entering, and leaving the facility that occurs over the affected segments. The speed improvements calculated in the figures render the maximum speed improvements than might be expected from the lane additions.
Figure 3-1: The Effects of Lane Additions on Speed on Urban Freeways and Expressways for Various Increases in Capacity (Speeds in Miles per Hour)

### Urban Freeway

- **3 lanes to 4 lanes**
- **2 lanes to 3 lanes**
- **1 lane to 2 or 2 to 4 lanes**

### Urban Expressway

- **3 lanes to 4 lanes**
- **2 lanes to 3 lanes**
- **1 lane to 2 or 2 to 4 lanes**
Figure 3-2: The Effects of Lane Additions on Speed on Urban Collectors and Arterials for Various Increases in Capacity (Speeds in Miles per Hour)

Urban Collector

- 3 lanes to 4
- 2 lanes to 3
- 1 lane to 2 or 2 to 4

Urban Arterial

- 3 lanes to 4
- 2 lanes to 3
- 1 lane to 2 or 2 to 4
Figure 3-3: The Effects of Lane Additions on Speed on Rural Freeways and Expressways for Various Increases in Capacity (Speeds in Miles per Hour)

**Rural Freeway**

- 3 lanes to 4
- 2 lanes to 3
- 1 lane to 2 or 2 to 4

**Rural Expressway**

- 3 lanes to 4
- 2 lanes to 3
- 1 lane to 2 or 2 to 4
Figure 3-4: The Effects of Lane Additions on Speed on Rural Collectors and Arterials for Various Increases in Capacity (Speeds in Miles per Hour)

Rural Collector

Rural Arterial

User Benefit Analysis for Highways
Calculating the Value of Time Savings

After the change in speed is calculated, the value of time savings resulting from these changes in speed can be calculated. This is one of the components of the total, user cost savings that arise from the improvement. The typical assumption made when adding a lane to an existing facility is that all of the users, both with and without the improvement, are traveling at the same speed. In reality, on a multilane facility traffic will tend to travel at different speeds in the various lanes. Because only a change in speed results in user benefits, a calculation at this level of detail is not necessary when analyzing lane additions.

The remaining assumption needed is the value of time that users apply to the time savings, and the mix of those user types on the facility. In each case, the improvement will change travel speed from the without improvement level of \( S_0 \) to the with improvement level \( S_I \). A vehicle of class \( c \) with an associated value of time per person per hour of \( M_c \) and a vehicle occupancy of \( O_c \) will see a reduction in the value of the time spent traversing the segment, per mile, of:

**Equation 3-3: Change in Travel Time Costs**

\[
\Delta H_c = M_c O_c \left( \frac{1}{S_0} - \frac{1}{S_I} \right)
\]

where:

- \( \Delta H_c \) = the value of travel time savings enjoyed by user class, \( c \) (in cents per vehicle-mile)
- \( M_c \) = the unit value of time for user class, \( c \) (in dollars per hour)
- \( O_c \) = the occupancy rate of vehicles of user class, \( c \)
- \( S_0, S_I \) = speeds without and with the improvement (in miles per hour)

The reader will recognize the quantity \( \Delta H_c \) is the first component of total user cost changes in the basic User Benefit Formula.

Calculating the Value of Operating Cost Savings

Additions of lanes to existing facilities not only changes overall speed, but also facilitates passing and better sorting of users by speed preferences.

**Equation 3-4: Change in Operating Costs**

\[
\Delta O_{C_c} = f^- (\Delta S)
\]

where:

\( \Delta O_{C_c} \) = change in operating costs (cents/mile) per mile for vehicle class \( c \) with the improvement

\( f^- (\Delta S) \) = a negative function of the change in speed

The quantity \( \Delta O_{C_c} \) is the second component of total user cost changes. Table 5-5, in the Operating Cost Module of Chapter 5, presents data that can be used to calculate change in fuel consumption from change in speed information.
Calculating the Value of Accident Cost Savings

Accident costs are also prominently a function of the speed and density of traffic. Because at this point in the manual we are interested only in user benefit analysis, the only accident costs of interest are those that directly or indirectly redound upon users. Some accident costs redound upon non-users, or the population in general. The cost of courts and police, for example, are typically not paid directly by the user, but rather are paid out of the type of funds that finance general government. These costs are relevant, but confound the calculation of user benefits if they are included in the calculations being illustrated here.

Accident costs generally have four elements:

- Injury, morbidity, and mortality of the user;
- Injury, morbidity, and mortality of those other than the user who must be compensated;
- Damage to the property of the user;
- Damage to the property of others.

As indicated earlier in this manual, the most accurate rendering of the change in the user cost of accidents is obtained from accident rate and value information, rather than changes in insurance premia or other indirect measures.

On the assumption that injury to the user and injury to other parties have like values, from the user’s perspective, accident costs can be calculated using statistics on accident rates by incident type and the unit value of each type of incident. In general terms, therefore, the change in accident costs perceived by vehicle class as a result of the improvement depend on the expected change in each type of accident incident times the expected value of those incidents. That is,

**Equation 3-5: Change in Accident Costs**

\[
\Delta AC_c = v_I \Delta I + v_D \Delta D + v_P \Delta P
\]

where:

- \(\Delta AC_c\) = change in accident costs (cents/veh mile) for vehicle class \(c\)
- \(\Delta I\) = change in expected number of injury accidents per vehicle mile
- \(\Delta D\) = change in expected number of fatal accidents per vehicle mile
- \(\Delta P\) = change in number of property-damage accidents per vehicle mile
- \(v_I\) = perceived cost associated with an injury accident (cents)
- \(v_D\) = perceived cost associated with a fatal accident (cents)
- \(v_P\) = perceived cost associated with a property-damage accident (cents)

Calculating User Benefits of Additional Lanes

Once the speed, time cost, operating cost and accident cost calculations are complete for a segment that is receiving the additional lane treatment, the analyst has the elements necessary to begin calculating user benefits. All that is necessary is to properly apply and treat the changes in volumes, by vehicle class, between the pre-improvement and post-
improvement scenarios, using the User Benefit Formula. That is, the effect of an additional lane is to change the perceived user costs as in the equation below. All that remains is to insert this result into the User Benefit Formula.

Equation 3-6: Change in User Costs

\[ \Delta U = \Delta H_c + \Delta OC_c + \Delta AC_c \]

where:

\[ \Delta U = \text{change in user costs (cents/veh mile) for vehicle class } c \]

The user benefit calculated from the change in user costs of Equation 3-6 is specific to one vehicle class, one road segment, one peak hour period, and one analysis period. To fully account for all benefits from adding additional lanes, this calculation has to be repeated to incorporate all vehicle classes, all relevant road segments, and all relevant travel periods within all relevant analysis period(s).

Incorporating Multiple Vehicle Classes

The calculation in Equation 3-6 can be employed directly in the User Benefit Formula in sketch planning by assuming that there is only one vehicle class, using only one value of time. If accurate average values for the value of time are used, and if the improvement does not alter significantly the vehicular mix of traffic, such simplifications are surprisingly accurate.

In cases in which the vehicle mix is likely to change upon addition of new lanes, however, it is more accurate to calculate user benefits for each vehicle class. The result is total hourly benefit for segment \( i \) that incorporates the separate effects of all vehicle classes. Total benefits are calculated through simple addition:

Equation 3-7: Aggregation of Benefits over Vehicle Classes

\[ B_{\text{Tot},i} = \sum_c B_{c,i} \]

where:

\[ B_{c,i} = \text{user benefits for user class } c, \text{ on segment } i \]

\[ B_{\text{Tot},i} = \text{total user benefits across all user classes, on segment } i \]

Incorporating Multiple Segments

Incorporating multiple segments is simply a matter of adding together the user benefits calculated for each, individual segment. However, it is important to maintain the proper sign on individual segment calculations. The formulae described are configured to yield positive numbers when benefits are positive. For most lane additions, benefits will tend to be positive on the directly affected segments. This is because most components of users costs will decline with the additional capacity, resulting in positive calculations in the User Benefit Formula since changes in user cost elements are measured as without improvement minus with the improvement.

As indicated earlier, however, there may be segments—perhaps at some distance from the segments with the improvements—that experience increases in traffic, decreases in speeds, and increases in travel times, operating costs, and/or accidents. The calculations
in Equation 3-6 properly calculate a negative benefit; this negative benefit must be added to the positive benefits of other segments on the network.

Hence, the inclusion of additional segments is simply a matter of summing across all of the involved segments as in the equation below:

**Equation 3-8: Aggregation of Benefits over Roadway Segments**

\[ B_{Tot,All} = \sum_i B_{Tot,i} \]

where:

- \( B_{Tot,i} \) = Total benefit for all user classes for segment \( i \)
- \( B_{Tot,All} \) = Total benefit for all user classes across \( I \) total segments

It is important to note that the calculation of benefits for each segment must be completed (using Equation 3-7) and then the benefits combined, as in Equation 3-8. This is necessary to properly calculate changes in consumer surplus given shifts in demand on the affected segments.

The definition of involved segments is somewhat dependent upon the quality of the network modeling that the analyst has performed. It is crucial to include segments whose traffic volumes are significantly affected by the project, or project benefits will be miscalculated. Analysts with good access to computer resources can as easily make these calculations for all network segments as they can for a few. Analysts who are doing the work by hand must be guided by the precision of their traffic impact analysis. If the network traffic analysis is very rough and ready, then only the major network segments will be analyzed in the first place.

As a rule of thumb, network segments whose volume-capacity ratio is less than 65 percent or so at every point in the project analysis life need not be included in the analysis. The reality is that the user benefit consequences of impacts on such segments are *de minimis*. A related rule of thumb is that street networks require more careful analysis than freeway networks, because the effective capacity of street segments is less, and the interactions of traffic are more complex.

**Where to Go from Here**

With the user benefit calculations for a new lane during the peak hour having been made for the requisite highway segments, the next steps for the analyst are as follows:

- Decide how to expand the calculation in Equation 3-6 through Equation 3-8 across various hours of the day, months of the year, and years of the project;
- Join the resulting user benefit calculations with other project user benefit and cost elements.

Chapter 6 of this manual provides rules of thumb for expanding benefits measured in the peak hour of the day to other hours of the day, months of the year, and project years. The analyst must decide whether these approximations are suitable, given the context of the project analysis. If not, the analyst should repeat the calculations performed in Equation
3-6 through Equation 3-8 for each time period before bringing the information forward to Chapter 6 of this manual.

The choice involves a trade-off between the level of effort and the level of precision required. In general, for capacity enhancement projects such as new lanes, the use of rules-of-thumb and other expansion factors is not unreasonable. At a minimum, however, the analyst should anticipate repeating the calculations in Equation 3-6 through Equation 3-8 for at least two peak hourly periods over the life of the project (e.g., the first year and the 20th year).

NEW HIGHWAY

Evaluation of a completely new highway is analogous to the addition of new lane capacity on an existing facility. That is, the primary benefits from a new highway derive from the changes in the same components of total user cost that are involved in evaluating new lane capacity. Both types of improvements have an effect on the performance of the highway network as a whole. The difference is that it is much more important to take a network-wide perspective in the case of a new highway, because the effects of a new highway on traffic volumes and costs elsewhere on the network are generally more significant in the case of a new highway.

The procedures presented earlier for lane improvements, therefore, are the same procedures that are used to evaluate the effect of a new highway on travel times and costs on other, affected segments. These procedures must be performed on all of the significantly affected segments or corridors. The reader should refer to the discussion in this earlier section of the manual to become familiar with these procedures.

There are, however, special procedures that must be applied on the new highway segments themselves. These special procedures are necessary to properly calculate user benefits on those segments and are discussed in this section.

The Basic Elements of New Highway Analysis

As with the analysis of new lane capacity, the analysis of the user benefits of new highways involves comparison of total user costs with and without the improvement. In the case of lane improvements, however, the analyst can easily observe the user costs on the affected segments without the improvement. In the case of new highways, however, the affected highway segments did not exist without the improvement (by definition), and thus, there is not an immediately obvious base case against which to measure the effects of the new highway segments.

The solution to this base case measurement problem can be simple, or complex, depending upon the circumstances. If a new highway is to connect two cities that are already connected by another road, for example, the performance of the existing road provides the base-case conditions for the analysis. The analyst simply obtains information on travel times, volumes, and costs on the existing facility, and uses this information to measure base case user costs for travelers on both the existing and proposed facility. User costs are then measured with the new highway in place, and the analysis is essentially a study of the changes in corridor user costs. Arithmetically, the analysis then proceeds in
a manner identical to that of the additional lane capacity analysis when applied to corridors or links.

If there is no existing highway, there is no simple way to perform the analysis using selective segment or corridor data. Rather, the analysis for a new highway in this case must be conducted on an origin-destination pair (O-D pair) basis. In this approach, the network affected by the project must be broken into a discrete number of geographic zones (usually called travel analysis zones, or TAZs). Figure 3-5 is a stylized characterization of 16 zones overlaid on a simple highway network configuration. The greater the number of zones, the more accurate is the user benefit analysis, of course, because trip lengths are more accurately rendered, as the distance between centroids is measured more accurately.

**Figure 3-5: Stylized Transportation Analysis Zone Overlay**

The travel volumes, travel times, and other user cost information are associated with travel between the centroids of each pair of the zones. These measurements are made with, and without, the new highway in place. For a network with \( z \) zones, there will be as many as \( z^2 \) O-D pairs, if all roads are two-way. Hence, \( z^2 \) measurements of user costs must be made for each with and without comparison.

The same formulae that are applied to a segment approach or a corridor approach are applied to the O-D pair data with, and without, the project. Specifically, the basic user benefit calculation is performed using Equation 3-6.

**The Special Case of Wilderness Roads**

In most cases, a new road simply provides new connections between existing travel zones. That is, most new roads connect zones that can be reached by other paths in the highway network without the improvement, even if those paths are represented by poor
or primitive roads. A *wilderness* or *development* road, in contrast, is a new road that extends into a travel analysis zone that was not previously reachable by road.

Measuring the user benefit of a new wilderness road still requires a calculation of the base case user cost associated with O-D pairs that involve the wilderness travel analysis zone. In the case of a true, wilderness road, of course, the base case user cost per trip may be represented by a non-highway mode, such as travel by foot, boat, or airplane. User costs must be calculated from such modes for each of the O-D pairs that involve the wilderness zone(s). It is important to calculate these pre-project costs accurately, or the economic benefit of the new wilderness road will be improperly stated.

It is not advisable, for example, to simply assign an arbitrarily-high user cost to a trip to a wilderness zone without a road simply because the wilderness zones are not accessible by road with the new highway. To do so will lead to overstatement of the user benefits of the new road. Rather, the user cost of a trip to a wilderness zone without a road should be based on the *lowest user cost* alternative that is available without the road.

**TRAFFIC CONTROL**

Traffic control devices (i.e., signals, signs, roundabouts, and ramp meters) play an important role in the efficient and safe flow of traffic. Control devices account for most of the delay that motorists experience on urban arterials and rural highways. From the user’s perspective, such devices affect travel times, vehicle operating costs, and accident costs. From an economic perspective, introducing a control device is beneficial if total user costs—evaluated across these three measures—goes down. Generally, control devices yield higher travel-time and operating costs, which are offset by safety-related benefits. However, in some cases, control devices can also reduce turbulence and improve traffic flow, travel times, and effective speeds.

In this section, we consider the effects of controls at individual intersections. The following section outlines methods to incorporate the costs and benefits associated with coordinated signal systems in user benefit analysis.

**Basic Elements of Traffic Control**

Traffic controls increase travel times and vehicle operating costs but are necessary in establishing right of way and in reducing system accidents. This section considers four specific types of controls.

- **Stop controlled intersections.** These include Two-Way-Stop-Controlled (TWSC) and All-Way-Stop-Controlled (AWSC) intersections, which use stop signs to control vehicle movements. At TWSC intersections, the stop-controlled approaches are typically minor streets while the non-controlled approaches are considered major streets. Often, a stop-controlled intersection is the status of the highway without the improvement. Hence, the information here is useful in estimating delay without a signalized or roundabout improvement to the intersection.

- **Signals.** Traffic signals require a share of vehicles to stop and remain stopped for a certain period of time. The signal’s cycle length, the roadway’s capacity, user demand, and intersection geometry all factor into a signal’s effect on traffic flow.
• **Roundabouts.** These traffic control devices consist of a center island, the circulating roadway, and four splitter islands. Rules dictate that vehicles entering a roundabout yield to vehicles within the circulating roadway. Roundabouts depress traffic flow and generate control delay but also reduce the number and severity of collisions. Depending upon the type of intersection control it replaces, roundabouts may improve or degrade operating speeds.

• **Ramp metering.** These devices provide for uniform gaps between vehicles entering from a highway ramp and are designed to reduce the turbulence caused by merging with the traffic on a main highway. This is a traffic control technology that has the theoretical effect of improving travel times on highways.

Conceptually, each type of control has a different effect on traffic flows and ultimately on travel times, operating costs, and accident costs. Empirical support for some of these impacts, however, is very limited. Consequently, this section focuses primarily on measuring the impact of control delay on travel times, and the effects of controls generally on accident rates.

**Measuring Control Delay Impacts of Projects**

The first step in the analysis of traffic controls is the calculation of control delay, which is the time lost while approaching and departing a controlled intersection. More specifically, control delay consists of four components:

- Initial deceleration as a vehicle approaches a controlled intersection,
- Queue move-up time,
- Stopped delay, and
- Final acceleration delay.

The measurement of control delay is unique for each type of traffic control. The *HCM 2000* provides a number of tools and procedures to assist in the calculation of delay. The *HCM 2000* provides a formula that can be used to roughly estimate control delay for minor movements at stop-controlled and signalized intersections if the flow rate capacity for the intersection is known, and the analysis period is long enough to capture the queuing that occurs when the intersection approaches oversaturation.

This relationship is presented in Equation 3-9, and the graphical analogue of the relationship is presented Figure 3-6 and Figure 3-7. In the first of these figures, volumes remain below capacity for the analysis period, \( T = 0.25 \). In the second of these figures, volumes exceed capacity and require a longer analysis period, \( T = 0.40 \). This is a crude way to incorporate the effects of residual queues and upstream contributions to traffic saturation.
Equation 3-9: Estimating Control Delay

\[
D_x = \frac{3,600}{C_x} + 900T \left[ \frac{V_x}{C_x} - 1 + \sqrt{\left( \frac{V_x}{C_x} - 1 \right)^2 + \left( \frac{3,600}{C_x} \right)^2} \right] + 5
\]

\( D_x \) = average control delay, movement \( x \), in seconds/vehicle

\( V_x \) = volume (flow rate) for movement \( x \), in vehicles per hour

\( C_x \) = flow rate capacity for movement \( x \), in vehicles per hour

\( T \) = analysis time period, set to embrace saturation queing, in hours;

The information in the equation and the figures can be used to approximate the incremental delay contribution of the intersection change associated with the project, relative to the base case. For example, the project may improve (or degrade) the capacity of the intersection, or it may insert an intersection where there was none before. By calculating the delay in both instances, the change in delay caused by the project can be estimated.

Figure 3-6: Intersection Control Delay for Minor Movements, by Entering Flow and Intersection Capacity (below saturation; \( T = 0.25 \))
The sketch planning level of analysis can be used to approximate the delay contribution of unsignalized intersections, signalized intersections, and roundabouts with simple (or “minor”) movements. For more complicated intersections, or for ramp meters, there is no choice but to perform more detailed calculations to derive the appropriate delay measure.

Stop-Controlled Intersections
A user’s delay at a stop-controlled intersection is measured from the point of deceleration, as a vehicle approaches a queue, until the vehicle departs the intersection and resumes free-flow speed. TWSC intersections involve a variety of movements that can complicate an analysis of delay. For example, left-hand turns from minor streets (with approach controlled) face a complex set of conflicting traffic including all flows on the major street and opposing through and right-hand turns from the minor street. Moreover, pedestrians may conflict with vehicular traffic. To incorporate the effects of unique characteristics, the HCM 2000 provides 11 related worksheets to measure delay for TWSC intersections (see Table 3-3).

The analysis of AWSC intersections is somewhat less involved. The general rule at AWSC intersections is to yield the right-of-way to the vehicle to the user’s right, although in practice users more typically yield the right-of-way to vehicles that reach the stop line first. Given that each approach is controlled, the dynamics of the intersection are
less complex than for TWSC intersections. The *HCM 2000* has a set of five worksheets available to analysts to measure delay in AWSC intersections (see Table 3-3).

### Table 3-3: Sources for Detailed Traffic Control Delay Measurements

<table>
<thead>
<tr>
<th>Roadway/Control Type</th>
<th>Information Source</th>
<th>Output Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Street/Signal</td>
<td>Signalized Intersection Worksheets (Ch. 16, Appendix J)</td>
<td>$D$, control delay (in seconds per vehicle)</td>
</tr>
<tr>
<td>Urban Street/TWSC</td>
<td>TWSC Unsignalized Intersection Worksheets (1-11)</td>
<td>$D$, control delay (in seconds per vehicle)</td>
</tr>
<tr>
<td></td>
<td>(Ch. 17, Appendix A)</td>
<td></td>
</tr>
<tr>
<td>Urban Street/AWSC</td>
<td>AWSC Unsignalized Intersection Worksheets (1-5)</td>
<td>$D$, control delay (in seconds per vehicle)</td>
</tr>
<tr>
<td></td>
<td>(Ch. 17, Appendix A)</td>
<td></td>
</tr>
<tr>
<td>Urban Street/Roundabouts</td>
<td><em>HCM 2000</em>, Equation 17-38 Other: FHWA-RD-00-67</td>
<td>$D$, control delay (in seconds per vehicle)</td>
</tr>
</tbody>
</table>

**Signalized Intersections**

The analyses outlined in this section are appropriate for three types of signals:

- **Pre-timed signals.** These signals have a predetermined and repetitive cycle lengths.
- **Fully actuated signals.** For this signal category, the timing of vehicle approaches into an intersection determines the cycle length.
- **Semi-actuated signals.** In this category, minor streets typically have vehicle sensors that determine signal cycles while major streets do not.

Intelligent signal systems, which coordinate cycle lengths across a number of signals and intersections according to traffic flows, are discussed in a subsequent section.

For individual traffic signals, the calculation of delay varies from relatively simple (for low volume roadways) to quite complex (for roadways with high traffic flows and complex geometric configurations). *HCM 2000* outlines a sketch methodology in Appendix H of Chapter 16, which is applicable for intersections with an average maximum queue of no more than 25 vehicles per lane and the road demand/capacity ratio is less than 0.8 (i.e., “undersaturated intersections”).

For more complex intersections with heavier traffic flows, the sketch analysis becomes impractical. In such cases, the analyst should consider a variety of intersection characteristics that impact delay, including the presence of turn lanes, bicycle lanes, bus stops, and pedestrian crosswalks. *HCM 2000* offers 12 interactive worksheets (see Table 3-3) that assist the analyst in estimating delay for a variety of different intersection configurations and signal types (e.g., pre-timed versus traffic actuated).
Roundabouts
With respect to roundabouts, control delay is the time that a driver spends queuing and then waiting for an acceptable gap in the circulating traffic flow while positioned at the front of the queue. Entry capacity and circulating flow determine the average control delay per vehicle. The methods for calculating control delay associated with roundabouts are similar to those employed for stop-controlled intersections. At the time of publication, HCM 2000 did not offer a unique worksheet to assist analysts in calculating roundabout delay. A recent FHWA report (FHWA-RD-00-67) recommends using Equation 3-9 as an approximation in settings where queuing is not predominant because of over saturation.

Ramp Metering
Ramp metering is a traffic control device whose purpose is to control the adverse effects of intensive merging of two dense traffic streams. It is usually applied to on-ramps of freeways and expressways. In the terms of the HCM 2000, analysis of ramp metering is analysis of traffic behavior in merge influence areas. The HCM 2000 does not discuss ramp controls, except in passing in Chapter 25. Nevertheless, the contribution of ramp metering components of a project to the feasibility analysis can be analyzed using merge influence calculations.

The motivation for ramp metering derives from situations where the traffic stream mounting the highway is initially traveling more slowly than the stream with which it is merging. This leads to merging of vehicles at different speeds and spacings on the two facilities. This, in turn, can result in turbulence at the point of merging, and deterioration in the performance of the freeway or expressway. The lights on ramp meters delay the vehicles on the ramp so as to introduce vehicle spacing that is compatible with the larger stream.

The evaluation of such components of projects involves modeling the combined impact of the ramp metering on the ramp flow (i.e., the vehicles on the ramp) and the approach flow (i.e., the vehicles on the freeway or expressway). Evaluating ramp metering involves comparing the total travel time of vehicles on the ramps and affected freeway segments with and without the ramp metering in place.

Merge analysis focuses on the highway segments that make up the merge influence area. HCM 2000 provides empirical relationships between traffic volumes and density in the merge influence area that permit calculating freeway travel times as a function of the freeway flows in the first two lanes approaching the merge area and the ramp flows merging with that traffic. The HCM 2000 provides detailed procedures for estimating the approaching freeway flows in the first two lanes, but for sketch planning purposes, the per lane traffic volumes can simply be prorated. The effect is to exaggerate the merge delays, which is a useful bias in analyses of turbulent traffic.
Equation 3-10: Estimating Merge Speeds

\[ S_{\text{merge}} = \frac{V_{\text{merge}}}{D_R} \leq \frac{(V_{12} + V_R)}{(5.475 + 0.00734V_R + 0.0078V_{12} - 0.00627L_A)} \]

where

- \( S_{\text{merge}} \) = the speed in the merge influence area (mph)
- \( V_{\text{merge}} \) = the total volume of traffic in the merge influence area (vehicle/hour)
- \( D_R \) = the length of the acceleration lane (miles)
- \( L_A \) = the density of vehicles in the merge influence area (vehicle/mile/ lane)
- \( V_{12} \) = the traffic flow entering the merge area in the first two lanes
- \( V_R \) = the peak on-ramp volume (vehicle/hour)

With information on the ramp and freeway volumes, the analyst can use Equation 3-10 to calculate speeds in the merge influence area in the base case. Note, however, that this empirical relationship exists only for unsaturated conditions; that is the reason for the inequality sign in the equation. In saturated conditions, speeds will be lower than measured by the equation.

The introduction of ramp metering affects \( V_R \) in Equation 3-10, generally by reducing the peak on-ramp volume per hour to a lower, average figure by metering traffic with synchronized traffic signals. This is done by reducing the effective capacity of the ramp. Table 3-4 shows the capacities of freeway ramps typically assumed in highway network modeling.

Table 3-4: Capacity and Freeflow Speeds of Typical Freeway Ramps

<table>
<thead>
<tr>
<th></th>
<th>Core Urban</th>
<th>Other Urban</th>
<th>Rural/Suburban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmetered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity (veh/hr.)</td>
<td>1300</td>
<td>1400</td>
<td>1400</td>
</tr>
<tr>
<td>Freeflow Speed (miles per hour)</td>
<td>30</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>Metered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity (veh/hr.)</td>
<td>700</td>
<td>800</td>
<td>900</td>
</tr>
<tr>
<td>Freeflow Speed (miles per hour)</td>
<td>25</td>
<td>30</td>
<td>35</td>
</tr>
</tbody>
</table>

The primary effect of introducing ramp metering is to introduce control delay on the ramp. The control delay can be approximated using the control delay relationship in Equation 3-9 and the effect of the metering on capacity. Given the typical capacity ratings of ramps with and without metering presented in Figure 3-8, the approximate effect of the ramp metering on delay per vehicle and total delay can be calculated by comparing the control delay without the capacity limitation, and the control delay with the capacity limitation. The total delay suffered by the ramp meter stream rises sharply
with ramp approach volumes because of the significant, effective choking of capacity that occurs with ramp metering.

**Figure 3-8: The Effect of Metering on Ramp Users' Travel Time by Ramp Volume and Location of the Metering Facility**

![Graph showing the effect of metering on travel time by ramp volume and location.](image)

**Incorporating Traffic Control Delay in User Benefit Analysis**

For each of the traffic control devices described above, there are potential effects on travel time, operating cost, and accident costs. In contrast to project impacts that can be evaluated using the User Benefit Formula applied on a per-mile basis to the appropriate segment length, traffic control devices’ effects are usually not calculable on a per-mile basis. Rather, they are usually calculable on a per intersection basis. The underlying arithmetic is similar; it is simply that the final calculation for traffic control device benefits must be performed before it is merged with other impact measures.

**Calculating the Effects on Travel Time**

The travel time impacts associated with the improvement are derived from the changes in delay experienced by vehicle users during a given period. In its most simple form, the calculation of the value of the change in control delay is represented in Equation 3-11, which is a restatement of Equation 3-3 with time denominated in seconds instead of hours.
Equation 3-11: Benefits of Travel-Time Savings at Intersections

\[ \Delta H_{\text{intersection}, c} = \frac{\Delta D}{3600} \left( \frac{V_{0,c} + V_{1,c}}{2} \right) M_c O_c \]

where:

\( \Delta H_{\text{intersection}, c} \) = change in the value of travel time through an intersection, user class \( c \)

\( \Delta D = D_0 - D_1 \) = the change in intersection delay per vehicle, in seconds

\( V_{0,c}, V_{1,c} \) = vehicle volumes without and with the intersection improvement (vehicle/hour)

\( M_c \) = the value of time (dollars/hour) for user class \( c \)

\( O_c \) = vehicle occupancy, in persons per vehicle

In the case of ramp metering, the change in delay on the ramp can be measured as in Equation 3-11 (i.e., with separate calculations of the delay with and without the meter in place), or directly using Figure 3-8. The change in travel time associated with the freeway portion of the facility is calculated from the speed calculation in Equation 3-10. The total impact of the ramp metering on travel times in the merge influence area is the sum of these two effects, as indicated in Equation 3-12. Under congested conditions, ramp metering may affect travel times outside the merge influence area as well, speeding traffic on other freeway segments and slowing traffic on local roads.

Equation 3-12: Benefits of Travel Time Savings with Ramp Metering

\[ \Delta H_{\text{total}} = \Delta H_{\text{intersection}} + \Delta H_{\text{merge}} \]

where:

\[ \Delta H_{\text{merge}} = \left( \frac{1}{S_{\text{merge},0}} - \frac{1}{S_{\text{merge},1}} \right) \left( \frac{V_{0,c} + V_{1,c}}{2} \right) 100 M_c O_c L_{\text{merge}} \]

\( \Delta H_{\text{intersection}} \) = change in value of travel time at intersection (cents)

\( \Delta H_{\text{Total}} \) = total change in value of travel time (cents)

\( V_{0,c}, V_{1,c} \) = the affected merge volumes (vehicle/hour), i.e., \( V_{\text{merge}} \)

\( S_{\text{merge},0}, S_{\text{merge},1} \) = speeds in the merge influence area without and with the improvement (miles/hour)

\( M_c \) = the value of time (dollars per hour) for user class \( c \)

\( O_c \) = vehicle occupancy, in persons per vehicles

\( L_{\text{merge}} \) = the length of the merge influence area, in miles

Calculating the Value of Increased Operating Cost

The change in queuing delay that results from additional control devices also changes operating costs. The primary effect on operating cost is the expense of idling or traveling very slowly while queued. Segment speeds may also be affected, but are not analyzed as part of intersection delay modeling. These segment speed changes are picked up in the analysis of other segments, using the User Benefit Formula. In the case of ramp metering,
However, the increased travel speeds that result on the freeway also have an effect on operating costs for that portion of the traffic, and they have been addressed directly. Therefore, the total change in operating cost is as in Equation 3-13.

**Equation 3-13: Change in Operating Costs**

\[
\Delta OC_c = f_c(\Delta D)\left(\frac{V_{0,c} + V_{1,c}}{2}\right)_{\text{intersection}} + L_{\text{merge}} g_c(\Delta S)\left(\frac{V_{0,c} + V_{1,c}}{2}\right)_{\text{highway}}
\]

where:

- \( f_c(\ ) \) = the relationship between delay and operating cost
- \( g_c(\ ) \) = the relationship between speed and operating cost

The information needed to make the calculations in this equation is included in the Operating Cost Module later in this manual.

**Calculating the Value of Accident Cost Savings**

The principal reasons to install traffic control devices are to establish rights-of-way, calm traffic, and reduce the incidence of collisions. From an economic perspective, for traffic control initiatives that increase delay, the addition of a traffic control device is beneficial only if the savings associated with a reduction in accidents outweighs the costs related to increased delays.

The basic elements of accident costs are as described elsewhere in this manual. That is, the change in accident costs is measured as the change in accident rates, relative to the base case, times the unit value of each particular reduced accident type. The only difference in the case of traffic control project elements is that the analyst must be careful to calculate the change in accidents per traffic control initiative, rather than on a per mile basis. As in the case of travel time and operating costs, the aggregation to total user benefits must occur prior to merging with other user benefit dimensions of the project. Thus, Equation 3-5 should be constructed as an aggregate change in accident costs, rather than as a per mile figure.

The available information to implement this measure is presented in the Accident Cost Module later in this manual.

**Where to Next?**

If the user benefit calculations in this section have been properly completed, the analyst has obtained total user benefit estimates, by user class. The analyst will need to make these estimates directly for different hours of the day, and aggregate to yearly information through explicit modeling of representative periods. Annualization and extrapolation techniques are presented later in this manual, but the nature of intersection delay does not lend itself to such rules of thumb.

The user benefit calculations made using the information in this chapter need only be readied for combining with other information in Chapter 6 of the manual.
SIGNAL SYSTEMS
Traffic signals account for much of the delay experienced by motorists on arterial roadways and includes the time associated with deceleration as a vehicle approaches a queue, the time spent in the queue, and acceleration time. The delay associated with any particular signal is a function of roadway capacity and the special geometric and design features of the intersection (e.g., presence of pedestrian crosswalks, left-hand turn lanes, bus stops, etc.).

The previous section on traffic control devices reported a number of analytic methods available to estimate delay associated with an individual signalized intersection. Rather than focus on individual intersections, this section outlines analytic methods to calculate user costs and benefits associated with signal systems—or a series of coordinated or uncoordinated signals on urban or rural arterials. These systems of signals are briefly addressed here because they are signalization improvements that can be evaluated on a per mile basis, rather than a per-improvement basis. This is a different format from the other traffic control analysis

Basic Elements of Signal Systems
The spacing and coordination of traffic signals determine their impacts on average vehicle speeds and accident rates. Signal systems are implemented to constrain capacity and coordinate flow on high volume arterials during peak usage. The impact of signal systems on traffic flows and ultimately user costs can be minimized during off peak, low volume periods through an appropriate design. On the other hand, poorly designed systems with irregular or random signal spacing and ineffective inter-signal coordination, can generate user delays during all hours of the day and even contribute to higher accident rates.

In general, the addition of signals will decrease the speeds by which vehicles traverse a roadway segment. Slower speeds increase user costs, measured in terms of the passengers’ time, as well as the vehicles’ operating costs. Ideally, safety improvements offset these costs, with benefits measured in fewer road-related deaths, injuries, and property damage.

Calculating Speeds
The determinants of roadway speed with respect to signal spacing and cycle lengths are well established. A recent TRB publication, Impacts of Access Management Techniques, provides a straightforward method to calculate travel speeds on roadways with differing signal densities and volume-to-capacity ratios. The analysis begins with a calculation of travel time (per minute) over a roadway segment, which is executed using a modified form of the BPR volume-delay relationship as in Equation 3-14.

Equation 3-14: Effect of Signals on Travel Time

\[ T = T_0(1 + e)^{0.3} \left[ 1 + \left( \frac{v}{c} \right)^4 \right]^{0.7} \]

where:
- \( T \) = actual travel time (minutes per mile)
- \( T_0 \) = free-flow travel time (minutes per mile)
- \( e \) = the number of effective signals per mile
- \( \frac{v}{c} \) = volume/capacity

If the signals are uncoordinated and regularly spaced, the number of effective signals equals the actual number of signals per mile. However, if signals are irregularly spaced or coordinated, the TRB publication offers methods to calculate \( e \).

Having estimated a travel time per minute, \( T \), the translation to a speed, \( S \) (in miles per hour) is straightforward:

\[ S = \frac{60}{T} \]

The speed calculation is made using the roadway and signal characteristics—with and without the improvement.

For segments on the road facility that receive addition signals, the change in speed will generally be negative, of course, generating disbenefits in this dimension of user benefits. However, as part of a network of such changes, overall speeds may increase if the signalization stabilizes traffic flow, permits one-way networking, or offers other systemic improvements. It is important, therefore, to make the appropriate user benefit calculations in the User Benefit Formula for all affected segments.

Calculating the Value of Changes in Travel Time

After the change in speed is calculated, the analysis can calculate the value of time costs per mile resulting from these changes. This is one of the components of the User Benefit Formula. The value of the time costs that result from decreased speeds will depend upon the users’ unit values of time, as well as the mix of those user types at the intersections. A vehicle of class \( c \) with an associated value of time per person per hour of \( M_c \) and a vehicle occupancy of \( O_c \) will see an increase in the value of the time spent traversing the signal system, per mile, as measured by the now familiar formula given in Equation 3-3.

There is one \( \Delta H_c \) for every vehicle class, which is the unit cost in travel time because it is expressed on a per unit (vehicle) basis. It is convenient to calculate unit cost changes first, and calculate user benefit totals later. The quantity \( \Delta H_c \) is the first component of total user cost changes in the User Benefit Formula.

Calculating the Value of Changes in Operating Cost

The reduction in average operating speed that results from the installation of additional signals also affects operating costs. The TRB formulation of travel time for signal systems combines queuing and segment travel times. Therefore, the analyst need only access information that measures the effect of speed on operating costs and, hence, the
change in operating cost that is associated with the change in speed. The standard equation, Equation 3-4, represents this calculation, which can be performed with the assistance of information in the Operating Cost Module in Chapter 5.

Calculating the Value of Accident Cost Savings

One of the reasons that signalization systems are installed is to reduce accidents at uncontrolled intersections, but the relationship between accident rates and the number of signals is not well established. Several studies have estimated the impact of signals—and their spacing—on accident rates. For example, a 1989 Georgia study concluded that accident rates increase by 40 percent as the number of signals on a roadway segment increased from two to four signals per mile\(^3\). A Florida-based study found an even stronger relationship, estimating accident rates more than double when signal density increases from two to four per mile\(^4\).

This is contrary to the conventional findings of standardized crash prediction models that find improvements in safety associated with individually improved controlled intersections\(^5\). The analyst, thus, has to make the decision to evaluate the effect on accidents on a per intersection basis, as in the previous section, or on the same, segment basis as the travel time and operating cost impact analysis.

In either case, the goal is to measure the change in total accident costs. If the calculations are done on a per intersection basis, however, the appropriate intersection volumes need to be applied because the accident cost changes need to be aggregated before combining with other user benefit information (see the previous chapter). If the calculations are done on a segment basis, then the conventional approach of estimating the change in accident costs per vehicle-mile is appropriate; this information can be incorporated with other user per vehicle-mile benefit information before being entered into the User Benefit Formula. In either case, the analyst can obtain helpful information on accident costs in the Accident Cost Module presented later in this manual.

Where to Next?

If the user benefit calculations in this chapter have been properly completed, the analyst has obtained total user benefit estimates for at least the peak period of every segment. Unless detailed hourly and yearly data is available, the analyst should go to Chapter 6 of the manual to explore options for annualizing, extrapolating and aggregating the user benefit information.

\(^3\)See Squires and Parsonson “Accident Comparison of Raised Median and Two-Way Left-Turn Lane Treatments” (1989).
\(^5\)See Vogt “Crash Models for Rural Intersections: 4-Lane by 2-Lane Stop-Controlled and 2-Lane by 2-Lane Signalized” (1999). See also Bauer and Harwood “Statistical Models of At-Grade Intersection Crashes” (1999).
INTELLIGENT TRANSPORTATION SYSTEMS IMPROVEMENTS

Intelligent Transportation Systems (ITS) include a wide variety of highway and other improvements that possess some degree of intelligence. This section focuses on the most common types of intelligent highway improvements. Other types of ITS improvements—those related to vehicles, fleet management, and transit systems, for example—are not addressed, though they may combine with intelligent highway improvements in an integrated ITS program.

General Categories of ITS Improvements

This section describes the analysis of the following general categories of ITS improvements:

- **Arterial Management Systems**, including advanced traffic signal control systems that allow for Adaptive Traffic Control.
- **Freeway Management Systems**, including Ramp Metering and facilities for determining, posting, and enforcing Variable Speed Limits. The benefits and costs of policies implementing variable speed limits are addressed under Pricing and Regulatory Policies.
- **Incident Management Systems**, including facilities for surveillance, dispatch, and rerouting.
- **Traveler Information Systems**, including information about weather conditions, road conditions, traffic conditions, incidents, recommended speeds, and alternative routes.
- **Infrastructure Operation and Maintenance Systems**, including facilities for weather surveillance, infrastructure condition monitoring, and failure notification.
- **Electronic Toll Collection**, which includes only the collection systems. The benefits and costs of tolling and pricing policies are addressed under Pricing and Regulatory Policies.
- **Weigh-in-Motion (WIM) and Electronic Credentialing**, which includes only the weighing and credentialing systems. The benefits and costs related to policies and regulations regarding weights and credentials are addressed under Pricing and Regulatory Policies.

ITS improvements can produce benefits in several ways. They may increase throughput, thereby reducing users’ time and operating costs. They may reduce accidents, thereby reducing costs associated with mortality, morbidity, injuries, and property damage. They may also reduce facility operating costs by optimizing maintenance activities and by doing so, saving labor costs. By increasing the effective capacity of existing facilities, they also can obviate the need for capital expenditures on new facilities and rights-of-way. The increase in effective capacity, however, does not add to the benefits accruing from increased throughput and therefore is not included in the benefits calculations.

Because the effects of ITS improvements may extend beyond the particular segments on which they are installed, the most accurate rendering of their effects is obtained by modeling the entire network. The procedures in this section present the evaluation
procedures for an improved subnetwork. In a full-scale project evaluation, these procedures must be replicated on all of the significantly affected segments, and aggregated properly to the project level. The aggregation procedure is presented later in this manual.

The benefits of ITS improvements derive from travel time savings and accident cost savings to persons, operating cost savings to operators of vehicles, and operating cost savings to operators of facilities. Consequently, both person activity and vehicle activity must be assembled to evaluate ITS improvements. Since different vehicle classes have different operating costs, and different persons may apply different values to their time savings, data on the composition of the vehicles and attributes of the users must be obtained.

Ultimately, the savings must be aggregated also over all hours of the day and all days of the year, and for representative analysis years over the project life. However, it is helpful to put aside the discussion of aggregation until later, and focus instead on the analysis of one period. User benefit analysis is the analysis of changes in travel time, operating cost and accident cost that occur as the result of an improvement. In other words, it is the difference between the network with and without the ITS improvement.

All of the ITS improvements covered here have the potential to save users time and to reduce their operating costs. In the case of ramp metering, travel time savings can result from both higher speeds on the affected freeway segments (which include segments upstream of the first metered ramp) and less delay on the ramp during congested periods (ramp metering may result in either more or less delay on the ramp). Improved predictability of travel times may also result in savings in travel time and operating costs. These savings can be estimated hourly from the physical characteristics of the freeway and the ramp, the traffic level on the freeway, and the arrival rate at the ramp. Normally, weekdays must be treated separately from weekends and holidays and, if traffic is seasonal, seasons also must be treated separately.

In the case of electronic toll collection, weigh-in-motion, and electronic credentialing, time savings result from both faster transaction processing and from less time waiting in the queue while other transactions are processed. The savings from reduced transaction time can be estimated by simply multiplying the average savings per transaction by the expected number of transactions. The savings from reduced queuing time may be estimated hourly from the arrival rate and number of stations, and then summed over days. Normally, weekdays must be treated separately from weekends and holidays and, if traffic is seasonal, seasons must be treated separately.

In the case of incident management, travel time reductions result from fewer lane-hours of closure due to incidents and from rerouting traffic to unblocked routes. Estimating travel time savings is more difficult for these ITS improvements because it requires forecasting the number and severity of incidents as well as the time of day at which the incidents will occur, their location, and traffic conditions on alternate routes. One approach is to estimate the savings that would have resulted in a representative past period had the improvements been in place. Applying such estimates to the future requires taking into account overall trends in the rate of incidents. The rate of incidents per million VMT has declined steadily over the past 20 years and probably will continue
to decline. One also should consider the potential for reductions in secondary incidents (accidents resulting from the existence of the primary incident) due to faster response, faster clearance, and rerouting of traffic away from the primary incident.

In the case of ITS improvements dedicated to implementing variable speed limits, the ITS improvements themselves probably will likely produce only safety benefits. The benefits associated with variable speed limits are estimated under Pricing and Regulatory Policies.

In the case of infrastructure operation and maintenance systems, the benefits redound to both users and operators of the facilities. To the extent that transportation facilities are funded by users (e.g., through fuel taxes), changes in facility operating costs may also be counted as user benefits. But they may not be counted twice. In many cases, infrastructure operation and maintenance systems reduce per-unit costs, but because agency budgets are not directly tied to per-unit costs, they result in the same amount of money being spent, but more maintenance being done. In these cases, the benefits accrue entirely through user cost savings. For example, an automated snowplow dispatch system may not change an agency’s snow removal budget, but it may allow more roads to be plowed sooner, reducing delays and perhaps reducing accidents.

The savings associated with Arterial Management Systems and Freeway Management Systems result from interactions too complicated for all but the most sophisticated microsimulation-based modeling systems to capture. An engineering rule-of-thumb approach does not apply well to these types of improvements, because the travel time savings they achieve depend more on the attributes of the network and the relationships between intersections (or freeway entrances) than on the attributes of the intersections themselves. TRANSIMS currently can model actuated traffic signals, but not systems of traffic signals that communicate with each other. Other models such as PARAMICS, FRESIM, and INTEGRATION 2.0 have the capability to address intelligent ramp metering systems. Additional information on these and other ITS models can be found at http://www.its.leeds.ac.uk/projects/smartest/links.html.

Given that modeling the travel time savings resulting from ITS improvements might cost as much as the improvements themselves, the analyst probably will have to rely on alternative sources of information. In these cases, the FHWA recommends using empirical data from similar implementations within the region or case studies where similar improvements were installed under similar circumstances. Applicable case studies may be found in Intelligent Transportation Systems Benefits: 2000 Update, FHWA report FHWA-OP-01-024. The U.S. Department of Transportation also maintains a database tracking both the benefits and unit costs of ITS and can be accessed at http://benefitcost.its.dot.gov/.

It is recommended that a range of potential savings be extrapolated from available case studies and that that range be carried all the way through the benefit-cost analysis. It is also recommended that, once appropriate case studies have been identified, the analyst follow up with the jurisdiction(s) involved to evaluate the applicability of the findings.

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6 TRANSIMS is a product of the Los Alamos National Laboratories and is currently being commercialized by PricewaterhouseCoopers. For more information, see http://www.transims.tsasa.lanl.gov/.
and to determine if adjustments are appropriate. For example, case studies by necessity begin by using without- and with-improvement data. Sometimes adjustments are made to control for secular trends such as increasing traffic volume and decreasing accident rates. If such adjustments were not made, the reported results would understate travel time savings and overstate accident-related savings.

General findings from selected case studies are presented below, by ITS improvement type:

**Arterial Management Systems**

Case studies provide a range of different benefits for arterial management systems. Studies report that the percent reduction in stops due to improved traffic signal control range from 10 to 41 percent. Changes in travel time range from an increase of 6 percent in one case study up to a 20 percent decrease in a different study. Reductions in delay due to traffic signal controls range from 14 to 44 across eight separate case studies. Case study examples also found that traffic control systems reduced fuel consumption by 2 to 13 percent.

**Ramp Metering**

Case studies report increased throughput on the ramps of 5 to 30 percent and travel time savings on the affected freeways of 22 to 52 percent (speed increases of 8 to 60 percent). The analysis in the previous section can be applied to this particular type of ITS improvement if special analyses are not available. It should also be noted that some jurisdictions have reported increased delays after implementing ramp metering, including jurisdictions cited as reporting reduced delays by the *Intelligent Transportation Systems Benefits: 2001 Update* report.

**Incident Management**

Case studies report reductions in the time it takes for an incident to clear of from 38 to 66 percent. Reported decreases in the frequency of secondary incidents range from 30 to 50 percent. One case study reported a 5 percent reduction in delay associated with non-recurring congestion.

**Traveler Information Systems**

Traveler information systems can result in travel time savings for individual travelers who might otherwise take a less efficient route. Information systems also affect travel times by allowing travelers the option of changing departure times to avoid congested conditions. Estimating these savings would require knowledge of how many travelers change their route choice and departure times because of the information provided and how much time they save on the more efficient route. Additionally, travelers already on the more efficient route may experience greater congestion and lower speeds that partially offset the travel time savings accruing to rerouted travelers.

**Infrastructure Operation and Maintenance**

Intelligent Infrastructure Operation and Maintenance systems vary widely and the travel time savings associated with them depend on the nature of the project and the details of the implementation. Case studies exist for intelligent de-icing and snow-removal dispatch
systems; however, while these estimate time savings for workers, they do not estimate time savings for travelers that result from having roads cleared sooner.

**Electronic Toll Collection, Weigh-in-Motion, and Electronic Credentialing**

Intelligent transaction-processing systems reduce the time required to process each individual transaction as well as the time spent waiting in queue for others’ transactions to be processed. If the physical configuration of the facility is not changed (i.e., there are the same number of stations and the same distance to merge, etc.) these savings may be estimated directly from the change in transaction time, given the number of stations and the arrival rate. The transaction time calculations do not lend themselves easily to formulae or diagrams. The worksheet below steps through the calculations. In the worksheet, provision is made for multiple “streams,” which are different sub-facilities with different average transaction times. For example, a toll facility might have separate sub-facilities for transponder-equipped vehicles, vehicles with exact change, and others.
## Worksheet 3-1: Travel Time Savings from Intelligent Transaction Processing—Sample Calculation

### INTELLIGENT TOLLING, WEIGHING, AND CREDENTIALING WORKSHEET

#### INPUT DATA

<table>
<thead>
<tr>
<th>Average Transaction Time in hours (t)</th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stream 1</td>
<td>Stream 2</td>
</tr>
<tr>
<td>Number of Stations (c)</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Arrival Rate per Hour (lambda) by Time Period</th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stream 1</td>
<td>Stream 2</td>
</tr>
<tr>
<td>1 AM Peak</td>
<td>1,500</td>
<td>200</td>
</tr>
<tr>
<td>2 Mid-Day</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>3 PM Peak</td>
<td>1,750</td>
<td></td>
</tr>
<tr>
<td>4 Off-Peak</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>5 Weekend Day</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shares of Stream Volumes by Vehicle Class</th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stream 1</td>
<td>Stream 2</td>
</tr>
<tr>
<td>1 Single-Occupant Cars</td>
<td>80%</td>
<td>34%</td>
</tr>
<tr>
<td>2 Multi-Occupant Cars</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>3 2-Axle Trucks</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>4 Heavy Trucks</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hours Per Week Represented by Time Periods (Hp)</th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 AM Peak</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2 Mid-Day</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>3 PM Peak</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>4 Off-Peak</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>5 Weekend Day</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>168</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COMPUTATIONS STEP 1: Probability that all stations are empty (Po)</th>
</tr>
</thead>
<tbody>
<tr>
<td>For each combination of stream, current/proposed, and time period, calculate the following:</td>
</tr>
<tr>
<td>If more than one station serves a stream, use:</td>
</tr>
</tbody>
</table>
| \[
| P_{n} = \left(\sum_{n=0}^{c} \frac{\lambda^{n}}{n!} \cdot \left(1-t \lambda / c\right)^{n}\right)^{-1} |
| c is the number of stations, t is the average time to process a transaction, and lambda is the arrival rate per hour |
| If only one station serves a stream, use: |
| \[
<p>| P_{n} = 1 - t \lambda / c |</p>
<table>
<thead>
<tr>
<th>Probability all stations empty</th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stream 1</td>
<td>Stream 2</td>
</tr>
<tr>
<td>1 AM Peak</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>2 Mid-Day</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>3 PM Peak</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>4 Off-Peak</td>
<td>0.54060</td>
<td>0.00000</td>
</tr>
<tr>
<td>5 Weekend Day</td>
<td>0.54060</td>
<td>0.00000</td>
</tr>
<tr>
<td>6 Weekend Day</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
</tbody>
</table>
For each combination of stream, current/proposed, and time period, calculate $W$ where:

$$W = t + P_o \left( \frac{(t\lambda)^c}{c!(c/t)(1-t\lambda/c)^c} \right)$$

$P_o$ comes from Step 1 above, $\lambda$ is the arrival rate per hour, $c$ is the number of stations, and $t$ is the average time to complete a transaction in that stream.

<table>
<thead>
<tr>
<th>Total Delay per Transaction</th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stream 1</td>
<td>Stream 2</td>
</tr>
<tr>
<td>1 AM Peak</td>
<td>0.0252</td>
<td>0.0000</td>
</tr>
<tr>
<td>2 Mid-Day</td>
<td>0.0087</td>
<td>0.0000</td>
</tr>
<tr>
<td>3 PM Peak</td>
<td>0.0604</td>
<td>0.0000</td>
</tr>
<tr>
<td>4 Off-Peak</td>
<td>0.0084</td>
<td>0.0000</td>
</tr>
<tr>
<td>5 Weekend Day</td>
<td>0.0086</td>
<td>0.0000</td>
</tr>
<tr>
<td>6</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

**COMPUTATIONS STEP 3: Expected total delay per year (D)**

For each combination of stream, current/proposed, and time period, calculate $D$ where:

$$D = 52W\lambda H_p$$

$W$ comes from Step 2 above, $\lambda$ is the arrival rate per hour, and $H_p$ is the hours per week represented by each time period.

<table>
<thead>
<tr>
<th>Total Delay per Year</th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stream 1</td>
<td>Stream 2</td>
</tr>
<tr>
<td>1 AM Peak</td>
<td>19,662</td>
<td>0</td>
</tr>
<tr>
<td>2 Mid-Day</td>
<td>3,903</td>
<td>0</td>
</tr>
<tr>
<td>3 PM Peak</td>
<td>54,965</td>
<td>0</td>
</tr>
<tr>
<td>4 Off-Peak</td>
<td>2,996</td>
<td>0</td>
</tr>
<tr>
<td>5 Weekend Day</td>
<td>891</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Delay per Year</td>
<td>81,908</td>
<td>0</td>
</tr>
</tbody>
</table>

**COMPUTATIONS STEP 4: Spread to Vehicle Classes, Sum Over Streams, and Convert to Dollars**

For each stream, multiply the total delay per year by the share for each vehicle class.

<table>
<thead>
<tr>
<th>Total Delay by Vehicle Class</th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stream 1</td>
<td>Stream 2</td>
</tr>
<tr>
<td>1 Single-Occupant Cars</td>
<td>65,526</td>
<td>0</td>
</tr>
<tr>
<td>2 Multi-Occupant Cars</td>
<td>8,191</td>
<td>0</td>
</tr>
<tr>
<td>3 2-Axle Trucks</td>
<td>5,734</td>
<td>0</td>
</tr>
<tr>
<td>4 Heavy Trucks</td>
<td>2,457</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Sum by configuration and subtract total delay under Alternative Configuration from total delay under Current Configuration and multiply by value of time by vehicle class to obtain value of time savings.

<table>
<thead>
<tr>
<th>Time Savings by Vehicle Class</th>
<th>Current - Alternative</th>
<th>Difference</th>
<th>times V of T</th>
<th>Value of Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Single-Occupant Cars</td>
<td>65,526</td>
<td>14,010</td>
<td>10.00</td>
<td>140,096</td>
</tr>
<tr>
<td>2 Multi-Occupant Cars</td>
<td>8,191</td>
<td>1,751</td>
<td>25.00</td>
<td>43,780</td>
</tr>
<tr>
<td>3 2-Axle Trucks</td>
<td>5,734</td>
<td>1,226</td>
<td>20.00</td>
<td>24,517</td>
</tr>
<tr>
<td>4 Heavy Trucks</td>
<td>2,457</td>
<td>525</td>
<td>25.00</td>
<td>13,134</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total is value of annual time savings in dollars. Total $221,526$
Worksheet 3-1: Travel Time Savings from Intelligent Transaction Processing

### Input Data

<table>
<thead>
<tr>
<th></th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 3</td>
<td></td>
<td></td>
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<tr>
<td>Stream 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average Transaction Time in hours (t)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number of Stations (c)</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Arrival Rate per Hour (lambda) by Time Period</strong></th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1 AM Peak</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2 Mid-Day</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3 PM Peak</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4 Off-Peak</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5 Weekend Day</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>6</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Shares of Stream Volumes by Vehicle Class**

<table>
<thead>
<tr>
<th></th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1 Single-Occupant Cars</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2 Multi-Occupant Cars</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3 2-Axle Trucks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4 Heavy Trucks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>6</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total over vehicle classes</strong></td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Hours Per Week Represented by Time Periods (Hp)**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1 AM Peak</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2 Mid-Day</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3 PM Peak</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4 Off-Peak</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5 Weekend Day</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>6</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total over time periods</strong></td>
<td>(must equal 168)</td>
<td></td>
</tr>
</tbody>
</table>

### Computations

**Step 1: Probability that all stations are empty (Po)**

For each combination of stream, current/proposed, and time period, calculate the following:

If more than one station serves a stream, use:

$$ P_0 = \left( \frac{1}{c!} \sum_{n=0}^{\infty} \left( \frac{1}{n!} \right) \left( \frac{c}{t} \right)^n \right)^{c-1} $$

If only one station serves a stream, use:

$$ P_0 = 1 - \frac{c}{t} \lambda / c $$

<table>
<thead>
<tr>
<th>Probability all stations empty</th>
<th>Current Configuration</th>
<th>Proposed Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1 AM Peak</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2 Mid-Day</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3 PM Peak</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4 Off-Peak</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5 Weekend Day</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>6</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For each combination of stream, current/proposed, and time period, calculate $W$ where:

$$ W = t + P_0 \left( \frac{\left( \frac{t}{\lambda} \right)^c}{c! \left( c/t \right)^c \left( 1 - t/\lambda c \right)^c} \right) $$

$P_0$ comes from Step 1 above, $\lambda$ is the arrival rate per hour, $c$ is the number of stations, and $t$ is the average time to complete a transaction in that stream.

### Total Delay per Transaction

<table>
<thead>
<tr>
<th>Stream 1</th>
<th>Stream 2</th>
<th>Stream 3</th>
<th>Stream 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-Day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM Peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off-Peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekend Day</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Total Delay per Year

For each combination of stream, current/proposed, and time period, calculate $D$ where:

$$ D = 52W\lambda H_p $$

$W$ comes from Step 2 above, $\lambda$ is the arrival rate per hour, and $H_p$ is the hours per week represented by each time period.

And sum over time periods.

<table>
<thead>
<tr>
<th>Stream 1</th>
<th>Stream 2</th>
<th>Stream 3</th>
<th>Stream 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-Day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM Peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off-Peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekend Day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Total Delay by Vehicle Class

For each stream, multiply the total delay per year by the share for each vehicle class.

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Stream 1</th>
<th>Stream 2</th>
<th>Stream 3</th>
<th>Stream 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Occupant Cars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-Occupant Cars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-Axle Trucks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Trucks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sum by configuration and subtract total delay under Alternative Configuration from total delay under Current Configuration and multiply by value of time by vehicle class to obtain value of time savings.

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Current</th>
<th>Alternative</th>
<th>Difference</th>
<th>$V$ of $T$</th>
<th>Value of Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Occupant Cars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-Occupant Cars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-Axle Trucks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Trucks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Total is value of annual time savings in dollars.
In the example above, a hypothetical toll facility had three stations, each of which had an average transaction time of 30 seconds (0.00833 hours). Two of the stations were replaced with automated stations with average transaction times of 10 seconds (0.00278 hours). The original single stream was divided into two streams, one the non-automated tollbooth and one for the automated facilities. Time periods were defined and vehicle counts specified. Vehicles were divided into vehicle classes and the number of hours per week accounted for by each time period was specified.

The remainder of the analysis is completed by applying the formulas shown in the worksheet. First, the probability that all stations serving a stream will be available when a vehicle arrives is calculated. Then the average wait time (in hours) for each stream in each time period is calculated. Then total annual wait times by stream and time period are calculated. Annual wait times are added up over time periods and spread to vehicle classes. Total annual wait times by vehicle class under the original and proposed configuration are subtracted to obtain wait-time savings by vehicle class, which are multiplied by the average value of time (per hour) for each vehicle class to obtain the value of time saved.

ITS improvements that reduce delay and improve speeds and travel times can be analyzed by incorporating the changes in the value of travel time per vehicle mile in the User Benefit Formula.

**Calculating the Value of Time Savings**

The primary intended benefit of ITS improvements is travel time savings. As long as the travel time savings arise from improvements in average speeds and can be reduced to changes in the value of travel time per vehicle mile, they can be incorporated in the User Benefit Formula. The speed changes are incorporated in the calculation of total user costs via Equation 3-3.

**Calculating the Value of Vehicle Operating Cost Savings**

The reduction in delay that may result from ITS improvements may also reduce operating costs. Changes in speed can be linked to operating cost savings using information in the Operating Cost Module. Generically, that information is used to calculate a speed-operating cost relationship of the general form of Equation 3-4.

The assumption of this formulation is that the information is reduced to a per vehicle-mile (or passenger mile) basis for inclusion in the basic User Benefit Formula.

**Calculating the Value of Accident Cost Savings**

ITS improvements may improve or degrade the accident rates experienced on the affected facilities. Although there is no specific information available on the relationship between accident rates and ITS improvements, the analyst may wish nonetheless to benchmark the accident rate effects of ITS improvements against other types of improvements. Information on the accident rate effects of other improvements, and the unit cost of injury, fatal, and property accidents is available in the Accident Cost Module. Incorporation of changes in accident costs in the User Benefit Formula is easiest if the impact on accident costs is reduced to a per vehicle mile (or passenger-mile) basis.
Equation 3-5 is the general form of the calculation of the component of user costs representing changes in the accident costs.

**Where to Next?**

If the user benefit calculations described in this chapter have been completed, the analyst has obtained total user benefit estimates for at least the peak period of several project years, for all of the affected user or vehicle classes and affected system segments. The integration of this information is performed using the guidelines of Chapter 6 of this manual. Chapter 6 also provides advice concerning methods of expanding selected, detailed calculations to annual figures, and over the life of the project. Not all improvement types are amenable to formulaic expansion of selected peak periods, unfortunately. In this case, the analyst will need to perform additional analyses or make cruder assumptions about expansion of selected analyses across the entire project’s life.
PRICING AND REGULATORY POLICIES
Transportation planning agencies are turning increasingly to policies that affect traveler behavior in lieu of, or in addition to, engineering solutions to transportation problems. These policies constitute a “project” that deserves evaluation as much as an engineering solution to a problem deserves evaluation. These “policy projects” use two, broad policy approaches: regulation and pricing. A very wide range of policies fall under this rubric.

The Basic Elements of Evaluating Pricing Policies
Pricing policies are policies that have the effect, intended or not, of changing the cash cost elements of user cost. Examples of pricing policies are:

- **Vehicle tolling.** Tolls are levied on vehicles as a means of road finance in a variety of ways, from tolls that are uniform by vehicle type and time and place of travel, to tolls that vary widely by vehicle type, traffic level, and place of travel (“congestion pricing”). Any institution of or change in the level of tolls, including lane pricing or “HOT Lanes,” could be viewed as a pricing policy project.

- **Fuel, tire, and vehicle fee levies.** The most common form of road finance is the levying of taxes on the purchase of fuel (at the wholesale or retail level) and fees or taxes levied on the purchase or registration of the vehicle or its tires. Any change in these levies could be viewed as a pricing policy project.

- **Indirect pricing policies.** Indirect pricing policies involve changes in prices elsewhere in the economy, with the aim of affecting travel behavior indirectly. Examples of common, indirect pricing policies are transportation system development charges (SDCs), transportation impact fees, and parking cash-out policies. To properly analyze these policies, the impact of the policy on the affected activity (i.e., real estate or the parking market) must be evaluated. Analyses of such external impacts are outside the realm of this manual. Indirect pricing policies, therefore, are not discussed further in this manual.

The analysis of pricing policies uses the user benefit arithmetic detailed earlier in Equation 2-1. That is, user benefits are calculated from the change in total user costs that results from the imposition of the price (or its removal) and the associated change in traffic volumes.

The important difference is that pure pricing policies, by definition, involve imposition of prices without any necessary connection to costs of providing services. Consequently, the revenues from these levies, at least conceptually, could be returned to road users. Of course, they would have to be returned in a way that did not undo pricing’s effect on travel behavior (e.g., through an income tax rebate, provision of a service of equal value, etc.). The point is that the changes in revenues associated with pure pricing policies must be accounted for in the user benefit analysis because they have the potential to be returned to users.

Tolling to Control Congestion
An example illustrates the importance of properly treating changes in revenues from prices. Figure 3-9 below depicts a pricing policy involving the imposition of a new, or higher toll to control congestion on a busy corridor or road segment. As in the figure, the
total user costs, represented by the relationship, $U$, increases with traffic volume, $V$, because of the congestable nature of the highway, and captured by the relevant volume-delay relationship.

Imposition of the toll, $Z$, shifts this total user cost relationship from $U$ to $U'$. This, in turn, discourages some use of the highway through the action of the demand relationship, $D$. Specifically, the number of trips is reduced from $V_0$ to $V_1$, and the equilibrium user cost per trip increases from $U_0$ to $U_1$. The revenue collected from the toll is equal to $V_1$ times $Z$, represented graphically by the area of the rectangle, $A$.

Figure 3-9: The Effect of Tolls on Traffic Volume, User Benefits and Toll Revenue

In this setting, the net user benefit is as calculated in Equation 3-15, derived from the User Benefit Formula. Note that in the case of an increase in tolls, the first part of Equation 3-15 will be negative, because user costs per mile are higher with the toll than without.
Equation 3-15: User Benefits Under Tolling

\[
B_c = \Delta U \left( \frac{V_0 + V_1}{2} \right) L + \Delta R
\]

\[
= \left[ (U_0 - U_1) \left( \frac{V_0 + V_1}{2} \right) + Z V_1 \right] L \text{ in the case of a per-mile toll}
\]

where

- \( B_c \) = user benefit to vehicle class \( c \) traffic (dollars)
- \( U_0 \) = User costs without the improvement (dollars)
- \( U_1 \) = User costs with the improvement (dollars)
- \( \Delta U = (U_0 - U_1) \) = change in user costs per vehicle mile (dollars)
- \( V_0 \) = volume of vehicles/hour before the improvement
- \( V_1 \) = volume of vehicles/hour after the improvement
- \( L \) = the segment or corridor length, in miles
- \( \Delta R \) = change in toll revenues (dollars)
- \( Z \) = change in the toll (dollars per vehicle mile)

However, the additional revenue collected by the toll is not lost to users, unless it is collected and never returned to them by any means. (Figuratively, the revenue is “burned.”) The additional revenue offsets the negative benefit calculated in the first half of the equation to some degree. Indeed, in the example depicted in Figure 3-9, it would appear that the increase in toll revenue more than offsets the source of negative benefits; that is,

\[
Z V_1 > (U_0 - U_1) \left( \frac{V_0 + V_1}{2} \right).
\]

Consequently, the imposition of a higher toll actually increases user benefit, despite increasing user costs. In the example, this occurs because the user cost per vehicle mile does not increase by as much as the toll because congestion is suppressed by reducing traffic volumes. This, in turn, lowers the travel time component of user cost. This is a demonstration of the potential benefit of congestion pricing, of course. But more importantly, it illustrates the importance of properly accounting for revenues from the pricing policy.

Since most pricing policies can be converted to per-mile or per-trip pricing, the calculations in Equation 3-15 can be applied directly to most practical instances of pricing policy. An actual application, of course, would require that the benefit calculation presented in Equation 3-15 be repeated for various vehicle classes and various times of travel and the relevant project years.

The Basic Elements of Evaluating Regulatory Policies

Regulatory approaches try to affect behavior by controlling use of highway facilities through legal or engineering means. Examples of regulatory policies include:
• **Speed limits.** Both upper and lower speed limits are imposed on roads to control accident costs or to optimize the operating capacity of the road.

• **Traffic calming.** Traffic calming refers to a broad group of policies that generally are designed to reduce the effective capacity of existing roads. It is used to slow traffic to control accidents, to restrict traffic diversion onto certain facilities, or to simply reduce the effective capacity of a facility as a means of limiting use of automobiles or other vehicles. A variety of engineering techniques, including speed-bumps, changes in signal timing and institution of ramp metering, are used to implement these policies.

• **Dedicated carpool lanes.** Under this approach, access to certain lanes of a facility is restricted to automobiles with vehicle occupancy levels of more than two or three passengers, or more. These restrictions may be placed on a facility when it is first built, or added or removed retroactively.

• **Parking policies.** Parking restrictions affect demand for highways indirectly, by making storage of the vehicle at the end of its trip more difficult.

• **Vehicle-type and weight restrictions.** Regulating the size and type of vehicles that may use a facility is a way to control facility capital and/or operating costs, improve overall traffic performance, or control accident costs.

As these examples make clear, the hallmark of regulatory policies is that they usually impose traffic quantity restrictions, enforced through various legal and engineering means. Consequently, analysis of the effects of regulatory policies is analogous, in many cases, to the analysis of capacity changes.

In most cases, regulatory policies can be modeled as reductions or increases in effective capacity, using the same (or reversed) techniques that are used to model increases in capacity that result from engineering initiatives. Normally, reductions in capacity, of course, would reduce user benefits. Presumably, however, in those instances, there are offsetting advantages (in terms of reduced accidents, for example) that make reductions in capacity beneficial on balance. In other cases, such as with dedicated carpool lanes, the limited access is believed to either offer benefits (in terms of higher speed) to one class of users or stimulate mode choice decisions (i.e., the decision to carpool or not). The presumption is that the benefits associated with these positive effects offset the losses to those whose use of the facility is restricted.

The appropriate analytical approach depends upon the general type of regulation, and the specific primary and secondary effects of the regulation.

**Regulations That Increase User Cost for Offsetting User Benefit**

Speed limits and vehicle calming are examples of policies whose primary effect is to increase certain components of user cost, with a secondary effect of reducing certain other user costs. A speed limit, for example, has the primary effect of increasing travel time (which reduces user benefit), but, secondarily, reduces accidents (which increases
user benefit). A freeway ramp meter delays users at the ramp (primary effect) in exchange for improved performance and reduced delay on the freeway itself (secondary effect).

The evaluation of policies of this type proceed using basic user benefit arithmetic, as presented in the User Benefit Formula described earlier in this manual. The analyst must only be sure to include both primary and secondary changes in user cost in the calculation. Proper measurement depends only upon accurate rendering of these changes in user cost and the accompanying changes in trips or traffic volumes that attend the implementation of the policy. This, in turn, may require engineering analysis of the effects of the particular policy (i.e., speed limits, ramp metering, etc.) on operating speeds and costs. The effect of an improvement on operating speeds is either obtained by formally modeling the volume-delay relationships, or through the many detailed worksheets available in the HCM 2000.

Regulations That Change User Cost to Influence Modal Behavior
Carpool lanes and parking restrictions are examples of policies whose primary effect is on the user’s travel time or operating cost, with a secondary effect on modal behavior. The analytic approach that needs to be taken differs in each case. The following are only offered as important examples of the analysis of such policies.

**Carpool Lanes**

The typical carpool lane project involves conversion of an existing lane or the addition of a new lane for use by carpools only. In such a case, the base case project assumes the presence of the lane without carpool restriction. Compared to the base case, institution of carpool restrictions increases the travel speed of some drivers and passengers (those who use the lanes) and usually decreases the speed (relative to the base case) of drivers and passengers who remain in the non-carpool lanes. To fully account for the change in user benefits of the carpool lane, therefore, benefit calculations must be performed on at least four sub-classes of the users of the affected road: (1) former drivers who are now passengers in the carpool lane; (2) former passengers in the non-carpool lanes who are now passengers in the carpool lane; (3) drivers who use the carpool lane; and (4) drivers and passengers who remain in the non-carpool lane. If the carpool lane is also offered to transit buses, it may be necessary to further bifurcate the first and second groups into car and bus passengers, since the user costs associated with carpool lane use are different. In addition, if a significant amount of induced (new) travel in the carpool or non-carpool lanes is expected as a result of the policy, additional user classes may be required to accurately render their respective changes in user cost and user benefits.

Equation 3-16 below summarizes the calculations that must be made for the four sub-classes described above. Equation 3-16 is derived from the basic User Benefit Formula. Note, however, that for the sake of clarity, an additional user cost element, $\Delta Q$, has been isolated to represent the cost associated with carpool formation. This cost element is in addition to the usual changes in travel time, operating costs, and accident costs ($\Delta H$, $\Delta OC$, and $\Delta AC$, respectively) that are part of the conventional user benefit analysis. However, it should be included either in operating cost or travel time costs components.

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*User Benefit Analysis for Highways*
depending upon the nature of the cost of carpool formation. It is broken out in this discussion only for exposition of the issue.

The reason for inclusion of $\Delta Q$, of course, is to respect the fact that passengers and drivers in the carpool lane incur costs related to the reduced travel flexibility and schedule delay associated with forming and operating as a carpool. Indeed, if this were not so, they would have formed carpools without the carpool lane. Note that $\Delta Q = 0$ for the fourth subclass of users—i.e., those users who remain in the non-carpool lane—since they incur no such costs.

**Equation 3-16: User Benefits with Carpool Lanes**

\[
B_1 = \Delta U \left( \frac{V_{1.0} + V_{1.1}}{2} \right) L = (\Delta VT_1 + \Delta OC_1 + \Delta AC_1 + \Delta Q_1) \left( \frac{V_{1.0} + V_{1.1}}{2} \right) L
\]

\[
B_2 = \Delta U \left( \frac{V_{2.0} + V_{2.1}}{2} \right) L = (\Delta VT_2 + \Delta OC_2 + \Delta AC_2 + \Delta Q_2) \left( \frac{V_{2.0} + V_{2.1}}{2} \right) L
\]

\[
B_3 = \Delta U \left( \frac{V_{3.0} + V_{3.1}}{2} \right) L = (\Delta VT_3 + \Delta OC_3 + \Delta AC_3 + \Delta Q_3) \left( \frac{V_{3.0} + V_{3.1}}{2} \right) L
\]

\[
B_4 = \Delta U \left( \frac{V_{4.0} + V_{4.1}}{2} \right) L = (\Delta VT_4 + \Delta OC_4 + \Delta AC_4) \left( \frac{V_{4.0} + V_{4.1}}{2} \right) L
\]

where:

- $B_1$ = benefits (cents) for carpool lane passengers (former drivers)
- $B_2$ = benefits (cents) for carpool lane passengers (former passengers)
- $B_3$ = benefits for carpool lane drivers (cents)
- $B_4$ = benefits for drivers and passengers not using carpool lane (dollars)
- $\Delta Q_c$ = the cost of carpool formation (cents) for user class $c$
- $V_{c,0}$ = the volume of user class $c$ without the improvement (vehicle/hour)
- $V_{c,1}$ = the volume of user class $c$ with the improvement (vehicle/hour)

Equation 3-16 reveals that analysis of carpool lanes requires knowledge of which users of the base-case road are likely to be part of the carpool population after the policy is instituted, and which will remain in the non-carpool lanes. The size of the user benefits is also dependent on the size of $\Delta Q$, the cost of carpool formation. This cost is inherently difficult to measure outside the context of a specialized demand model, but even reasonable guesses are helpful. If modest assumptions about the size of $\Delta Q$ make net benefits zero, for example, the project can quickly be deemed infeasible.

**Parking and Other Destination-Based Restrictions**

Some advocate the use of parking restrictions in lieu of other, direct pricing policies such as tolls or congestion pricing. Cities like Portland, Oregon, and Pittsburgh, Pennsylvania, for example, regulate the number of parking spaces that can be built or operated to serve commute parking needs. Other programs limit the proportion of workers at a workplace who may come to work by single-occupant automobile and park at the company’s
parking lot. (These are so-called, employer-based regulations.) All of these policies have the intention of encouraging the use of transit and carpooling over single occupant vehicles (SOVs).

Such policies can be complicated to analyze, because their effect depends on the nature and effectiveness of their implementation. In addition, these policies are frequently accompanied by transit enhancements or incentive programs that also need to be included in the evaluation. Maintaining this manual’s focus on highway users, the elements of these policies that involve evaluation of transit strategies are ignored here.

The analysis on highway users themselves is facilitated by turning what is primarily rationing policy into an equivalent change in user costs. Specifically, there is a parking charge that will have the same, quantitative effect as the regional parking restrictions. With information on how the quantity of parking services is affected by price, the price-equivalent of a rationing policy can be determined. The usual approach is to assume a price-elasticity of demand for parking, and to solve for the change in the level of parking charges that yields the regulation change in the quantity of parking spaces or parking space-hours. Equation 3-17 demonstrates how to calculate the price-equivalent user cost of a parking restriction policy using this information.

**Equation 3-17: Change in Parking Costs**

\[
\Delta P = \frac{P_i \Delta S_i / S_i}{e_{S_i}^P}
\]

where:

- \( P_i \) = the user cost of parking (cents) in the base case, for parking type \( i \)
- \( \Delta S / S = \) the regulated percentage change in parking use
  (expressed in parking spaces or parking space-hours)
- \( e_{S_i}^P = \) the price elasticity of parking demand (conventionally, \( e_{S_i}^P < 0 \))
- \( \Delta P_i = \) the price-equivalent effect of the parking restriction

If a parking restriction is being put in place, \( \Delta S / S \) is negative, and as a result, \( \Delta P \) is positive. Relative to the base case, a parking restriction is tantamount to an increase in parking price and, correspondingly, an increase in user cost of trips to the restricted destination. Using this approach, therefore, a parking restriction can be evaluated using the arithmetic of Equation 2-1 and Equation 3-17 above, whereby the parking restriction policy is the source of the increase in user costs (\( \Delta U \)) through its effect on vehicle operating costs (\( \Delta OC \)). It is important to note, however, that unless the parking restriction is actually implemented through a parking pricing policy, there is no offsetting increase in revenue (i.e., \( \Delta R=0 \)) as in the case in Equation 3-17 where the pricing is actually implemented. This illustrates the important economic point that pricing is a more efficient way to obtain a quantitative goal than is a direct regulation of quantity.

**Regulations That Balance User and Road-Authority Costs**

Vehicle weight limitations and truck-only facilities are examples of policies whose primary effect is to change the user cost of the weight-limited vehicle, but which have the secondary impact of affecting the road authority’s capital, operating, or maintenance
expenses. Such policies also have an additional secondary effect on traffic stream performance, to the extent that the policy results in a change in effective road capacity and traffic flow.

Another broad class of regulations of this type are policies such as bans on highway construction and “pricing through congestion” policies that are believed by some to save the highway authority more than is lost to inconvenienced users.

**Weight Limitations and No-Truck Routes**

The logic of posting vehicle weight limitations or no-truck routes is that the increased costs of the user is offset by lower development, maintenance or rehabilitation costs to the highway authority. The proper treatment of the associated reductions in highway authority costs is analogous to any other capital or operating expense of the project, and should be treated as a project cost rather than a user cost. From the user benefit side, analysis of this type of regulation involves calculation of the change in user cost ($\Delta U$) that is occasioned by the regulation, and then proper implementation of the benefit calculation that is represented by the User Benefit Formula. Generally, the analysis must be done for at least two classes of users, automobiles and trucks. This is because the limitation or restriction on truck movements may have impacts on the performance of automobile traffic. The appropriate base case is the facility operating without the weight or other restrictions on truck traffic.

In implementing the User Benefit Formula in this context, there are some special considerations to bear in mind:

- The increase in user operating cost often comes about through the need for the truck or bus operator to take a more circuitous route to avoid use restrictions. In such cases, the analysis needs to be done on a corridor or origin-destination pair basis (rather than a link-level basis). The $\Delta U$ and the vehicle volumes are measured accordingly by corridor or origin-destination (O-D) pair before implementing the User Benefit Formula.

- The increase in user cost in other cases comes about by having to make shipments in small vehicles more frequently over the weight-limited road segment(s). In this case, link-level analysis can be used to implement the User Benefit Formula.

**Truck-Only Highways**

The decision to build truck-only highways, or to split an existing facility or corridor of facilities into auto-only and truck-only facilities is a special case of the use restriction example above. It is mentioned separately to emphasize the appropriate base case that should be used in the analysis. Specifically:

- To evaluate the feasibility of a new, trucks-only facility, the base case should be modeled on the highway network without the facility;

- To evaluate the trucks-only policy restriction, however, the base case should be the new facility without the trucks-only policy. This approach assumes that such a facility has already been deemed otherwise feasible, and the only incremental
feasibility consideration is to determine whether the highway corridor or network is better or worse off dedicating the facility to trucks only.

In either case, analysis of truck-only facilities requires measurement of the effect of trucks on the flow of mixed traffic in order to properly measure the associated changes in operating cost, travel time, and accident rates. The HCM 2000 should be used to develop estimates of the impact of mixed traffic on vehicle flow characteristics of a facility. Some accident cost information relating to traffic mix is presented in the Accident Cost Module later in this manual.

Bans or Restrictions on Highway Construction
The ultimate highway regulation, in some sense, is banning or restricting highway development. Vancouver, British Columbia, is famous for having banned freeway construction in the 1960s, for example. More commonly, other policies, such as transit investment or regulation of land use, take credit in their own benefit-cost analyses for having saved the full cost of the highways that otherwise would have been built. The issue for this manual is how to evaluate policies (or their removal) that restrict highway development, whether in the name of another beneficial use or not.

In general, a policy of banning construction of highway projects is best analyzed with the highway project as the base case, and the removal of the project as the “project” case. From the standpoint of this manual, highway projects should only be built if they offer user benefits that exceed (in present value) the various costs of developing and operating the facility over its life. Consequently, if the base-case project is economically feasible, its removal will be found to impose a transportation cost on society equal to the present value of its user benefits over costs. In addition, other social and environmental impacts of the base case should be considered in light of the transportation cost.

The more complex case is a regulation that substitutes another policy, say land-use regulation, for highway development. Should the analyst of that policy include in its benefits the saved spending on highways that otherwise would have occurred? If a highway is not built, what is lost is the present value of the lifetime benefits of the highway, and what is gained is the saved development and operating costs. Thus, what is lost (for a feasible project) is the net of benefits over costs. If some other policy offers a higher net benefit to the same user population, it should certainly be built in lieu of the highway alternative. All of the benefits of doing so, however, are captured in its own net benefit calculation. It cannot claim as a benefit having saved the development of another alternative.

Where to Next?
This chapter has attempted to show how various regulator policies can be characterized in a manner consistent with the User Benefit Formula and the other basic user cost calculations offered in this manual. Depending upon the nature of the project, the analyst should follow the general procedures in Chapters 2 and 6 of this manual, or draw upon the information relating to particular improvement types in other chapters.
Chapter 4. Evaluating Safety Improvements

Many modern highway projects are developed with the purpose of improving the safety, rather than the capacity of the highway network. Evaluating safety improvements is, in many ways, a more complex undertaking than evaluating operational improvements because the affected facility’s engineering characteristics are usually more intimately involved in the safety problems and their solutions. In addition, the empirical evidence linking specific changes in engineering characteristics and the resulting changes in accident rates is very limited, or based on small studies in settings that may not be relevant to the analyst’s setting.

As a practical matter, these circumstances limit the amount of direct, empirical information that a user benefit manual can provide. Hence, this chapter is focused primarily on how to think about the user benefits that arise from various kinds of engineering improvements, providing links to the *HCM 2000* and other sources, and identifying key empirical issues that the analyst may need to resolve locally.

This chapter focuses on four, generic classes of safety improvements:

- *Geometric improvements* in the curvature and grade of the roadway;
- *Lane improvements* in the form of special lanes to relieve certain types of safety concerns;
- *Access management improvements* designed to limit the interaction of incompatible traffic activities;
- *Roadside improvements* that provide safety enhancements to road users.

There is a natural overlap, of course, between safety improvements and the benefits that these improvements may generate because of effective increases (or decreases) in capacity that often result from the improvements. Analysis of capacity enhancements is addressed in detail elsewhere in this manual. However, safety improvements, as we shall see, often result in improved facility speeds. Consequently, the analysis of safety improvements involves, significantly, analysis of changes in travel time costs of users.

**Sources of Information Relating to the Effects of Safety Improvements**

**Geometric Improvements**

The term *geometry* can be applied to numerous aspects of road and highway design. In this section, we limit our focus to improvements targeted at horizontal and vertical curves. Improvements to road geometry are generally targeted at improving safety by reducing curve angles. These improvements are categorized into the following groups:

- *Horizontal Curve Improvements*. These projects are directed at making horizontal curves more gradual by straightening curved sections of existing roads.
- *Vertical Curve Improvements*. These projects are designed to limit the elevation or vertical angle of curves. This helps improve sight distances and traffic flow at intersections.
As discussed below, this also has an impact on queuing and flow at intersections, if the geometric improvement is done on an intersection approach.

Improvements that lessen the degree of vertical and horizontal curves result in the general benefits:

- Reductions in accidents and encroachments,
- Improved sight distances,
- More consistent travel speeds, and
- Reductions in queuing and delay times at intersections.

As this suggests, the primary intended effect on user costs of these particular geometric improvements may be a reduction in accident costs. However, improvements in sight distances, consistency of travel speeds, and reductions in delay contribute user benefits in the form of reduced user costs due to shorter travel times.

A change in the curvature of a highway segment will have an effect on travel time. Sharp curves or grades require that vehicles decrease speeds, lowering the effective speed of the segment. Curve improvements focus on making curves more gradual, allowing vehicles to travel through the segment at a more constant (higher) speed.

To calculate the effect of the change in travel time has on user costs, one has to calculate travel times both without and with the geometric improvement. To do this, information is needed on the following:

- **Traffic volumes.** If the geometric improvement changes traffic volumes on the segment, then volumes both without and with the improvement are needed for the calculation of travel time impacts.

- **Design speed.** Dramatic changes in road curvature may result in changes in design speed or the free-flow speed for the segment. For example, if an improvement substantially reduces the curvature of a highway segment, then the posted speed for that segment may increase. While traffic will not always flow at the posted speed, the design speed is combined with traffic volumes and other factors to determine travel times in the calculations discussed below.

The *HCM 2000* provides many tools and procedures to assist in the calculation of segment speeds. These procedures permit detailed consideration of segment features, including the effects of access points and weaving on the capacity and speed of a highway or arterial segment.

Table 4-1 presents references to the relevant worksheets in the *HCM 2000* that can be used to calculate segment speeds on various types of roadway segments or delay at intersections. If the proposed improvement simply involves an overall change in the grade of a given road segment (without a change in free-flow speed), then in many cases, modeling the incremental impact of the change involves changing only a single parameter (grade) on a single *HCM 2000* worksheet.
Table 4-1: Worksheets in the HCM 2000 for Calculating Speed or Delay on Roadway Segments or Intersections of Various Types

<table>
<thead>
<tr>
<th>Roadway Segment or Intersection Type</th>
<th>HCM 2000 Worksheets</th>
<th>Output of HCM 2000 Worksheets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signalized Intersections</td>
<td>Signalized Intersection Worksheet (Ch. 16)</td>
<td>$D$, intersection delay</td>
</tr>
<tr>
<td>Unsignalized Intersections</td>
<td>Unsignalized Intersections Worksheet (Ch. 17)</td>
<td>$D$, intersection delay</td>
</tr>
<tr>
<td>Two-Lane Highway</td>
<td>Directional Two-Lane Highway Segment Worksheet (Ch. 20)</td>
<td>$S$, segment speed</td>
</tr>
<tr>
<td>Multilane Highway</td>
<td>Multilane Highways Worksheet (Ch. 21)</td>
<td>$S$, segment speed</td>
</tr>
<tr>
<td>Freeway</td>
<td>Basic Freeway Segments Worksheet (Ch. 23)</td>
<td>$S$, segment speed</td>
</tr>
</tbody>
</table>

**Lane Improvements**

Lane improvements can encompass a very broad range of projects across highway types, some of which have been discussed in other chapters of this guidebook. The simple addition of lanes to streets and highways to increase capacity, for example, has been discussed earlier in the manual.

This section focuses on other lane improvements that do not fit neatly into the pure, capacity-enhancing project designation. Specific lane improvement types addressed in this section include:

- **Lane and Shoulder Widening.** This involves increasing the width of existing lanes or highway. Increasing lane width has been shown in repeated studies to reduce accidents.

- **Climbing or Passing Lanes.** The addition of climbing or passing lanes to a highway segment allows traffic flows to segregate based on speed. The addition of these lanes provides both safety and operational benefits by making vehicle speeds more homogenous within lanes.

- **Weaving Lanes.** Weaving lanes are those freeway lanes where vehicles are both entering and exiting the facility. As with climbing and passing lanes, these serve to enhance both highway safety and operation.

Each of these improvement types have a distinct operational benefit, as they improve the effective capacity of the roadway, in addition to a safety benefit, as accident rates are reduced both by widening lanes and by segregating traffic based on speeds. Both the operational and safety effects of these improvements and their effect on user costs are discussed in this section.

For each of the types of lane improvements, there may be a change in segment speeds, traffic volume, accident rates, and possibly the mix of vehicle classes. Increasing lane and/or shoulder widths will generally enhance traffic flow and increase speeds with a decrease in accidents. Similarly, adding a climbing lane or passing lane or a weaving
segment to a freeway will increase the overall capacity of a segment by removing slower moving vehicles from the overall traffic flow.

Table 4-2 identifies each of these improvements and their related highway types and sections in the HCM 2000. Each of these chapters in the HCM 2000 show the calculations needed to calculate travel speeds for each of the improvement types discussed here based on traffic volumes and characteristics of the highway such as capacity, free flow speed, grade, and other design features.

<table>
<thead>
<tr>
<th>Type of Lane Improvement</th>
<th>Highway/Intersection Type</th>
<th>HCM 2000 Worksheets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widening</td>
<td>All Types</td>
<td>Chs. 15, 20, 21, 23</td>
</tr>
<tr>
<td>Climbing/Passing Lanes</td>
<td>Two-Lane Highway, Multilane Highway, Freeway</td>
<td>Chs. 20, 21, 23</td>
</tr>
<tr>
<td>Weaving</td>
<td>Freeway</td>
<td>Ch. 24</td>
</tr>
</tbody>
</table>

Note that some multilane improvements, especially those involving multiple passing or climbing lanes, are complex. Chapter 5 of the HCM 2000 addresses these more complicated configurations. For all types of lane improvements, the analyst will need to calculate the change in speed by estimating travel time per mile per hour both without and with the improvement.

For passing, climbing, and weaving lanes, speed calculations need to be made for the individual lanes on the segment, as speeds on existing lanes will vary from speeds on the additional climbing or passing lane. In the case, adding a passing lane, traffic speeds will be higher than on the existing lanes while with climbing and weaving lanes, the speeds will be slower in these lane additions than in the existing lanes. Depending on the design and traffic volumes, however, weaving lanes can have the effect of reducing speeds for all lanes on the highway. In general for weaving lanes, a reduction in speed of approximately 6 miles per hour (10 kilometers per hour) relative to the highway as a whole is considered as a tolerable degree of congestion for weaving sections.7

The HCM 2000 provides guidance, methodology, data, and worksheets for making such calculations associated with these types of lane improvements. In general, an analyst will need to complete the appropriate segment or intersection worksheet from the HCM 2000 identified above. Table 4-3 below provides additional references in the HCM 2000 specifically referencing speed/delay associated with various types of lane improvements.

Improvements to lane width can be done on all types of highway segments. Consequently, the *HCM 2000* provides separate adjustments in its worksheets for lane width adjustments. Changes in both lane width and shoulder width affect traffic speeds. As lane width increases, up to a certain threshold point (i.e., 3.6 m for two-lane highways), free-flow speed generally increases. In each application, the calculation is basically the same with segment speeds calculated for each highway type without and with the increase in lane width.

The addition of a climbing lane presents a slightly more complicated calculation than the simple lane addition discussed elsewhere in this manual. Climbing lanes improve operational performance of a segment by segregating slower moving vehicles from the main traffic flow. As these slower moving vehicles are primarily trucks, information on traffic volumes by vehicle class is needed to accurately assess the operational improvements of a climbing lane. Similar to a climbing lane, a passing lane improves the operation of a segment by allowing faster vehicles the opportunity to pass slower moving traffic. Both passing and climbing lanes are applicable to several different types of highways, with each highway type requiring a different calculation. Table 4-2 highlights the appropriate chapters in the *HCM 2000* for each application for a given highway type for calculating changes in speeds that result from these improvements.

The addition of weaving lanes applies primarily to freeways and should improve free flow speed in the remaining freeway lanes. The *HCM 2000* provides a formula for calculating speeds for highway segments that contain a weaving segment. For the entire weaving area (all lanes), the average speed is given by:

### Table 4-3: HCM 2000 Worksheets by Improvement and Highway Type

<table>
<thead>
<tr>
<th>Type of Lane Improvement</th>
<th>Two-Lane Highway</th>
<th>Multilane Highway</th>
<th>Freeway</th>
<th>Unsignalized Intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widening</td>
<td>Ex. 20-4 “Adjustment for Lane and Shoulder Width”</td>
<td>Ex. 21-4 “Adjustment for Lane Width”</td>
<td>p. 22-9, “Lane Width Consideration”</td>
<td>p. 16-9 “Adjustment for Lane Width,” Ex. 16-7 “Adjustment Factors for Saturation Flow Rate”</td>
</tr>
<tr>
<td>Climbing</td>
<td>pp. 20-13 to 20-28, Ex. 20-12 to 20-26, Passing and Climbing Lanes</td>
<td>pp. 21-7 to 21-11, Ex. 21-8 to 21-11, Heavy Vehicle Adjustments and Grades</td>
<td>pp. 23-8 to 23-12, Ex. 23-8 to 23-11, Heavy Vehicle Adjustments and Grades</td>
<td>—</td>
</tr>
<tr>
<td>Weaving</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Ch. 24 pp. 1-30</td>
</tr>
</tbody>
</table>
Equation 4-1: Change in Speed in Weaving Area

\[
S = \frac{v}{\frac{v_w}{S_w} + \frac{v_{nw}}{S_{nw}}}
\]

where:

\[S = \text{Average speed for all vehicles in the weaving area (mph)}\]
\[S_w = \text{Average speed of weaving vehicles in the weaving area (mph)}\]
\[S_{nw} = \text{Average speed of non-weaving vehicles in the weaving area (mph)}\]
\[v = \text{Total flow rate in the weaving area (equivalent pcph)}\]
\[v_w = \text{Weaving flow rate in the weaving area (equivalent pcph)}\]
\[v_{nw} = \text{Non-weaving flow rate in the weaving area (equivalent pcph)}\]

The HCM 2000 includes a series of equations for estimating speeds for weaving vehicles \((S_w)\) and non-weaving vehicles \((S_{nw})\) based on maximum and minimum design speeds and weaving intensity factors tailored to fit the individual segment design characteristics and traffic volumes. As discussed below, the speed calculations shown in Equation 4-1 can be used directly to complete the change in speed calculation needed to estimate user costs. For climbing lanes it is important to have separate speed and volume data by vehicle class, as these improvements are targeted to improving traffic flows due in part to slower speeds of trucks and other large vehicles.

Access Management

Access management includes several types of improvements to transportation facilities. All access management improvements seek to minimize or reduce the amount of potential interference to vehicles on a facility caused by vehicles entering or exiting the facility. The primary effect of managing access is to allow vehicles on a facility to maintain speed and to minimize the interferences caused by vehicles entering the roadway. As a result, the primary benefits from managing access come from changes in travel time, changes in operating cost and changes in accident costs in the highway network. As with other types of improvements, these benefits arise from the reduction in total user cost, i.e., the total of travel time, operating, and accident costs.

A typical freeway in urbanized areas consists of two or more lanes of travel in each direction, physical separation of the traffic moving in each direction, no signalized control of traffic operations (other than ramp meters), and limited access and egress to the facility. Typical urban streets have intersections that may be regulated by signals or signs, perhaps spaced relatively near each other. Urban streets may or may not be physically segregated by direction of flow.

The difference between urban freeways and streets is important in understanding the effects of access management. Under normal conditions, performance of urban freeways tends to be free flowing. As flow levels increase, interchanges begin to act as bottlenecks.
because of weaving maneuvers and merging. Access management techniques for freeways and rural highways include:

- Medians,
- Frontage roads, and
- Spacing of access and exit points.

In contrast to freeways, urban streets have more access points, resulting in increased opportunities for delay. Urban streets may or may not have parking permitted on their outside lanes, and intersections can include other streets or driveways. These streets are also used by a greater variety of vehicles, including streetcars, bicycles and pedestrians in addition to the cars, trucks, and buses found on freeways.

Access management of urban streets can include:

- Medians,
- Spacing of access points (driveways),
- Frontage roads, and
- Turning lanes (left turn, u-turns, two-way turn).

The engineering performance of the road segment is determined by its engineering characteristics, as encapsulated in the volume-delay relationship. Analysis worksheets in the HCM 2000 are used to calculate changes in speed and delay associated with changes in access. These intermediate calculations require additional information on the segment:

- Number of access points;
- Design speed;
- Design type based on physical and geometric characteristics of segment.

The traffic mix and other factors do not typically change significantly with the implementation of access management techniques such as medians and turn lanes. The primary effect on speed from access management improvements is to separate through traffic flows from vehicles that have slowed or stopped to make turns or exit the roadway.

The HCM 2000 provides many tools and procedures to assist in the calculation of segment speeds. These procedures permit detailed consideration of segment features, including the effects of road geometry and weaving on the capacity and speed of a highway segment. Speed can be calculated for local streets and roads, highways and freeways. The most accurate rendering of the effects of access management procedures on speed, therefore, is through the use of the calculation procedures detailed in the HCM 2000.

Table 4-4 presents references to the relevant worksheets of HCM 2000 that can be used to calculate segment speeds on various roadway types.
Table 4-4: Worksheets in *HCM 2000* for Calculating Speed on Roadway Segments of Various Types

<table>
<thead>
<tr>
<th>Roadway Segment Type</th>
<th>HCM 2000 Worksheets</th>
<th>Output of HCM 2000 Worksheets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Street</td>
<td>Urban Street Worksheet (Ch. 15)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Intersections</td>
<td>Uniform Delay Worksheet for Left Turns (Ch. 16)</td>
<td>D, Delay</td>
</tr>
<tr>
<td>Two-Lane Highway</td>
<td>Directional Two-Lane Highway Segment Worksheet (Ch. 20)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Multilane Highway</td>
<td>Multilane Highways Worksheet (Ch. 21)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Freeway</td>
<td>Basic Freeway Segments Worksheet (Ch. 23)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Freeway ramps</td>
<td>Ramps and Ramp Junctions Worksheet (Ch. 25)</td>
<td>S, segment speed</td>
</tr>
</tbody>
</table>

In some cases, access management improvements involve only changing a parameter (access-point density) on a single, *HCM 2000* worksheet. For urban streets, access management determines the design category of the facility for analysis (*HCM 2000*, Chapter 15, Exhibit 15-4). Driveway density, whether the directional flows are physically separated, on-street parking, left-turn accessibility, speed limits, frequency of signals, pedestrian activity and roadside development all determine the design category. The design category is one of several inputs to calculate delay on an Urban Street (Worksheet 15-16).

In addition to the tools available in the *HCM 2000*, the Transportation Research Board issued a report that deals specifically with the user cost impacts associated with a variety of access management techniques. The techniques covered in *Impacts of Access Management Techniques (NCHRP Report 420)* are listed in Table 4-5 along with the user costs that are covered in the discussion. Note that in addition to travel times, accident rate information is included for many of these specific access management techniques.
The techniques described in detail in *NCHRP Report 420* can be used to estimate changes in user costs that are necessary for conducting the benefit-cost analysis for the improvement. This section will discuss in general terms two access management techniques, broadly categorized as *medians* and *turn lanes*.

**Medians**

One of the most common improvement types is the addition of a median to help direct traffic and to separate turning vehicles from vehicles continuing through the lane. Medians can consist of unraised, painted medians that help direct traffic flows, raised nontraversable medians that prevent turns, and two-way left-turn lanes that provide a lane for left turns for traffic in both directions. The addition of medians has been shown to reduce delays and, as discussed later in this section, reduce accident rates relative to segments that do not utilize medians to control traffic flows.

Table 4-6 illustrates the relationship between different median options and traffic delay times. As shown in the table, delay times increase with the number of access points. This results from cars entering the roadway and from vehicles in the roadway slowing down to turn off at the access points. The density of access points along a stretch of roadway will significantly increase the associated delay times across all road and improvement

---

**Table 4-5: Access Management Techniques Covered in *NCHRP Report 420***

<table>
<thead>
<tr>
<th>Access Management Technique</th>
<th>NCHRP Report 420 Chapter Number</th>
<th>User Cost Components Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Signal Spacing</td>
<td>Chapter 3 (Technique 1a)</td>
<td>Travel Time</td>
</tr>
<tr>
<td>Spacing for Unsignalized Access</td>
<td>Chapter 4 (Technique 1b)</td>
<td>Travel Time, Accident Rates</td>
</tr>
<tr>
<td>Corner Clearance</td>
<td>Chapter 5 (Technique 1c)</td>
<td>(None—determines minimum corner clearance)</td>
</tr>
<tr>
<td>Access Separation Distance at Interchanges</td>
<td>Chapter 9 (Technique 1d)</td>
<td>(None—determines minimum separation distance)</td>
</tr>
<tr>
<td>Nontraversable Median on Undivided Highways</td>
<td>Chapter 6 (Technique 2a)</td>
<td>Travel Time, Accident Rates</td>
</tr>
<tr>
<td>Replace TWLTL with Nontraversable Median</td>
<td>Chapter 6 (Technique 2b)</td>
<td>Travel Time, Accident Rates</td>
</tr>
<tr>
<td>Left-Turn Deceleration Lanes</td>
<td>Chapter 7 (Technique 3a)</td>
<td>Travel Time, Accident Rates</td>
</tr>
<tr>
<td>Install Continuous TWLTL on Undivided Highway</td>
<td>Chapter 6 (Technique 3c)</td>
<td>Travel Time, Accident Rates</td>
</tr>
<tr>
<td>U-Turns as Alternative to Direct Left Turns</td>
<td>Chapter 8 (Technique 3d)</td>
<td>Travel Time, Accident Rates</td>
</tr>
<tr>
<td>Install Jug Handle and Eliminate Left Turns Along Highways</td>
<td>Chapter 8 (Technique 3e)</td>
<td>(None—mentioned, but not analyzed, in Report 420)</td>
</tr>
<tr>
<td>Frontage Roads</td>
<td>Chapter 10 (Techniques 6a and 6b)</td>
<td>(None—configuration recommendations only)</td>
</tr>
</tbody>
</table>
types. The addition of either a two-way left-turn lane (TWLTL) or a raised median helps to remove turning traffic from the main traffic flow and substantially reduces delay times. As these data show, delay times are decreased by over 50 percent relative to an undivided street where through traffic is forced to share lanes with turning vehicles.

Table 4-6: Annual Delay (Hours) to Major Street Left-Turn and Through Vehicles

<table>
<thead>
<tr>
<th>Driveways per Mile</th>
<th>ADT 37,500</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Undivided</td>
<td>TWLTL</td>
<td>Raised Median</td>
</tr>
<tr>
<td>30</td>
<td>11,600</td>
<td>4,300</td>
<td>4,400</td>
</tr>
<tr>
<td>60</td>
<td>13,100</td>
<td>4,600</td>
<td>5,300</td>
</tr>
<tr>
<td>90</td>
<td>13,700</td>
<td>4,600</td>
<td>5,100</td>
</tr>
</tbody>
</table>

Note: Assumes 10 percent left turns, four-lane highway.


Naturally, the delay costs increase as traffic volumes increase. An issue, then, is the traffic volume threshold level for installing an access management improvement such as a raised median.

The NCHRP Report 395 provides guidelines for threshold traffic volumes where raised medians and TWLTL lanes should be considered. The guidelines in NCHRP Report 395 were adapted for Table 4-7, below, to show threshold traffic volumes where there would be a net benefit to switching to non-traversable medians, based on reductions in delay, accidents and factoring in construction costs of adding a median or turn lane. As the body of this table illustrates, threshold levels are lower for those situations where the frequency of left turns is high, there is a high access point density, and where traffic volumes and capacity levels are higher due to a greater number of lanes.
Table 4-7: Threshold Traffic Volumes for Installing Non-traversable medians, by Road Type and Land Use

<table>
<thead>
<tr>
<th>Business and Office Land Use</th>
<th>Left-Turn Percent per 1,320-ft Segment Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Number of Lanes</td>
<td>Access Points per Mile</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Residential and Industrial Land Use</th>
<th>Left-Turn Percent per 1,320-ft Segment Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Number of Lanes</td>
<td>Access Points per Mile</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>90</td>
</tr>
</tbody>
</table>

Source: NCHRP Report 420, adapted from tables in Appendix C.

Turn Lanes
A similar improvement to installing a median is to provide a separate lane for left turning traffic. This allows traffic that is stopped to make a turn to be removed from other lanes so that through traffic is unaffected. For this reason, it is almost always preferable to have a dedicated left turn lane rather than a shared turn lane where through traffic is delayed by turning vehicles.

As discussed, the HCM 2000 contains detailed worksheets for calculating capacity and speeds for different improvement types, including turning lanes. While the HCM 2000 provides the definitive methods for calculating speed changes due to changes in access conditions, they require a fair amount of detailed data on traffic volumes and segment design characteristics. NCHRP Report 420, in Table 75, provides simplified calculations for capacity that provide accurate estimates under general conditions. These calculations for a variety of access improvement projects are shown in Table 4-8.
### Table 4-8: Simplified Capacity Calculations for Left Turn Lanes

<table>
<thead>
<tr>
<th>Description</th>
<th>Lane Capacity per Cycle</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Through lane with no opposing (conflicting) left-turns or shared lane on one-way street</td>
<td>$c = \frac{g}{h}$</td>
<td></td>
</tr>
<tr>
<td>Through lane with opposing (conflicting) left-turns</td>
<td>$c = \frac{g}{h} - (l_2 - s_2)$</td>
<td>$l_2 \geq s_2$</td>
</tr>
<tr>
<td>Single Shared lane (on two-lane street)</td>
<td>Minimum of:</td>
<td></td>
</tr>
<tr>
<td>Conflict:</td>
<td>$c = \frac{g}{h} - (l_2 - l_1 - s_2)$</td>
<td>$(l_2 - l_1 - s_2) \geq 0$</td>
</tr>
<tr>
<td>Blockage:</td>
<td>$c_s = \frac{g}{h} - Bo_2$</td>
<td></td>
</tr>
<tr>
<td>Shared lane on multilane street</td>
<td>Minimum of:</td>
<td></td>
</tr>
<tr>
<td>Conflict:</td>
<td>$c = \frac{g}{h} - (l_2 - s_2)$</td>
<td>$l_2 \geq s_2$</td>
</tr>
<tr>
<td>Blockage:</td>
<td>$c_s = \frac{g}{h} - Bo_2$</td>
<td></td>
</tr>
</tbody>
</table>

- $g = \text{effective green time}$
- $h = \text{headway, adjusted for factors other than left turns (sec/veh)}$
- $l_1 = \text{left turns per cycle in given direction}$
- $l_2 = \text{opposing left turns per cycle}$
- $s_2 = \text{opposing sneakers per cycle}$
- $o_2 = \text{effective opposing traffic per lane per cycle}$
- $B = \text{modified blockage (impedance factor)}$
- $C = \text{capacity (vehicle/lane/cycle)}$
- $c_s = \text{capacity, vehicle/lane/cycle (shared lane blockage)}$

Constraints: When constraint not met, use $c = \frac{g}{h}$

Source: NCHRP Report No. 420, p. 94.

The impedance factor $B$ is adjusted to reflect the uneven distribution of traffic among lanes based on the number of left turns per cycle. The range of values for the impedance factor is shown in Table 4-9.
Table 4-9: Impedance Factor for Simplified Left-Turn Lane Capacity Calculations

<table>
<thead>
<tr>
<th>Left Turns per Cycle</th>
<th>Impedance Factor B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.30</td>
</tr>
<tr>
<td>1</td>
<td>0.48</td>
</tr>
<tr>
<td>2</td>
<td>0.72</td>
</tr>
<tr>
<td>3</td>
<td>0.84</td>
</tr>
<tr>
<td>4</td>
<td>0.90</td>
</tr>
<tr>
<td>5</td>
<td>0.96</td>
</tr>
<tr>
<td>6 or more</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Source: NCHRP Report No. 420 p. 95.

The information presented in the previous two tables provides a simplified version of calculating capacity and changes in capacity for a variety of left-turn treatments. This information can then be used in the HCM 2000 worksheets to calculate changes in speed due to the improvement, or they can be used directly in a volume-delay formula to calculate delay due to changes in capacity resulting from the improvement.

**Roadside Improvements**

In addition to changes to the road itself, highway safety can be improved by changing features adjacent to the road. This section addresses the effects on user benefits of improving roadside features to reduce the occurrence and severity of accidents should the vehicle leave the road.

The design features covered in this section mirror those discussed in the Roadside Design Guide published by AASHTO. Specifically, the analysis steps covered in this section can be used to analyze:

- Roadside topography and drainage features,
- Sign and luminaire supports (and similar structures),
- Roadside barriers,
- Median barriers,
- Bridge railings and transitions, and
- Barrier end treatments and crash cushions.

Roadside improvements are undertaken both to keep vehicles on the road and to reduce the incidence and severity of accidents should a vehicle leave the road. A vehicle leaving the road is referred to as an encroachment, to distinguish them from accidents which occur when the vehicle strikes an object or causes some other form of damage. This distinction is important, as not all encroachments result in accidents.

In some instances, it is beneficial to use barriers to redirect cars back onto the highway rather than allow encroachment on off-road areas. These include bridges, roads near cliffs or sharp drop-offs, and highways with high-speed, two-way traffic with no barriers.
separating opposing traffic flows. Types of roadside improvements that reduce encroachments in these situations include:

- **Roadside barriers.** Structures that are designed to keep vehicles from leaving the roadway.

- **Median barriers.** Structures designed to prevent vehicles from crossing into other lanes of traffic.

- **Bridge railings.** Barriers designed to prevent vehicles from leaving the road at bridge crossings.

Other roadside improvements are designed to reduce the severity of accidents once the vehicle has left the roadway. Roadside improvements designed to reduce the incidence and severity of accidents include:

- **Clear roadside designs.** Potential roadside impediments are removed entirely to reduce accident risks should the vehicle leave the road. This is referred to as the “clear zone” or “forgiving roadside” design concept.

- **Drainage projects.** The design geometry of roadside drainage projects will affect the severity of off-the-road accidents.

- **Breakaway sign/lamp supports.** Supports that are designed to bend or break upon impact. These include lighting and signage supports in addition to similar roadside features such as utility poles, callboxes, fire hydrants, and mailbox supports.

- **Barrier end treatments and crash cushions.** These features help reduce accident severity by gradually decelerating an impacting vehicle to a stop or by redirecting the vehicle around the barrier or other object.

Specific design issues for each of these roadside improvement types are included in AASHTO’s *Roadside Design Guide*. Table 4-10 shows the specific chapters for each of these improvement types, categorized into projects reducing encroachments and projects reducing or mitigating accidents.

**Table 4-10: Chapter References for Roadside Design Improvement Types**

<table>
<thead>
<tr>
<th>Roadside Improvement Type</th>
<th>AASHTO Roadside Design Guide Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Encroachment Reduction Features</strong></td>
<td></td>
</tr>
<tr>
<td>Roadside Barriers</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>Median Barriers</td>
<td>Chapter 6</td>
</tr>
<tr>
<td>Bridge Railings</td>
<td>Chapter 7</td>
</tr>
<tr>
<td><strong>Accident Mitigation Features</strong></td>
<td></td>
</tr>
<tr>
<td>Clear Zone Roadside Designs</td>
<td>Chapter 3</td>
</tr>
<tr>
<td>Drainage</td>
<td>Chapter 3</td>
</tr>
<tr>
<td>Breakaway Supports</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>Barrier End Treatments and Crash Cushions</td>
<td>Chapter 8</td>
</tr>
</tbody>
</table>
By definition, roadside improvements generally will not significantly affect traffic volumes, as these improvements are designed to reduce accident severity if and when vehicles leave the road. The exception is for those improvements where safety is dramatically improved to the point where traffic volumes on the segment increase.

If the roadside improvement is expected to affect traffic volumes, then the change in volume information can be used to determine the effect on travel speeds using the volume-delay relationships provided in the HCM 2000. Using the volume-delay equations in these worksheets, the without- and with-improvement traffic volumes are entered to determine the change in speeds resulting from the roadside improvement. Table 4-11 references the appropriate worksheets by road type to do these calculations.

Table 4-11: Worksheets in HCM 2000 for Calculating Speed on Roadway Segments of Various Types

<table>
<thead>
<tr>
<th>Roadway Segment Type</th>
<th>HCM 2000 Worksheets</th>
<th>Output of HCM 2000 Worksheets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Street</td>
<td>Urban Street Worksheet (Ch. 15)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Two-Lane Highway</td>
<td>Directional Two-Lane Highway Segment Worksheet (Ch. 20)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Multilane Highway</td>
<td>Multilane Highways Worksheet (Ch. 21)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Freeway</td>
<td>Basic Freeway Segments Worksheet (Ch. 23)</td>
<td>S, segment speed</td>
</tr>
</tbody>
</table>

Incorporating the Effects of Safety Improvements in User Benefit Analysis

To incorporate the effects of safety improvements in user benefit analysis, it is helpful to maintain the distinction among travel time cost, operating cost and accident cost impacts.

Measuring Effects on Travel Time Costs

The changes in the total cost of travel time associated with safety improvements are a result of revisions in either segment speed, or queuing delay. The data sources and worksheets described in the previous section are the analyst’s source of these measurements. By analyzing the effect of the safety improvement on a segment or corridor’s performance, relative to the base case conditions, the analyst obtains measures of changes in speed or queuing delay. The changes in speed or delay calculated from such information are then used to calculate the travel time cost component of total user cost.

In the case of changes in segment speeds, the information on speeds converts to changes in travel time costs per vehicle mile (or passenger mile), through the standard formulae presented elsewhere in the manual:
Equation 4-2: Change in Speed
\[ \Delta S = S_0 - S_1 \]
where:
- \( S_0 \) = Speed without the improvement (miles/hour)
- \( S_1 \) = Speed with the improvement (miles/hour)

Equation 4-3: Change in Value of Travel Time
\[ \Delta H_c = M_c O_c \left( \frac{1}{S_0} - \frac{1}{S_1} \right). \]

For segments on the road facility that receive the improvement, the change in speed will generally be positive. This may not be the case for every segment in the network, however, if the improvement results in increases in traffic volumes in other segments.

For safety improvements that affect an intersection or any other queues in the network, the travel time savings associated with the improvement are generally measured in terms of total delay experienced by traffic measured at that intersection or point during a given period. As discussed in the previous section, the HCM 2000 has details for either signalized intersections and unsignalized intersections, in particular. Chapter 3 of this manual also provides functions and graphs synthesizing some of the HCM 2000 information. This information can also be used to approximate intersection queuing delay.

The change in average delay is represented as:

Equation 4-4: Change in Delay
\[ \Delta D = D_1 - D_0 \]
- \( D_0 \) = delay without improvement (seconds)
- \( D_1 \) = delay with improvement (seconds)
- \( \Delta D \) = change in delay (seconds)

For improvements to intersection approaches, a vehicle of class \( c \) with an associated value of time per person per hour of \( M_c \) and a vehicle occupancy of \( O_c \) will see a reduction in the value of the time spent traversing the intersection of:

Equation 4-5: Change in Value of Travel Time Due to Delay
\[ \Delta H'_c = \frac{100M_c O_c \Delta D}{3,600} \]
where:
- \( \Delta H'_c \) = the value of travel time due to delay for user class \( c \) (in cents per vehicle-mile)
- \( M_c \) = the unit value of time for user class \( c \) (in dollars per hour)
- \( O_c \) = the occupancy rate of vehicles of user class, \( c \)

Depending upon whether the safety improvements affect a segment or an intersection, the change in the value of travel time is simply added to the change in user cost portion of the
User Benefit Formula (for final benefit computation later), or multiplied immediately by the average of the with- and without-improvement volumes. The former is the approach that can be taken with segment improvements; the latter is required where the improvement is not on a per-mile basis, but rather on a per-instance basis, as in improvements in intersection geometry. Needless to say, these calculations have to be done separately for each relevant user class, turning motion, or other necessary dimensions of the analysis. They also must be performed, potentially, at several points within a day, at different times of the year, and for different project years if simple annualization and aggregation is not possible.

The Value of Time Module in Chapter 5 provides guidance and more specific detail for performing the calculations outlined here.

**Measuring Effects on Operating Cost Savings**

The change in average operating speed (or intersection delay) that results from geometric improvements also affects operating costs, including vehicle operating and ownership costs and inventory costs of goods in transit on the vehicle. The analyst must consider which of these costs will be affected with the proposed improvement and then determine the change in costs anticipated with the project. It is important to note that not all operating costs will be affected by safety improvements. Moderate changes to road geometry, for example, are unlikely to affect fuel costs significantly, but may affect tire scuffing, etc.

In general, operating costs will be a function of speed, as in the equation below.

**Equation 4-6: Change in Operating Costs**

\[
\Delta OC_c = f'(\Delta S)
\]

The Operating Cost Module in Chapter 5 provides more specific detail on operating costs and how to calculate operating costs based on other parameters such as travel speed and vehicle life. The quantity \(\Delta OC_c\) is the second component of total user cost changes in the User Benefit Formula. The analyst must determine in each case whether to represent the change in operating costs on a per vehicle mile basis, or for an individual improvement (e.g. an intersection). By analogy with the earlier discussion of travel time costs, the effect of this choice is seen when the affected volumes are applied to the change in cost, and whether facility length or trip length enters into the calculation.

**Calculating the Value of Accident Cost Savings**

Accident costs are a function of the speed, density of traffic, and the geometric design of the facility in question. Reductions in such costs are the primary motivating factor for safety improvements.

The change in accident costs is conceptually a product of changes in accident cost rates, and the unit cost of accidents, as in the following, familiar equation:
Equation 4-7: Change in Accident Costs

\[ \Delta AC_c = v_I \Delta I + v_D \Delta D + v_P \Delta P \]

where:

- \( \Delta AC_c \) = change in accident costs for vehicle class c (cents per vehicle mile);
- \( \Delta I \) = change in expected number of injury accidents per vehicle mile;
- \( \Delta D \) = change in expected number of fatal accidents per vehicle mile;
- \( \Delta P \) = change in expected number of property damage incidents per vehicle mile;
- \( v_I \) = perceived cost associated with an injury accident (cents);
- \( v_D \) = perceived cost associated with a fatal accident (cents);
- \( v_P \) = perceived cost associated with a property damage incident (cents).

Ideally, the analyst will use facility-specific accident and traffic volume data to generate the without-improvement and with-improvement accident rates. If segment-specific data are not available, the National Highway Traffic Safety Administration publishes aggregated accident rate information. The Accident Costs Module in Chapter 5 provides additional information on methods for calculating accident rates and resources available to assist in these calculations. The Accident Cost Module also provides details and guidance for valuing changes in accident rates.
Chapter 5. User Benefit Analysis Modules

INTRODUCTION
Each of the highway improvement types discussed in the manual will have an impact on some or all of the components in the User Benefit Formula presented at the beginning of this manual. The Analysis Modules in this section present more detailed information for each of the User Benefit Formula components:

- The first module is the Value of Time Module, which presents information on how changes in travel times should be valued. This includes differentiating time valuations by type of trip.

- The second module is the Operating Cost Module, which discusses the costs associated with owning and operating a vehicle. This module shows how changes in travel speeds affect operating costs. The effect of travel times on inventory and cargo costs is also presented.

- The third module is the Accident Cost Module, which presents information on calculating accident costs. This involves calculations of accident costs, accident rates, and encroachment rates for various improvement types. This module also provides information on empirical work and computer software tools that have been developed to estimate accidents and accident costs based on road and roadside design features.

- The last module in this section is the Project Management Module, which addresses how the user benefit components are impacted during the construction period. This module shows the calculation of project management costs, which includes construction costs, the effect of the construction period on user costs (primarily through delays), and the potential impact of various innovative contracting procedures on reducing overall project and user costs.

Once the calculations are completed from these analysis modules, the analyst will have each of the components needed to complete the calculations in the User Benefit Formula. The next section, Chapter 6, will lead the reader through how each of the outputs from the individual Analysis Modules are used to calculate project costs and benefits over the life of the project.

VALUE OF TIME MODULE
The majority of the improvement types described in this manual will affect travel times for users of the facility. As a consequence, the change in travel times for traversing the improved segment is one of the primary components of user costs and benefits that need to be evaluated. This section describes how changes in travel times with and without the improvement can be converted to a dollar value. Once the value of the change in travel time is calculated, it is combined with the other components of user costs to determine the user benefits associated with the improvement.

The value that users assign to their travel time will depend upon the opportunity cost of that time, and the consumption opportunities that the user associates with traveling on highways. The opportunity cost perspective suggests that the value of travel time should
bear some relationship to the after-tax wage of the traveler, since that is an alternative use of time—especially in a commute travel context. Even in a leisure context, the value of time is likely linked in some way to the hourly wage rate because work is a meaningful alternative to leisure as well. Finally, in a commercial setting involving truck drivers or other hired labor (where the value of the time of hired labor is involved) the wage rate is even more obviously important, since that is the explicit cost of the labor.

Considering these factors, it makes sense that the value that users associate with their travel time will depend upon the context of the travel, and the characteristics of the traveler (especially the wage rate) and, perhaps, the vehicle involved. Economists have spent considerable time examining the behavior of travelers, and the trade-offs between travel time and cash they appear to make. In so doing, the value of time can be measured or inferred. These studies, so called revealed preference studies, confirm that the wage rate is, indeed, an important determinant of absolute and relative time values, but that the variation in values is greater than can be explained by variations in wage rates alone.

The variation that is observed in time studies gives the analyst the latitude to use time values estimated from local studies if they fall within normal ranges. It is imperative, however, that the analyst use time values in a consistent manner and make sure that the decision to proceed with a project does not depend on unusual assumptions about the value of time. One of the first empirical tasks in a highway user benefit evaluation process is to assemble a table of values of time, by its various types of travel and/or user categories. These values allow the conversion of quantities of time to dollar-valued time.

Table 5-1 below gives some guidance as to the values of time that should be used in highway benefit analysis. These values are also used in the sample calculation Worksheet 5-1 and Worksheet 5-4. Clearly, if a high quality, localized value of time study is available, it should be used instead of these guideline values.
Table 5-1: Guidelines for Assigning Values of Time in Highway Project Analysis

<table>
<thead>
<tr>
<th>Transportation Mode and Trip Purpose</th>
<th>Recommended Value of Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(For Use in Worksheet 5-1 and Worksheet 5-4)</td>
</tr>
<tr>
<td>AUTO</td>
<td></td>
</tr>
<tr>
<td>Drive Alone Commute</td>
<td>50% of the wage rate</td>
</tr>
<tr>
<td>Carpool Driver Commute</td>
<td>60% of the wage rate</td>
</tr>
<tr>
<td>Carpool Passenger Commute</td>
<td>40% of the wage rate</td>
</tr>
<tr>
<td>Personal (local)</td>
<td>50% of the wage rate</td>
</tr>
<tr>
<td>Personal (intercity)</td>
<td>70% of the wage rate</td>
</tr>
<tr>
<td>Business</td>
<td>100% of total compensation</td>
</tr>
<tr>
<td>TRANSIT BUS</td>
<td></td>
</tr>
<tr>
<td>In-Vehicle Commute</td>
<td>50% of the wage rate</td>
</tr>
<tr>
<td>In-Vehicle Personal</td>
<td>50% of the wage rate</td>
</tr>
<tr>
<td>Excess (waiting, walking, or transfer time) Non-business</td>
<td>100% of the wage rate</td>
</tr>
<tr>
<td>Business (all time)</td>
<td>100% of total compensation</td>
</tr>
<tr>
<td>TRUCK</td>
<td></td>
</tr>
<tr>
<td>In-Vehicle Business</td>
<td>100% of total compensation</td>
</tr>
<tr>
<td>Excess (waiting time) Business</td>
<td>100% of total compensation</td>
</tr>
</tbody>
</table>


Note that Table 5-1 differentiates among the values of time of automobile, truck, and (bus) transit users, and differentiates between automobile drivers and passengers. Table 5-1 also differentiates among values of time by the purpose of the trip. In an ideal setting, information would be available in all of these dimensions. Then, if the improvement affects, say, the use of carpools, or the amount of truck traffic, the analysis can more accurately incorporate the impact of these shifts among user types on the benefit calculation.

Recent research has sought to further distinguish the value of travel time based on other categories beside trip purpose. Value of travel time varies by household income level and whether the traveler is driving or is a passenger. For drivers, driving conditions also affect the value of travel time. Drivers are willing to pay up to twice as much to avoid a minute of driving in congested conditions as they are to avoid a minute of driving in uncongested conditions. Recent research indicates that household income levels, as well as the traveler’s own wage rate, help determine the value of time, and that using a constant percent of the traveler’s wage will tend to underestimate the value of time for low-wage individuals and overestimate the value of time for high-wage individuals.

The percentages of compensation shown in Table 5-1 are careful to distinguish between wages and total compensation for different types of trips. The opportunity cost of an hour of a commercial truck driver’s time, for example, is the benefit-loaded cost of hiring the driver, not just the driver’s base wage. As Table 5-2 indicates, on average, total...
compensation is 18 percent greater than the hourly wage, and 20 percent higher for the trucking and warehousing sector, in particular. This information on wages and compensation is also used in the sample calculations presented in Worksheet 5-1 and Worksheet 5-4.

Table 5-2: Average Wages and Total Compensation, by Industry (2000 $)

<table>
<thead>
<tr>
<th>Industry Type</th>
<th>Average Wage ($/hr.)</th>
<th>Average Total Compensation ($/hr.)</th>
<th>Total Compensation as a Percent of the Average Wage</th>
</tr>
</thead>
<tbody>
<tr>
<td>All employees</td>
<td>$18.56</td>
<td>$21.93</td>
<td>118%</td>
</tr>
<tr>
<td>Private industry</td>
<td>$18.42</td>
<td>$21.31</td>
<td>116%</td>
</tr>
<tr>
<td>Transportation &amp; public utilities</td>
<td>$22.76</td>
<td>$27.19</td>
<td>119%</td>
</tr>
<tr>
<td>Trucking and warehousing</td>
<td>$16.84</td>
<td>$20.23</td>
<td>120%</td>
</tr>
<tr>
<td>Finance, real estate, insurance</td>
<td>$29.01</td>
<td>$33.44</td>
<td>115%</td>
</tr>
<tr>
<td>Services</td>
<td>$17.51</td>
<td>$19.98</td>
<td>114%</td>
</tr>
<tr>
<td>Private household services</td>
<td>$7.64</td>
<td>$7.83</td>
<td>103%</td>
</tr>
<tr>
<td>Government</td>
<td>$19.34</td>
<td>$25.39</td>
<td>131%</td>
</tr>
<tr>
<td>Federal non-military</td>
<td>$24.06</td>
<td>$35.52</td>
<td>148%</td>
</tr>
<tr>
<td>Federal military</td>
<td>$18.08</td>
<td>$28.22</td>
<td>156%</td>
</tr>
<tr>
<td>State and local</td>
<td>$18.56</td>
<td>$23.17</td>
<td>125%</td>
</tr>
</tbody>
</table>

Source: Data are from the National Income and Product Accounts (NIPA) of the United States, for 2000 (Department of Commerce, Bureau of Economic Analysis).

In practice, it is often the case that a complete and accurate tableau of time values is not available, or the analyst does not have the resources to model the travel behavior at the necessary level of detail. In such cases, it is possible to use only a few values of time in the detailed analysis, but then use sensitivity analysis to systematically explore how dependent the results are on the particular time value selected. In general, if the project remains feasible (or infeasible) irrespective of the time value used, then the analyst can be more confident of the feasibility analysis.

Conventionally, travel time is measured in minutes, and the value of time is measured in dollars per hour. To complete the calculation for the value of travel for use in the User Benefit Formula, each of the components needs to be expressed in cents per vehicle-mile, which has become the accepted convention for costs for highway-related projects. For example, at a travel time value of 10 dollars per hour, and a speed of 30 miles per hour, travel time contributes about 33 cents per person-mile to the user cost of travel. If average vehicle occupancy were, say, 1.3 persons per vehicle, this would translate into

---

8 The hourly wage reported in Table 5-2 is the hourly average of all cash compensation (including wages, salary, and overtime compensation).
approximately 43 cents per vehicle-mile. Obviously, at higher values of time and vehicle occupancies, this component of user cost is proportionately higher, and at higher speeds, it is proportionately lower.

For those projects whose primary outcome is a change in delay (rather than travel times due to changes in speed), the change in the value of time will be expressed in *cents per minute* rather than on a per vehicle mile basis, as the delay-related improvements (such as traffic signals) typically do not have a distance or speed component, but rather focus on delay times.

Projects that are designed primarily as safety improvements will also affect travel times, as fewer incidents will reduce delays due to accidents. For example, Table 5-3 shows the average delay due to heavy vehicle crashes for a range of vehicle and road types.

**Table 5-3: Hours of Delay per Heavy Vehicle Crash by Roadway Class, Location, and Severity**

<table>
<thead>
<tr>
<th>Roadway Class</th>
<th>Property Damage Only</th>
<th>Injury</th>
<th>Fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interstate</td>
<td>2,260</td>
<td>7,344</td>
<td>21,749</td>
</tr>
<tr>
<td>Other Freeway</td>
<td>1,766</td>
<td>5,737</td>
<td>16,990</td>
</tr>
<tr>
<td>Major Arterial</td>
<td>949</td>
<td>3,082</td>
<td>9,127</td>
</tr>
<tr>
<td>Minor Arterial</td>
<td>594</td>
<td>1,929</td>
<td>5,711</td>
</tr>
<tr>
<td>Collector</td>
<td>31</td>
<td>102</td>
<td>301</td>
</tr>
<tr>
<td>Local Street</td>
<td>9</td>
<td>28</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interstate</td>
<td>814</td>
<td>2,646</td>
<td>7,835</td>
</tr>
<tr>
<td>Major Arterial</td>
<td>416</td>
<td>1,350</td>
<td>3,999</td>
</tr>
<tr>
<td>Minor Arterial</td>
<td>255</td>
<td>829</td>
<td>2,454</td>
</tr>
<tr>
<td>Major Collector</td>
<td>10</td>
<td>34</td>
<td>100</td>
</tr>
<tr>
<td>Minor Collector</td>
<td>4</td>
<td>14</td>
<td>42</td>
</tr>
<tr>
<td>Local Street</td>
<td>1</td>
<td>4</td>
<td>12</td>
</tr>
</tbody>
</table>


In all cases, the value of travel time is a simple matter of multiplying the change in travel time or delay by the dollar value placed on that time.

For a project that results in a change in travel speeds or travel times, the value of time is normally expressed in *cents per vehicle mile*. Throughout this manual, the user cost components for speed related projects have been converted into this unit so that they can be directly imported into the User Benefit Calculation. To review the initial discussion of the User Benefit Formula, the value of travel time is given by:
Equation 5-1: Value of Travel Time Saved

\[ \Delta H_c = 100 M_c O_c \left( \frac{1}{S_0} - \frac{1}{S_1} \right) \]

where:
- \( \Delta H_c \) = the value of travel time savings enjoyed by user class \( c \) (cents per vehicle-mile)
- \( M_c \) = the unit value of time for user class \( c \) (dollars per hour)
- \( O_c \) = the occupancy rate of vehicles of user class \( c \)
- \( S_0, S_1 \) = the speed without (\( S_0 \)) and with (\( S_1 \)) the improvement (miles per hour)

For a project that results in an intersection delay, the effect on the value of travel time is:

Equation 5-2: Value of Time Saved Due to Change in Delay

\[ \Delta H_{\text{intersection, } c} = \frac{\Delta D}{3600} \left( \frac{V_{0,c} + V_{1,c}}{2} \right) 100 M_c O_c \]

where:
- \( \Delta H_{\text{intersection, } c} \) = change in the value of travel time through an intersection, user class \( c \)
- \( \Delta D = D_0 - D_1 \) = the change in intersection delay per vehicle, in seconds
- \( V_{0,c}, V_{1,c} \) = vehicle volumes without and with the intersection improvement
- \( M_c \) = the value of time for user class \( c \) (dollars per hour)
- \( O_c \) = vehicle occupancy, in persons per vehicle

For both Equation 5-1 and Equation 5-2, the hourly wage and compensation rates discussed in this module are used to help determine the appropriate value of \( M_c \).

Application: Value of Time Calculation

Worksheet 5-1 illustrates the value of time calculation for a hypothetical improvement of adding a lane to a two-lane street. In this example, travel speeds are estimated to increase from 28 mph to 33 mph for autos, and from 23 mph to 26 mph for trucks. Information from Table 5-1 and Table 5-2 was used to assign wage and compensation information as well as the correct ratios for valuing travel time for each vehicle type. As shown at the bottom of Worksheet 5-1, the addition of the lane results in a savings of about 7.5 cents per VMT for autos and 10.7 cents per VMT for trucks in this hypothetical example.
### Worksheet 5-1: Value of Time—Sample Calculation

<table>
<thead>
<tr>
<th>General Information</th>
<th>Site Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst: Me</td>
<td>Facility: Facility 1</td>
</tr>
<tr>
<td>Agency/Company: My Agency</td>
<td>Segment: Segment 1</td>
</tr>
<tr>
<td>Project: Demo</td>
<td>Analysis Time Period: PM Peak</td>
</tr>
<tr>
<td>Date Performed: 1/1/2002</td>
<td>Analysis Year: 2005</td>
</tr>
<tr>
<td>Segment Length (mi.): 0.5</td>
<td></td>
</tr>
</tbody>
</table>

#### Inputs

<table>
<thead>
<tr>
<th>Autos</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of hourly wage (Table 5-1): 50%</td>
<td>Percentage of hourly wage (Table 5-1): 100%</td>
</tr>
<tr>
<td>Average hourly wage (Table 5-2): $18.56</td>
<td>Average hourly wage (Table 5-2): $20.23</td>
</tr>
<tr>
<td>Average vehicle occupancy: 1.5</td>
<td>Average vehicle occupancy: 1.05</td>
</tr>
<tr>
<td>Speed without Improvement (mph): 28</td>
<td>Speed without Improvement (mph): 23</td>
</tr>
<tr>
<td>Speed with Improvement (mph): 33</td>
<td>Speed with Improvement (mph): 26</td>
</tr>
<tr>
<td>Delay without improvement (min.):</td>
<td>Delay without improvement (min.):</td>
</tr>
<tr>
<td>Delay with improvement (min.):</td>
<td>Delay with improvement (min.):</td>
</tr>
</tbody>
</table>

#### Calculations

<table>
<thead>
<tr>
<th>Autos</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of time per hour: $13.92 (wage X percentage X occupancy)</td>
<td>Value of time per hour: $21.24 (wage X percentage X occupancy)</td>
</tr>
<tr>
<td>For speed change:</td>
<td></td>
</tr>
<tr>
<td>Time without improvement (min.): 1.071</td>
<td>Time without improvement (min.): 1.304</td>
</tr>
<tr>
<td>Time with improvement (min.): 0.909</td>
<td>Time with improvement (min.): 1.154</td>
</tr>
<tr>
<td>(1 / speed) X length X 60</td>
<td>(1 / speed) X length X 60</td>
</tr>
<tr>
<td>Travel time saved per vehicle (min.): 0.162</td>
<td>Travel time saved per vehicle (min.): 0.151</td>
</tr>
<tr>
<td>or</td>
<td></td>
</tr>
<tr>
<td>For delay change:</td>
<td></td>
</tr>
<tr>
<td>Travel time saved per vehicle (min.): 0.000</td>
<td>Travel time saved per vehicle (min.): 0.000</td>
</tr>
<tr>
<td>(delay without - delay with)</td>
<td>(delay without - delay with)</td>
</tr>
<tr>
<td>Value of time saved per vehicle (VOT per hour * time saved / 60): $0.0377</td>
<td>Value of time saved per vehicle (VOT per hour * time saved / 60): $0.0533</td>
</tr>
<tr>
<td>Value of time saved per VMT (VOT per vehicle / length): $0.0753</td>
<td>Value of time saved per VMT (VOT per vehicle / length): $0.1066</td>
</tr>
</tbody>
</table>
### Worksheet 5-1: Value of Time

<table>
<thead>
<tr>
<th>General Information</th>
<th>Site Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Facility</td>
</tr>
<tr>
<td>Agency/Company</td>
<td>Segment</td>
</tr>
<tr>
<td>Project</td>
<td>Analysis Time Period</td>
</tr>
<tr>
<td>Date Performed</td>
<td>Analysis Year</td>
</tr>
<tr>
<td></td>
<td>Segment Length (mi.)</td>
</tr>
</tbody>
</table>

#### Inputs

<table>
<thead>
<tr>
<th>Autos</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of hourly wage (Table 5-1)</td>
<td>Percentage of hourly wage (Table 5-1)</td>
</tr>
<tr>
<td>Average hourly wage (Table 5-2)</td>
<td>Average hourly wage (Table 5-2)</td>
</tr>
<tr>
<td>Average vehicle occupancy</td>
<td>Average vehicle occupancy</td>
</tr>
<tr>
<td>Speed without Improvement (mph)</td>
<td>Speed without Improvement (mph)</td>
</tr>
<tr>
<td>Speed with Improvement (mph)</td>
<td>Speed with Improvement (mph)</td>
</tr>
<tr>
<td>or</td>
<td>or</td>
</tr>
<tr>
<td>Delay without improvement (min.)</td>
<td>Delay without improvement (min.)</td>
</tr>
<tr>
<td>Delay with improvement (min.)</td>
<td>Delay with improvement (min.)</td>
</tr>
</tbody>
</table>

#### Calculations

<table>
<thead>
<tr>
<th>Autos</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of time per hour (wage X percentage X occupancy)</td>
<td>Value of time per hour (wage X percentage X occupancy)</td>
</tr>
<tr>
<td>For speed change:</td>
<td></td>
</tr>
<tr>
<td>Time without improvement (min.)</td>
<td>Time without improvement (min.)</td>
</tr>
<tr>
<td>Time with improvement (min.)</td>
<td>Time with improvement (min.)</td>
</tr>
<tr>
<td>(1 / speed) X length X 60</td>
<td>(1 / speed) X length X 60</td>
</tr>
<tr>
<td>Travel time saved per vehicle (min.):</td>
<td>Travel time saved per vehicle (min.):</td>
</tr>
<tr>
<td>or</td>
<td>or</td>
</tr>
<tr>
<td>Value of time saved per vehicle (VOT per hour * time saved / 60)</td>
<td>Value of time saved per vehicle (VOT per hour * time saved / 60)</td>
</tr>
<tr>
<td>Value of time saved per VMT (VOT per vehicle / length)</td>
<td>Value of time saved per VMT (VOT per vehicle / length)</td>
</tr>
</tbody>
</table>
OPERATING AND OWNERSHIP COSTS MODULE

Vehicle operating and ownership costs are one of the three user cost components that are common across all improvement types and serve as inputs to the User Benefit Formula. This section discusses in greater detail the possible effect of the improvement on operating costs and how the change in operating costs can be quantified.

The focus of these calculations is the operating costs that are directly perceived by the user as out-of-pocket expenses. In other words, these costs will have a direct effect on driving behavior, and include driving expenses such as fuel costs and insurance premiums. Indirect costs, such as state patrol or parking fees that are paid by an employer, are not directly paid by the user and, therefore, are not included in the calculation of user costs.

When evaluating a particular improvement project, the analyst needs to determine which costs are relevant to that project. For example, if an improvement is being analyzed for a street that carries predominantly residential traffic, it may be that the project’s effect on inventory costs for commercial trucks will be insignificant and can therefore be safely ignored in the operating cost calculations. The relevant costs vary from project to project and each of the improvement chapters of this guidebook provides guidance as to which costs might be relevant for each of the project types.

Measuring Operating and Ownership Costs

Throughout this guidebook, the term operating costs has been used as a composite of the costs associated with owning and operating the vehicle over the road segments involved in the project analysis. Specifically, operating and ownership costs involve the following cost elements:

- **Operating Costs.** These include fuel and oil, maintenance, and tires.
- **Ownership Costs.** These include insurance, license and registration fees and taxes, economic depreciation, and finance charges. In special cases, they also include the inventory cost of the cargo on the vehicle.

In simple settings, these costs can be presented in an average form, prorated over vehicle miles traveled. Operating costs can be calculated on a per vehicle-mile basis. Similarly, ownership costs can be calculated on an annualized basis, and then prorated over vehicle-miles traveled. With either method, to calculate the effect of an improvement project on user costs, the operating costs will need to be calculated both without and with the improvement. The difference between these two cost calculations is the change in operating costs that is attributable to the improvement. As discussed with the improvement types, it is the change in per-unit operating costs resulting from the improvement that is relevant for the User Benefit Formula.

Table 5-4 presents one popular computation of operating and ownership costs per mile. These costs are also used in the sample operating costs calculation shown in Worksheet 5-2.
Table 5-4: Automobile Operating and Ownership Costs (Cents), 2000.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>Small Car</th>
<th>Midsize Car</th>
<th>Large Car</th>
<th>SUV</th>
<th>Van</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OPERATING COSTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(cents per mile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel and oil</td>
<td>5.0</td>
<td>5.9</td>
<td>6.5</td>
<td>6.7</td>
<td>6.0</td>
</tr>
<tr>
<td>Maintenance</td>
<td>3.2</td>
<td>3.5</td>
<td>3.6</td>
<td>3.8</td>
<td>3.6</td>
</tr>
<tr>
<td>Tires</td>
<td>1.3</td>
<td>1.7</td>
<td>2.3</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Total Operating Costs</strong></td>
<td>9.5</td>
<td>11.1</td>
<td>12.4</td>
<td>12.0</td>
<td>11.0</td>
</tr>
<tr>
<td>(cents per mile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OWNERSHIP COSTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(dollars per year)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insurance</td>
<td>1,046</td>
<td>915</td>
<td>1,046</td>
<td>1,360</td>
<td>1,005</td>
</tr>
<tr>
<td>License, registration, taxes</td>
<td>181</td>
<td>230</td>
<td>288</td>
<td>424</td>
<td>405</td>
</tr>
<tr>
<td>Depreciation</td>
<td>2,967</td>
<td>3,468</td>
<td>4,221</td>
<td>3,771</td>
<td>3,585</td>
</tr>
<tr>
<td>Finance charge</td>
<td>623</td>
<td>839</td>
<td>1,106</td>
<td>990</td>
<td>920</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>4,818</td>
<td>5,452</td>
<td>6,662</td>
<td>6,545</td>
<td>5,914</td>
</tr>
<tr>
<td>Depreciation Adjustment (per</td>
<td>156</td>
<td>166</td>
<td>174</td>
<td>133</td>
<td>162</td>
</tr>
<tr>
<td>1,000 miles over or under 15,000 miles annually)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Ownership Costs</strong></td>
<td>40.4</td>
<td>46.2</td>
<td>57.9</td>
<td>58.8</td>
<td>51.0</td>
</tr>
<tr>
<td>(cents per mile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10,000 miles per year</td>
<td>40.4</td>
<td>46.2</td>
<td>57.9</td>
<td>58.8</td>
<td>51.0</td>
</tr>
<tr>
<td>15,000 miles per year</td>
<td>32.1</td>
<td>36.3</td>
<td>44.4</td>
<td>43.6</td>
<td>39.4</td>
</tr>
<tr>
<td>20,000 miles per year</td>
<td>28.0</td>
<td>31.4</td>
<td>37.7</td>
<td>36.1</td>
<td>33.6</td>
</tr>
<tr>
<td><strong>TOTAL COST PER MILE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(cents per mile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10,000 miles per year</td>
<td>49.9</td>
<td>57.3</td>
<td>70.3</td>
<td>70.8</td>
<td>62.0</td>
</tr>
<tr>
<td>15,000 miles per year</td>
<td>41.6</td>
<td>47.4</td>
<td>56.8</td>
<td>55.6</td>
<td>50.4</td>
</tr>
<tr>
<td>20,000 miles per year</td>
<td>37.5</td>
<td>42.5</td>
<td>50.1</td>
<td>48.1</td>
<td>44.6</td>
</tr>
</tbody>
</table>


Some of the costs presented in Table 5-4 probably are higher than the average costs occasioned by users on the road. Depreciation and finance costs are significantly higher in the first 60,000 miles of a car’s life than in the next 90,000, but Table 5-4 assumes that all cars are retired from service after 60,000 miles. More representative ownership costs could be obtained by halving the depreciation and finance costs shown in Table 5-4.
In some project settings, situation specific calculations may be necessary. For example, if a project has the effect of reducing the average grade of a highway route, improving a rough road surface, or changing operating speeds, it may be important to incorporate specific changes in operating costs associated with these effects. Similarly, if unusual vehicles are involved, it may be necessary to construct ownership and operating costs from the ground up from the individual cost components. These calculations are discussed below.

Fuel costs can be calculated directly from fuel consumption information. To calculate fuel costs per vehicle mile, for example, the following calculation is used:

**Equation 5-3: Fuel Costs (Cents per VMT)**

\[ C_{\text{fuel}} = 100E_{\text{gpm}}P_{\text{fuel}} = 100P_{\text{fuel}} / E_{\text{mpg}} \]

where:

- \( C_{\text{fuel}} \) = user cost of fuel, in cents per vehicle-mile
- \( E_{\text{gpm}} \) = fuel efficiency, in gallons per mile
- \( E_{\text{mpg}} \) = fuel efficiency, in miles per gallon
- \( P_{\text{fuel}} \) = fuel price, in dollars per gallon

This equation is also used to calculate fuel costs per mile in the sample operating cost calculations presented in Worksheet 5-2.

Fuel costs represent less than 20 percent of total ownership and operating costs, and operating and ownership costs are typically one-half or less of total user costs. Hence, fuel costs are less than 10 percent of total user costs. At current fuel prices, it may be difficult to justify projects whose only purpose is to save fuel unless those projects are very low in cost. The analyst must decide whether the additional cost of modeling fuel cost savings is warranted, given its likely small overall effect on user costs. However, for particular projects, it may nonetheless be worthwhile to calculate the effect of road geometry directly on a component of operating costs, such as fuel costs. In addition, if a project is otherwise of marginal feasibility, the benefits associated with fuel cost saving may be important in determining overall project feasibility.

The fuel costs in Table 5-4 include between one and two cents per mile of federal and state highway user taxes. If a project will not change average fuel efficiency, their inclusion will have no effect on the User Benefits formula, which is based on differences in per-unit costs. If a project will change fuel efficiency, the user benefit calculation will be affected. In this case, the analyst also should consider whether it is worth accounting for the effects of the change in user fee revenue on the capital budget of the agency building the improvement. Methods for accounting for changes in user fee revenues are discussed in Chapter 6.

In Table 5-5, the relationship between speed and fuel consumption is portrayed for both automobiles and trucks. This information is also used in the calculations shown for operating costs in Worksheet 5-2.
Table 5-5: Fuel Consumption for Autos and Trucks, by Average Operating Speed

<table>
<thead>
<tr>
<th>Speed</th>
<th>Gallons per Mile</th>
<th>Autos</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mph</td>
<td>0.117</td>
<td>0.503</td>
<td></td>
</tr>
<tr>
<td>10 mph</td>
<td>0.075</td>
<td>0.316</td>
<td></td>
</tr>
<tr>
<td>15 mph</td>
<td>0.061</td>
<td>0.254</td>
<td></td>
</tr>
<tr>
<td>20 mph</td>
<td>0.054</td>
<td>0.222</td>
<td></td>
</tr>
<tr>
<td>25 mph</td>
<td>0.050</td>
<td>0.204</td>
<td></td>
</tr>
<tr>
<td>30 mph</td>
<td>0.047</td>
<td>0.191</td>
<td></td>
</tr>
<tr>
<td>35 mph</td>
<td>0.045</td>
<td>0.182</td>
<td></td>
</tr>
<tr>
<td>40 mph</td>
<td>0.044</td>
<td>0.176</td>
<td></td>
</tr>
<tr>
<td>45 mph</td>
<td>0.042</td>
<td>0.170</td>
<td></td>
</tr>
<tr>
<td>50 mph</td>
<td>0.041</td>
<td>0.166</td>
<td></td>
</tr>
<tr>
<td>55 mph</td>
<td>0.041</td>
<td>0.163</td>
<td></td>
</tr>
<tr>
<td>60 mph</td>
<td>0.040</td>
<td>0.160</td>
<td></td>
</tr>
<tr>
<td>65 mph</td>
<td>0.039</td>
<td>0.158</td>
<td></td>
</tr>
</tbody>
</table>


Table 5-5 provides information that can be used to calculate the fuel component of operating costs as a function of speed. Recall from the improvement type chapters that operating costs can be calculated as a negative function of speed. With a change in speed resulting from an improvement, changes in fuel costs can be calculated with the following formula:

**Equation 5-4: Change in Fuel Costs as a Function of Speed**

\[
\Delta C(S)_{\text{fuel}} = (gal_{c,\text{speed0}} - gal_{c,\text{speed1}})P_c
\]

\( \Delta C(S)_{\text{fuel}} \) = change in fuel costs as a function of speed for vehicle class c (cents)

\( gal_{c,\text{speed1}} \) = gallons per mile for vehicle class c, pre-improvement speed

\( gal_{c,\text{speed2}} \) = gallons per mile for vehicle class c, post-improvement speed

\( P_c \) = fuel price per gallon for vehicle class c (cents)

The factors shown in Table 5-5 for specific pre-improvement and post-improvement speeds combined with the price of fuel costs allows Equation 5-4 to be used to calculate speed related costs for each vehicle class. An example of this calculation is provided at the end of this section in the sample calculation shown in Worksheet 5-2.

The following figures also show how fuel costs change with speeds for a range of different fuel prices and speeds. Figure 5-1 shows the tradeoff between fuel costs and speed for automobiles.
Similarly, Figure 5-2 shows the same fuel cost-speed relationship for trucks at several different fuel price levels.

Fuel costs also can be expressed as a function of time rather than as a function of travel speed. This conversion is necessary to estimate operating costs for those improvements.
such as traffic signals and ramp metering that result in traffic delays. Table 5-6 shows the costs of fuel consumption per minute as a result of delays. Although these factors are a function of delay, the fuel consumption is due primarily to acceleration of vehicles after being delayed, rather than fuel consumed idling during delay periods.

Table 5-6: Fuel Consumption (Gallons) per Minute of Delay by Vehicle Type

<table>
<thead>
<tr>
<th>Free Flow Speed</th>
<th>Small Car</th>
<th>Big Car</th>
<th>SUV</th>
<th>2-Axle SU</th>
<th>3-Axle SU</th>
<th>Combo</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.011</td>
<td>0.022</td>
<td>0.023</td>
<td>0.074</td>
<td>0.102</td>
<td>0.198</td>
</tr>
<tr>
<td>25</td>
<td>0.013</td>
<td>0.026</td>
<td>0.027</td>
<td>0.097</td>
<td>0.133</td>
<td>0.242</td>
</tr>
<tr>
<td>30</td>
<td>0.015</td>
<td>0.030</td>
<td>0.032</td>
<td>0.122</td>
<td>0.167</td>
<td>0.284</td>
</tr>
<tr>
<td>35</td>
<td>0.018</td>
<td>0.034</td>
<td>0.037</td>
<td>0.149</td>
<td>0.203</td>
<td>0.327</td>
</tr>
<tr>
<td>40</td>
<td>0.021</td>
<td>0.038</td>
<td>0.043</td>
<td>0.177</td>
<td>0.241</td>
<td>0.369</td>
</tr>
<tr>
<td>45</td>
<td>0.025</td>
<td>0.043</td>
<td>0.049</td>
<td>0.206</td>
<td>0.280</td>
<td>0.411</td>
</tr>
<tr>
<td>50</td>
<td>0.028</td>
<td>0.048</td>
<td>0.057</td>
<td>0.235</td>
<td>0.321</td>
<td>0.453</td>
</tr>
<tr>
<td>55</td>
<td>0.032</td>
<td>0.054</td>
<td>0.065</td>
<td>0.266</td>
<td>0.362</td>
<td>0.495</td>
</tr>
<tr>
<td>60</td>
<td>0.037</td>
<td>0.060</td>
<td>0.073</td>
<td>0.297</td>
<td>0.404</td>
<td>0.537</td>
</tr>
<tr>
<td>65</td>
<td>0.042</td>
<td>0.066</td>
<td>0.083</td>
<td>0.328</td>
<td>0.447</td>
<td>0.578</td>
</tr>
<tr>
<td>70</td>
<td>0.047</td>
<td>0.073</td>
<td>0.094</td>
<td>0.360</td>
<td>0.490</td>
<td>0.620</td>
</tr>
<tr>
<td>75</td>
<td>0.053</td>
<td>0.080</td>
<td>0.105</td>
<td>0.392</td>
<td>0.534</td>
<td>0.661</td>
</tr>
</tbody>
</table>

Source: ECONorthwest calculations based on HERS model equations.

Equation 5-5 calculates fuel costs as a function of time and can use the input values from Table 5-6 directly:

**Equation 5-5: Change in Fuel Costs Due to Delay**

\[
\Delta C(D)_{c,fuel} = (gal_{c,min}) (D_0 - D_i) P_c
\]

\(\Delta C(D)_{c,fuel}\) = change in fuel costs as a function of delay (cents)

\(gal_{c,min}\) = gallons per minute for vehicle class c,

\(D_0\) = average delay before improvement (minutes)

\(D_i\) = average delay after improvement (minutes)

\(P_c\) = fuel price per gallon for vehicle class c (cents)

Ownership costs often need to be calculated separately, especially when the type of vehicle using the facility is unusual or particularly costly to acquire, license or insure. Truck traffic, in particular, involves the operation of very costly vehicles, and vehicles that may be carrying costly cargo. In general, the best approach to incorporating ownership costs in user benefit analysis is to calculate ownership costs on a per vehicle-mile basis. There are two approaches to that are used in making these calculations, depending upon the type of ownership cost.

For ownership costs that are naturally annual or periodic, such as licensing and insurance costs, it is workably accurate to divide these annual costs by the number of miles traveled by the vehicle annually. These costs are typically not incurred on a per-mile basis, although trip licensing of heavy trucks is common practice, and many insurance policies have annual mileage brackets. Nevertheless, across a population of such vehicles, such an
approach renders accurately the impact on total ownership costs in these categories of changes in vehicle miles traveled.

For ownership costs that are incurred once in the lifetime of the vehicle (such as vehicle purchase costs and purchase excise taxes), *depreciation* or *amortization* of the ownership costs is required to first turn the ownership cost into a periodic value, and then reduce it to a per-vehicle mile basis. The approaches differ in the way in which economic wear-and-tear of the vehicle, on the one hand, and financing costs, on the other hand are incorporated:

- **The depreciation** approach takes the capital value of the vehicle (purchase price) and spreads it over the life of the vehicle using a depreciation schedule. Straight-line depreciation schedules are the only schedules that are practical to use in the mixed fleet setting of highway user benefit analysis. Any other approach would impose hopelessly detailed information requirements about the vintage of the fleet, the market value of used vehicles, etc. Financing costs need to be added to the depreciation costs, because there is an opportunity cost to tying up funds in a vehicle for its whole life. The calculations in Table 5-4 use the straight-line depreciation approach to calculating vehicle ownership costs.

- **The amortization** approach is the preferred approach to annualizing ownership costs because it simultaneously accommodates the notion of a finite vehicle life and the opportunity cost of the funds tied up in the vehicle. The amortization approach calculates the level payment, at the relevant opportunity cost of capital (interest rate), that will fully spread the cost of the vehicle over its life. Since this is actually the annual cost that would be borne under the conditions of a lifetime lease or mortgaging of the purchase, this approach is realistic and natural.

The amortization approach involves the following, standard finance textbook formula:

**Equation 5-6: Vehicle Life Amortization (Annual Value)**

\[
PMT = \frac{P_{veh} \cdot r \left[ \left(1 + r \right)^L - SV \right]}{\left(1 + r \right)^L - 1}
\]

where:

- \(PMT\) = annual, amortized value (dollars)
- \(P_{veh}\) = capital value (price) of the vehicle (dollars)
- \(r\) = interest rate (opportunity cost of vehicle capital), per annum
- \(L\) = expected life of the vehicle, in years
- \(SV\) = Salvage value (dollars)

Figure 5-3 displays Equation 5-6 in graphical form assuming zero salvage value. Equation 5-6 is also used in the operating cost calculations shown in Worksheet 5-2. Note that the amortized cost is sensitive to the interest rate, and to the vehicle’s life, but that once the expected life reaches 20 years, the effect of additional years of life on amortized cost is relatively modest.

The formula in Equation 5-6 is applicable not only to the purchase price of a vehicle, but also one-time taxes and any other user costs that are paid once in the lifetime of the vehicle.
vehicle. Once the one-time ownership costs have been amortized, it is a simple matter to convert the annual costs to per-mile costs by dividing by the expected annual number of miles the vehicle is to be driven.

**Figure 5-3: Annual Amortized Cost, by Interest Rate and Life (per $1,000 of Capital Value)**

Since the amortized value of the vehicle PMT is an annual value, it can be converted to cost per vehicle mile by dividing the term by the annual VMT:

**Equation 5-7: Amortized Cost per VMT**

\[
PMT_{\text{mile}} = PMT \times 100/VMT
\]

where:

- \( PMT_{\text{mile}} \) = amortized value per vehicle mile (cents)
- \( VMT \) = annual vehicle miles

If an improvement is expected to change the life of a vehicle, then this will affect the annualized value of the vehicle as calculated in Equation 5-6. This change in PMT should be included in the change in operating costs by calculating the change in PMT with and without the improvement.

The annual capital cost component of vehicle ownership can be further adjusted for cases where the vehicle is used more intensively than is typical. In such a case, the life, \( L \), is shortened, and the expected annual number of miles the vehicle is to be driven is increased.
For those improvement projects that result in a change of delay rather than a change of speed, the amortization calculation needs to be adjusted to show the costs per minute of delay. The annual amortized value of the vehicle remains unchanged and is simply converted from an annual number to a cost per minute:

**Equation 5-8: Vehicle Amortization (Per Minute Value)**

\[
PMT_{\text{min}} = \frac{PMT \times 100}{365 \times 24 \times 60}
\]

where:

- \(PMT_{\text{min}}\) = amortized value per minute (cents)
- \(PMT\) = annual amortized value of the vehicle (dollars)

The change in capital costs due to delay then is a matter of multiplying the amortized cost per minute by the length of delay:

**Equation 5-9: Change in Capital Costs Due to Delay**

\[
\Delta PMT(D)_{\text{min}} = PMT_{\text{min}} \times \Delta D
\]

where:

- \(\Delta PMT(D)_{\text{min}}\) = amortized value per minute (cents)
- \(\Delta D\) = change in delay (minutes)

*Inventory costs of cargo* are a special category of user costs that arise because the shipper is a user of a truck shipping service. When valuable cargo is inventoried while in transit, the owner of that cargo is burdened with the interest carrying costs. Namely, had the owner of the cargo had cash, instead of cargo, he would have been enjoying a market return on that cash. Depending upon the value of the cargo in a truck, the speed of the truck, and the assumed interest carrying cost, inventory costs may be significant.

To calculate inventory costs on a per vehicle-mile basis, an hourly interest rate must be computed along with the amount of time it takes for the vehicle to travel a mile. The resulting formula for inventory costs, per vehicle-mile is:

**Equation 5-10: Inventory Costs (Cents per VMT)**

\[
I(S) = 100 \times \frac{r}{8760} \times \frac{1}{S} \times P_{\text{cargo}}
\]

where:

- \(I(S)\) = inventory costs (cents per vehicle-mile) as a function of speed
- \(r\) = interest rate, per annum
- \(P_{\text{cargo}}\) = value of the cargo, in dollars
- \(S\) = speed of the vehicle, in miles per hour

Figure 5-4 shows inventory costs per vehicle mile, as a function of vehicle speed and cargo value. The figure is calculated using an interest rate of 10 percent—the costs at other interest rates are proportionally larger or smaller.
Changes in speeds, therefore, will result in a change in operating costs per vehicle mile:

**Equation 5-11: Change in Inventory Costs Due to Change in Travel Speed**

\[
\Delta I(S) = 100 \times \frac{r}{8760} \times \left( \frac{1}{S_0} - \frac{1}{S_1} \right) \times P_{\text{cargo}}
\]

where:
- \( \Delta I(S) \) = change in inventory costs (cents per vehicle-mile)
- \( S_0 \) = speed before the improvement (miles per hour)
- \( S_1 \) = speed after the improvement (miles per hour)

Inventory costs should be added to the user cost, per vehicle-mile, that is attributed to trucks and other vehicles carrying cargo.

The inventory cost associated with a change in delay is relatively straightforward. The cost of the inventory is amortized to reflect costs per minute:

**Equation 5-12: Inventory Costs (Cents per Vehicle per Minute)**

\[
I(D) = 100 \times \frac{r}{8760 \times 60} \times P_{\text{cargo}}
\]

where:
- \( I(D) \) = inventory costs per vehicle-minute of delay (cents per minute)
- \( r \) = interest rate, per annum
- \( P_{\text{cargo}} \) = value of the cargo, in dollars
An improvement project that results in delay (rather than a change in speed) would have the following effect on inventory costs:

**Equation 5-13: Change in Inventory Costs (Cents) Due to Delay**

\[ \Delta I(D) = I(D) \times \Delta D \]

where:

\[ \Delta I(D) = \text{change in inventory costs (cents per minute)} \]
\[ \Delta D = \text{change in delay (minutes)} \]

**Speed-Based Changes in Operating Costs**

Inventory costs and fuel costs are the two operating cost components that will vary with speed and can be used to calculate the change in operating costs resulting from an improvement. As discussed with the individual improvement types and shown in Figure 5-1, Figure 5-2, and Figure 5-4, these operating costs are a negative function of speed. Since both of these equations provide cost estimates in cents per vehicle mile, calculating the change in operating costs as a negative function of speed is simply a matter of adding these two components together:

**Equation 5-14: Change in Vehicle Operating Costs Due to Changes in Speed**

\[ \Delta OC(S)_c = g_c(S) = \Delta C(S)_{fuel,c} + \Delta I(S)_c \]

where:

\[ \Delta OC(S)_c = \text{change in operating costs (cents per vehicle - mile) for vehicle class } c \]
\[ \Delta C(S)_{fuel,c} = \text{change in fuel costs (cents per vehicle - mile) for vehicle class } c \]
\[ \Delta I(S)_c = \text{change in inventory costs (cents per vehicle - mile) for vehicle class } c \]

As discussed above, fuel costs generally comprise a relatively small portion of total vehicle ownership and operating costs. Given that many improvement projects focus on decreasing delays and increasing travel speeds, however, fuel costs may comprise the majority or even all of the change in operating costs that result from a project. Depending on the project, the calculation shown in Equation 5-14 may be adequate to estimate the change in operating cost component of the User Benefit Formula. A sample calculation using the change in speed-based operating costs as well as other operating and ownership costs is included at the end of this module.

**Delay-Based Changes in Operating Costs**

A similar calculation is made for those improvement projects that result in a change in delay. Each of the user cost components that were estimated as a function of time were converted to a unit measure of cents per minute delay. To calculate the total effect of delay on these operating costs, the common units allow the components to be added together directly:
Equation 5-15: Change in Operating Costs Due to Delay

$$\Delta OC(D)_c = f_c(D) = \Delta C(D)_{\text{min},c} + \Delta I(D)_c + \Delta PMT(D)$$

where:

$$\Delta OC(D)_c$$ = change in operating costs in cents per delay minute for vehicle class $c$

The common units of either cents per vehicle mile or cents per minute delay will allow these operating unit costs to entered with the other user cost components in the User Benefit Formula.

**Application: Operating Cost Calculation**

The following example illustrates how a project might affect operating costs; the sample information is included in Worksheet 5-2. In this hypothetical example, an existing two-lane highway with signalized intersections is being converted to a freeway, which will dramatically improve travel speeds for both autos and trucks. Auto speeds are expected to increase from 45 to 60 mph while trucks speeds will increase from 35 to 50 mph.

Worksheet 5-2 shows all the input data and calculations needed to determine the effect of this hypothetical project on operating costs. As shown below, the increase in travel speeds is expected to decrease operating costs for autos through a reduction in fuel costs from 6.3 to 6.0 cents per mile. Trucks realize operating cost savings through a reduction in fuel costs, with a reduction from 25.48 to 23.24 cents per mile. Note that the fuel costs used in this example do not include gas taxes. The increase in average truck speeds also decreases inventory costs from 6.52 to 4.57 cents per mile as less time is spent on the road.

The bottom of the table shows the total operating costs for autos and trucks both without and with the improvement. The improvement results in a total change in operating costs of 0.30 cents per VMT for autos and 4.48 cents per VMT for trucks. These final numbers reflect the total change in operating costs for each vehicle class and are the numbers that the analyst would use as one of the cost components in the User Benefit Formula.
Worksheet 5-2: Operating and Ownership Cost—Sample Calculation

<table>
<thead>
<tr>
<th>General Information</th>
<th>Site Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst: Me</td>
<td>Facility: Facility 1</td>
</tr>
<tr>
<td>Agency/Company: My Agency</td>
<td>Segment: Segment 1</td>
</tr>
<tr>
<td>Project: Demo</td>
<td>Analysis Time Period: PM Peak</td>
</tr>
<tr>
<td>Date Performed: 1/1/2002</td>
<td>Analysis Year: 2005</td>
</tr>
</tbody>
</table>

**Inputs**
- Finance Rate: 10.0%

<table>
<thead>
<tr>
<th>Autos</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed (mph):</strong></td>
<td><strong>Speed (mph):</strong></td>
</tr>
<tr>
<td>without improvement: 45</td>
<td>without improvement: 35</td>
</tr>
<tr>
<td>with improvement: 60</td>
<td>with improvement: 50</td>
</tr>
<tr>
<td><strong>Fuel Cost Per Gallon:</strong></td>
<td><strong>Fuel Cost Per Gallon:</strong></td>
</tr>
<tr>
<td>without improvement: $1.50</td>
<td>without improvement: $1.40</td>
</tr>
<tr>
<td>with improvement: $0.040</td>
<td>with improvement: $0.182</td>
</tr>
<tr>
<td><strong>Fuel Consumption per Mile (Table 5-5):</strong></td>
<td><strong>Fuel Consumption per Mile (Table 5-5):</strong></td>
</tr>
<tr>
<td>without improvement: 0.042</td>
<td>without improvement: 0.182</td>
</tr>
<tr>
<td>with improvement: 0.040</td>
<td>with improvement: 0.166</td>
</tr>
<tr>
<td><strong>Other Operating Costs per Mile (Table 5-4):</strong></td>
<td><strong>Other Operating Costs per Mile (tires, maintenance, etc.):</strong></td>
</tr>
<tr>
<td>(tires, maintenance, etc.)</td>
<td>$0.050</td>
</tr>
<tr>
<td>Vehicle Life (years): 10</td>
<td>Vehicle Life (years): 8</td>
</tr>
<tr>
<td>Vehicle Cost: $20,000</td>
<td>Vehicle Cost: $60,000</td>
</tr>
<tr>
<td>Salvage Value at End of Life: $2,000</td>
<td>Salvage Value at End of Life: $5,000</td>
</tr>
<tr>
<td>Miles per Year: 15,000</td>
<td>Miles per Year: 50,000</td>
</tr>
<tr>
<td>Insurance per Year (Table 5-3): $1,000</td>
<td>Insurance per Year: $1,500</td>
</tr>
</tbody>
</table>

**Calculations**
- **Autos**
  - Fuel Cost per VMT (Equation 5-3): without improvement: $0.0630
    - with improvement: $0.0600
  - Total Operating Cost per VMT: without improvement: $0.1030
    - with improvement: $0.1000
  - Amortized Vehicle Cost Per Year: $3.129
    - (Equation 5-6)
- **Trucks**
  - Fuel Cost per VMT (Equation 5-3): without improvement: $0.2548
    - with improvement: $0.2324
  - Total Operating Cost per VMT: without improvement: $0.3048
    - with improvement: $0.2824
  - Amortized Vehicle Cost Per Year: $10,809
    - (Equation 5-6)
  - Inventory Cost per Hour: $2.2831
    - (Equation 5-10)
  - Inventory Cost per Mile: without improvement: $0.0652
    - with improvement: $0.0457
    - (cost per hour / miles per hour)
  - Amortized Vehicle Cost per VMT: $0.2086
  - Insurance Cost per VMT: $0.0667
  - Ownership Cost per VMT: without improvement: $0.2753
    - with improvement: $0.2753
    - (vehicle + insurance)
  - Oper. and Ownership Cost per VMT: without improvement: $0.3783
    - with improvement: $0.3753
    - (operating + ownership)
  - Oper. and Ownership Savings / VMT: $0.0030
    - (without - with)
  - Vehicle Cost per VMT: $0.2162
  - Insurance Cost per VMT: $0.0300
  - Ownership Cost per VMT: without improvement: $0.5510
    - with improvement: $0.5286
    - (vehicle + insurance + inventory)
  - Oper. and Ownership Cost per VMT: without improvement: $0.8558
    - with improvement: $0.8110
    - (operating + ownership)
  - Oper. and Ownership Savings / VMT: $0.0448
    - (without - with)
### Worksheet 5-2: Operating and Ownership Cost

<table>
<thead>
<tr>
<th>General Information</th>
<th>Site Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Facility</td>
</tr>
<tr>
<td>Agency/Company</td>
<td>Segment</td>
</tr>
<tr>
<td>Project</td>
<td>Analysis Time Period</td>
</tr>
<tr>
<td>Date Performed</td>
<td>Analysis Year</td>
</tr>
<tr>
<td></td>
<td>Segment Length (mi.)</td>
</tr>
</tbody>
</table>

#### Inputs

<table>
<thead>
<tr>
<th>Autos</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed (mph):</strong></td>
<td></td>
</tr>
<tr>
<td>without improvement</td>
<td>without improvement</td>
</tr>
<tr>
<td>with improvement</td>
<td>with improvement</td>
</tr>
<tr>
<td><strong>Fuel Cost Per Gallon</strong></td>
<td></td>
</tr>
<tr>
<td>without improvement</td>
<td>Fuel Cost Per Gallon</td>
</tr>
<tr>
<td>with improvement</td>
<td>with improvement</td>
</tr>
<tr>
<td><strong>Fuel Consumption per Mile (Table 5-5):</strong></td>
<td>Fuel Consumption per Mile (Table 5-5):</td>
</tr>
<tr>
<td>without improvement</td>
<td>without improvement</td>
</tr>
<tr>
<td>with improvement</td>
<td>with improvement</td>
</tr>
<tr>
<td><strong>Other Operating Costs per Mile (Table 5-4):</strong></td>
<td>Other Operating Costs per Mile (tires, maintenance, etc.)</td>
</tr>
<tr>
<td>(tires, maintenance, etc.)</td>
<td></td>
</tr>
<tr>
<td>Vehicle Life (years)</td>
<td>Vehicle Life (years)</td>
</tr>
<tr>
<td>Vehicle Cost</td>
<td>Vehicle Cost</td>
</tr>
<tr>
<td>Salvage Value at End of Life</td>
<td>Salvage Value at End of Life</td>
</tr>
<tr>
<td>Miles per Year</td>
<td>Miles per Year</td>
</tr>
<tr>
<td><strong>Insurance per Year (Table 5-3):</strong></td>
<td>Insurance per Year</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Calculations

<table>
<thead>
<tr>
<th>Autos</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel Cost per VMT (Equation 5-3):</strong></td>
<td>Fuel Cost per VMT (Equation 5-3):</td>
</tr>
<tr>
<td>without improvement</td>
<td>without improvement</td>
</tr>
<tr>
<td>with improvement</td>
<td>with improvement</td>
</tr>
<tr>
<td>(cost per gallon X gallons per mile)</td>
<td>(cost per gallon X gallons per mile)</td>
</tr>
<tr>
<td><strong>Total Operating Cost per VMT:</strong></td>
<td>Total Operating Cost per VMT:</td>
</tr>
<tr>
<td>without improvement</td>
<td>without improvement</td>
</tr>
<tr>
<td>with improvement</td>
<td>with improvement</td>
</tr>
<tr>
<td>(fuel cost per VMT + other oper. cost)</td>
<td>(fuel cost per VMT + other oper. cost)</td>
</tr>
<tr>
<td><strong>Amortized Vehicle Cost Per Year:</strong></td>
<td>Amortized Vehicle Cost Per Year:</td>
</tr>
<tr>
<td>(Equation 5-6)</td>
<td>(Equation 5-6)</td>
</tr>
<tr>
<td><strong>Inventory Cost per Hour</strong></td>
<td>Inventory Cost per Hour</td>
</tr>
<tr>
<td>(Equation 5-10)</td>
<td>(Equation 5-10)</td>
</tr>
<tr>
<td><strong>Insurance Cost per Mile:</strong></td>
<td>Insurance Cost per Mile</td>
</tr>
<tr>
<td>without improvement</td>
<td>without improvement</td>
</tr>
<tr>
<td>with improvement</td>
<td>with improvement</td>
</tr>
<tr>
<td>(cost per hour / miles per hour)</td>
<td>(cost per hour / miles per hour)</td>
</tr>
<tr>
<td><strong>Amortized Vehicle Cost per VMT</strong></td>
<td>Amortized Vehicle Cost per VMT</td>
</tr>
<tr>
<td><strong>Insurance Cost per VMT</strong></td>
<td>Insurance Cost per VMT</td>
</tr>
<tr>
<td><strong>Ownership Cost per VMT</strong></td>
<td>Ownership Cost per VMT</td>
</tr>
<tr>
<td>without improvement</td>
<td>without improvement</td>
</tr>
<tr>
<td>with improvement</td>
<td>with improvement</td>
</tr>
<tr>
<td>(vehicle + insurance)</td>
<td>(vehicle + insurance + inventory)</td>
</tr>
<tr>
<td><strong>Oper. and Ownership Cost per VMT</strong></td>
<td>Oper. and Ownership Cost per VMT</td>
</tr>
<tr>
<td>without improvement</td>
<td>without improvement</td>
</tr>
<tr>
<td>with improvement</td>
<td>with improvement</td>
</tr>
<tr>
<td>(operating + ownership)</td>
<td>(operating + ownership)</td>
</tr>
<tr>
<td><strong>Oper. and Ownership Savings / VMT</strong></td>
<td>Oper. and Ownership Savings / VMT</td>
</tr>
<tr>
<td>(without - with)</td>
<td>(without - with)</td>
</tr>
</tbody>
</table>
ACCIDENT COSTS MODULE

Any type of highway improvement may potentially have a safety component that reduces either the rate or severity of accidents. This improvement in safety will affect user costs by reducing the costs of accidents borne by users of the facility. The analysis issues associated with calculating accident costs are discussed in detail below.

The accident cost component of the User Benefit Formula is determined by combining two separate elements:

*Accident Frequency.* The accident frequency reflects the likelihood of an accident occurring on a given highway segment or feature such as an intersection. The accident frequency information is combined with the accident cost information to calculate the expected cost of accidents for each vehicle class.

*Accident Unit Costs.* The perceived cost of accidents is needed to calculate the accident component of user costs. This includes all costs from an accident resulting from death, injuries, and property damage that are perceived by the user. The accident unit costs are calculated net of insurance costs to avoid double counting that portion of costs that are already covered by insurance.

A comprehensive discussion of all the analysis tools available for estimating accidents is far beyond the scope of this manual. Rather, the accident cost module provides guidance to these resources as well as information on the underlying models and techniques that these models rely on.

The first part of the module provides information on resources available for estimating changes in *accident rates* while that latter part of the module provides information on *accident unit costs.* Following the discussion of accident frequencies and costs, information on how to combine these components for use in the User Benefit Formula is presented. This module concludes with a hypothetical example illustrating how the changes in accident costs are calculated.

**Accident Frequency**

Ideally, the analyst will have access to historical accident data for the highway or highway segment that is being considered for an improvement project. Segment specific data over several years provides the most accurate indicator of accident rates for that segment, as it is a reflection of both road geometry and user characteristics.

In absence of segment-specific information, detailed accident rate data are published annually by the National Highway Traffic Safety Administration. This includes annual accident data by accident severity and vehicle type at both the national and state levels. In contrast to segment-specific accident data, these data are aggregated and reflect accident rates for all highway types across all driving periods and driving conditions.

Table 5-7 shows the number of vehicles involved in accidents by accident type and vehicle type for 2000 as reported by the National Highway Traffic Safety Administration. Table 5-7 also shows accidents per million VMT by vehicle type and accident costs per VMT (gross and net of insurance reimbursement by vehicle type).
### Table 5-7. Motor Vehicle Accident Involvement and Costs in 2000

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Fatal Accidents</th>
<th>Injury (Non-Fatal) Accidents</th>
<th>Property Damage Only Accidents</th>
<th>All Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>27,496</td>
<td>2,396,000</td>
<td>4,467,000</td>
<td>6,890,500</td>
</tr>
<tr>
<td>Light trucks</td>
<td>20,295</td>
<td>1,209,000</td>
<td>2,621,000</td>
<td>3,850,300</td>
</tr>
<tr>
<td>Large trucks</td>
<td>4,930</td>
<td>101,000</td>
<td>351,000</td>
<td>456,900</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>2,940</td>
<td>53,000</td>
<td>14,000</td>
<td>69,900</td>
</tr>
<tr>
<td>Buses</td>
<td>322</td>
<td>13,000</td>
<td>43,000</td>
<td>56,300</td>
</tr>
<tr>
<td><strong>All Vehicles</strong></td>
<td><strong>55,983</strong></td>
<td><strong>3,772,000</strong></td>
<td><strong>7,496,000</strong></td>
<td><strong>11,323,900</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Vehicle Involvement per Million VMT in 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>0.017 1.496 2.789 4.301</td>
</tr>
<tr>
<td>Light trucks</td>
<td>0.022 1.308 2.837 4.167</td>
</tr>
<tr>
<td>Large Trucks</td>
<td>0.024 0.491 1.706 2.220</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>0.281 5.058 1.336 6.674</td>
</tr>
<tr>
<td>Buses</td>
<td>0.042 1.710 5.657 7.410</td>
</tr>
<tr>
<td><strong>All Vehicles</strong></td>
<td><strong>0.020 1.372 2.726 4.118</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Accident Costs (cents per VMT) by Vehicle Type (year 2000 dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>4.20 11.16 0.61 15.97</td>
</tr>
<tr>
<td>Light trucks</td>
<td>5.37 9.76 0.62 15.76</td>
</tr>
<tr>
<td>Large trucks</td>
<td>5.86 3.66 0.38 9.90</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>68.62 37.73 0.29 106.65</td>
</tr>
<tr>
<td>Buses</td>
<td>10.36 12.76 1.24 24.36</td>
</tr>
<tr>
<td><strong>All Vehicles</strong></td>
<td><strong>4.98 10.23 0.60 16.01</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Accident Costs Net of Insurance Reimbursement (cents per VMT) by Vehicle Type (year 2000 dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>4.16 6.75 0.03 10.94</td>
</tr>
<tr>
<td>Light trucks</td>
<td>5.32 5.91 0.03 11.26</td>
</tr>
<tr>
<td>Large trucks</td>
<td>5.81 2.22 0.02 8.04</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>68.00 22.83 0.02 90.84</td>
</tr>
<tr>
<td>Buses</td>
<td>10.27 7.72 0.06 18.05</td>
</tr>
<tr>
<td><strong>All Vehicles</strong></td>
<td><strong>4.93 6.19 0.03 10.62</strong></td>
</tr>
</tbody>
</table>


### Modeling Changes in Accidents

A substantial amount of research has been devoted to developing models and empirical relationships between highway design features and accident rates. One of the primary
challenges is that human error (rather than facility design) is often the primary cause of accidents. Consequently, even under ideal conditions where accident data are available and a model is properly estimated, the resulting model will only be able to predict that fraction of accidents that result from design features of the highway and not those caused by human errors. Within this context, there are many tools available for predicting accidents across a range of highway and roadway facility types. This section provides a general description of these tools and references to more detailed sources of information.

**Accident Prediction Tools and Resources**

Several major research efforts are underway for developing comprehensive modeling tools for predicting accidents and changes in accident frequencies for highway improvements. These are discussed briefly below and represent the state-of-the-art analytical tools for predicting accidents.

*Highway Safety Manual*

The *Highway Safety Manual* is a multistage, multiyear research project that is intended to be the most comprehensive effort to date for developing tools for evaluating highway safety and predicting the safety effects of highway improvements. In addition to developing new tools, *Highway Safety Manual* will incorporate both the Interactive Highway Safety Design Model (IHSDM) and the Comprehensive Highway Safety Improvement Model (CHSIM) currently in development.

*Interactive Highway Safety Design Model*

The IHSDM builds on a large body of existing work devoted to the development of accident prediction models for rural two-lane roads. The first stage of the IHSDM focuses on rural road segments and rural intersections and the underlying statistical models for these are discussed below. The first phase of the IHSDM is scheduled to be released in 2003.

*Comprehensive Highway Safety Improvement Model*

The CHSIM project is designed to provide highway agencies with better analytical tools that can be easily accessed by state and local agencies. This includes better tools for identifying improvement sites with high potential for safety benefits and to help the allocation of resources towards projects with the highest levels of safety benefits. The software portion of CHSIM is anticipated for 2005.

*Highway Safety Information System (HSIS)*

The HSIS database is maintained by the FHWA and contains crash, roadway inventory, and traffic volume data for multiple states. This database is a resource for accident-related data if more segment-specific data are not available.

*ROADSIDE*

The AASHTO ROADSIDE model is the companion analytic tool for the *Roadside Design Guide* and utilizes various engineering design equations to determine how changes in road and roadside features will impact both accident and encroachment rates.
This model has the advantage of incorporating both road and roadside features into the accident predictions. This model is discussed in more detail below.

**Crash Outcome Data Evaluation System (CODES)**

CODES is a collaborative effort between states designed to provide medical and financial outcome information relating motor vehicle crashes. This information is based on actual police and hospital report data and will be useful to refining estimates of accident costs and help inform safety related highway improvement decisions.

These models and data sources are generally considered the best available for predicting accidents and the impacts on accidents due to changes in roadway design features. As such, they should be the first choice for an analyst looking to estimate changes in accidents. Table 5-8 below provides sources for additional information on these resources.

**Table 5-8: Sources for Information on Accident Prediction Tools**

<table>
<thead>
<tr>
<th>Safety Analysis Tool</th>
<th>Website Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive Highway Safety Design Model (IHSDM)</td>
<td><a href="http://www.tfhrc.gov/safety/ihsdm/ihsdm.htm">http://www.tfhrc.gov/safety/ihsdm/ihsdm.htm</a></td>
</tr>
<tr>
<td>Highway Safety Manual (HSM)</td>
<td>www4.trb.org/trb/crp.nsf/All+Projects/NCHRP+17-18(4)</td>
</tr>
<tr>
<td>Highway Safety Information System (HSIS)</td>
<td><a href="http://www.tfhrc.gov/safety/hsis/hsis2.htm">www.tfhrc.gov/safety/hsis/hsis2.htm</a></td>
</tr>
</tbody>
</table>

In addition to the resources discussed above, there are empirical studies that can be used to approximate changes in accidents due to changes in specific design features. Some of this work, like the studies completed on rural two-lane roads, is incorporated into the models discussed above.

The following discussion provides equations that relate changes in accidents to changes in specific highway or street features. These formulas are arranged by highway feature type and will be useful for providing estimates of the safety impacts of a proposed improvement if more detailed modeling tools are not available. Sample calculations showing how changes in accidents can be calculated from these formulas are also provided in the text as well as in the sample calculation worksheet provided at the end of this section.

**Highway Capacity Improvements**

Accident frequency is a function of a variety of factors, including highway design features, traffic volumes, and congestion levels. In absence of more detailed information, accident frequency can be modeled as a function of the volume-capacity ratio. This provides an approximation of the safety benefits of capacity improvements. The relationship between the volume-capacity ratio and accident rates on urban freeways is
shown graphically in Figure 5-5.\(^9\) This relationship can also be used in Worksheet 5-3 and Worksheet 5-4 to predict changes in accident rates for urban freeway applications. 

Figure 5-5: Accidents and Volume-Capacity Relationship for Urban Freeways

![Figure 5-5: Accidents and Volume-Capacity Relationship for Urban Freeways](image)


By converting this relationship to a proportional form, it also can be used to provide an approximation of accident reductions for any urban highway. In equation form, the relationship between the proportional change in the accident rate and a change in the volume-capacity ratio is expressed by Equation 5-16:

Equation 5-16: General Formula Relating Changes in Accident Rates to Changes in Capacity for Urban Highways

\[ A_g = \frac{3.0234 \left( \frac{V_i}{C_i} \right) - 1.11978 \left( \frac{V_i}{C_i} \right)^2}{3.0234 \left( \frac{V_o}{C_o} \right) - 1.11978 \left( \frac{V_o}{C_o} \right)^2} - 1 \]

where:

- \( A_g \) = Proportional change in accident rate
- \( \left( \frac{V_o}{C_o} \right) \) = Volume-capacity ratio for urban freeway segment without improvement
- \( \left( \frac{V_i}{C_i} \right) \) = Volume-capacity ratio for urban freeway segment with improvement

If the capacity for the segment is improved so that the volume-capacity ratio falls from 1.0 to 0.80, for example, the resulting calculation using Equation 5-16 yields a value of –0.11, or a reduction in the accident rate of 11 percent from the before-improvement accident rate.

**Sample Calculation: Urban Freeway Capacity Improvement**

Consider the example of a freeway with a volume-capacity ratio of 1.2 and an accident rate of 1.5 accidents per million VMT. With the addition of a new lane for the segment, the volume capacity ratio is expected to fall to 0.7. Using Equation 5-16, the proportional change in the accident rate is a reduction of 22 percent. Multiplying this reduction by the before-improvement accident rate of 1.5 yields an accident rate of 1.17 accidents per million VMT after the improvement.

This relationship is a simple approximation of the effects that changes in capacity have on highway safety. Accidents are caused by a host of other factors, however, including the combined effect of highway and roadside design features. More sophisticated analytical tools have been developed that incorporate these other factors and should be used whenever possible for predicting accidents. The most current models for a variety of different highway and improvement types are discussed below.

**Rural Two-Lane Roads**

A substantial amount of empirical work has been completed for developing statistical models predicting accidents on two-lane rural roads, and this work is serving as the basis for the IHSDM discussed above. The FHWA Report *Prediction of the Expected Safety Performance of Rural Two-Lane Highways* \(^{10}\) provides information on the statistical models that were developed for the IHSDM and is a useful source of information for an analyst looking to predict changes in accidents on rural roads due to a range of different

improvements types. These models are summarized below and include models for rural road segments and rural at-grade intersections.

The basic prediction method follows an algorithm that combines the statistical model with information on the specific road being evaluated:

- Estimate accidents using base model for either road segments or at-grade intersections
- Apply calibration and accident modification factors (if application is different from base)
- Adjust result using Empirical Bayes procedure (if using observed accident data)

Each of these steps is summarized below.

**Rural Road Segments**

The IHSDM base model for rural road segments predicts the number of accidents based on traffic volumes and roadway features. The base model assumes the following features:

- 12-foot lane width,
- 6-foot shoulder width,
- Roadside hazard rating\(^\text{11}\) of three,
- Driveway density of five driveways per mile,
- No horizontal and vertical curvature, and
- Level grade.

A series of accident modification factors are also incorporated into the model to account for road features that are different from the base model. The model can also be calibrated using a simple scalar to adjust the model estimates to more closely match local traffic volumes, if these differ substantially from the base model data.\(^\text{12}\)

For rural road segments, the base model is given by Equation 5-17. This equation can also be used to predict changes in accidents with and without the improvement in the calculations presented in Worksheet 5-3.

\(^{11}\) The roadside hazard rating has a scale of one to seven, with seven representing the most severe hazard. See Zegeer et al (1988) for a discussion of how the hazard rating was developed.

\(^{12}\) The base models for the IHSDM models were estimated using data from Washington and Minnesota with Washington conditions assumed for the base model. If the application of the model were to an area where traffic volumes were 20 percent greater than Washington, for example, then the model estimates would be calibrated to local conditions by multiplying the prediction results by 1.2.
Equation 5-17: IHSDM Base Model for Rural Road Segments

\[ A = \frac{AADT \times 365}{1,000,000} \times 0.6148 \times L \]

where:
- \( A \) = predicted number of accidents on the segment
- \( AADT \) = annual average daily traffic volume on segment
- \( L \) = length of segment (miles)

A series of accident modification factors are used to adjust the base model to different conditions other than those assumed for the base case. Accident modification factors (AMFs) were determined in the study by a panel of experts for the following features:

- Lane width,
- Shoulder width,
- Shoulder type,
- Horizontal curves (length, radius, spiral transitions, super-elevation),
- Grades,
- Driveway density,
- Two-way, left-turns,
- Passing lanes/short four-lane sections, and
- Roadside design.

Each of these AMFs has multiple values given different design or segment characteristics. Additional detail on AMF values is provided in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways* for those interested in predicting accidents in situations that differ significantly from the base model conditions.

**Sample Calculation: Predicted Accidents on Rural Road Segments**

The sample calculation shown below is for a 1-mile rural road segment with a traffic volume of 1,500 vehicles per day. Using Equation 5-17, predicted number of accidents for this segment is 0.337 annually.

\[ A_0 = \frac{1,500 \times 365}{1,000,000} \times 0.6148 \times 1 = 0.337 \]

where:
- \( A_0 \) = Predicted number of accidents on the segment without the passing lane

In this example, the analyst is considering the effect of adding a passing lane to this segment. A rural road with a passing lane has an associated AMF of 0.75. For all the IHSDM models, the AMFs are applied to the base model in multiplicative fashion. The
predicted number of accidents using equation would then be multiplied by the AMF value of 0.75 to adjust the base prediction for the presence of a passing lane. Using the AMF value of 0.75 for a passing lane, predicted accidents are adjusted in following manner:

\[ A_i = (0.75) A_0 \]
\[ A_i = (0.75)(0.337) = 0.252 \]

where:

\[ A_i \] = predicted number of accidents on the segment with the passing lane

In this simple example, the addition of the passing lane will reduce accidents by 0.084 \((0.337 – 0.252)\) annually.

**Rural At-Grade Intersections**

Base models have been developed for rural three-leg stop-controlled intersections, rural four-leg stop-controlled intersections, and rural four-leg signalized intersections. These models are similar to the base model for rural road segments in that they can be calibrated to match local conditions and each have AMFs that allow the models to be adjusted to account for design features that are not included in the base model. Each of the rural intersection models is discussed below.

**Three-Leg Stop-Controlled Intersections**

The base model for rural three-leg stop-controlled intersections is given by:

**Equation 5-18: IHSDM Base Model for Rural Three-Leg Stop-Controlled Intersections**

\[ A = \exp[-10.9 + 0.79 \ln(ADT_1) + 0.49 \ln(ADT_2)] \]

where:

\[ A \] = predicted number of accidents at the intersection
\[ ADT_1 \] = average daily traffic volume on the major road
\[ ADT_2 \] = average daily traffic volume on the minor road

This base model assumes a roadside hazard rating of two and that there is no right turn lane on the major road. This equation can also be used in Worksheet 5-3 to predict changes in accidents with and without the improvement.

**Four-Leg Stop-Controlled Intersections**

A similar model applies to rural four-leg stop-controlled intersections and can be used to predict changes in accidents in Worksheet 5-3:
Equation 5-19: IHSDM Base Model for Rural Four-Leg Stop-Controlled Intersections

\[ A = \exp[-9.34 + 0.60 \ln(ADT_1) + 0.61 \ln(ADT_2)] \]

where:

- \( A \) = predicted number of accidents at the intersection
- \( ADT_1 \) = average daily traffic volume on the major road
- \( ADT_2 \) = average daily traffic volume on the minor road

For four-leg stopped controlled intersections, the base model assumes that there are no driveways within 250 feet of the intersection and a zero degree skew angle.

**Four-leg Signalized Intersections**

The base model for four-leg signalized rural intersections is given by the following equation and is also applicable to the calculations shown in Worksheet 5-3:

Equation 5-20: IHSDM Base Model for Rural Four-leg Signalized Intersections

\[ A = \exp[-5.73 + 0.60 \ln(ADT_1) + 0.20 \ln(ADT_2)] \]

where:

- \( A \) = predicted number of accidents at the intersection
- \( ADT_1 \) = average daily traffic volume on the major road
- \( ADT_2 \) = average daily traffic volume on the minor road

For signalized intersections, the base model assumes the following:

- No protected left turn phase,
- 28.4 percent of minor-road traffic turning left,
- 9 percent of trucks entering the intersection,
- No vertical curves, and
- No driveways within 250 feet of the intersection.

Like the model for road segments, AMFs have been developed for intersection conditions that differ from the base model for each of the intersection models described above.

For each of the intersection models, AMFs have been developed to allow adjustments for the following:

- Skew angle,
- Traffic control (Adjusts for difference between minor-leg stop-controlled (base) and all-way stop controlled),
- Exclusive left-turn and right-turn lanes, and
- Intersection sight distance.
Detailed calculations for these AMFs are provided in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways* and will be incorporated into the forthcoming IHSDM software.

**Sample Calculation: Accidents for Rural Three-Leg Stop-Controlled Intersections**

The calculation of accidents for rural intersections is very similar to the calculation for rural road segments. For example, a three-leg stop-controlled intersection without a right-turn lane and with a traffic volume of 3,000 vehicles per day on the major road and 2,000 on the minor road, the predicted number of accidents per year using Equation 5-18 is:

\[
A_0 = \exp[-10.9 + 0.79 \ln(3,000) + 0.49 \ln(2,000)] = 0.427
\]

where:

\[A_0 = \text{predicted number of accidents at the intersection without a right turn lane}\]

The AMF for adding a dedicated right hand-turn lane to the major road is 0.95. As a consequence, the predicted number of accidents in the case where a right-turn lane is added to the intersection is 0.406 (0.95 x 0.427). The net effect on accident frequencies at the intersection with the addition of the right-turn lane is a reduction of 0.021 accidents per year.

**Empirical Bayes Method**

Each of the calculations using the preceding models for rural segments and intersections assumes that there are no observed accident data available for calculating accident levels before the improvement. If accident data are available, it can be incorporated in the analysis to evaluate the effect of safety improvements. Care must be taken, however, to adjust the observed accident rates for the regression to the mean phenomena. The regression to the mean issue is simply the condition that, over time, accident rates will eventually settle down to an average rate. The period observed, however, might be significantly different than the long run average. If, for example, an intersection was observed to have five accidents a year for three years when the long run accident rate is actually three accidents a year, then, over time, the annual accident rate would fluctuate to produce the three accident average. If the five-per-year average is used, it will result in a significant over-estimation of the effect of a safety improvement as some of the observed reduction in accidents over time would come from the natural tendency for accidents to fall to their average of three per year.

A method, known as the Empirical Bayes (EB) Method, has been developed to adjust observed accident data to account for the regression to the mean effect and is being incorporated into the algorithm used in the IHSDM.\(^\text{13}\) Using observed data, we can adjust for the regression to the mean problem to determine expected accidents:

\[\text{expected accidents} = \frac{\text{observed accidents}}{\text{empirical Bayes adjustment factor}}\]

---

\(^{13}\) See Hauer (1997) for a detailed discussion of the EB method theory. See also Harwood et al (2000) for detail on how the EB method is used within the IHSDM.
Equation 5-21: Empirical Bayes Method

\[ A_E = w(A_p) + (1 - w)A_O \]

where:

- \( A_E \) = expected accidents
- \( A_p \) = predicted accidents
- \( A_O \) = observed accidents
- \( w \) = weights for observed and predicted accidents
  \[ w = \frac{1}{1 + kA_p} \]
- \( k \) = overdispersion parameter

The EB adjustment is then a weighted average between the predicted and observed accident rates, with the weight calculated on a parameter designed to account for overdispersion. For the IHSDM, the following values for this parameter are suggested for rural roads:

<table>
<thead>
<tr>
<th>Rural Road Type</th>
<th>Value for Overdispersion Parameter, ( k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadway Segment</td>
<td>0.31</td>
</tr>
<tr>
<td>Three-Leg Stop-Controlled Inter.</td>
<td>0.54</td>
</tr>
<tr>
<td>Four-Leg Stop-Controlled Inter.</td>
<td>0.24</td>
</tr>
<tr>
<td>Four-Leg Signalized Inter.</td>
<td>0.11</td>
</tr>
</tbody>
</table>

As this discussion suggests, the EB method is appropriate in those situations where the analyst has information on both historical accident rates as well as predicted accident rates for the existing segment.

**Sample Calculation: Empirical Bayes Method**

Based on these parameters, suppose there is a rural roadway segment that has observed accidents of five per year and a predicted value of 4.0 accidents per year. With the rural roadway segment, the overdispersion parameter \( k \) will have a value of 0.31 yielding weights of 0.45 and 0.55. Using these weights and the observed and predicted accident rates in Equation 5-21, the expected accidents using the EB procedure is given by:

\[ A_E = 0.45(4) + (0.55)(5) = 4.55 \]

The value of 4.55 would be the appropriate value for measuring accidents before the safety improvement. If the predicted value of 4.0 is used for the before improvement case, the calculation would underestimate the effect of the improvement on the reduction in accidents. If the observed value of 5.0 were used, the regression to the mean effect is not taken into account and the calculation would overstate the accident reductions resulting from the improvement.
Urban Intersections

A series of models have been developed for intersections and discussed in the FHWA report *Statistical Models of At-Grade Intersection Accidents* (1996). These models were estimated based on CALTRANS data and provide predictive tools for estimating accidents at intersections for both urban and rural roads. While a variety of different model specifications were explored in this report, only the recommended models from the study are discussed below as these offer the best available prediction tools.

The following tables show the coefficient values and the variables needed to estimate accidents by road type (urban or rural), number of streets at the intersection (three-leg or four-leg) and intersection control system (stop or signalized). These models were estimated using either a negative binomial model (rural intersections, urban three-leg intersections) or a lognormal regression model (urban four-leg intersections). These calculations for both of these model specifications rely on the following equation:

**Equation 5-22: Basic Accident Prediction Equation for Three-Leg and Four-Leg Urban Intersections**

\[
A = \exp \left( \sum_{i=1}^{N} \beta_i X_i \right)
\]

where:

- \( A \) = total number of accident in a three-year period
- \( \beta \) = coefficients
- \( X \) = models variables
- \( N \) = number of variables in the model

This model was estimated for accidents on urban three-leg stop-controlled intersections. The parameter values for this model are given in Table 5-10.
Table 5-10: Recommended Negative Binomial Coefficient Values for Urban Three-Leg Stop-Controlled Intersections (For Use in Equation 5-22)

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Variable</th>
<th>Variable Description</th>
<th>stop controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_0$</td>
<td>$X_0$</td>
<td>Intercept</td>
<td>-6.808</td>
</tr>
<tr>
<td>$B_1$</td>
<td>$X_1$</td>
<td>Major-road ADT (log)</td>
<td>0.775</td>
</tr>
<tr>
<td>$B_2$</td>
<td>$X_2$</td>
<td>Crossroad ADT (log)</td>
<td>0.266</td>
</tr>
<tr>
<td>$B_3$</td>
<td>$X_3$</td>
<td>Major road left turn prohibition</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left-turns prohibited</td>
<td>-0.478</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left-turns permitted</td>
<td>0</td>
</tr>
<tr>
<td>$B_4$</td>
<td>$X_4$</td>
<td>Crossroad right-turn channelization</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No free right turns</td>
<td>-0.601</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provision for free right turns</td>
<td>0</td>
</tr>
<tr>
<td>$B_5$</td>
<td>$X_5$</td>
<td>Major road left turn channelization</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No left turn</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Painted left turn lane</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Curbed left turn lane</td>
<td>0.192</td>
</tr>
<tr>
<td>$B_6$</td>
<td>$X_6$</td>
<td>Design Speed of major road</td>
<td>-0.006</td>
</tr>
<tr>
<td>$B_7$</td>
<td>$X_7$</td>
<td>Presence of Median on major road</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Divided</td>
<td>-0.160</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Undivided</td>
<td>0</td>
</tr>
<tr>
<td>$B_8$</td>
<td>$X_8$</td>
<td>Average lane width on major road</td>
<td>-0.030</td>
</tr>
</tbody>
</table>

Source: Statistical Models of At-Grade Intersection Accidents, Federal Highway Administration, November 1996, p. 65.

Urban streets with four street intersections (four-leg) were modeled in both stop controlled and signalized applications. The variables and coefficient estimates for these models are shown in Table 5-11. As with the rural models, these parameters can be used in Equation 5-22 to estimate accident levels at urban intersections under a variety of design conditions.
Table 5-11: Recommended Lognormal Coefficient Values for Urban Four-Leg Intersections—Stop-Controlled and Signalized (For Use in Equation 5-22)

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Variable</th>
<th>Variable</th>
<th>stop controlled</th>
<th>signalized</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_0$</td>
<td>$X_0$</td>
<td>Intercept</td>
<td>-5.073</td>
<td>-3.744</td>
</tr>
<tr>
<td>$B_1$</td>
<td>$X_1$</td>
<td>Major-road ADT (log)</td>
<td>0.635</td>
<td>0.517</td>
</tr>
<tr>
<td>$B_2$</td>
<td>$X_2$</td>
<td>Crossroad ADT (log)</td>
<td>0.294</td>
<td>0.234</td>
</tr>
<tr>
<td>$B_3$</td>
<td>$X_3$</td>
<td>Major road left turn</td>
<td>Left-turns prohibited</td>
<td>-0.969</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Left-turns permitted</td>
<td>0</td>
</tr>
<tr>
<td>$B_4$</td>
<td>$X_4$</td>
<td>Access control on major road</td>
<td>None</td>
<td>-0.518</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Partial</td>
<td>0</td>
</tr>
<tr>
<td>$B_5$</td>
<td>$X_5$</td>
<td>Average lane width on major road</td>
<td>-0.091</td>
<td>-0.051</td>
</tr>
<tr>
<td>$B_6$</td>
<td>$X_6$</td>
<td>Number of lanes on major road</td>
<td>3 or less</td>
<td>0.340</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 or 5</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 or more</td>
<td>0</td>
</tr>
<tr>
<td>$B_7$</td>
<td>$X_7$</td>
<td>Crossroad right-turn channelization</td>
<td>No free right turns</td>
<td>-0.331</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Provision for free right turns</td>
<td>0</td>
</tr>
<tr>
<td>$B_8$</td>
<td>$X_8$</td>
<td>Major road right-turn channelization</td>
<td>No free right turns</td>
<td>-0.119</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Provision for free right turns</td>
<td>0</td>
</tr>
<tr>
<td>$B_9$</td>
<td>$X_9$</td>
<td>Lighting</td>
<td>No</td>
<td>-0.175</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td>$B_{10}$</td>
<td>$X_{10}$</td>
<td>Signal Timing</td>
<td>Pretimed</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Semi actuated</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fully actuated</td>
<td>0.636</td>
</tr>
<tr>
<td>$B_{11}$</td>
<td>$X_{11}$</td>
<td>Signal Phasing</td>
<td>Two-phase</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Multiphase</td>
<td>-0.221</td>
</tr>
<tr>
<td>$B_{12}$</td>
<td>$X_{12}$</td>
<td>Number of lanes on crossroad</td>
<td>3 or less</td>
<td>-0.134</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 or more</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Statistical Models of At-Grade Intersection Accidents, Federal Highway Administration, November 1996, p. 59, 73.

The information presented in Table 5-10 and Table 5-11 can be combined using Equation 5-22 to predict changes in accidents in the calculations shown in Worksheet 5-3.

**Sample Calculation: Accidents for Urban Three-Leg Stop-Controlled Intersections**

A simple example shows how the parameters given in Table 5-10 can be combined with Equation 5-22 to estimate the number of accidents at a specific intersection. Consider a three-leg stop-controlled urban intersection with 12-foot lane widths, major-road traffic volume of 8,000 vehicles per day, crossroad volume of 6,000 vehicles per day, and a
design speed of 35 mph. In addition, left-turns are permitted and there is a painted left turn lane. Free right turns are not permitted and there is an undivided median. Given this information and Table 5-10, estimated accidents for a three-year period is calculated by:

$$A_0 = \exp\left[-6.808 + 0.775 \ln(8000) + 0.266 \ln(6000) - 0.601 - 0.006(35) - 0.030(12)\right]$$

$$A_0 = 3.67$$

Those terms that have zero values in this scenario (i.e., painted left turn lane) drop out of the equation. The traffic volumes are logged values of ADT, which cancels out the exponential function for these terms. For this segment, then, the model predicts 3.67 multiple vehicle accidents over a three-year period.

This information can be used to evaluate the safety benefits of adding a divided median to the intersection. This improvement has the effect of changing the value for the “median” variable from 0 to 1 signifying the presence of a divided median in the accident prediction equation. Predicted accidents with this new feature is given by:

$$A_0 = \exp\left[-6.808 + 0.775 \ln(8000) + 0.266 \ln(6000) - 0.601 - 0.006(35) - 0.16 - 0.03(12)\right]$$

$$A_0 = 3.13$$

In this hypothetical example, the addition of a divided median will reduce accidents from 3.67 to 3.13 over a three-year period, a reduction of 15 percent. The safety effects of other roadway features can be evaluated in analogous fashion using the coefficients and variables shown in Table 5-10.

Roadside Design and Accident Rates

The AASHTO Roadside Design Guide presents a model ROADSIDE that is used to estimate accident costs based on roadway and roadside design features and incorporates different levels of accident severity. Depending upon the level of detail of the data available to the analyst, ROADSIDE can provide estimates of accident costs tailored very specifically to the design features of the road. A summary of the calculations used in the model is provided here to illustrate the capabilities of the model.

The ROADSIDE model is designed to predict accident rates taking into account the features of both the road and the roadside. This is accomplished by modeling two distinct accident components. An encroachment occurs when a vehicle leaves the roadway, an accident occurs when a vehicle strikes an object or another vehicle. This is an important distinction, as not all encroachments will result in accidents.

The parameters that affect encroachments and accidents are largely determined by engineering features of the road, including design speeds, curvature, and roadside slope gradient, and angle of departure once a vehicle leaves the road. These factors will also

---

vary depending on whether traffic is in the lane adjacent to the roadside being analyzed, or in an opposing traffic lane.

The ROADSIDE model provides methods to estimate both encroachments and accidents based on the engineering factors discussed above. Where detailed design data are available, the ROADSIDE model can be used to predict changes in accidents for use in Worksheet 5-3. Encroachments are modeled as a function of traffic volume and road geometry for both adjacent and opposing traffic:

**Equation 5-23: Encroachment Calculation in ROADSIDE Model**

\[ EF = ER \times V^{EP} \times G \times C \times U \]

where:
- \( EF \) = encroachment frequency (encroachments/mile/year)
- \( ER \) = encroachment rate (encroachments/mile/year/vehicle/day)
- \( V \) = Traffic volume (vehicles/day)
- \( EP \) = encroachment power parameter (default = 1.0)
- \( G \) = grade adjustment factor
- \( C \) = curve adjustment factor
- \( U \) = user adjustment factor

The collision frequency is calculated based on a similar set of parameters:

**Equation 5-24: Collision Frequency**

\[ CF_T = CF_{US,A} + CF_{UC,A} + CF_{F,A} + CF_{DS,O} + CF_{DC,O} + CF_{F,O} \]

where:
- \( CF_T \) = total collision frequency (per year)
- \( CF_{US,A} \) = frequency of collisions with upstream side of hazard by adjacent traffic
- \( CF_{UC,A} \) = frequency of collisions with corner of hazard by adjacent traffic
- \( CF_{F,A} \) = frequency of collisions with face of hazard by adjacent traffic
- \( CF_{DS,O} \) = frequency of collisions with downstream side of hazard by opposing traffic
- \( CF_{DC,O} \) = frequency of collisions with downstream corner of hazard by opposing traffic
- \( CF_{F,O} \) = frequency of collisions with face of hazard by opposing traffic

Each of the collision rate components in Equation 5-24 is in turn estimated as a function of encroachment angle, traffic volumes, width of hazard, number of lanes, lane width, and other design factors. The specific equations are listed below.

**Equation 5-25: Collision Frequency—Upstream of Hazard, Adjacent Traffic**

\[ CF_{US,A} = EF_{adj} \times (1/\tan \theta) \times \left[ \sum_{i=1}^{n} LEP(A + SW \times \cos \theta + \{i - 1\}) \right] \]
Equation 5-26: Collision Frequency—Upstream Corner, Adjacent Traffic
\[ CF_{UC,A} = EF_{adj} \times \left( \frac{1}{\sin \theta} \times \sum_{i=1}^{SW} LEP(A + SW \times \cos \theta + \{i-1\}) \right) \]

Equation 5-27: Collision Frequency—Face of Hazard, Adjacent Traffic
\[ CF_{F,A} = EF_{adj} \times \left( \frac{L}{5280} \right) \times LEP(A) \]

Equation 5-28: Collision Frequency—Downstream of Hazard, Opposing Traffic
\[ CF_{DS,O} = EF_{opp} \times \left( \frac{1}{\tan \theta} \times \sum_{i=1}^{W} LEP(A + (NL \times LW) + SW \times \cos \theta + \{i-1\}) \right) \]

Equation 5-29: Collision Frequency—Downstream Corner, Opposing Traffic
\[ CF_{DC,O} = EF_{opp} \times \left( \frac{1}{\sin \theta} \times \sum_{i=1}^{W} LEP(A + \cos \theta + \{i-1\}) \right) \]

Equation 5-30: Collision Frequency—Face of Hazard, Opposing Traffic
\[ CF_{F,O} = EF_{opp} \times \left( \frac{L}{5280} \right) \times LEP(A + NL \times LW) \]

where:
- \( EF_{adj} \) = frequency of encroachments by adjacent traffic
- \( EF_{opp} \) = frequency of encroachments by opposing traffic
  (0 for one-way or divided roads)
- \( \theta \) = encroachment angle
- \( W \) = width of hazard (feet)
- \( LEP(Y) \) = lateral extent probability of an encroachment exceeding extent \( Y \)
- \( A \) = lateral offset from the edge of the nearest driving lane to the hazard
- \( SW \) = swath width (effective weight of the vehicle)
- \( L \) = length of hazard (miles)
- \( NL \) = number of lanes
- \( LW \) = lane width (feet)

The results of these calculations are accident (collision) frequencies per year, broken out into accidents involving adjacent and opposing traffic and by head-on, side, or corner impact. ROADSIDE does not provide data related to the distribution of fatal, injury, and property-damage-only accidents for these categories, although one might reasonably expect that they would differ (e.g., with head-on accidents resulting in a larger proportion of fatalities). Without additional data, the analyst may use total collisions from Equation 5-24 with per-accident costs for all accidents from Table 5-17 in the user benefit calculation.

Access Control and Accident Rates
The empirical work surrounding access management improvements has generally focused on the relationships between traffic volumes, the number of access points and
associated delays, and the safety and operational benefits of installing medians and turn lanes. The following tables show how these improvements have been found to reduce accident rates. Some of the relationships shown for the intersection models are also applicable to the access management techniques discussed later in this section.

The following accident reduction factors for access management do not provide as sophisticated a prediction method as the models presented earlier in this section, which take into account traffic volumes and a range of design features. Nevertheless, they do provide some guidance on accident reductions due to changes in facility designs when more detailed information or analysis tools are not available. This information also may be used in the calculations shown in Worksheet 5-3, but are likely to be less accurate than the calculations using the models discussed earlier in this section.

Historical accident-rate data provided in Table 5-12 and Table 5-13 show that accidents on a per VMT basis are significantly lower on streets and highways that have medians and left turn lanes. A summary analysis of accident rate prediction models also supports this finding, as shown in Table 5-14. Raised medians on urban streets and highways improve safety by restricting turns to intersections. The information provided in these tables shows also how accident rates for all road types increase with both traffic volumes and access point density.

### Table 5-12: Accident per Million VMT by Median Type—Urban and Suburban Areas

<table>
<thead>
<tr>
<th>Total Access Points by Mile</th>
<th>Undivided Highway</th>
<th>Two-Way Left-Turn Lane</th>
<th>Non-Traversable Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤20</td>
<td>3.8</td>
<td>3.4</td>
<td>2.9</td>
</tr>
<tr>
<td>20.1–40</td>
<td>7.3</td>
<td>5.9</td>
<td>5.1</td>
</tr>
<tr>
<td>40.1–60</td>
<td>9.4</td>
<td>7.9</td>
<td>6.8</td>
</tr>
<tr>
<td>&gt;60</td>
<td>10.6</td>
<td>9.2</td>
<td>8.2</td>
</tr>
<tr>
<td>All</td>
<td>9.0</td>
<td>6.9</td>
<td>5.6</td>
</tr>
</tbody>
</table>


### Table 5-13: Accidents per Million VMT by Median Type—Rural Areas

<table>
<thead>
<tr>
<th>Total Access Points by Mile</th>
<th>Undivided Highway</th>
<th>Two-Way Left-Turn Lane</th>
<th>Non-Traversable Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤15</td>
<td>2.5</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>15.1–30</td>
<td>3.6</td>
<td>1.3</td>
<td>1.2</td>
</tr>
<tr>
<td>&gt;30</td>
<td>4.6</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>All</td>
<td>3.0</td>
<td>1.4</td>
<td>1.2</td>
</tr>
</tbody>
</table>

As these data indicate, the density of access points has a pronounced effect on accident rates. Access points such as driveways and unsignalized intersections increase the number of vehicles entering the roadway. In addition, unrestricted right and left turns lower traffic speeds, which increases the incidence of accidents.

Table 5-14: Accident Rates Based on an Average of Seven Computer Models

<table>
<thead>
<tr>
<th>ADT</th>
<th>Undivided Highway</th>
<th>Two-Way Left-Turn Lane</th>
<th>Non-traversable Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>48</td>
<td>39</td>
<td>32</td>
</tr>
<tr>
<td>20,000</td>
<td>126</td>
<td>60</td>
<td>55</td>
</tr>
<tr>
<td>30,000</td>
<td>190</td>
<td>92</td>
<td>78</td>
</tr>
<tr>
<td>40,000</td>
<td>253</td>
<td>112</td>
<td>85</td>
</tr>
</tbody>
</table>


Table 5-15 provides generalized accident reduction factors associated with installing different types of left-turn lanes on different road types. These factors were derived from a summary of studies contained in *NCHRP 420* and can be used to predict changes in accident rates when more site-specific information are not available. As these studies show, the addition of left-turn lanes can reduce accidents and accident rates from 15 to 65 percent. These reduction factors can be used in Worksheet 5-3 if more detailed information is not available.

Table 5-15: Summary of Accident Reductions Due to Left-Turn Treatments

<table>
<thead>
<tr>
<th>Left-Turn Treatment</th>
<th>Accident Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsignalized</td>
<td></td>
</tr>
<tr>
<td>Add Left-Turn Lane</td>
<td>65% (all accident types)</td>
</tr>
<tr>
<td>(physical separation)</td>
<td>24% (fatal + injury)</td>
</tr>
<tr>
<td>Add Left-Turn Lane</td>
<td>27% to 30%</td>
</tr>
<tr>
<td>(painted separation)</td>
<td></td>
</tr>
<tr>
<td>Signalized</td>
<td>40%</td>
</tr>
<tr>
<td>Add Left-Turn Lane</td>
<td>15%</td>
</tr>
<tr>
<td>(physical separation)</td>
<td></td>
</tr>
<tr>
<td>Add Left-Turn Lane</td>
<td></td>
</tr>
<tr>
<td>(painted separation)</td>
<td></td>
</tr>
</tbody>
</table>


Accident Unit Costs

The preceding discussion focused on the tools and methods available for calculating changes in accidents resulting from street or highway improvements. The second half of
the accident calculation involves determining the costs of accidents and ultimately the benefit from reducing these costs due to an improvement.

Each of the improvement types discussed in this guidebook utilizes accident costs categorized into fatal, injury, or property damage accidents. In the accident cost component of the User Benefit Formula, these costs are defined as:

\[ v_I = \text{perceived cost associated with each injury accident}; \]
\[ v_D = \text{perceived cost associated with each fatal accident}; \]
\[ v_P = \text{perceived cost associated with each property damage incident}. \]

In practice, there is a wider range of severity levels that are often assigned to accidents. For injury accidents, accident costs increase with severity of injury as medical associated costs increase. Two separate severity rankings are commonly used to evaluate accidents, both are included below.

The FHWA has developed guidelines for standardized per-injury accident cost estimates by severity level for use in this type of analysis. Table 5-16 shows accident costs by Abbreviated Injury Scale (AIS), which includes five separate categories for injury accidents. Note that these costs have been reported by the National Highway Traffic Safety Administration to include the costs of delay associated with accidents. In keeping with the structure of this manual, we have separated out the delay cost component of the accident costs. These costs should be included in the travel time component of user costs, but depending on the data available it may be more convenient to include them in the accident cost calculation. They are presented in this table as separate costs to emphasize that these costs should not be double counted as both accident costs and travel time costs.

Table 5-16: Accident Cost by Abbreviated Injury Scale (2000 $)

<table>
<thead>
<tr>
<th>Severity</th>
<th>Description</th>
<th>Cost per Injury (2000 $)</th>
<th>Delay Cost Component</th>
<th>Cost per Injury without Delay Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIS 1</td>
<td>Minor</td>
<td>15,017</td>
<td>777</td>
<td>14,240</td>
</tr>
<tr>
<td>AIS 2</td>
<td>Moderate</td>
<td>157,958</td>
<td>846</td>
<td>157,112</td>
</tr>
<tr>
<td>AIS 3</td>
<td>Serious</td>
<td>314,204</td>
<td>940</td>
<td>313,264</td>
</tr>
<tr>
<td>AIS 4</td>
<td>Severe</td>
<td>731,580</td>
<td>999</td>
<td>730,581</td>
</tr>
<tr>
<td>AIS 5</td>
<td>Critical</td>
<td>2,402,997</td>
<td>9,148</td>
<td>2,393,849</td>
</tr>
<tr>
<td>AIS 6</td>
<td>Fatal</td>
<td>3,366,388</td>
<td>9,148</td>
<td>3,357,240</td>
</tr>
</tbody>
</table>


The preceding tables show accident costs on a per-injury basis, and each accident can involve multiple injuries. For use in the User Benefit Formula, however, these costs must be converted to an accident unit cost, which is conventionally the accident costs per vehicle mile. The conversion of the per-injury costs to accident costs per vehicle mile involves two steps. First, per-injury costs must be converted to per-accident costs. Then per-accident costs must be converted to per-VMT costs. These conversions have been
performed for the accident cost data included in Table 5-7 using national accident rate information and costs.

Because part of the cost of accidents is reimbursed to the user through insurance reimbursements, and because insurance premiums are counted among ownership or operating costs, it is necessary to subtract the insured portion of accident costs when developing accident unit costs.\textsuperscript{15} Insurance reimbursements typically cover all but a relatively small deductible for property-damage-only accidents. They often cover a smaller part of the perceived user cost of an injury accident, especially a fatal accident.

Data on insurance reimbursements is reported by type of coverage, rather than by type of accident and is reported per claim, rather than per accident or per injury. Property damage payments averaged $2,010 per claim in 2000 and combined bodily injury and personal injury protection payments averaged $13,593 per claim. We make the simplifying assumptions that each involved vehicle generates one claim, and that every injury accident also generates a property-damage claim. Accounting for the average number of injuries per accident, and the number of vehicles per accident, by type of accident, yields the results shown in Table 5-17. The average reimbursement percents shown in Table 5-17 may be used to adjust accident unit costs for insurance reimbursement. In many cases, all the analyst will have to work with is a single rate for all types of accidents, so the accident unit cost should then be reduced by 34 percent. Unlike the previous tables, the data in Table 5-17 are per accident rather than per injury. Consequently, the information provided on net perceived user costs of accidents (column 5 of the table) should be used in Worksheet 5-3 and Worksheet 5-4 for calculating accident costs.

\textsuperscript{15} In some instances, people involved in accidents will not report crashes to their insurance companies for fear of incurring higher rates or having coverage dropped altogether. In these cases, subtracting out insurance reimbursements will understate the accident costs perceived by the user. This is likely to be small portion of accidents costs, however, particularly for accidents involving serious injuries and fatalities. Without additional information on the degree to which accidents go unreported it is recommended accident costs net of insurance reimbursements be used in the calculation of user benefits.
Table 5-17: Insurance Reimbursement Calculation (year 2000 dollars and rates)

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Fatalities or Injuries or Property Damaged per Accident</th>
<th>Accidents per Million VMT</th>
<th>Average Perceived User Cost</th>
<th>Average Insurance Reimbursement</th>
<th>Net Perceived User Cost (Use in Worksheet 5-3 and Worksheet 5-4)</th>
<th>Average Reimbursement Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>1.12</td>
<td>0.014</td>
<td>3,753,200</td>
<td>29,500</td>
<td>3,723,700</td>
<td>1%</td>
</tr>
<tr>
<td>Injury (non-fatal)</td>
<td>1.54</td>
<td>0.753</td>
<td>138,100</td>
<td>29,500</td>
<td>108,600</td>
<td>21%</td>
</tr>
<tr>
<td>All Injury Accidents</td>
<td>1.53</td>
<td>0.766</td>
<td>202,300</td>
<td>29,500</td>
<td>172,800</td>
<td>15%</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>1.75</td>
<td>1.559</td>
<td>3,900</td>
<td>3,700</td>
<td>200</td>
<td>95%</td>
</tr>
<tr>
<td>All Accidents</td>
<td>1.68</td>
<td>2.325</td>
<td>69,300</td>
<td>15,400</td>
<td>53,900</td>
<td>22%</td>
</tr>
</tbody>
</table>


Combining Accident Frequency and Accident Cost Information

Once information is obtained for both accident frequencies and accident costs, it can be combined to estimate accident costs in both the before improvement and after improvement scenarios. In general, the change in accident costs is the change in the number of accidents times the costs of these accidents for a given highway improvement.

These accident cost components may be separated into injury accidents, fatal accidents, and accidents involving only property damage. The change in accident unit costs, then, is a combination of the change in accident rates and costs of each of these components:

Equation 5-31: Change in Accident Costs (All Accident Types)

\[ \Delta AC_c = v_i \Delta I + v_D \Delta D + v_P \Delta P \]

where:

\[ \Delta AC_c \] = change in accident costs (cents per vehicle mile) for vehicle class \( c \)

\[ \Delta I \] = change in expected number of injury accidents (per vehicle mile)

\[ \Delta D \] = change in expected number of fatal accidents (per vehicle mile)

\[ \Delta P \] = change in number of property-damage accidents (per vehicle mile)

\[ v_i \] = perceived cost associated with an injury accident (cents)

\[ v_D \] = perceived cost associated with a fatal accident (cents)

\[ v_P \] = perceived cost associated with a property-damage accident (cents)
As with all of the user cost components, we are interested only in those costs that are borne directly by the user. That is, those costs that are perceived by users and will have a direct effect on their transportation choices. For accidents, these perceived or direct user costs include the expected costs associated with an injury or property damage accident that the user would have to bear. In addition to these direct costs, there are indirect costs of accidents that are borne by society. These would include such things as police response to accidents, which is paid from general tax fund revenues. While these indirect costs are fully borne by society, they are not perceived directly from the user’s point of view and do not directly affect their transportation decisions. For these reasons, the user cost calculation will focus exclusively on the direct costs of accidents as perceived by the user.

Finally, most accident prediction methods focus on predicting the number of accidents rather than forecasting a change in the accident rate. For use in the User Benefit Formula, however, changes in accident costs must be converted to a cost per VMT value so they can be added directly to the other user cost components. This is demonstrated in the following example and worksheet calculations.

**Application: Accident Cost Calculation**

Worksheet 5-3 uses hypothetical data to illustrate the accident cost calculation. This sample calculation is also contained in the electronic worksheets included as part of this manual. In order to be used in the User Benefit Formula, the calculations are done to show the change in accident costs in cents per VMT.

In this hypothetical example, an analyst is evaluating a project that will add a passing lane to a rural road segment. This segment is a half mile long and has an annual traffic volume of 2,200,000 per year. Vehicle miles traveled for this segment is the annual traffic volume times the segment length, or 1,100,000 vehicle miles traveled. For simplicity, this example assumes one vehicle type for the segment.

In this example, the road segment corresponds to the design features for the base model for rural road segments shown in Equation 5-17. Using this equation, the analyst predicts 0.676 accidents for this segment without the improvement. The accident modification factor for adding a passing lane is 0.75 to a rural road segment. Multiplying this factor times the predicted accidents yields 0.507, which is the number of accidents that are expected with the addition of the passing lane.

The analysts used the national data included in Table 5-17 on the distribution of accidents to categorize total accidents into fatal, injury, and property damage only accidents on the segment. Based on the national accident data, fatal injuries are approximately 0.50 percent of all accidents, injury accidents are 33.3 percent, and property damage only are 66.2 percent of all accidents. Using these proportions, accidents for the segment are distributed so that the total is comprised of 0.0034 fatal accidents, 0.2252 injury accidents.

---

16 Note that for an example using an intersection rather than a road segment, segment length can set to equal the intersection zone, which is approximately 0.1 of a mile. Any segment length can be used to apply the worksheets to intersections, as long as the other user benefit and benefit-cost calculations use the same segment length.
accidents, and 0.4477 property damage only accidents without the improvement. With the improvement, accidents fall to 0.0025 fatal accidents, 0.1689 injury accidents, and 0.3358 property damage accidents for the segment each year. The analyst also uses national accident cost data shown in Table 5-17 to determine the costs per accident.

Using this information, Worksheet 5-3 shows how these accident levels are converted to accident rates per million vehicle miles. The accident rates per million VMT are combined with accident cost data to estimate the change in the accident unit cost as a result of this improvement. As shown at the bottom of the worksheet, the capacity improvement is expected to reduce accident unit costs by $0.0048 per VMT for the segment.
### Worksheet 5-3: Accident Cost—Sample Calculation

<table>
<thead>
<tr>
<th>General Information</th>
<th>Site Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Facility 1</td>
</tr>
<tr>
<td>Agency/Company</td>
<td>Segment 1</td>
</tr>
<tr>
<td>Project</td>
<td>Analysis Time Period: All</td>
</tr>
<tr>
<td>Date Performed</td>
<td>Analysis Year: 2005</td>
</tr>
</tbody>
</table>

| Segment Length (mi.) | 0.5 |

<table>
<thead>
<tr>
<th>Accident Cost (net of insurance reimbursement):</th>
<th>From Table 5-17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>$3,723,700</td>
</tr>
<tr>
<td>Injury</td>
<td>$108,600</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>$200</td>
</tr>
</tbody>
</table>

#### Inputs

- **Annual Traffic Volume**: 2,200,000
- **Number of Accidents**:
  - Number of Fatal Accidents per Year: 0.0034
  - Number of Injury Accidents per Year: 0.2252
  - Number of P.D.O. Accidents per Year: 0.4477
- **Annual VMT**: 1,100,000

#### Calculations

- **Accidents per Million VMT (Table 5-17)**:
  - Fatal: 0.0031
  - Injury: 0.2047
  - Property Damage Only: 0.4070
- **Accident Cost per VMT (Table 5-17)**:
  - Fatal: $0.0115
  - Injury: $0.0222
  - Property Damage Only: $0.0001
- **Accident Cost per VMT (all types)**: $0.0338

- **Accident Cost Savings per VMT**:
  - Fatal: $0.0030
  - Injury: $0.0056
  - Property Damage Only: $0.0000
  - All Accidents (without - with): $0.0086
# Worksheet 5-3: Accident Cost

### General Information
- **Analyst:**
- **Agency/Company:**
- **Project:**
- **Date Performed:**

### Site Information
- **Facility:**
- **Segment:**
- **Analysis Time Period:**
- **Analysis Year:**
- **Segment Length (mi.):**

### Inputs
- **Accident Cost (net of insurance reimbursement):**
  - Fatal:
  - Injury:
  - Property Damage Only:

### Without Improvement
- **Annual Traffic Volume**
- **# of Accidents**

### With Improvement
- **Annual Traffic Volume**
- **# of Accidents**

Accidents can be calculated from the following:
- Eq. 5-16 (urban highways), Eq. 5-17 (rural road segments), Eqs 5-18, 5-19, 5-20 (rural intersections), Eq 5-22 and Table 5-10 and Table 5-11 (urban intersections), Table 5-12, Table 5-13, Table 5-14 (Left turns and access management improvements). If both observed and predicted accident information are available, the without improvement accidents should be adjusted using the Empirical Bayes method (Equation 5-21 and Table 5-9).

### Calculations
- **Number of Fatal Accidents per Year**
- **Number of Injury Accidents per Year**
- **Number of P.D.O. Accidents per Year**

### Accident Cost per VMT (all types)
- **(fatal + injury + P.D.O.)**

### Accident Cost Savings per VMT:
- **Fatal**
- **Injury**
- **Property Damage Only**
- **All Accidents**
  - (without - with)
PROJECT MANAGEMENT MODULE

The preceding analysis modules have so far been focusing on calculating the benefits of highway improvements of completed highway projects. These benefits are estimated by comparing a fully constructed improvement project to a base case scenario where the project is not built. Before project benefits can be enjoyed, however, highway users must first endure the project construction phase. This module addresses the calculations needed to assess the impacts of project construction on the same user cost components addressed in the User Benefit Formula.

The impact on user costs of improvement projects during the construction phase is often omitted from benefit-cost analysis. This omission is significant, as construction zones have an obvious impact on user costs. Traffic capacity is restricted in construction zones when lanes are closed, thereby increasing travel times and user costs. Accidents in construction zones will also increase user costs, although evidence is inconclusive as to whether accidents occur more frequently in construction zones relative to non-construction zones. As a consequence, a full benefit-cost evaluation of a proposed project should include the effect on user costs of the construction period in addition to the benefits of the project once it is completed.

One reason that the effect on construction costs are ignored is that they are often taken as a given or a necessary cost component associated with completing a highway project. Innovative project management and contracting methods have been developed that help mitigate the costs imposed on users during the construction phase of the project. As there is now a wide range of contracting options from which to choose, it is appropriate to incorporate these project management options into the benefit-cost framework. As discussed in this section, some of the innovative contracting techniques are designed to minimize the duration of the construction phase. Consequently, an analyst may wish to compare different contracting options for the same project to determine if there is an opportunity to reduce users costs during the construction phase. The range of contracting methods allows a comparison of different project management options to determine which option will minimize the impact on user costs during the project construction phase.

Incentive-based contracting methods and their potential effect on highway user costs during the construction period are discussed in this chapter. These contracting methods are evaluated in the context of the same user cost categories assessed for the highway improvement types discussed in the other chapters of this manual. For ease of discussion, it is useful to first view the construction phase as a completely separate project from the costs and benefits of the completed project. This allows a straightforward comparison of construction costs across project management options.

The Basic Elements of Project Management

Construction contracts for highway improvement projects have traditionally been awarded based on a low bid contracting system. Under low bid contracting, bids are submitted in secret and the contract is awarded to the lowest bidder. As discussed in the AASHTO Primer on Contracting 2000, this system has not always optimized the overall quality of the final product and it is not necessarily the most efficient means to procure services for all types of highway contracts. External issues such as decreasing
transportation budgets and political pressures also affect contracting decisions. The innovative contracting methods discussed in this chapter have been developed and adopted by some state DOTs in response to these issues.

It is convenient to analyze the impacts of project construction separately from the analysis of benefits of the highway improvement itself. In effect, the construction period and the selection of contracting method can be viewed as a separate project. The same tools and calculation methods used to estimate project benefits and costs can also be used to assess the effect on user costs due to project construction. The costs from the construction phase are then added to the net benefits estimated for the project once construction is completed.

The costs associated with highway construction projects have two distinct components:

- **Construction Costs.** Construction costs include all labor, materials, and other direct expenses incurred during the construction of the improvement project. Contract methods are developed to reduce the duration of construction projects (thereby changing the construction costs) by giving contractors incentives to finish projects on time or ahead of schedule. As this suggests, shorter construction periods can result in lower construction costs if labor costs are reduced.

- **User Costs.** These include all costs incurred by highway users during the construction period. Construction projects decrease highway capacity and travel speeds. Consequently, the same user cost components evaluated for the project itself (value of time, operating costs, accident costs) are affected during the construction period. Quantifying these effects using similar tools will provide guidance for selecting across contracting options.

Innovative contracting methods have been developed that utilize both of these cost components in order to streamline the construction process and reduce overall construction costs. For example, some contracting methods require payments by contractors for lane rentals, which will increase construction costs. The lane rental, however, is designed to reduce the construction period, which will reduce user costs as construction delay times are reduced. The overall effect is a reduction in the total construction costs, even though the actual construction contract increases with lane rental fees.

The *AASHTO Primer on Contracting 2000* describes a variety of innovative contracting methods and provides information on which states have adopted these techniques. These contracting methods are summarized below.

**Quality Assurance**

The following contracting techniques have been used to develop contracts that are designed to assure quality as part of the compensation process.

- **Performance-Related Specifications (PRS).** This refers to quality assurance specifications with a contract that describes the desired levels of key materials and construction quality characteristics in order to improve overall performance. Because specific materials and components are explicitly included in the contract,
it provides a rational means to make performance-related price adjustments if alternatives are substituted.

- **Construction Warranties.** Construction warranties are built into some contracts to hold contractors responsible for the reliability and durability of the project after construction is completed. Due to the myriad factors outside a contractor’s control that can affect the life of a project, requiring construction warranties is somewhat controversial.

- **Warranty Performance Bidding (A-Q Bidding).** This contracting method provides an incentive for the contractor to provide a warranty for work completed. For evaluating contractor bids using this method, A is the cost of construction, and Q is a credit received for each warranty year that the contractor bids beyond a minimum number of years.

- **Life-Cycle Cost Bidding.** Under this system, the life-cycle costs of materials are evaluated in the bid, rather than only first costs. This allows downstream costs such as maintenance and disposal to be incorporated into the construction bid.

- **Price/Qualifications-Based Bidding.** This method evaluates both the price of the bid as well as the experience and qualifications of the contractor for awarding highway project contracts.

**On-Time and Early Completion Incentives**

Some innovative contract designs have built in incentives for completing projects on time or ahead of schedule. These contracts take a variety of different forms for providing time-based incentives. Specific techniques are described below.

- **Incentive/Disincentive (I/D) Provisions for Early Contract Completion.** This method allows an agency to compensate a contractor for each day that the project is completed ahead of schedule, and to penalize the contractor for each day past the deadline. Incentive/disincentive amounts are set to equal the effect of the delay on user costs.

- **No Excuse Incentives.** This method provides a bonus if a contract is completed by a particular date. The bonus is lost if this date is not met, regardless of the reason or if the delay was beyond the contractor’s control.

- **Cost-Plus-Time Bidding (A+B Bidding).** For award consideration, bids under this method are evaluated both on the cost of contract items (A) and cost of time delay (B) for each construction day based on the formula:
  \[ A + (B \times \text{Road User Cost/Day}) \]

- **Lane Rental.** This method is similar A + B bidding in that contractors are encouraged to minimize road user impacts during construction. With this contracting method, a lane rental fee is incorporated into the contract based on the cost of delay.

Additional details on these methods are included in AASHTO’s *Contracting Primer* and in Gillespie (1998). Gillespie also includes a discussion on which states have used I/D
contracts and provides information on what tools are available to help quantify the effects on user costs.

Construction-Design Contracts

Some contracting methods incorporate both design and construction tasks into one contract. This allows the bidders flexibility in proposing designs and developing cost estimates for those projects they are best equipped to complete.

• Design-Build. The design-build contract allows the maximum flexibility for contractor innovation in selecting the project design, materials, and construction methods. The contracting agency specifies the final product for the construction project and the design criteria. Bidders then submit bids that optimize their construction abilities within these parameters.

• Design-Build-Warrant. This option combines the design-build technique with a warranty provision. This allows contractors to present the design that they will be able to build most cost effectively.

• Design-Build-Maintain. Similar to the other design-build contracts, this method has a provision for the contracting agency to maintain the project once construction is completed, in addition to the project design and construction components.

• Systems Manager. This method is used in ITS projects, where it is desirable to procure the services of a system manager during the planning, design and construction of a project. The systems manager helps coordinate and train workers across different project segments to ensure that the ITS system will work properly once construction is completed.

Other Contracting Techniques

Other innovative contracting techniques have been employed in an effort to reduce project costs and to allow contractors more flexibility in developing their proposals.

• Bid Averaging. With bid averaging, the low and high bids are not considered in the award process. The remaining bids are averaged and the contract awarded to that firm that submits the bid closest to the average amount. This is designed to encourage firms to provide reasonable bids for the project.

• Indefinite Delivery/Indefinite Quantity (ID/IQ). This technique is also referred to as job order, task order, area-wide, county-wide, city-wide, and open ended contracting. With this method, contactors bid on individual work items with the location to be determined under future work orders. For example, a contractor will bid on the cost of installing one street light. The number and location of street lights that ultimately are installed are determined later and then work orders are issued.

• Alternate Bids/Designs. This option allows contractors to propose alternative designs as part of the bid submission. This method is usually used for major structures such as bridges and is designed to increase competition and potentially save money with design improvements.
The *AASHTO Primer on Contracting 2000* provides additional detail on each of the contracting methods, as well as a list of which states have adopted the contracting methods and contacts for obtaining additional information.

**Public-Private Partnerships**

An additional project management issue concerns funding project construction, operation, and maintenance. Public agencies that are cash-flow constrained can get beneficial projects built by partnering with private entities and thereby augmenting public funds with private funds. Whether or not such partnering makes sense depends upon the economic value of the improvements, and the cost of private funds.

Partnering also requires that the private partners have a means of collecting revenues from users upon completion, and thus may require modifying the project characteristics to include a tolling policy, or the analysis of value-capture tax policies. As this suggests, this puts some constraints on the types of projects that can reasonably be considered candidates for a public-private partnership.

**Effect of Project Management on Construction Costs**

The majority of the innovative contracting methods will have an effect on the construction costs of the project. Some methods, such as lane rentals and cost-plus-time bidding, will increase the size of the construction contract. Other methods such as design-build contracts are intended to reduce construction costs through more efficient construction processes. In addition, those methods that penalize contractors for delays are implemented to reduce the negative impact of construction on user costs. While construction costs will increase using these contracts, they reduce the costs on users due to construction delays. Relative to traditional low bid contracting, these innovative contracts should have a *net benefit* if the increase in contract construction costs is less than the reduction in user costs during the construction period.

Since contract construction costs are sometimes increased to take into account the impact on users costs, it is necessary to evaluate both the effect of a contract on construction costs and on user costs. Only by comparing both of these cost components can the analyst make an informed decision between alternative contracting methods.

In all cases, the total construction costs for the project for the duration of the construction period need to be included in the analysis for each of the alternative contracting methods being considered. The next section discusses how to evaluate the impact of each contract method on user costs. The end of this chapter shows how to combine user costs and construction costs associated with a particular contracting method to make comparisons across alternative contracting methods.

**Effect of Project Management on User Costs**

Construction periods will affect travel times, operating costs, and highway safety, which are all of the components included in the User Benefit Formula. Consequently, the User Benefit Formula can be modified to estimate the effect on user costs of the construction period. The construction user cost components can be estimated using the same techniques discussed with the highway improvement types and detailed in the analysis modules of this manual. Specific impacts on the individual user cost components due to
the construction period are discussed below, followed by a discussion of how these costs should be aggregated to determine the total impact on user costs due to project construction under different contracting methods.

Calculating Speeds
Construction projects will affect travel speeds in potentially three distinct ways:

- Construction zones routinely have reduced speed limits to ensure safety during the construction periods.
- If lanes are closed during the construction period then the capacity of the segment is decreased.
- Traffic volumes will change if users choose alternative routes to avoid the delays of the construction zone.

The first two of these factors will increase travel times for the construction zone and therefore will affect the calculation of user costs during project construction.

As with the highway improvement, changes in volume during construction can be combined with the change in the posted or free-flow speed for the roadway to determine the change in travel speeds for the segment under construction. As before, this is estimated using the appropriate volume-delay relationships provided in the HCM 2000. An additional resource that provides detailed information on quantifying construction zone speeds, queues, and costs is the FHWA’s Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin, which is available online at http://isddc.dot.gov/OLPFiles/FHWA/010114.pdf.

Using the volume-delay equations in these worksheets, the before-construction and during-construction traffic volumes are entered to determine the change in speeds resulting from the roadside improvement. During the construction phase there will be a change in traffic volume and free-flow speed that needs to be entered into the volume-delay equation. Table 5-18 references the appropriate worksheets by road type to do these calculations.

<table>
<thead>
<tr>
<th>Roadway Segment Type</th>
<th>HCM 2000 Worksheets</th>
<th>Output of HCM 2000 Worksheets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Street</td>
<td>Urban Street Worksheet (Ch. 15)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Two-Lane Highway</td>
<td>Directional Two-Lane Highway Segment Worksheet (Ch. 20)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Multilane Highway</td>
<td>Multilane Highways Worksheet (Ch. 21)</td>
<td>S, segment speed</td>
</tr>
<tr>
<td>Freeway</td>
<td>Basic Freeway Segments Worksheet (Ch. 23)</td>
<td>S, segment speed</td>
</tr>
</tbody>
</table>
Using the volume-delay equations in these worksheets, the without- and with-
improvement traffic volumes and free-flow speeds are entered to determine the change in 
speeds resulting from construction:

**Equation 5-32: Change in Speed Due to Construction Zone**

\[ \Delta S_k = S_{t,k} - S_0 \]

where:

\( \Delta S_k \) = change in speed due to construction under contract method \( k \)

\( S_{t,k} \) = speed during construction (miles per hour)

\( S_0 \) = speed before construction (miles per hour)

Unlike the highway improvement itself where the resulting \( \Delta S \) is likely to be positive, for 
the construction period \( \Delta S_k \) will be negative as travel speeds decrease.

**Calculating the Cost of Reduced Travel Speeds in Construction Zones**

Once the change in speeds is determined, the cost of construction delay is calculated 
using the same techniques discussed earlier for highway improvements. In this case, the 
calculation is for a cost of delay rather than the benefit of time savings, but otherwise the 
calculation is identical.

The cost of the time delay that results from slower travel times through the construction 
zone will depend upon the unit value that users apply to delay time, and the mix of those 
user types on the facility. A vehicle of class \( c \) with an associated value of time per person 
per hour of \( M_c \) and a vehicle occupancy of \( O_c \) will see an increase in the value of the time 
spent traversing the segment, per mile, of:

**Equation 5-33: Change in Value of Travel Time Due to Construction**

\[ \Delta H_{k,c} = 100M_cO_c \left( \frac{1}{S_{t,k}} - \frac{1}{S_0} \right) \]

where:

\( \Delta H_{k,c} \) = value-of-time cost of construction delay (cents per vehicle mile) under method \( k \)

\( M_c \) = value of time (dollars per hour) for class \( c \)

\( O_c \) = vehicle occupancy for class \( c \)

\( S_0, S_{t,k} \) = speeds before and during construction (miles per hour)

As with the improvement calculations, there is a separate \( \Delta H_{k,c} \) for every vehicle class for 
the construction period.

The quantity \( \Delta H_{k,c} \) is the first component of total user cost changes that are affected 
during the construction period. This cost is separate from the \( \Delta H_c \) associated with the 
completed project and discussed in the preceding Value of Time Analysis Module, as that 
term is calculated for the improvement itself once construction has been completed.
Calculating the Value of Operating Cost Savings

The effect on the user from construction zones will be primarily through changes in speed due to slower design speeds and decreased capacity of the facility if the construction involves lane closures. As discussed below, there may also be an effect on safety, as construction zones tend to be more hazardous than normal driving conditions.

Changes in speed will have an effect on vehicle operating costs, as operating costs generally will *increase* due to the decrease in speeds for a construction zone. This decrease in speeds will also affect inventory costs of trucks hauling cargo through the zone. The Operating Cost Module provides information on converting changes in travel speed into changes in operating costs for use in the User Benefit Formula.

Calculating the Value of Accident Cost Savings

Safety in construction zones has been an area of concern and many techniques have been developed to help reduce the number of accidents in these zones. Techniques include reduced speeds (and increased enforcement) in work zones, work training, lane marking, and other measures to increase worker visibility.

While the factors contributing to accidents are somewhat different in construction zones, the calculation of the change in user costs resulting from construction is identical to the method used for the project improvement and input into the User Benefit Formula. As before, the relevant costs are those that are directly perceived by the user. This includes the driver’s perceptions of the potential costs associated with injury, property damage, and death, both to himself or for others such as those working in the construction zone.

Equation 5-34 uses the original accident cost component formula for calculating the change in accident costs resulting from the project construction:

**Equation 5-34: Change in Accident Costs Due to Construction**

\[
\Delta AC_{k,c} = v_I \Delta I + v_D \Delta D + v_p \Delta P
\]

where:

- \(\Delta AC_{k,c}\) = change in accident costs (cents per vehicle mile) for vehicle class \(c\) under method \(k\)
- \(\Delta I\) = change in expected number of injury accidents per vehicle mile
- \(\Delta D\) = change in expected number of fatal accidents per vehicle mile
- \(\Delta P\) = change in number of property-damage accidents per vehicle mile
- \(v_I\) = perceived cost associated with an injury accident (cents)
- \(v_D\) = perceived cost associated with a fatal accident (cents)
- \(v_p\) = perceived cost associated with a property-damage accident (cents)

For each type of accident, the change in accident rate is calculated for the construction period relative to the highway segment before construction began. The Accident Cost Module has additional information on how to calculate these components for various types of improvement projects.
Calculating Costs and Benefits of Project Management Options

Once the speed, time cost, operating cost and accident cost calculations have been done for the construction period, the analyst has the necessary information to determine the impacts on user costs due to a particular contracting method. Once the effect on user costs is determined, this information is combined with construction costs to get the total costs associated with a particular contracting method.

The calculation of the effect on user costs is the same as that shown in the User Benefit Formula. That equation is replicated here with slightly different notation to differentiate user costs from the construction period from the user benefits of the completed project. For the construction period, the impact on user costs is given by:

Equation 5-35: Change in User Costs Due To Construction

\[
UC_{k,c} = (\Delta H_{k,c} + \Delta OC_{k,c} + \Delta AC_{k,c}) \left( \frac{V_{k,c,0} + V_{k,c,1}}{2} \right) L
\]

where:

\(UC_{k,c}\) = user cost (cents) for vehicle class \(c\) under contracting method \(k\)
\(V_{k,c,0}, V_{k,c,1}\) = volume (PCE/hour) of vehicle class \(c\) before and during construction
\(L\) = length of the construction zone (miles)

The user cost \(UC_{k,c}\) for contracting method \(k\) is specific to one vehicle class, one road segment, one hourly period, and one analysis period. As with the evaluation of project benefits, the cost estimates need to be expanded and aggregated across vehicle types and travel periods.

For a particular hour, aggregating user costs is simply a matter of adding up the costs calculated for each vehicle type:

Equation 5-36

\[
UC_{k} = \sum_{c} UC_{k,c}
\]

where:

\(UC_{k}\) = total hourly user cost (cents) under contract method \(k\)

The Diurnal Aggregation Module included in this guidebook can be used to aggregate hourly construction costs into daily estimates if there are perceived to be substantial changes in traffic volumes in the construction zone across periods of the day. Based on the aggregation methods in that section, the total daily user costs from construction are a function of the hourly costs, which will vary based on traffic volumes:
Equation 5-37

\[ UC_{k,d} = g(UC_{k,h}) \]

where:

- \( UC_{k,d} \) = total daily user costs (cents) for the construction period under contracting method \( k \)
- \( g(UC_{k,h}) \) = function to convert hourly user costs to daily user costs

Given a relatively short construction period (measured in days and weeks versus years for the completed project), it is likely sufficient to simply multiply the daily user cost estimate by the number of construction days. If the construction period is anticipated to extend several months or years, then these daily numbers may need to be seasonally adjusted over time.

To calculate the total effect on user costs of the construction period that has duration time \( D \), the daily user costs are multiplied by the number of construction days:

**Equation 5-38: Total User Costs Over Construction Period**

\[ UC_k = UC_{k,d} \times D \]

where:

- \( UC_k \) = total daily user costs (cents) during construction under contracting method \( k \)
- \( D \) = duration of construction (days)

The final step in evaluating a particular project management option is to combine both the construction costs and the user costs to get total costs associated with the option:

**Equation 5-39: Project Management Costs (Construction Costs + User Costs)**

\[ PM_k = CC_k + UC_k \]

where:

- \( PM_k \) = total project management costs under contracting method \( k \)
- \( CC_k \) = construction costs under contracting method \( k \)

This final result is a measure of the costs during the construction period if a particular contract method \( k \) is utilized as a project management option. Note that construction costs \( (CC_k) \) can consist of a combination of public and private funds depending on whether the project is funded through a public-private partnership. Chapter 6 of this manual addresses discounting and the various treatments of public and private funds based on market risk and the opportunity costs of funds.

When project management costs are included in the analysis through the use of innovative contracting methods, then it is appropriate to include both construction costs and the user costs during the construction phase as part of the overall project cost. The total project management costs shown in Equation 5-39 would then be treated in the
analysis the same way as the overall project costs, including the benefit-cost calculations presented in Chapter 6. For instance, when benefit-cost ratios are being used to rank projects for allocation of capital funds, then the user costs during the construction phase would be included along with the construction costs in the denominator of the benefit-cost ratio.

**Application: Project Management Cost Calculations**

To select across several alternative contract methods, the calculations discussed in this chapter need to be completed separately for each contract option. Table 5-19 presents a hypothetical example that illustrates how this is done.

In this example, there is a highway improvement project that is expected to cost $2,000,000 in construction costs and is expected to take 15 days to complete. During these 15 days, the user cost impact is estimated to be $20,000 per day due primarily to construction delays. The first contracting option is to award the contract under the low bid system. This scenario is shown in the first column of Table 5-19. In this case, construction costs are $2,000,000 and the construction period runs the entire 15-day period. This period results in $300,000 in user costs for a total of $2,300,000 in project management costs for the construction period.

The far right column on Table 5-19 shows the same project as it might look under a contracting process that requires lane rental. In this situation, the contractor has to rent the lane, with the rental price set equal to the daily user costs associated with the construction period. In this example, since user costs are $20,000, the lane rental fee is set at $20,000 per day. Under these conditions, the contractor is internalizing the costs to the users of the construction delay. This provides an incentive to complete the construction phase as soon as possible in order to avoid incurring additional lane rental costs. In this hypothetical example, the lowest bidder submitted a bid to complete the construction in 12 days rather than the 15 originally expected.

The last two rows of Table 5-19 highlight the importance of examining user costs in combination with normal construction costs when evaluating contract options. Under the low bid contracting, it might appear that the project costs are lower since the contract will only show the construction costs of $2,000,000. However, under this bidding method the $300,000 in user costs is still being incurred by society. The true cost of the project from the project management perspective is then the full $2,300,000. Under the lane rental contract option, the contractor now has an incentive to reduce the impact on users, since they must pay the full value of these user costs. The result is a reduction in days needed to complete the project and, consequently, less impact on highway users. While this increases the contract amount to $2,240,000, the overall project costs are reduced by $60,000 over the low bid method. In this example, then, lane rental would be preferred to the traditional low bid contracting system.
Worksheet 5-4 shows the calculations necessary to determine the user costs imposed by an hour of construction during a particular analysis time period for a particular vehicle class. To determine lane rental rates for a particular analysis time period (e.g., p.m. peak), the analyst would use Worksheet 5-4 once for each vehicle class and add together the results. To determine a per-day incentive/disincentive rate, the analyst would use Worksheet 5-4 once for each combination of vehicle class and analysis time periods, multiply each result by the number of hours per week represented by the analysis time period, sum those products, and divide the result by seven to obtain a per-day rate.

**Where to Next?**

In summary, these project management user cost calculations focus only on the costs from the *construction* period relative to the pre-improvement road without construction. The earlier chapters of this handbook address the estimation of costs and benefits of improvement projects once the construction phase has ended. The next section of this handbook (Chapter 6) shows how these separate estimates are combined to evaluate the merits of improvement projects by incorporating both construction costs and user benefits once the project is completed.
Worksheet 5-4: User Cost for Project Management Options—Sample Calculation

<table>
<thead>
<tr>
<th>General Information</th>
<th>Site Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Facility</td>
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<tr>
<td>Agency/Company</td>
<td>Segment</td>
</tr>
<tr>
<td>Project</td>
<td>Analysis Time Period</td>
</tr>
<tr>
<td>Date Performed</td>
<td>Analysis Year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inputs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed during construction phase (mph)</td>
<td>25</td>
</tr>
<tr>
<td>Speed before construction phase (mph)</td>
<td>55</td>
</tr>
<tr>
<td>Volume of Vehicles per hour during Construction</td>
<td>400.00</td>
</tr>
<tr>
<td>Volume of Vehicles per hour before Construction</td>
<td>500.00</td>
</tr>
<tr>
<td>Value of time per person per hour ($)</td>
<td>Table 5-1 and Table 5-2</td>
</tr>
<tr>
<td>Average vehicle occupancy</td>
<td>1.50</td>
</tr>
<tr>
<td>Accident cost per fatal accident</td>
<td>Table 5-16</td>
</tr>
<tr>
<td>Accident cost per injury accident</td>
<td>Table 5-16</td>
</tr>
<tr>
<td>Accident cost per property-damage-only accident</td>
<td>Table 5-16</td>
</tr>
<tr>
<td>(accident costs are net of insurance reimbursement)</td>
<td></td>
</tr>
<tr>
<td>Change in fatal accidents per million VMT</td>
<td>0.100</td>
</tr>
<tr>
<td>Change in injury accidents per million VMT</td>
<td>1.000</td>
</tr>
<tr>
<td>Change in property-damage-only accidents per million VMT</td>
<td>20.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calculations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of time per VMT during construction</td>
<td>$0.56</td>
</tr>
<tr>
<td>Value of time per VMT before construction</td>
<td>$0.25</td>
</tr>
<tr>
<td>(Value of time per hour X occupancy / speed)</td>
<td></td>
</tr>
<tr>
<td>Change in Value of Time per VMT (during - before)</td>
<td>$0.30</td>
</tr>
<tr>
<td>VMT per hour during construction</td>
<td>2,000</td>
</tr>
<tr>
<td>VMT per hour before construction</td>
<td>2,500</td>
</tr>
<tr>
<td>(vehicles per hour X length)</td>
<td></td>
</tr>
<tr>
<td>User Cost of Delay (Change in Value of Time X (VMT during + VMT before) / 2)</td>
<td>$683</td>
</tr>
<tr>
<td>Change in fatal accident cost per million VMT</td>
<td>$372,370</td>
</tr>
<tr>
<td>Change in injury accident cost per million VMT</td>
<td>$108,600</td>
</tr>
<tr>
<td>Change in property-damage-only accident cost per million VMT</td>
<td>$4,000</td>
</tr>
<tr>
<td>(cost per accident X change in accidents)</td>
<td></td>
</tr>
<tr>
<td>Change in accident costs per VMT ((fatal + injury + property-damage-only) / 1000000)</td>
<td>$0.48</td>
</tr>
<tr>
<td>User Cost of Accidents (change in cost X (VMT during + VMT before) / 2)</td>
<td>$1,091</td>
</tr>
<tr>
<td>Total user cost per hour for this analysis time period and vehicle class (delay + accidents)</td>
<td>$1,775</td>
</tr>
</tbody>
</table>
### Worksheet 5-4: User Cost for Project Management Options

<table>
<thead>
<tr>
<th>General Information</th>
<th>Site Information</th>
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<tbody>
<tr>
<td>Analyst</td>
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<td>Analysis Year</td>
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#### Inputs

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Speed during construction phase (mph)</td>
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</tr>
<tr>
<td>Speed before construction phase (mph)</td>
<td></td>
</tr>
<tr>
<td>Volume of Vehicles per hour during Construction</td>
<td></td>
</tr>
<tr>
<td>Volume of Vehicles per hour before Construction</td>
<td></td>
</tr>
<tr>
<td>Value of time per person per hour ($)</td>
<td></td>
</tr>
<tr>
<td>Average vehicle occupancy</td>
<td></td>
</tr>
<tr>
<td>Accident cost per fatal accident</td>
<td></td>
</tr>
<tr>
<td>Accident cost per injury accident</td>
<td></td>
</tr>
<tr>
<td>Accident cost per property-damage-only accident</td>
<td></td>
</tr>
<tr>
<td>(accident costs are net of insurance reimbursement)</td>
<td></td>
</tr>
<tr>
<td>Change in fatal accidents per million VMT</td>
<td></td>
</tr>
<tr>
<td>Change in injury accidents per million VMT</td>
<td></td>
</tr>
<tr>
<td>Change in property-damage-only accidents per million VMT</td>
<td></td>
</tr>
</tbody>
</table>

#### Calculations

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of time per VMT during construction</td>
<td></td>
</tr>
<tr>
<td>Value of time per VMT before construction</td>
<td></td>
</tr>
<tr>
<td>(Value of time per hour X occupancy / speed)</td>
<td></td>
</tr>
<tr>
<td>Change in Value of Time per VMT (during - before)</td>
<td></td>
</tr>
<tr>
<td>VMT per hour during construction</td>
<td></td>
</tr>
<tr>
<td>VMT per hour before construction</td>
<td></td>
</tr>
<tr>
<td>(vehicles per hour X length)</td>
<td></td>
</tr>
<tr>
<td>User Cost of Delay (Change in Value of Time X (VMT during + VMT before) / 2)</td>
<td></td>
</tr>
<tr>
<td>Change in fatal accident cost per million VMT</td>
<td></td>
</tr>
<tr>
<td>Change in injury accident cost per million VMT</td>
<td></td>
</tr>
<tr>
<td>Change in property-damage-only accident cost per million VMT</td>
<td></td>
</tr>
<tr>
<td>(cost per accident X change in accidents)</td>
<td></td>
</tr>
<tr>
<td>Change in accident costs per VMT (fatal + injury + property-damage-only) / 1000000</td>
<td></td>
</tr>
<tr>
<td>User Cost of Accidents (change in cost X (VMT during + VMT before) / 2)</td>
<td></td>
</tr>
<tr>
<td>Total user cost per hour for this analysis time period and vehicle class</td>
<td></td>
</tr>
<tr>
<td>(delay + accidents)</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 6. Benefit-Cost Calculations

Chapter 2 of this manual introduced the basic elements of benefit-cost calculations. The purpose of this chapter is to implement those methods and calculate the basic economic feasibility of the project. Economic feasibility in the context of highway user benefit analysis balances user benefits against the costs of developing and operating the improvements.

The user benefits component of economic feasibility is constructed using the calculation elements that have been developed in other chapters. These calculation elements are the result of analysis of individual project components or dimensions. As we have seen, the user benefit components are dominated by a few factors, such as time and operating cost savings. These factors are dependent upon other factors, such as the base case conditions, the performance characteristics of the project, and a few, key economic parameters such as the value of time and the operating cost of vehicles. This information is idiosyncratic to the specific problem, and much of it must be developed by the analyst.

This is even more so the case in the context of project cost elements. The cost elements of most projects depend crucially on individual project features and the regional economic setting of the project activity. This chapter can only provide general guidance, therefore, about project cost.

The preparation of economic feasibility—benefit-cost—calculations involves five steps:

- **Drawing together** the calculation elements, in the right units of measurement, from the user benefit performance measurement activity and the project cost data;
- **Aggregating, interpolating, and extrapolating** data as necessary to economize on the effort to perform detailed calculations;
- **Measuring net present values** associated with the benefits and costs;
- **Performing sensitivity analysis** to see how robust the results are with respect to key project parameters; and
- **Making project selection decisions** based on the results of the feasibility analysis.

The remainder of this chapter leads the analyst through these steps.

**DRAWING TOGETHER THE CALCULATION ELEMENTS**

The first step in testing for economic feasibility is assembly of the various calculation elements germane to the project. This manual helps via its workflow structure. The various modules of the manual have been designed to yield up calculation elements that can be brought together as the analysts develop them. Nevertheless, the assembly of the data necessary to evaluate a highway improvement is a significant and complex task. In particular, the analyst should think carefully about the unit of measurement. There are important, natural differences in the units in which the various calculation elements are gauged. This is because different categories of improvements are more naturally measured in different ways. For example, traffic volumes are usually more conveniently measured in vehicle-miles, rather than passenger-miles.
**Improvement Formats**

Depending upon which modules the analyst determines are relevant to the project being evaluated, user benefit calculations may be in one of three *improvement formats*:

- **Per lane or facility mile.** Data in this format presents total benefits per lane or facility mile of the affected project improvement. Data is kept in this format to be useful during sketch planning exercises, when the exact scale of the facility is still being determined.

- **Per improvement element.** For certain types of improvements, such as signalization, access, and safety, the worksheets in this manual yield up user benefits for each instance of particular type of improvement in the same setting.

- **Per improvement.** Some types of improvements are not easily analyzed or made divisible by the number of lane or facility miles, or the number of improvement elements. In general, improvements that must be analyzed using trips rather than vehicle-miles are not amenable to being measured in a disaggregated fashion.

The procedures below for integrating this information allow the analyst to enter information in any of these worksheets. User benefits can be added across all formats and User Benefit Summary worksheets, to the extent that some improvements involve several modules. The analyst must be careful, of course, not to redundantly include the same user benefits in more than one module calculation or User Benefit Summary worksheet.

**Traffic Formats**

There are four traffic formats that can be used in most of the modules of this manual:

- Vehicle-miles,
- Passenger-miles,
- Vehicle-trips, and
- Passenger-trips.

The analyst needs to be consistent, of course, in the use of these traffic formats when making calculations in the modules, and carrying these traffic formats forward into the economic feasibility calculations. It is possible, and sometimes necessary, to convert traffic information among the four formats during the feasibility calculations. It is important, however, that the conversion be done in a manner that is consistent with the assumptions made in the user benefit modules.

Specifically, the default assumed by the User Benefit Formula is that changes in user cost are measured per vehicle mile, and that traffic volumes are measured in numbers of vehicles (in PCEs, as necessary). If vehicle trips are used, then the changes in user cost need to be measured per trip. If passenger-miles or trips are used, then the traffic volumes need to be in passengers or passenger trips, respectively. Finally, if user benefits per mile are not relevant units of measurement (as in the treatment of changes in intersection delays), the user has been advised in this manual to calculate the benefits directly, applying the appropriate intersection volumes, but with no mileage weighting.
The traffic format information is recorded in the User Benefit Worksheet, and is used in the extrapolation calculations as well.

**EXTRAPOLATING AND AGGREGATING USER BENEFIT CALCULATIONS**

User benefit calculations require information that can be costly and time-consuming to develop. This is especially true of improvements that affect large highway networks, and require detailed editing of the network characterization and computation time. Consequently, it is often necessary to limit the number of detailed analyses. It is often the case that only one or two detailed analyses can be performed.

This circumstance is problematic for evaluating economic feasibility, because highway improvements are put in place in a dynamic environment and are long-lived. Limiting the analysis to the PM peak in a particular project year, for example, risks ignoring consumer benefits in the off-peak periods. Similarly, *ad hoc* extrapolation or interpolation in future or intervening analysis years can lead to serious over- or underestimation of project benefits and costs.

**General Guidance for Extrapolation and Interpolation**

There are two, typical dimensions of extrapolation and interpolation that must be considered in highway project settings. One is extrapolation from a particular travel hour within the day to other travel hours of a day or week. This is referred to in this manual as the *diurnal travel measurement* problem. The other is extrapolation from a particular year of analysis to earlier or later years of the project life. This is referred to in this manual as the *annual travel measurement* problem.

There are three, generic types of extrapolations that the analyst will have to master in measuring and extrapolating project benefits.

- **Simple factor extrapolation.** Some project benefits are amenable to relatively simple extrapolation because the user benefits are fixed, or trend over time only in response to a particular, predicable variable. The benefits of Intelligent Transportation Systems (ITS) improvements, for example, are related to transactions with vehicles, and the number of transactions scales relatively easily with traffic volumes. Weigh-in-motion projects are an example of such a transactions-oriented project. In these cases, the analyst can easily produce annual estimates of benefits once forecasts of traffic growth or some other trending variable are obtained.

- **Complex factor extrapolation.** Still other types of project benefits can be extrapolated even though the underlying relationships are complex because there is a stable mathematical relationship between traffic volumes and user benefits in both the base case and the project case. This relationship can be exploited to estimate the project’s saving in user costs relative to the base case. Congestion relief-related projects, such as additional lanes, lane improvements, and geometric improvements are candidates for these more sophisticated extrapolation techniques, as are improvements whose benefits are proportional to congestion relief. Accident rates on highways, for example, display a fairly predictable relationship to volume/capacity ratios. This chapter provides extensive guidance for extrapolating travel benefits related to capacity improvements.
• *Idiosyncratic extrapolation.* Some highway improvements are much less amenable to extrapolation (especially annualization of travel benefits) without custom, detailed analyses. In general terms, these projects tend to be related to phenomena that play out erratically with changes in traffic volumes. Improvement in delays at intersections, for example, can depend critically on how the development of other parts of the network build out, or congest, over time. Similarly, reductions in accident costs because of improvements in road geometry are notoriously difficult to measure formulaically because there are unique aspects to each situation. This manual provides information and references to techniques for measuring the benefits of safety improvements in another chapter.

As this discussion suggests, unless there are simple or complex trending techniques available, the analyst may have no choice but to formally assess how the project performs at several (at least three) points in the project’s life, several time periods in the day or week, and over the course of a year. From these data, the analyst can then use conventional, linear, or non-linear extrapolation and interpolation techniques to fill in the intervening periods to obtain the full suite of data over the project’s life. Table 6-1 provides some general guidance on the level of extrapolation detail needed for different project types.

**Table 6-1: Recommended Uses of Extrapolation Procedures**

<table>
<thead>
<tr>
<th>Simple Extrapolation Procedures Are Usually Acceptable</th>
<th>Detailed Extrapolation Procedures Are Often Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional Lanes</td>
<td>Access Management</td>
</tr>
<tr>
<td>Lane Improvements</td>
<td>Pricing/Regulatory Policies</td>
</tr>
<tr>
<td>Geometric Improvements</td>
<td>Roadside Improvements (accident-related)</td>
</tr>
<tr>
<td>Roadside Improvements (non-accident)</td>
<td>Traffic Control</td>
</tr>
<tr>
<td>ITS Improvements</td>
<td>Signal Systems</td>
</tr>
</tbody>
</table>

**Formulaic Extrapolation and Interpolation Approaches**

In those cases where simple, or *formulaic* extrapolation procedures are feasible, it is possible for the analyst to exploit one or two detailed analyses to characterize the project’s benefits over various hours of the day or week and extrapolate them to annual and lifetime benefits. The purpose of this section is two-fold:

• To provide specific, empirical extrapolation techniques for the important class of highway projects that improve capacity; and

• To provide a general illustration of how the benefits of highway improvements are extrapolated and aggregated from daily to annual and lifetime benefits. Although the specific formulas are not useful for every type of improvement, the general process is similar.

In general, the analyst will typically have information on travel benefits in certain *peak* or *study hours* during the weekday. This needs to be used to perform *diurnal (daily) travel benefit measurement* and, ultimately, *annual travel benefit measurement*. The annual travel benefit measurement is then aggregated over all of the years in the project’s life.
There are two approaches for dealing with the diurnal travel benefit measurement problem. The first is to use sophisticated travel demand models to measure the vehicle loads that all of the segments in the network will bear for each hour of every day for a particular analysis year. This is a very tall order for the analyst, especially regarding hour by hour modeling loads since there often is little data on the hourly pattern of traffic for every segment of the network. In addition, most travel demand models do not have the capability of modeling the time-of-travel choice accurately.

The second approach is to model the relationship between peak hour and non-peak hour travel volumes or benefits, and apply factors to the peak hour calculations to expand those measures to the entire day. The conventional method of solving the diurnal travel measurement problem is through the use of factors applied to AM or PM peak travel volumes. For travel demand modeling applications, this is satisfactory because one is only concerned about the engineering performance of the facility at various times of the day, or days of the week.

When the analyst is asked to evaluate the economic benefits of additional highway capacity, however, the projection of traffic volumes from daily, or peak periods, to other periods of the day is only the first step to measuring user benefits during those periods. The analyst must decide whether to perform formal benefit calculations for each of the other time periods, or use a technique to approximate the effect on benefits from the relative levels of traffic. The choice involves a trade-off between the level of effort and the level of precision required.

Analogously, there are two approaches to the annual travel benefit measurement problem. The analyst can explicitly model each and every year of the project’s life, or the analyst can model a few years of the project period and use interpolation and extrapolation approaches to provide information between, or beyond, years for which formal modeling results are available.

Some useful methods for performing diurnal travel benefit measurement analysis and for annual travel benefit measurement are discussed in the sections below. These methods are facilitated by three simplifications:

- **A focus on capacity enhancement.** The methods below focus on extrapolating the travel time benefits that accompany capacity enhancement. The methods can be used to extrapolate other benefits associated with the enhancement if they are roughly proportional to travel time benefits (such as savings in vehicle operating costs and accidents in some cases). The methods should be used with extreme caution, however, to extrapolate the benefits of other types of improvements.

- **Measuring vehicle volumes and the value of time in terms of PCE.** Thus, it is assumed that the analyst has used vehicle occupancy rates and vehicle characteristics to convert the value of time per person per hour to value of time per PCE, and nominal vehicle volumes to PCE volumes.

- **Assumption of BPR-type volume-delay relationships.** The mathematical form of BPR-type volume-delay relationships facilitates derivation of extrapolation formulae and the formulae often depend explicitly on the coefficients of the BPR relationship. It is important to know, therefore, the BPR relationship that most
closely corresponds to the volume-delay behavior of the individual links or the aggregate corridor being studied. Table 3-2 earlier in this manual provides some general guidance in this regard.

Through the use of these methods, where appropriate, the analyst need only do detailed measurement of travel benefits in, say, the PM peak hour of a weekday. Using that information, the analyst can then extrapolate the PM peak benefits to the entire weekday, the entire week, then the entire year, and finally to all relevant future or prior years affected by the project. This chapter presents the extrapolation techniques for capacity improvements in some detail.

It is possible to use a study hour other than the peak hour. The formulae and approximations below are illustrated using the peak hour as the study hour, but other study hours can be used with the formulae presented below. However, the expansion factors that are presented below assume peak hour modeling.

**Measuring Diurnal Travel Benefits**

In this section, methods are discussed that permit extrapolation of the detailed modeling of a single hour’s travel benefits to measure other hours of the day. Capacity enhancement projects are typically built for peak-period traffic relief, but generate benefits in other times of the day as well. However, the benefits per hour are much less in off-peak periods because the opportunities to improve travel time are much less.

Figure 6-1 and Figure 6-2 show the volume-capacity ratio in both directions on an urban facility over a 24-hour weekday period, and the corresponding, relative travel time savings per vehicle mile. As the figures illustrate, the relative travel time savings per vehicle mile displays a more exaggerated pattern, by hour, than does the V/C ratio itself. This non-linear relationship between traffic volumes and travel benefits is what makes extrapolation difficult, and the non-linearity depends upon the “congestibility” of the facility—i.e., it depends on the shape of the volume-delay relationship. Moreover, different types of highway facilities display relatively more- or less-“peaky” volume patterns over the course of the day. In particular, peak-hour conditions prevail only briefly in some settings, and persist for much of the day in other settings. As Figure 6-1 and Figure 6-2 illustrate, the conditions also vary in the peak vs. the reverse travel directions of the facility.

Consequently, the relationship between **peak-hour benefits** and **total daily benefits** depends upon four main factors:

- The level of benefits in the peak hour;
- The share of average daily traffic (ADT) that is represented by the peak hour;
- The shape of the volume-delay relationship of the road segment or corridor; and
- The direction (peak or reverse) of travel.
Figure 6-1: Diurnal Pattern of V/C Ratios and Relative Travel Time Savings (Low Exponent BPR Function)

Source: ECONorthwest from Highway 101 data, Sonoma County, California.

Figure 6-2: Diurnal Pattern of V/C Ratios and Relative Travel Time Savings (High Exponent BPR Function)

Source: ECONorthwest from Highway 101 data, Sonoma County, California.
Typically, if the peak is very sharp and short, the peak-hour benefits represent a larger share of total, daily travel time savings when the volume-delay relationship rises sharply at high V/C ratios. Nevertheless, significant total travel time savings are usually found in off-peak periods, especially on urban facilities with high overall ADT. Although weekend data are seldom available, ideally these hours should be included in the analysis, too.

**Measuring Benefits in the Peak or Study Hour**

The first step in the process of measuring diurnal travel benefits is to measure travel benefits to all traffic, \( B_{h, \text{total}} \), in the peak hour. Ideally, this information is available from a local travel demand model of some type. However, for sketch planning purposes, or for smaller departments without modeling capability, peak or study hour benefits can also be calculated directly from information about a particular corridor or link.

For all the calculations presented in this manual, traffic volumes with and without the improvement are needed to calculate user benefits. This calculation is complicated by the fact that an improvement on one segment can increase traffic volumes through *induced demand* for trips. That is, the improvement will generate additional trips on the facility from either the shifting of trips to the improved segment from other segments or by encouraging new trips. Whatever the source of the additional traffic, induced demand is incorporated in the user benefit calculations through the traffic volume variables.

While network models can account for the shifting of trips across different segments within the network, the ability of most of these models to address induced demand has been limited. To address this, estimation techniques relying on travel demand elasticities have been developed for use with the four-step urban travel models to account for induced demand.\(^{17}\) These methods are incorporated here in the expansion of the user benefit calculation for use when limited traffic data are available. In particular, the following equations use demand elasticities to calculate the change in traffic volumes when traffic model estimates are not available, or when the model results do not account for induced demand.

Equation 6-1 and Equation 6-2 present the calculations involved in estimating \( B_{h, \text{total}} \) for large changes and small changes in capacity, respectively. Equation 6-1 shows the calculation of benefits beginning with the calculation where the before-improvement traffic volumes and the with-improvement traffic volumes are available. Several variations of this equation are presented to show how the benefit formula is modified for use when estimates of the with-improvement traffic volume are not available. In this case, the elasticity of demand for trips is used to calculate the with-improvement traffic volumes based on the overall sensitivity of trip demand to changes in travel time.

As might be expected, the peak period benefits, \( B_{h, \text{total}} \), depend upon the extent to which the beneficial reduction in delay generated by the capacity improvement is offset by

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\(^{17}\) See “Accounting for Induced Travel in Evaluation of Urban Highway Expansion” by Patrick DeCorla-Souza and Henry Cohen (http://www.fhwa.dot.gov/steam/smite.htm) for a discussion of the relationship between four-step urban travel models and the economic methods used with the model results to capture the effect of induced demand.
inducement of new traffic. Induced traffic re-congests the facility and extinguishes delay reductions caused by the improvement, but provides benefits to new users. As discussed, the degree of induced demand is determined by the elasticity of travel demand parameter $e^{V_T}$ shown in both equations. Consequently, the equations illustrate:

- The benefits of capacity improvements increase with demand elasticities greater than zero in absolute value (i.e., $|e^{V_T}| > 0$). It is important, therefore, to select the correct demand elasticity.
- Benefits are greater when the initial congestion level is higher (i.e., when the initial V/C is higher).

Equation 6-1 should be used when the increase in capacity caused by the improvement is large (e.g., >10 percent). As the mathematics of the equation makes clear, the solution to this formula must be sought iteratively because the change in travel time is a function of itself (through the volume-delay relationship). (A calculation aid that does this is provided in the companion CD-ROM to this manual.) Equation 6-2 can be used when the changes in capacity are small. This equation does not require iteration and can be solved for directly.

Because travel benefits depend on the demand elasticity, it is important to use an appropriate elasticity. As a practical matter, short-run travel demand elasticities, $e^{V_T}$, are typically low, and in the range of 0.0 to -0.2 based on the authors’ experience with travel demand model analysis. As travelers make other adjustments in their behavior to exploit the new capacity of the facility in the long run, even more re-congestion will occur than is observed in the short run (i.e., the long-run elasticity is greater than the short-run elasticity). However, if long-run elasticities were used in the analysis of the project for the short-run periods, the result would be to overestimate the benefits of the project. That is, applying long-run elasticities attributes more flexibility to travelers to change their behavior in the short run than has been observed in practice. Consequently, this manual recommends that low, short-run elasticities be used in the formulaic approximations of project benefits if formal estimates of demand changes are not available.
Equation 6-1: Calculating $B_{h,\text{total}}$ for Large Changes in Capacity

$B_{h,\text{total}} = \frac{M}{60} \left[ \frac{V_h + \Delta V_h + \Delta T_h}{2} \right] \left[ \Delta T_h \right]$  
(This is the standard user benefit formula)

$= \frac{M}{60} \left[ \frac{V_h + \Delta V_h}{2} \right] \left[ \Delta T_h \right] = 0$

$= \frac{M}{60} V_h \left[ \Delta T_h \right] + \frac{\Delta T_h^2 e_r^{V_h}}{2T_h}$

where:

$\Delta T_h = t_o a \left[ \frac{V_h \left( 1 + e_r^{V_h} \frac{\Delta T_h}{T_h} \right)^b}{C \left( 1 + \frac{\Delta C}{C} \right)} \right] - \left( \frac{V_h}{C} \right)^b$

$M =$ value of travel time in dollars per hour per PCE

$T_h =$ travel time before improvement, in minutes per mile

$\Delta T_h =$ change in travel time caused by the improvement, in minutes per mile

$V_h =$ vehicle volume before improvement (in PCE)

$\Delta V_h =$ change in vehicle volume cause by the improvement

$e_r^{V_h} =$ elasticity of travel demand with respect to travel time, $T(\leq 0)$

$C =$ capacity prior to improvement

$\Delta C =$ change in capacity caused by the improvement

$t_o =$ travel time at the design speed, in minutes per mile

$a, b =$ parameters of the volume-delay relationship (BPR-type)

Equation 6-2: Calculating $B_{h,\text{total}}$ for Small Changes in Capacity

$B_{h,\text{total}} = - \frac{M}{60} V_h T_h \left[ \Psi + \frac{\Psi^2 e_r^{V_h}}{2} \right]$

where:

$\Psi \approx \Delta T_h \approx \left[ \frac{-b t_o a \left( \frac{V_h}{C} \right)^b}{t_o + a t_o \left( \frac{V_h}{C} \right)^b} \right] \left( \frac{\Delta C}{C} \right)$

Dealing with Multiple Vehicle Classes

The previous peak-hour benefit equations assume, for simplicity, one vehicle class, with one average value of time. It is important to measure benefits by vehicle class if the value
of time per vehicle mile is significantly different for each vehicle class (either because of traveler income differences, vehicle occupancy differences, or operational considerations as in the case of vehicles with for-hire labor and/or cargo inventory costs such as taxis and trucks).

If multiple vehicle classes are being studied, Equation 6-1 or Equation 6-2 can be proliferated to permit measurement of peak hour benefits separately for each class as in Equation 6-3. These various benefit measurements can be maintained separately, or aggregated after annualization, as discussed later in this chapter.

**Equation 6-3: Measuring Travel Benefits by Vehicle Class**

\[
B_{h,i} = -\frac{M_i}{60} \left[ V_{h,i} + V_{h,i} + \Delta V_{h,i} \right] \left[ \Delta T_h \right]
\]

\[
= -\frac{M_i}{60} V_{h,i} \left[ \Delta T_h + \frac{\Delta T_h^2 e_{V,i}}{2T_h} \right]
\]

where:

- \( B_{h,i} \) = travel time benefits for vehicle class \( i \) in dollar per hour per facility mile
- \( M_i \) = value of travel time to vehicle class \( i \) in dollars per hour per vehicle
- \( V_{h,i} \) = vehicle volume before improvement (in PCE), for vehicle class \( i \)
- \( \Delta V_{h,i} \) = change in vehicle volume cause by the improvement, for vehicle class \( i \)
- \( e_{V,i} \) = elasticity of travel demand with respect to travel time, \( T \), for vehicle class \( i \) (\( \leq 0 \))

**Extrapolating Peak Hour Benefits to Other Hours of the Day**

The mathematical nature of BPR-type volume-delay relationships yields simple, approximation methods that can also be exploited to extrapolate or interpolate travel time savings among periods of the day. Specifically, with information on the mathematical shape of the volume-delay relationship used in the analyst’s regional models, travel time savings per vehicle mile or totaled across all vehicles can be scaled across hours of the day. For volume-delay relationships that have the BPR-like form, the relationship is as represented in Equation 6-4.
Equation 6-4: Using Peak Hour Benefits to Measure Benefits in other Hours

\[
\begin{align*}
B_{m,\text{total}} &= -\frac{M_m V_m T_m}{60} \left[ \Psi_m + \frac{\Psi_m \epsilon_T^m}{2} \right] \\
B_{h,\text{total}} &= -\frac{M_h V_h T_h}{60} \left[ \Psi_h + \frac{\Psi_h \epsilon_T^h}{2} \right]
\end{align*}
\]

\[
\begin{align*}
\geq -\frac{M_m V_m T_m \Psi_m}{60} \quad \text{if } e_T^m \geq e_T^h \quad \text{and } \left| e_T^m \right|, \left| e_T^h \right| \leq 0.5 \\
\leq -\frac{M_h V_h T_h \Psi_h}{60}
\end{align*}
\]

\[
\begin{align*}
\approx -\frac{M_m}{60} \left( \frac{V_m}{V_h} \right)^{b+1} \approx \left( \frac{K - \text{factor}_m}{K - \text{factor}_h} \right)^{b+1}
\end{align*}
\]

\[
\approx \left( \frac{V_m}{V_h} \right)^{b+1} \left( \frac{K - \text{factor}_m}{K - \text{factor}_h} \right)^{b+1} \quad \text{if } M_m = M_h
\]

where:

\( h, m \) = indicate variables associated with travel in hour \( h \) and \( m \), respectively

\( M \) = Value of time in dollars per hour

\( V \) = Volume of vehicles per hour (in PCE)

\( T \) = Travel time in minutes per mile

\( K - \text{factor}_j \) = ratio of traffic in the study hour \( j \) to AADT

The approximation provided in Equation 6-4 can be used for sketch planning purposes and where other data are not available. The approximation that uses only the ratio of traffic volumes and the parameter \( b \) assumes that the value of time and the travel demand elasticity is the same in both hours and that the benefits to induced traffic relative to existing traffic are in the same proportions in both time periods. (The latter is approximately true for elasticities less that 0.5 in absolute value.) If these assumptions are not accurate, the exact formula in the equation must be used.

For analysts using other volume-delay relationships, having at hand a BPR-like approximation of the volume delay relationship is very helpful for sketch planning purposes in projecting travel-time savings across hours of the day. Using only one hour’s detailed benefit calculation, benefits can be extrapolated to other time periods of the day if the pattern of traffic volumes over the day is known. Aggregation across daily hours to daily totals can then be done with simple addition across all hours. That is,

\[
B_{\text{daily, total}} = \sum_{m=1}^{24} B_{m,\text{total}}
\]

**Extrapolating Peak Hour Benefits Directly to Daily Benefits**

Figure 6-1 and Figure 6-2, discussed earlier, display an example of the diurnal pattern of traffic volumes and the corresponding pattern of relative benefits that can be calculated.
from those hourly volumes. Often, this diurnal pattern of traffic volumes is not known, however, so that making hour-by-hour calculations is not possible. Hourly traffic station counts are expensive and burdensome to collect, and consequently most jurisdictions do not have traffic counting stations in many locations. For sketch planning purposes, in particular, it is sometimes helpful to use rules of thumb to extrapolate peak hour benefits directly to daily benefits.

This is possible because there is a fairly regular empirical relationship—among highways in many settings—between the share of traffic in the peak (busiest) hour on a facility and the traffic for the entire day (in a given direction on the facility). This, in turn, permits the share of benefits in the peak hour to be used to estimate total daily benefits on a facility in a particular direction on the facility. (Again, as discussed earlier, not all project types generate benefit patterns that can be formulaically extrapolated; some require detailed analysis in order to be extrapolated.)

Figure 6-3 shows the frequency of various peak hour traffic shares for a sample of 250 highway segments for which hourly volumes are available for 24-hour periods. Very high shares of peak hour traffic are relatively rare, with the average in the range of nine percent, including most urban, commute-oriented facilities. The regularity of this relationship, and its relatively narrow range, permits the analyst to scale benefits from hourly data to daily estimates easily if there is a relationship between volumes and benefits. Using the data for the sample 250 highway segments, the relationship between volumes and benefits can be established empirically.

The peak hour share of daily traffic is also fairly symmetric in the primary and secondary directions of a facility. Generally, therefore, the two directions of traffic flow do not have to be analyzed separately, at least for sketch planning purposes. As Figure 6-4 illustrates, however, the relationship is not perfectly symmetric, with the secondary direction share generally being somewhat lower than the primary direction share. This is the result of the commonly observed, broader PM peak due to combined work and shopping return trips. (One-way facilities, of course, have zero flows in the secondary direction, and are excluded from the trendline calculations in the figure.)

In scaling peak hour benefits to daily benefits for sketch planning purposes, the asymmetry in volumes on bi-directional facilities can be ignored. For more precise analysis, however, the analyst will need estimates of benefits for both the a.m. and p.m. peak directions on a facility, and some understanding of the relative shares of the peak hour in the 24-hour flows in each direction.
Empirical analysis indicates that in those special cases where the project is primarily a capacity enhancement, rules of thumb can be applied to scale peak hour benefit measures.
to daily benefits. The rules of thumb derive from the regular, mathematical form of the volume-delay relationship and the empirical regularity of the relationship between peak hour volume shares and the pattern of total daily volumes. Figure 6-5 illustrates the regularity of this relationship for the sample of 250 highway segments and simulations of capacity-related benefits. Over a fairly wide range, the volume share of the peak hour is linearly related to the benefit share of the peak hour. (Under unusually “peaky” conditions, the linearity of the relationship is less consistent.)

The approximate relationship between peak hour user benefits and total daily benefits is presented in Equation 6-5. Use of this relationship permits distilling the peak-hour to daily benefit expansion to a single expansion factor, η. Figure 6-6 presents the expansion factor for various peak-hour traffic shares and BPR exponent values. These expansion factors can be used to expand peak-hour benefit calculations to daily values when other data are not available. Since the expansion factor can be applied to a particular direction on the facility, the analyst can perform this calculation for each direction, using the appropriate peak volume share and peak hour benefit for each direction, if such directional data are available and if the patterns of traffic are sufficiently different.

Figure 6-5: The Relationship Between Peak Hour and Daily Benefits (Using $b = 10$)
Equation 6-5: The Peak-Hour-to-Daily Benefit Expansion Factor

\[ B_{\text{daily, total}} = \frac{1}{\left( -0.057b^2 + 1.636b + 1.34 \right) \frac{V_h}{V_{\text{daily}}} + 0.004b^2 - 0.098b - 0.03} \]

\[ = \eta B_{h, \text{total}} \]

where:

\[ V_h = \text{peak hour volumes (PCE)} \]
\[ V_{\text{daily}} = \text{total daily volumes (PCE)} \]
\[ \frac{V_h}{V_{\text{daily}}} = K = K - \text{factor} \]
\[ B_{h, \text{total}} = \text{peak hour benefits to all traffic} \]
\[ B_{\text{daily, total}} = \text{daily benefits to all traffic} \]
\[ b = \text{the exponent in the BPR-type volume-delay formula} \]
\[ \eta = \text{peak-to-daily benefit expansion factor (1 < } \eta \text{ < 24)} \]

Figure 6-6: The Benefit Expansion Factor for Capacity Enhancements, for Various BPR Exponents (b) and Various Daily Peak Traffic Factors
Dealing with Peak Spreading

One of the difficulties in projecting diurnal volumes far into the future is that the diurnal pattern of volume-capacity ratios will change as users change their departure times to avoid the most congested hours of travel. This poses a problem for the analyst who wishes to measure user benefits in the face of such peak spreading. From a strictly mathematical standpoint, there is no limit to the traffic volumes and congestion levels that might be predicted. In reality, travelers will change departure times when delay times become too great. Consequently, predictions of very high initial congestion levels and subsequent benefits due to reduced congestion should be evaluated with peak spreading in mind. Without accounting for peak spreading behavior, calculations of user benefits may overstate the true benefits that will be realized with the improvement.

Part of the problem is that the available empirical means of modeling peak spreading are fairly rudimentary. Typically, the travel demand modeler simply establishes a maximum V/C ratio for the peak hour, and then adds additional volume beyond the associated maximum volume to the immediately adjacent (shoulder) hours until they, too, reach the maximum, etc. It is also possible to model the empirical tendency for peaks to spread across facilities with varying daily traffic volume, as illustrated in Figure 6-7. Equation 6-6 shows that one can think in terms of a peaking factor between minus one and zero. When \( z = -1.0 \), traffic growth goes completely outside the peak hour; when \( z = 0 \), the traffic growth is added proportionately to the peak hour. The analyst wishing to address peaking in this fashion should choose a value of \( z \) accordingly. (In the cross-section of facilities in Figure 6-7, the implied \( z \) is \(-0.047\)).
Figure 6-7: Peaking Factors Tend to Decline with ADT

Equation 6-6: The Approximate Relationship between K-Factors and ADT for Weekdays
(Using data from 250 Washington State facilities)

\[ K = \frac{V_h}{V_T} = \frac{V_h}{ADT} \approx \alpha ADT^z \]

therefore:

\[ e^{V_h}_{ADT} = z + 1 \]

where:

- \( K \) = K-factor or peaking factor for the facility
- \( V_T = ADT \) = average daily weekday traffic
- \( e^{V_h}_{ADT} \) = elasticity of peak hour volumes to daily volumes (likely \( 0 < e^{V_h}_{ADT} \leq 1 \))
- \( z \) = the "peaking" coefficient (-1 < z < 0)

The alternative to such procedures is to ignore the peak-spreading phenomenon. As it turns out, some bias in the measurement of benefits is introduced either way. Let us take first the case where the analyst obtains information that measures the spreading of the peak volumes over time. As the peak spreads, the V/C ratios of hours nearest the peak become more like the V/C ratio of the peak, by definition. This, in turn, means that the benefits of the project, as measured at the peak, are attributed to some adjacent time periods as well. The analyst can use a formula like that in Equation 6-4 to extrapolate from the benefits measured for a given hour of the day (typically the peak hour) to other
hours of the day. This is appropriate, but underestimates the benefit of congestion relief because the peak spreading itself is onerous. That is, users would prefer to travel during conventional hours; having to change scheduled travel times is a user cost burden that is not otherwise accounted for. So, using peak spreading data tends to underestimate user benefits of highway improvements.

Alternatively, the analyst can ignore the peak spreading. The effect of doing so is that the V/C ratios in every time period during the day or week are expanded proportionately with additional, projected traffic growth. The V/C ratios during the peak hours may grow to levels that are not observed empirically, whilst the shoulder hour ratios would grow more slowly than if peak spreading were allowed. Because of the highly non-linear nature of the volume-delay relationship, the result of this treatment of traffic growth typically is a greater user benefit from capacity enhancement than is measured using peak spreading data. Logic suggests that ignoring peak spreading tends, therefore, to overestimate user benefits. The reason is that peak spreading does occur empirically, which implies that the user cost burden of rescheduling departure times is less onerous than bearing the extraordinary delays at the peak.

In summary, if traffic is projected to grow over the project’s life, extrapolating user benefits to account for diurnal travel patterns cannot be done precisely without introducing bias. Because the analyst is usually charged with seeing whether a project is potentially feasible, however, this manual recommends that the diurnal analysis be done without modeling peak spreading. (Later in this chapter, however, use is made of the empirical relationship in Equation 6-6 to facilitate extrapolation when only one year of detailed analysis is possible.) If the project is not feasible under these conditions, then the analyst has saved the additional effort of having to model explicitly the pattern of peak spreading. If the project is only marginally feasible, the analyst may wish to test whether the peak spreading assumption is driving this conclusion, and re-analyze user benefits with peak spreading.

The broader issue, of course, is the decision to extrapolate in the first place. As the discussion above suggests, it is possible to develop approximation methods by relying on the mathematical form of the typical, volume-delay relationship. This facilitates calculation of user benefits for time periods that have not been modeled explicitly, at least for sketch planning purposes.

It should be re-emphasized, of course, that the technique works best in cases in which most user benefits result from travel-time savings, or other savings that are proportional to such benefits. Development of diurnal benefit data may require three or more runs to permit accurate aggregation to all affected hours of the day. In an urban highway context, for example, the a.m. peak, the p.m. peak, and a representative midday hour are three candidates for specific analysis before extrapolation. Modeling of off-peak and night hours through formulas is more acceptable because the user benefit calculation errors introduced are likely to be small.

Measuring Weekly Benefits
Most demand models focus on peak hour travel during a typical weekday. In reality, of course, highway improvements benefit travelers on weekends, and traffic volumes vary
across the days of the week. Monday is often the busiest travel day, and Friday is often the lightest, for example.

Unfortunately, generalizations about the relationship between weekday and weekend traffic, and variations within the weekday, are hard to make. The patterns depend importantly on such factors as the types and location of weekend recreational and shopping activities, the types of jobs in the region, the availability of transit service on weekends, and other factors. In addition, patterns of peaking of traffic are different; weekend peaks often are closer to the middle of the day and late evening, for example, than are weekday peaks. Peak traffic volumes also tend to be lower, reducing the potential for significant congestion relief benefits from highway capacity improvements.

In most cases, the benefits of capacity enhancements to Saturday or Sunday traffic are less than one-third of the benefits to traffic in a weekday. The analyst must decide if the nature of regional traffic patterns is such that explicit modeling of weekend traffic makes sense, given the small contribution of the weekend to total benefits.

- If explicit modeling is necessary (say, in recreational corridors), this manual recommends that the estimation of weekend benefits be performed manually and added to the annual weekday benefits measurement. This is cumbersome, but the idiosyncratic nature of weekend traffic patterns makes it difficult to provide useful rules of thumb.

- If weekend traffic has no unusual characteristics, and is generally light relative to weekday traffic, this manual recommends that the analyst focus on accurate measurement of weekday travel benefits and not attempt detailed modeling or extrapolation of weekend travel benefits. The analyst may chose to add another 5 to 10 percent to the weekday travel benefit estimate to account for weekend benefits if the project feasibility decision is sensitive to the benefit measurement. In cases where the analyst is considering various project alternatives in the same corridor, crude treatment of weekend benefits is unlikely to affect the ranking of project alternatives.

**Equation 6-7: Converting Weekday to Weekly and Monthly Benefits**

\[ B_{\text{monthly}} = \mu B_{\text{weekly}} = \kappa B_{\text{weekday}} \]

where:

- \( B \) = travel benefits
- \( \kappa \) = weekday-to-weekly expansion factor
  \[ \cong 5.0 \text{ to } 5.50 \text{ if no specific information is available} \]
- \( \mu \) = weekly-to-monthly expansion factor
  \[ \cong 4.345 \text{ if no specific information is available} \]

**Measuring Monthly Benefits**

Once a decision has been made about how to treat weekends, it is a simple matter to calculate *monthly benefits:*
Multiply weekly benefits by the average number of weeks in a month \( ((365/12)/7 = 4.3452) \) or the specific number of weeks in the actual study month;

Alternatively, daily benefits of weekdays and weekend days can be aggregated directly, if this detail is available.

An easier way to convert monthly benefit measurements to annual benefits, is to model the peak month of the year. This is consistent with the usual practice of highway departments who take ad hoc traffic counts during the busiest part of the year when evaluating the performance of a facility that is being reviewed.

Measuring Annual Benefits
To this point, the manual has discussed how to measure the following:

- Peak hour benefits,
- Daily benefits,
- Weekly benefits, and
- Monthly benefits.

These measurements can be maintained separately for each user class, if the analyst needs to maintain that level of detail.

The next step is to measure annual benefits. Feasibility analysis of highway projects requires measurement of user benefits associated with each year of the project. This, in turn, means that the user benefits are first estimated for each vehicle or passenger class for each hour of the representative day or week. The aggregation of user benefit data generally means aggregation of data by both user class and hour of the day to an annual, total user benefit figure. It is assumed, for the purposes of this discussion, that the necessary extrapolation from the study hour or period has been performed as necessary in the manner discussed earlier.

Aggregation of daily or monthly user benefits to annual totals is straightforward when traffic patterns are relatively constant, seasonally. Common practice, in fact, is to multiply the total daily weekday benefits by 250 (i.e., ignoring benefits to weekend traffic or excluding them as a concession to the inaccuracy of the expansion). If analysis has been done to expand daily benefit estimates to weekly, weekly benefit calculations are simply multiplied by 52 weeks.

When seasonal characteristics are important, however, such shorthand approaches may seriously underestimate a project’s total user benefits. Since most of the sources of user benefits are volume-related—some in a very non-linear way—seasons with even modestly lower traffic volumes may have significantly lower, daily user benefits. Mountainous, snow-prone, heat-prone, and recreational areas display particularly great seasonal variation in traffic volumes. There is, therefore, great variation in monthly user benefits associated with many, typical types of projects. Conversely, projects that are specifically directed at “off-season” travel problems (such as grade reduction to improve winter traction) may not yield benefits the rest of the year.
Figure 6-8 illustrates the importance of considering seasonal traffic variation. Although the urban interstate facility displays very little variation in traffic volumes during the year, other facilities display very dramatic variations. Areas with winter orientations, such as a highway that provides ski area access, have sharply inverse seasonal traffic patterns.

**Figure 6-8: Examples of Seasonal Patterns for Different Road Locations**

If user benefits are simply proportional to traffic volume, the benefits can be scaled using average daily traffic levels applied to the days or weeks that make up each season. If user benefits are non-linearly proportional to traffic volumes, as in the case of most capacity-enhancing improvements, the scaling will be non-linear in the same manner as it was in the hourly-to-daily aggregation.

As an aid to the analyst without information on the seasonal pattern of traffic, Figure 6-8 and Figure 6-9 provide some indication of the pattern of seasonal peaking. Figure 6-9 measures seasonal peaking as the ratio of peak month ADT divided by AADT for highways in the state of Oregon, where particularly good hourly traffic counting equipment is in place at many locations, and the state’s diverse geography permits observation of many different types of peaking patterns. It suggests that approximately 70 percent of the facilities measured had seasonal peaking factors of 1.3 or less. Except in regions with extreme weather variations, the peaking ratios in this figure probably bound the range of peaking factors that analysts are likely to encounter.
Figure 6-9: Average Daily Traffic in Peak Month as Share of Annual Daily Traffic (from 122 Oregon Facility Count Data)

Figure 6-10: Relationship Between Seasonal Peaking Factor and Seasonal Expansion Factor (b = 10 in BPR Function)
The relationship in Figure 6-10 can be simulated for various exponents of a BPR volume delay function, under the assumption that the intra-day peaking structure is constant over time. Analysis of this data in a manner similar to that done for daily peaking behavior provides a rule of thumb to annualize benefits for capacity enhancement projects.

Equation 6-8 displays the approximate mathematical relationship between daily benefits measured in the peak month and total, annual benefits. This equation relates the monthly-to-annual expansion factor to the BPR exponent and the seasonal peaking ratio. Figure 6-11 graphs this relationship. Figure 6-11 can be used to expand daily travel benefits to annual totals if the seasonal peaking factor is known, and the mathematical shape of the volume-delay relationship can be characterized with BPR-type exponential delay functions.

The figure reveals a number of interesting factors that the analyst should take into account:

- The expansion factor from the benefits enjoyed in the peak month would be 12 if the seasonal peaking factor were 1.0 exactly;
- The expansion factor declines, fairly sharply, with increases in the volume-delay exponent or the seasonal peaking factor;
- For the seasonal peaking factors common for urban interstates (1.05 to 1.2), the expansion factor may be as low as 6.0 to as much as 10.0;
- Within the range of seasonal peaking factors that encompasses most non-urban roads (1.2 to 1.5), the expansion factor may be as low as 3.0 to as much as 8.0.

This illustrates the importance of modeling the seasonal traffic pattern explicitly, if the analyst’s budget permits. The usual daily-to-annual expansion factor of 250 times the peak day, however, seriously overstates the benefits of capacity enhancement in many settings. The expansion factors presented in the equations and figures below can be helpful in sketch planning exercises, and in settings where the resources to do detailed modeling are not available.
Equation 6-8: Peak-Month-to-Annual Benefit Expansion Factor

\[
B_{\text{annual}} = \left[ \frac{1}{(0.076b + 0.206)\left(\frac{ADT_{\text{peak}}}{AADT} - 1\right) + \frac{1}{12}} \right] B_{\text{peak-month}}
\]

where:

\[ADT_{\text{peak-month}} = \text{peak month average daily traffic volume}\]
\[AADT = \text{average annual daily traffic volume}\]
\[B_{\text{peak-month}} = \text{peak month daily benefits}\]
\[B_{\text{annual}} = \text{total annual benefits}\]
\[b = \text{the exponent in a BPR-type volume-delay formula}\]
\[\zeta = \text{peak month-to-annual benefit expansion factor (} 1 < \zeta < 12\)\]

Figure 6-11: Expansion Factor from Peak Month to Annual Benefits (For Various BPR Exponents (b) and Seasonal Peaking Factors)

Summary of Annual Travel Benefit Measurement Techniques
The various expansion factors that have been discussed thus far in this chapter are summarized in Table 6-2 for each step of the measurement process. Of course, at any step
of this process, actual data or local modeling results should be used if they are available in lieu of the rules-of-thumb offered here. For projects whose benefits are not proportional to travel time savings, the analyst has no choice but to obtain detailed, actual measurements.

Because of the multiplicative nature of the expansion process, note also that in Step 5 in the table, annual benefits can be measured directly from peak-hour benefits \( (B_h) \) by multiplying the four expansion factors together, yielding an hourly-to-annual expansion factor of \( \theta \).

The obvious implication of the wide theoretical and practical ranges of the expansion factors is that it is very important to use the correct factors, and no simple rule of thumb applies to all situations.

**Table 6-2: Summary of Expansion Factors for Measuring Annual Benefits**

<table>
<thead>
<tr>
<th>Step</th>
<th>Measurement</th>
<th>Equation Reference</th>
<th>Expansion Factor</th>
<th>Theoretical and Practical Factor Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Peak- or Study-Hour Benefits, ( B_h, \text{total} )</td>
<td>Equation 6-1</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equation 6-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Daily Benefits, ( B_{daily, \text{total}} = \eta B_h, \text{total} )</td>
<td>Equation 6-4</td>
<td>( \eta )</td>
<td>( 1 &lt; \eta &lt; 24 ) \</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( 1 &lt; \eta &lt; 16 ) \</td>
</tr>
<tr>
<td>3</td>
<td>Weekly Benefits = ( B_{weekly, \text{total}} = \kappa B_{daily, \text{total}} )</td>
<td>Equation 6-7</td>
<td>( \kappa )</td>
<td>( 1 &lt; \kappa &lt; 7 ) \</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( 5 &lt; \kappa &lt; 5.5 ) \</td>
</tr>
<tr>
<td>4</td>
<td>Peak Month Benefits, ( B_{monthly, \text{total}} = \mu B_{weekly, \text{total}} )</td>
<td>Equation 6-7</td>
<td>( \mu )</td>
<td>( 1 &lt; \mu &lt; 4.4 ) \</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( \mu = 4.333 ) \</td>
</tr>
<tr>
<td>5</td>
<td>Annual Benefits, ( B_{annual} = \zeta B_{monthly, \text{total}} = \eta \kappa \mu \zeta B_h, \text{total} = \theta B_h, \text{total} )</td>
<td>Equation 6-8</td>
<td>( \zeta )</td>
<td>( 1 &lt; \zeta &lt; 12 ) \</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( 1.5 &lt; \zeta &lt; 10 ) \</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( \theta )</td>
<td>( 1 &lt; \theta &lt; 8760 ) \</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( 32 &lt; \theta &lt; 3810 ) \</td>
</tr>
</tbody>
</table>

**Aggregation Across User Classes**

If the analyst has maintained separate benefit measurements for individual vehicle classes, they must be aggregated in order for project feasibility analysis to be conducted. The analyst can chose to aggregate either before or after the study year(s) data has been extrapolated or interpolated to other years.

In most instances, total user benefit is simply the sum of the user benefits for the individual user classes. Thus, user benefits can be added across different vehicle types, value of time classes, or any other user class distinction that was preserved by the analyst in generating the hourly, daily, or annual user benefit data. Specifically, in general, Equation 6-9 is all that needs to be implemented to properly aggregate across user classes.
Equation 6-9: Aggregating Benefits Across User Classes

\[ B_h = \sum_i B_{h,i} \]

where:

- \( B_h \) = total benefits in hour \( h \)
- \( B_{h,i} \) = total benefits in hour \( h \), for user class \( i \)

For theoretical completeness, it should be noted that in implementing Equation 6-9, the implicit assumption is made that the social benefit of a project is the simple sum of the benefits to individual user classes. By this assumption, therefore, positive benefits to one class of users offset negative benefits to another user class dollar for dollar, from a social perspective. Similarly, by assumption, benefits to different user classes receive equal weight in the total, user benefit calculation.

As it happens, economic theory does not require that social benefits be the simple sum of individual benefits. Social welfare may be improved, some would argue, if more or less weight were given to one class of individuals (users, in our case) or another. In this case the user benefit aggregation proceeds as in Equation 6-10.

Equation 6-10: Using Social Weighting Factors to Aggregate Benefits Across User Classes

\[ B_h = \sum_i w_i B_{h,i} \]

where:

- \( B_h \) = total benefits in hour \( h \)
- \( B_{h,i} \) = total benefits in hour \( h \), for user class \( i \)
- \( w_i \) = the social weighting factor for user class, \( i \) (\( w > 0 \))

Though the notion of variable social weighting of user benefits by class is theoretically supportable, the socially-weighted aggregation of benefits is problematic to implement because it is not clear who the authority is that will determine the appropriate social weighting factors, \( w \). It also can be used mischievously in economic feasibility analysis because judicious selection of the weights can make a project look better, or less good, depending upon the weights used and the scale of benefits by user class.

There is good reason to not use social weighting in highway project analysis at all. The reason is that in the private, market economy at large, of course, no social weighting occurs. In the marketplace, consumers of various types compete on a simple, dollar for dollar basis. The market directs resources where the simple sum of dollar values is the greatest. This makes the use of social weighting of user benefits for highway projects suspect. The fact that highway projects are typically developed by public agencies in the United States does not, in and of itself, justify a different arithmetic of the feasibility or desirability of the project.

The political process, nonetheless, may wish to understand the distribution of user benefits among different user classes. This purpose can be served by presenting tabulations of user benefits disaggregated by user class, as a supplement to the aggregate tabulations of total user benefits and economic feasibility.
Measuring Annual Travel Benefits in Other Project Years

The same mathematical advantages of the BPR-type, volume-delay formulation that permitted extrapolation of hourly to daily data also facilitates projection of annualized travel benefit measurements made in one study year to other project years. The mathematical trend in user benefits over time is linked to the mathematical relationships that describe the relationship between volume-capacity ratios and travel times or speeds. Since these so-called volume-delay relationships generally have an exponential mathematical form, the user benefits from capacity improvements grow exponentially as background traffic growth continues.

Figure 6-12 illustrates this phenomenon, using data from a hypothetical corridor improvement over the first 25 years of the project’s life under conditions of constant, annual traffic growth. As the figure makes clear, travel-time savings per vehicle mile grow linearly in the logarithm of savings, at a level that is determined by the initial volume-capacity ratio.

**Figure 6-12: User Travel Time Savings, by Project Year and Initial V/C Ratio**

Note: This figure employs a Bureau of Public Roads volume-delay relationship specification and incorporates an assumption of traffic growth of two percent per year, and an assumption of a 30 percent improvement in capacity.

The implication of this perspective is two-fold. First, user benefits should not be interpolated and extracted using simple, linear extrapolation. Rather, the interpolation and extrapolation should be logarithmic. Logarithmic interpolation and extrapolation can be performed using information on benefits from two different project years. Specifically, using Equation 6-11, the user benefits in any year \( t \) can be calculated from the user benefits in two other years, separated by \( x \) years.
Equation 6-11: Extrapolating Benefits Using Logarithmic Extrapolation

\[ B_t = \exp(\alpha + \beta t) \]

where:
\[ \alpha = \ln(B_m) - bm \]
\[ \beta = \frac{\ln(B_{m+x}) - \ln(B_m)}{x} \]

\( B_t \) = benefits in year \( t \)

\( B_m, B_{m+x} \) = benefits in years \( m \) and \( m + x \), (for which the analyst has benefit measurements)

The second implication of the mathematics of most volume-delay relationships in this setting is that the exponential rate by which travel-time savings per vehicle-mile grow over time is approximately a constant multiple of the rate of growth of traffic, as in Equation 6-12.

Equation 6-12: Calculating the Rate of Growth of Benefits from Two Year's Benefit Calculations

\[ r = \frac{\ln(B_n/B_t)}{n} = \rho g \]

where:
\( r \) = exponential rate of growth of travel time benefits
\( B_t \) = benefits in project year \( t \)
\( B_n \) = benefits in project year \( n \)
\( g \) = rate of growth of traffic volumes
\( \rho \) = a constant, specific to the volume-delay relationship and other factors

The precise constant multiple \( \rho \) depends on the particular volume-delay relationship employed, and the results of the modeling of benefits over time. Volume-delay relationships that yield greater delays at high V/C ratios will have higher implied constants.

The implied constant \( \rho \) can be calculated from two, detailed benefit calculations. Once the constant has been calculated, it can be used to project (forward or backward) benefits from a single, modeled benefit year. This is very helpful for sketch planning in a setting in which performing many detailed model runs can be prohibitively costly and time-consuming.

Even if the analyst has access to only one year’s benefit calculation, it is still possible to crudely estimate benefits in other years by relying on the mathematics of the benefit calculation. Specifically, because annual benefits are proportional to hourly benefits, the ratio of benefits in one year to another is related to the level of peak-hour traffic in the two years. However, because some of the expansion factors and the value of time also may vary over time, it is important to accommodate growth in these factors in an extrapolation formula. Equation 6-13 illustrates how such an extrapolation formula is developed.
The resulting growth rate in benefits, \( r \), can be used to project forward or backward from any given year’s benefit measurement. Note several implications of this relationship:

- Benefit growth rates are positively related to the growth in traffic, the growth in the hourly value of time, and the BPR exponent. It is relatively easy, therefore, to generate very high annual growth rates, and the analyst should be alert to the possibility of unreasonable benefit projections resulting from ad hoc assumptions about the growth variables.

- This formulation accommodates daily peak spreading, but assumes that daily-to-weekly, weekly-to-monthly, and monthly-to-annual expansion factors are fixed over time. The growth in benefits will be lower the more that these expansion factors increase.
factors tend to decline over time with traffic growth spreading to other time periods.

Using these benefit annualization techniques, the analyst can develop estimates of user benefits for numerous years over the project’s life. It should be noted, however, that the techniques are only approximations, and are best reserved for sketch planning settings. Moreover, user benefits that are not directly linked to travel-time savings from capacity improvements will not display the same, exponential growth over the life of the project. For such other user benefits, linear interpolation and extrapolation is generally the only practical technique.

The Final Step: Adding in Non-Capacity-Related Benefits

The calculations made above for benefits created by capacity improvements apply the basic user benefit formula to a specific type of benefits, namely travel time savings resulting from capacity enhancements. If there are other types of benefits, that are not proportional to these benefits, they need to be calculated, annualized and added to the annual capacity-related travel time benefits before proceeding to perform the overall, benefit-cost analysis.

SETTING UP THE BENEFIT-COST FRAMEWORK

As was discussed in the introduction to this manual, the purpose of user benefit analysis is to determine the economic desirability or feasibility of a highway project. This, in turn, requires a comparison of user benefits to the costs incurred to generate those benefits. Since user benefits and costs play out only over time, the comparison must be done in a manner that incorporates the effect of the passage of time. This is the so-called time value of money notion, which motivates calculating values in present value terms.

This chapter assumes that the analyst has assembled or estimated the user benefits associated with each year of the project, using the aggregation procedures described earlier. The steps that remain are to determine the project planning horizon, assemble project cost information and calculate present value and other economic feasibility measures.

The Project Horizon

The first step in measuring project net present values is to confirm the project planning horizon, how to treat terminal values of user benefits and project costs, and the refinement of discounting procedures.

The project horizon is the period over which user benefits and project costs are modeled for the purpose of economic feasibility analysis. Since highway projects are long-lived, typically, most transportation economists assume at least a 25- or 30-year project life beyond the date at which the project’s development is approved, with terminal values for compact treatment of the more uncertain, longer-term benefits and costs. For projects with long development times, therefore, the implementation horizon will be extended to capture with as much accuracy as possible the evolution of costs and benefits over a reasonable time range. Finally, when considering different project alternatives addressing the same engineering problem, the analyst should assume the same project life for each project alternative unless more detailed information is available.
Policy projects, on the other hand, are often best thought of as having shorter lives, because their durability is determined by policy makers rather than the characteristics of the facility. For policy projects (e.g., regulatory policies) planning horizons of as short as five or ten years may be appropriate, and terminal values may be limited to consideration of the cost of dismantling the policy.

The project horizon consists of two distinct periods: the period before the project is actually implemented (the *planning period*, which encompasses the pre-implementation engineering, right-of-way acquisition, and other similar activities) and the period after commencement of development and operation of the project (the *implementation period*). Implementation consists of three distinct activities (as shown in Figure 6-13), which may overlap in time. The first two consist of *development* and *implementation*. Finally, the *terminal period* has its end at the end of the operation period for valuation purposes, even though the actual activities of winding down the operation of a highway and salvaging a highway facility may take longer.

**The Evaluation Date**

In Figure 6-13, the planning period is \(m\) periods long, and the implementation period is \(n+1\) periods long. Period 0 is the nominal start of the implementation period. It also commonly is the *evaluation date*. That is, it is the period to which other costs and benefits are discounted or compounded. In the figure, Period 0 is assumed to be forward in time, but Period 0 could also be the present, i.e., the date at which spending on planning activities and implementation activities are both being considered. In this case, the figure and the period numbering would appear as in Figure 6-14.

Note that the planning period intervals are denoted with negative signs in the first figure. This convention is important to preserve for accurate treatment of planning costs in the present value calculation procedures presented later. That is, if the valuation date is forward of the present time, costs incurred until that date need to be compounded, rather than discounted. Incorporating negative signs for such periods will cause the present value arithmetic to do this automatically.

*Figure 6-13: Timeline of Highway Project Planning and Implementation, Forward Evaluation Date*

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In the remainder of this chapter, the assumption is made that the evaluation date is forward of the present, since this is the case that incorporates various actual conditions most flexibly.

**Prior Planning Costs as Sunk Costs**

Often the analyst is brought into a project feasibility evaluation exercise long after planning, and even preliminary engineering research have been completed on a project. Should the analyst include such costs in the project feasibility analysis? Perhaps surprisingly, the answer is, “no.” The reason is that such past costs are what economists call *sunk costs*; they are costs and resources that cannot be recovered, regardless of whether the project goes ahead or not, and are thus not.

Evaluation of sunk planning costs may be relevant to a retrospective review of such efforts, but it is irrelevant to project feasibility. It is important, of course, that project feasibility not ignore the costs of planning and preliminary analysis of project alternatives. This planning process definitely should be reviewed for its contribution to the development and selection of viable project alternatives. The “project” in such an analysis is the planning process, however, not a particular highway project. From the perspective of an individual project, such planning process costs are costs that would have been incurred with or without the particular project going ahead. They are, therefore, irrelevant to forward-looking project analysis.

**Frequency and Periodicity of Discounting**

As the discussion of Figure 6-13 and Figure 6-14 illustrates, the analyst needs to confirm what the *frequency* of the project analysis is, and whether to use *beginning of period* or *end of period* discounting procedures. Most highway analyses are performed using an annual analysis frequency and *end-of-year* discounting conventions. The annual analysis frequency is used because the cost of developing data at a finer grain is very costly. In addition, there is often so much uncertainty in the timing of benefits and costs that finer grain introduces only a false sense of precision.

The selection of the end-of-period discounting convention is not a theoretically compelled convention. The use of finite periods in present value analysis is, in the first place, an approximation to the reality of a continuous-time process. Theory would say that the project’s various timelines start and end at precise instances in time. Any use of a discrete time approximation to this process introduces some inaccuracy, especially at high discount rates.
From a continuous time perspective, the implementation begins at the beginning of period 1, and the end of the period –1 is end of the planning period. The commonly used end-of-period discounting convention allows period 0 to serve as a limbo period, during which any expenditures are undiscounted and uncompounded. During this period, planning ends and implementation begins, making period 0 a convenient choice for the valuation date.

The choice of analysis frequency (i.e., the size of the periods used to define the planning period and the implementation period), is related to the issue of calculation accuracy. In most practical instances, the use of annual data frequency for user benefits and costs is acceptable because of the uncertainty and inaccuracy of any finer characterization of the data. In some cases, however, it may be important to perform some of the present value calculations at higher frequency, even if the overall analysis is done on an annual basis. An example of such an instance is where there are very large, accurately known, development expenditures that are going to occur at a very specific point in time. Because development expenditures occur at the beginning of the implementation period, they are not subject to deep discounting in the present value mathematics. Consequently, the timing of such expenditures within an evaluation year may affect the net benefit calculation more than inaccuracies in measuring a long stream of user benefits. User benefits, in any case, are likely to occur with variable timing.

Particular costs can be treated with higher frequency without disturbing the general, annual period focus of the analysis; this is done by simply bringing the particular high-frequency pattern of expenditure “forward” to its present value at the end of the analysis year in which they occur. Equation 6-14 presents the calculation that should be used to bring sub-period cost information to the equivalent end-of-year cost used elsewhere by the analyst.

Equation 6-14: Converting Sub-Period Costs to End-of-Year Costs

\[
C_i = \sum_{z=1}^{k} \frac{C_z}{\left(1 + \frac{d}{k}\right)^{k-z}}
\]

where:
- \(C_i\) = year-end cost measure
- \(C_z\) = sub-period costs for subperiod \(z\)
- \(d\) = the annual discount rate
- \(k\) = the number of sub-annual periods (e.g., \(k = 12\) for monthly data)

By using Equation 6-14, the analyst can accommodate the analysis selectively to high frequency periods. This may be useful in cases where very large costs or benefits occur early in the year, and the discount rate employed is high. In many cases, however, aggregation on an annual basis is sufficient.
Basic Present Value Arithmetic and the Selection of the Discount Rate

The present value calculation is not fundamentally complex, although a lot of information has to be assembled to make the calculation useful. In addition, decisions about how to treat uncertainty and the selection of the discount rate affect present value calculations.

The Basic Present Valuation Formula

The basic present value arithmetic, in a situation without considerations of risk or uncertainty is as described in Equation 6-15. Note that the equation uses an assumed evaluation date of \( t = 0 \), the assumed implementation date, as discussed above. Thus, costs incurred before this date are discounted using a negative exponent (colloquially, these costs are compounded rather than discounted). Note also that the terminal value, \( T \), is assumed to occur in the \( n \)th year of the project.

**Equation 6-15: Basic Present Valuation Formula**

\[
P V = \sum_{t=m}^{n} \frac{(B-C)_{t}}{(1+d)^{t}} + \frac{A_{n}}{(1+d)^{n}}
\]

where:
- \( d \) = risk-free discount rate
- \((B-C)_{t}\) = the net benefit stream in period \( t \)
- \( A_{n}\) = the terminal asset value of the project
- \( t = 0 \) is the valuation date

This equation portrays the basic arithmetic that is at the center of present value calculations. The key to correct application of present valuation techniques is the selection of the correct discount rate, the proper treatment of risk and uncertainty and, of course, accurate measurement of benefits, costs, and terminal values.

Selecting the Discount Rate

The selection of the discount rate is very important to project feasibility analysis. As indicated in the introduction to this manual, choosing the discount rate is entwined with the analyst’s decision about how to treat risk and uncertainty in the present value calculations. The purpose of the discount rate is to characterize the opportunity cost or time value of the invested funds or the lost benefits that would be associated with the project over time.

The selection of discount rates has historically been contentious. In fact, there is much less latitude in the choice of discount rate than is conventionally assumed. Economic theory constrains the choices of the analyst, once the analyst has clarified the perspective of the analysis.

There are, nonetheless, choices that the analyst must make regarding the discount rate to make sure that its selection is consistent with the manner in which the rest of the information in the present value calculation is developed. These options will be discussed before recommending a method for finding the correct discount rate.
Handling Uncertainty in the Discount Rate vs. Other Methods

A common mistake of many analysts is to not make clear how risk and uncertainty regarding the project is handled. Many analysts use a risk-free rate without recognizing the limited circumstances in which it is appropriate to do so. Specifically, it is only appropriate to use a risk-free rate to characterize the opportunity cost of funds in the project if:

- The analyst has incorporated risk directly in the estimates of costs and benefits;
- The analyst plans to perform sensitivity analysis on the parameters about which he or she is uncertain, or;
- The project’s costs and benefits are so well-known and articulated that there is no uncertainty to the estimates or risk of the project failing to deliver these costs and benefits on schedule. This circumstance is very unlikely, except in the case of very short-horizon projects that replicate similar projects in similar circumstances.

In all other cases, a common practice is to accommodate risk by adding a positive risk premium to the risk-free rate. Specifically, the basic present value calculation is changed to that in Equation 6-16. Risk premia are always positive additions to the risk-free rate.

Equation 6-16: Incorporating Risk Premia in the Discount Rate

\[ PV = \sum_{t=0}^{n} \frac{(B - C)_t}{(1 + d + \pi)^t} + \frac{A_n}{(1 + d + \pi)^n} \]

where:
- \( \pi \) = the assumed risk premium

This treatment of risk is less preferable than using the risk-free rate and formal modeling of the range over which all of the other key factors (\( B, C, T, \) etc.) are likely to play out. In risk analysis, statistical techniques are used to determine a range of different outcomes assuming different possible values for underlying parameters. In a project application, risk analysis can be used to estimate the range of project benefits assuming different conditions for project life, user benefits, project costs, and growth rates for these and other analysis parameters such as traffic volumes and wage and compensation levels used to calculate the value of travel time.

The formal mechanism for handling uncertain values in a complex calculation is called Monte Carlo or Latin Cube analysis. These methods involve calculating, usually by computer, the present value calculation under a controlled range of all of the variables that are uncertain. A statistical distribution of each such variable is assumed, and the computer, with each run, draws randomly from every variable’s distribution and calculates the resulting present value. After many such runs (usually thousands) the result is a distribution of present value outcomes. The analyst can then express precisely what the expected value of the present value is, as well as the probability that it will be higher or lower than that amount.

Computerized Monte Carlo analysis is easily conducted using commercial software such as @RISK™. The analyst can approximate the outcome under simplified circumstances, however, by using basic statistical relationships. The calculation of present value over a
discrete number of periods (e.g., years) is basically a sum of products. Consequently, some simple statistical relationships can be exploited. Specifically, the standard deviation of a sum of independent items has a simple formula, as in Equation 6-17.

**Equation 6-17: Standard Deviation of a Sum with Independent Items**

If \( Y = \sum_{i=1}^{n} a_{i} X_{i} \), then

\[
\mu_Y = \sum_{i=1}^{n} a_{i} \mu_{X_{i}}, \quad \text{and} \quad \sigma_{Y} = \sqrt{\sum_{i=1}^{n} a_{i}^{2} \sigma_{X_{i}}^{2}}
\]

where:

- \( \mu = \) expected or mean value
- \( \sigma = \) standard deviation

Equation 6-17 shows the calculation of the mean and standard deviation for any random variable \( Y \) that is a function of different values of a random variable \( X \) across \( N \) different periods. An example of this would be having the total cost of project \( Y \) as a function of the annual costs of the project \( X \) over a 30-year life of a project. In this basic formula, the variable \( Y \) is defined as the sum of \( X \) from each period multiplied by a factor \( a_{i} \) for that period. Note that the factor \( a_{i} \) can be equal to one or some other nonzero value. Given these definitions, the mean of \( Y \) is the sum of the mean of \( X \) from each period multiplied by the \( a_{i} \) term from that period. Similarly, the standard deviation of \( Y \) is a function of the sum of the \( X \) variance terms (\( \sigma_{X_{i}}^{2} \)) multiplied by the squared \( a_{i} \) term for each period.

Equation 6-17 provides the simplest calculation of the mean and standard deviation for a variable that is a function of a series of independent variables. A logical application of this calculation is in the present value formula itself. For example, the analyst typically estimates only the expected, or mean annual net present values (\( B-C \)). But the analyst may wish to measure the effects of some uncertainty in these estimates. From Equation 6-17, the analyst need only assert a standard deviation for the annual net benefit calculations (which can differ each year and, logically, may be greater in the out years of the estimates), and the standard deviation of the present value can be calculated. This standard deviation for the basic present value formulation described earlier can be calculated from Equation 6-18.
Equation 6-18: Standard Deviation of the Present Value with Independent Items

\[ \sigma_{PV}^2 = \sum_{t=m}^{n} \left( \frac{(B - C)}{(1 + d)^t} \right)^2 \sigma_{(B-C),t}^2 + \left( \frac{1}{(1 + d)^n} \right) \sigma_{A_n}^2 \]

\[ \sigma_{PV} = \sqrt{\sigma_{PV}^2} \]

where:

- \( \sigma_{PV} \) = standard deviation of the present value
- \( \sigma_{(B-C),t} \) = standard deviation of the net benefits in year \( t \)
- \( \sigma_{A_n} \) = standard deviation of the salvage value in year \( n \)

Equation 6-18 applies to circumstances in which the uncertainty in each period is independent of the uncertainty in other periods. This is a good way to characterize situations where, each year, random forces are likely to impinge upon the level of net benefits in each period. In statistical terms, the uncertainty from one period to the next is uncorrelated serially.

In many cases in highway benefit-cost analysis, however, the uncertainty in one period translates into the same uncertainty in the next period. If, for example, the uncertainty in net benefits derives mainly from uncertainty about the value of time, an error made in one period’s net benefit calculation will be in the same direction as the error in the next period’s calculation. In this case, the uncertainty is correlated serially. In such instances, the standard deviation of the present value is as expressed in Equation 6-19.

Equation 6-19: Standard Deviation of the Present Value, Serially Dependent Items

\[ \sigma_{PV} = \sum_{t=m}^{n} \left( \frac{(B - C)}{(1 + d)^t} \right) \sigma_{(B-C),t} + \left( \frac{1}{(1 + d)^n} \right) \sigma_{A_n} \]

It is highly recommended that the analyst employ some mechanism for addressing the inherent uncertainty of project feasibility analysis. Policy makers will always ask the analyst for the best estimate (i.e., the expected or mean present value), but the level of confidence the analyst has in this estimate is an important adjunct to this information.

**The Discount Rate and the Treatment of Inflation**

The choice of the discount rate must be consistent with the treatment of inflation in the analysis. If the net benefits and terminal value calculations are all in real terms (i.e., uninflated and expressed in constant dollars), then the discount rate should be in real terms as well. Conversely, if the net benefits and terminal value are measured in nominal (i.e., inflated) dollar terms over the project’s life, then the discount rate should incorporate a consistent inflation-expectations element.

Typically, a constant expected rate of inflation is used throughout the analysis, and the inflation expectations affecting net benefit flows are the same as those that affect the nominal interest rate. In this case, it is easy to see that working with nominal dollar values and a nominal discount rate is essentially equivalent to working with real dollar values and a real discount rate, as in Equation 6-20.
Equation 6-20: The Equivalency of Nominal and Real Discounting Procedures

\[
P V = \sum_{t=m}^{n} \frac{(B - C)_t (1 + \omega)}{(1 + d + \omega)^t} + \frac{T_n (1 + \omega) \varphi}{(1 + d + \omega)^n} \approx \sum_{t=m}^{n} \frac{(B - C)_t}{(1 + d)^t} + \frac{T_n}{(1 + d)^n}
\]

where:

- \(d\) = the real discount rate
- \((B - C)_t\) = the real net benefit stream in period \(t\)
- \(T_n\) = the real terminal value of the project
- \(\omega\) = the expected rate of inflation

In cases in which certain components of the net benefit stream are expected to inflate at different rates than other goods and services in the economy, the analyst must be careful to treat inflation expectations consistently in the measurement of cash flows and selection of the discount rate. As Equation 6-21 illustrates, the analyst has a choice of incorporating a net real inflation rate in the benefit flows, or using a nominal discount rate and nominal cash flows in the analysis. The latter is the choice usually made by analysts.

Equation 6-21: Alternative Ways of Incorporating Real Inflation in Net Benefits

\[
P V = \sum_{t=m}^{n} \frac{(B - C)_t (1 + \varphi)}{(1 + d_R + \omega)^t} + \frac{T_n (1 + \varphi)}{(1 + d_R + \omega)^n}
\approx \sum_{t=m}^{n} \frac{(B - C)_t (1 + \kappa)}{(1 + d_R)^t} + \frac{T_n}{(1 + d_R)^n}
\]

where:

- \(d_R\) = the real discount rate
- \(\omega\) = the expected, general nominal rate of inflation
- \(\varphi\) = the expected nominal rate of inflation of project net benefits, \(\varphi <\omega\)
- \(\kappa\) = the expected net real rate of inflation of project net benefits, \(\kappa <0\)

Obviously, in the case in which there is net, real inflation in project net benefits, this net real inflation has to be treated directly. It is not sufficient to extrapolate net benefit measures in current dollars and discount by the real rate. The changes in the constant-dollar values of net benefits must be calculated directly, or nominal inflation rates and discount rates must be used throughout.

Short-Term vs. Long-Term Discount Rates

In theory, present value analysis should employ a policy toward the discount rate(s) that is consistent with the term or time period over which funds will be sequestered in the highway investment. This follows from the fact that the purpose of discounting is to account for the lost time value of money associated with tying up funds in a project, or failing to deliver valuable benefits.

Precise application of this principle can get quite complex since different elements of funds and benefits have different terms or periods over which opportunity cost is
experienced. In practice, the discount rate used each period should be derived from the rate implicit in market securities of total terms similar to the project being evaluated. Thus, the discount rate used to analyze a project with a 30-year life should not be derived only from today’s 6-month interest rate, for example. Rather, the annual discount rate used in the analysis, for example, should be the annual rate implicit in a 30-year security’s returns.

Private vs. Public Interest Rates

Although it is commonly done, there is virtually no justification for using anything but private market interest rates to derive discount rates for highway projects. The reasons are threefold:

- **Public agencies keep their idle funds in market investments.** The cash management facilities of virtually all public agencies permit the agencies to invest in market securities. Consequently, the opportunity cost of funds to a public agency is the same as it is for private entities, the private market return.

- **Public funds are obtained from private sources.** Public funds for highways are obtained, through various means, from private sources (highway users, general tax payers, etc.). If funds are used for highways, they cannot be used by the private sources for their private investment purposes. Hence, the social opportunity cost of public investment is foregone private investment.

- **The user benefits of highways are mostly private.** Since the user benefits generated by highways are mostly private, it is the private opportunity cost of these benefits that is relevant to the ultimate value of the facility to the public. This, too, argues also for use of private discount rates.

The counterargument is that public agencies are able to borrow at rates lower than other entities in the economy, and that these lower rates are the true measure of public investment opportunity costs. In fact, however, these lower rates are obtained by a tax-exemption procedure that itself imposes private costs (in terms of raising the tax burden on private sources of income) that are at least as great as the subsidy enjoyed by the public agency. Hence, again, the total social cost of public borrowing is at least as great as the private cost of borrowing.

For all of these reasons, private investment returns should be used to guide the selection of discount rates, even on public projects.

Practical Advice for Selecting a Discount Rate

Given the factors described above, the analyst needs to decide between using a nominal or real discount rate and whether or not this rate should incorporate a risk premium. Generally speaking, project budgets tend to be expressed in nominal annual dollars, which would necessitate using a nominal discount rate. As discussed above, it is recommended that a discount rate be selected that reflects the private cost of capital even for public investment projects. This implicitly assumes some element of risk in the investment.

On the basis of the considerations above, the rules of thumb for determining the appropriate discount rate depends upon the rate context:
• *Riskless nominal rate.* If the analyst has structured the analysis in such a way that a riskless, nominal discount rate is required, the best source is the current yield on U.S. government securities with a term similar to the project being analyzed.

• *Riskless real rate.* Government securities are the appropriate place to look for riskless real rates as well. The yield on conventional government securities is, of course, a nominal rate. However, the federal government also issues inflation-protected bonds (“Treasury Inflation-Indexed Bonds”), in terms of five, 10, and 30 years. The difference between the yield of these bonds and conventional bonds of the same term is the market’s estimate of inflation. At the time of this writing, the implicit, riskless real rate was approximately 3.5 percent. Economists generally expect the pre-tax real rate in an economy to be in the 3.0 to 4.0 percent range.

• *Risk premia.* Risk premia can be added to the relevant riskless rates to obtain the risk-adjusted discount rate in the case where the analyst is incorporating risk adjustment via the discount rate. The selection of the risk premium to use is best guided by private sector analogues, wherever possible. Private entities providing transportation services to the public often fund investments in these facilities with issuance of debt (bonds) and equity. The yield offered on such securities in the marketplace (of similar term to the project being considered) minus the yield of riskless government securities provides a rough guide to the size of the risk premium. Project risk is very idiosyncratic and conservatism argues for a larger, rather than smaller, risk premium. However, it can be argued that a large public highway agency has a portfolio of highway investments (much like a large private firm), and that, therefore, the risk premia borne by private transportation companies is relevant. Obviously, private firms that are in the business of providing highway services are the best analog.

In summary, the selection of a discount rate is relatively straightforward as long as the analyst uses a rate consistent with other assumptions of the analysis.

**Assembling Project Cost Data**

This manual is not a project costing manual. It is necessary to discuss project cost data briefly, however, to emphasize the necessary consistency between the approach taken to measure user benefits and the approach taken to measuring project costs.

As emphasized in the first section of this manual, certain costs associated with a project must be handled in the user benefit calculations, and certain other costs must be handled in the project cost calculations. If costs are not appropriately handled, important project feasibility measures like the benefit-cost ratio and project ranking will be miscalculated. The rule used to assign costs to these two areas is as follows:

• If a cost is borne and perceived by the users of highways (i.e., charged directly to users), it should be dealt with in the user benefit calculation. From this perspective, the user benefit calculation is net user benefits, i.e., gross user benefits, net of user-borne costs. Since user benefits often arise from reductions in user-borne costs (time and other costs), this rule is obvious, but not consistently followed;
• On the other hand, if a cost is borne by the highway authority or other providers of the services the user is enjoying, it should be assessed as a project cost. That is, if the costs constitute claims on a highway authority’s scarce budget resources, they should be considered project costs. Failure to treat project costs properly will affect the project prioritization process. Hence, a project’s cost should include the present value of any obligation to incur costs (or commit to incur costs in the future) that burden the authority’s funds. This may include costs in addition to construction costs. For example, if building a project results in a permanent obligation of the highway authority to commit maintenance funds over the life of the facility, the present value is part of project costs. The present value of the stream of all such costs is the relevant project cost for feasibility analysis.

If the user benefit calculation procedures in this manual have been followed carefully, the effect of the project on costs borne by users will have been accounted for in user benefit calculations. It is still necessary to assemble data on the cost of developing and operating the facility, however.

What remains are the construction and operating costs that are incurred by an agency or operator to deliver the assumed user benefits. These costs are somewhat idiosyncratic to the project’s setting and characteristics. In addition, some of the cost elements are changing rapidly. The cost of implementing highway pricing strategies, for example, is changing rapidly with the advance of electronic technology. This manual only alerts the analyst to the categories of costs and their proper treatment in the benefit-cost framework. The figures offered in this section should only be taken as illustrative.

Construction and Other Development Costs
Many highway projects, whether involving a new route, expanded capacity, or rehabilitation of an existing facility, involve construction activity. Construction cost attribution is particularly important in highway benefit-cost analysis because it is an “up front” cost, and thus is not subject to significant discounting in the benefit-cost procedure. Small errors in attribution of the amount or timing of construction costs can significantly affect the measured economic feasibility of the project.

The amount and timing of construction costs should be tabulated so that the analyst can apply the appropriate discount factor later in the process. The timing of costs should be measured by when funds are actually spent on the project, not when they are committed or programmed for use. This is because idle funds can be invested in securities that have returns equal to the assumed time value of funds. (See the earlier discussion of discount rates.)

Adjusting Development and Operating Cost Estimates for Inflation
Construction and other development costs also should be adjusted to reflect the impact of inflation on those costs up to the point they are actually incurred. Figure 6-15 shows an 80-year history of the commonly used, Engineering News-Record (ENR) Construction Index. In the 1990s, construction inflation has been relatively low, averaging only 2.5 percent per annum. This is down sharply from earlier periods; construction cost inflation in the 1980s averaged 3.5 percent and 7.8 percent in the 1970s.
Construction cost indices should be applied with care to right-of-way (land) cost elements of highway development. Site values tend to inflate at a rate that is reflective of regional, nominal economic growth and its demands on sites. This is certainly influenced by general inflation phenomena, but also depends on site supply restrictions, property tax policy and other artifacts of the market for land. This topic is discussed later in this chapter.

Creating Construction Cost Estimates

It is perilous for the analyst to estimate project costs without the assistance of a project costing program or a qualified engineer experienced in project costing. Yet, the analyst frequently is asked to evaluate small changes in the facility design or operation, and it is time-consuming and costly to cycle through formal project costing exercises. This is particularly true in a sketch planning context.

Fortunately, there is some costing information available to the sketch planner. The Federal Highway Administration’s Highway Economic Requirements System (HERS) model is a mechanism that can be used to estimate project costs in the absence of custom project costing effort. HERS is used generally by states to plan future budgetary expenses given the condition of their facilities, and other factors. As such, the HERS data can be used to estimate project costs when more project-specific information is not available.
The HERS program is the only publicly available costing mechanism that is routinely updated, refined, and tested against actual costing experience. Because of the updating process, analysts should regularly check with the FHWA to see if HERS has changed. HERS does not provide costing assistance for all types of projects. Data on the cost of developing intersections and roundabouts, and improving signalization and other facility refinements are not available in a consistent, HERS-like framework. For these projects, therefore, the analyst has no choice but to have cost estimates developed to support the feasibility analysis.

Where possible, this manual provides information consistent with HERS. For those types of improvements encompassed by HERS, very useful data can be developed quickly and inexpensively for use as ballpark estimates of costs when more project-specific information is not available. Table 6-3, Table 6-4, and Table 6-5 provide some of the key parametric information contained in the current HERS model (HERS is being updated). Table 6-3 shows the approximate cost per lane-mile of selected, major highway construction activities. Table 6-4 and Table 6-5 present information on a unit cost basis, so that a project engineer can quickly develop sketch estimates of project costs from more detailed, project component information. Table 6-6 provides state adjustment factors contained in HERS. This manual is not a costing manual, of course, so this information is presented simply to provide information to the sketch planner and to alert the user to the nature of the detailed information available.

Table 6-3: HERS Estimates of Construction Costs, per Lane Mile (Updated to 2000 Dollars)

<table>
<thead>
<tr>
<th>Facility Class and Terrain</th>
<th>Recon-struct &amp; Add High Cost Lanes</th>
<th>Recon-struct &amp; Add Normal Lanes</th>
<th>Recon-struct &amp; Widen Lanes</th>
<th>Major Widening at High Cost</th>
<th>Major Widening at Normal Cost</th>
<th>Minor Widening</th>
<th>Resurface &amp; Improve Shoulders</th>
<th>Resurface</th>
<th>ROW Costs per Lane Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural Interstate Flat terrain</td>
<td>596</td>
<td>596</td>
<td>672</td>
<td>560</td>
<td>375</td>
<td>375</td>
<td>303</td>
<td>208</td>
<td>117</td>
</tr>
<tr>
<td>Rural Interstate Rolling terrain</td>
<td>697</td>
<td>697</td>
<td>741</td>
<td>577</td>
<td>399</td>
<td>399</td>
<td>326</td>
<td>220</td>
<td>113</td>
</tr>
<tr>
<td>Rural Interstate Mountainous terrain</td>
<td>803</td>
<td>803</td>
<td>883</td>
<td>818</td>
<td>527</td>
<td>527</td>
<td>447</td>
<td>269</td>
<td>145</td>
</tr>
<tr>
<td>Rural Other Principal Arterial Flat terrain</td>
<td>752</td>
<td>752</td>
<td>572</td>
<td>489</td>
<td>384</td>
<td>384</td>
<td>297</td>
<td>144</td>
<td>74</td>
</tr>
<tr>
<td>Rural Other Principal Arterial Rolling terrain</td>
<td>778</td>
<td>778</td>
<td>644</td>
<td>553</td>
<td>429</td>
<td>429</td>
<td>327</td>
<td>157</td>
<td>74</td>
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<tr>
<td>Rural Other Principal Arterial Mountainous terrain</td>
<td>1,106</td>
<td>1,106</td>
<td>844</td>
<td>691</td>
<td>801</td>
<td>801</td>
<td>466</td>
<td>215</td>
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<tr>
<td>Rural Minor Arterial Flat terrain</td>
<td>653</td>
<td>653</td>
<td>441</td>
<td>348</td>
<td>379</td>
<td>379</td>
<td>247</td>
<td>145</td>
<td>62</td>
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<tr>
<td>Rural Minor Arterial Rolling terrain</td>
<td>710</td>
<td>710</td>
<td>555</td>
<td>474</td>
<td>524</td>
<td>524</td>
<td>258</td>
<td>147</td>
<td>66</td>
</tr>
<tr>
<td>Rural Minor Arterial Mountainous terrain</td>
<td>960</td>
<td>960</td>
<td>866</td>
<td>622</td>
<td>665</td>
<td>665</td>
<td>342</td>
<td>184</td>
<td>104</td>
</tr>
<tr>
<td>Rural Major Collector Flat terrain</td>
<td>575</td>
<td>575</td>
<td>503</td>
<td>357</td>
<td>361</td>
<td>361</td>
<td>199</td>
<td>101</td>
<td>35</td>
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<tr>
<td>Rural Major Collector Rolling terrain</td>
<td>630</td>
<td>630</td>
<td>610</td>
<td>441</td>
<td>359</td>
<td>359</td>
<td>209</td>
<td>111</td>
<td>41</td>
</tr>
<tr>
<td>Rural Major Collector Mountainous terrain</td>
<td>843</td>
<td>843</td>
<td>780</td>
<td>608</td>
<td>613</td>
<td>613</td>
<td>279</td>
<td>142</td>
<td>51</td>
</tr>
<tr>
<td>Urban Sections Freeways/Expressways</td>
<td>8,817</td>
<td>3,791</td>
<td>2,781</td>
<td>1,703</td>
<td>8,950</td>
<td>3,924</td>
<td>1,651</td>
<td>493</td>
<td>230</td>
</tr>
<tr>
<td>Urban Sections Other Divided</td>
<td>5,244</td>
<td>2,094</td>
<td>1,712</td>
<td>971</td>
<td>5,607</td>
<td>2,459</td>
<td>910</td>
<td>337</td>
<td>154</td>
</tr>
<tr>
<td>Urban Sections Other Undivided</td>
<td>3,704</td>
<td>1,354</td>
<td>1,489</td>
<td>888</td>
<td>4,183</td>
<td>1,834</td>
<td>963</td>
<td>295</td>
<td>174</td>
</tr>
</tbody>
</table>
Table 6-4: HERS Estimates of Unit Construction Costs, per Element (Urban Facilities, Updated to 2000 Dollars)

<table>
<thead>
<tr>
<th>Cost Element</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearing and grubbing per square yard</td>
<td>Any terrain $ 2.30</td>
</tr>
<tr>
<td>Earthwork per cubic yard</td>
<td>Flat terrain $ 7.35</td>
</tr>
<tr>
<td></td>
<td>Rolling terrain $ 7.35</td>
</tr>
<tr>
<td></td>
<td>Mountainous terrain $ 7.35</td>
</tr>
<tr>
<td>Drainage per foot</td>
<td>Narrow pipe culverts $ 87.60</td>
</tr>
<tr>
<td></td>
<td>Wide pipe culverts $ 175.67</td>
</tr>
<tr>
<td></td>
<td>Small box culverts $ 795.27</td>
</tr>
<tr>
<td></td>
<td>Wide box culverts $ 1,870.23</td>
</tr>
<tr>
<td>Structures each</td>
<td>$ 1,172,341.23</td>
</tr>
<tr>
<td>Guard rails and curbs per mile</td>
<td>Curbed median or shoulder $ 197,983.51</td>
</tr>
<tr>
<td></td>
<td>Guard rail or concrete median $ 245,254.68</td>
</tr>
<tr>
<td></td>
<td>Guard rail at shoulder $ 239,371.29</td>
</tr>
<tr>
<td>Fencing per mile</td>
<td>$ 125,922.60</td>
</tr>
<tr>
<td>Lighting per mile</td>
<td>$ 875,668.79</td>
</tr>
<tr>
<td>Painting of traffic lanes per mile</td>
<td>2 lanes $ 23,151.18</td>
</tr>
<tr>
<td></td>
<td>4 lanes $ 38,393.75</td>
</tr>
<tr>
<td></td>
<td>6 lanes $ 49,677.73</td>
</tr>
<tr>
<td></td>
<td>8 lanes $ 56,101.61</td>
</tr>
<tr>
<td>Pavement costs per square yard</td>
<td>4 inch aggregates $ 5.18</td>
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<tr>
<td></td>
<td>6 inch aggregates $ 7.50</td>
</tr>
<tr>
<td></td>
<td>8 inch aggregates $ 9.94</td>
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<tr>
<td></td>
<td>12 inch aggregates $ 14.91</td>
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<td>13 inch aggregates $ 17.87</td>
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<td>2 inch asphaltic concrete $ 7.79</td>
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<td>3 inch asphaltic concrete $ 9.08</td>
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<td>6 inch portland cement concrete $ 23.48</td>
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<td>7 inch portland cement concrete $ 27.15</td>
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<td>9 inch portland cement concrete $ 32.22</td>
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<tr>
<td></td>
<td>10 inch portland cement concrete $ 36.82</td>
</tr>
<tr>
<td></td>
<td>12 inch portland cement concrete $ 42.95</td>
</tr>
<tr>
<td></td>
<td>15 inch portland cement concrete $ 52.16</td>
</tr>
<tr>
<td>Surface treatment</td>
<td>light pavement sections $ 2.71</td>
</tr>
</tbody>
</table>

Table 6-5: HERS Estimates of Unit Construction Costs, per Element (Rural Facilities, Updated to 2000 Dollars)

<table>
<thead>
<tr>
<th>Cost Element</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearing and grubbing per square yard</td>
<td></td>
</tr>
<tr>
<td>Any terrain</td>
<td>$ 1.89</td>
</tr>
<tr>
<td>Earthwork per cubic yard</td>
<td>$ -</td>
</tr>
<tr>
<td>Flat terrain</td>
<td>$ 6.05</td>
</tr>
<tr>
<td>Rolling terrain</td>
<td>$ 6.05</td>
</tr>
<tr>
<td>Mountainous terrain</td>
<td>$ 7.10</td>
</tr>
<tr>
<td>Drainage per foot</td>
<td>$ -</td>
</tr>
<tr>
<td>Narrow pipe culverts</td>
<td>$ 72.08</td>
</tr>
<tr>
<td>Wide pipe culverts</td>
<td>$ 144.54</td>
</tr>
<tr>
<td>Small box culverts</td>
<td>$ 654.39</td>
</tr>
<tr>
<td>Wide box culverts</td>
<td>$ 1,538.94</td>
</tr>
<tr>
<td>Structures each</td>
<td>$ 964,673.83</td>
</tr>
<tr>
<td>Guard rails and curbs per mile</td>
<td>$ -</td>
</tr>
<tr>
<td>Curbed median or shoulder</td>
<td>$ 162,912.79</td>
</tr>
<tr>
<td>Guard rail or concrete median</td>
<td>$ 201,809.64</td>
</tr>
<tr>
<td>Guard rail at shoulder</td>
<td>$ 196,968.76</td>
</tr>
<tr>
<td>Fencing per mile</td>
<td>$ 103,616.33</td>
</tr>
<tr>
<td>Lighting per mile</td>
<td>$ 720,553.53</td>
</tr>
<tr>
<td>Painting of traffic lanes per mile</td>
<td>$ -</td>
</tr>
<tr>
<td>2 lanes</td>
<td>$ 19,082.58</td>
</tr>
<tr>
<td>4 lanes</td>
<td>$ 31,592.81</td>
</tr>
<tr>
<td>6 lanes</td>
<td>$ 40,877.20</td>
</tr>
<tr>
<td>8 lanes</td>
<td>$ 46,163.50</td>
</tr>
<tr>
<td>Pavement costs per square yard</td>
<td>$ -</td>
</tr>
<tr>
<td>4 inch aggregates</td>
<td>$ 4.26</td>
</tr>
<tr>
<td>6 inch aggregates</td>
<td>$ 6.16</td>
</tr>
<tr>
<td>8 inch aggregates</td>
<td>$ 8.18</td>
</tr>
<tr>
<td>12 inch aggregates</td>
<td>$ 12.27</td>
</tr>
<tr>
<td>13 inch aggregates</td>
<td>$ 14.70</td>
</tr>
<tr>
<td>2 inch asphaltic concrete</td>
<td>$ 6.40</td>
</tr>
<tr>
<td>3 inch asphaltic concrete</td>
<td>$ 7.47</td>
</tr>
<tr>
<td>4 inch asphaltic concrete</td>
<td>$ 10.18</td>
</tr>
<tr>
<td>6 inch asphaltic concrete</td>
<td>$ 14.96</td>
</tr>
<tr>
<td>8 inch asphaltic concrete</td>
<td>$ 21.01</td>
</tr>
<tr>
<td>6 inch portland cement concrete</td>
<td>$ 19.31</td>
</tr>
<tr>
<td>7 inch portland cement concrete</td>
<td>$ 22.34</td>
</tr>
<tr>
<td>8 inch portland cement concrete</td>
<td>$ 24.30</td>
</tr>
<tr>
<td>9 inch portland cement concrete</td>
<td>$ 26.51</td>
</tr>
<tr>
<td>10 inch portland cement concrete</td>
<td>$ 30.29</td>
</tr>
<tr>
<td>12 inch portland cement concrete</td>
<td>$ 35.35</td>
</tr>
<tr>
<td>15 inch portland cement concrete</td>
<td>$ 42.92</td>
</tr>
<tr>
<td>Surface treatment per sq. yard</td>
<td>$ -</td>
</tr>
<tr>
<td>light pavement sections</td>
<td>$ 2.23</td>
</tr>
</tbody>
</table>

Table 6-6: HERS State Adjustment Factors

<table>
<thead>
<tr>
<th>State</th>
<th>Factor</th>
<th>State</th>
<th>Factor</th>
<th>State</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL</td>
<td>0.912</td>
<td>LA</td>
<td>1.056</td>
<td>OK</td>
<td>1.023</td>
</tr>
<tr>
<td>AK</td>
<td>1.725</td>
<td>ME</td>
<td>1.215</td>
<td>OR</td>
<td>0.977</td>
</tr>
<tr>
<td>AZ</td>
<td>0.863</td>
<td>MD</td>
<td>1.131</td>
<td>PA</td>
<td>1.257</td>
</tr>
<tr>
<td>AR</td>
<td>0.827</td>
<td>MA</td>
<td>1.301</td>
<td>RI</td>
<td>0.775</td>
</tr>
<tr>
<td>CA</td>
<td>1.096</td>
<td>MI</td>
<td>1.141</td>
<td>SC</td>
<td>1.115</td>
</tr>
<tr>
<td>CO</td>
<td>0.897</td>
<td>MN</td>
<td>0.904</td>
<td>SD</td>
<td>0.713</td>
</tr>
<tr>
<td>CT</td>
<td>0.896</td>
<td>MS</td>
<td>1.150</td>
<td>TN</td>
<td>0.896</td>
</tr>
<tr>
<td>DE</td>
<td>0.887</td>
<td>MO</td>
<td>0.791</td>
<td>TX</td>
<td>0.725</td>
</tr>
<tr>
<td>DC</td>
<td>0.923</td>
<td>MT</td>
<td>0.932</td>
<td>UT</td>
<td>0.912</td>
</tr>
<tr>
<td>FL</td>
<td>0.922</td>
<td>NE</td>
<td>0.981</td>
<td>VT</td>
<td>1.287</td>
</tr>
<tr>
<td>GA</td>
<td>1.058</td>
<td>NV</td>
<td>1.017</td>
<td>VA</td>
<td>1.161</td>
</tr>
<tr>
<td>HA</td>
<td>1.360</td>
<td>NH</td>
<td>0.635</td>
<td>WA</td>
<td>1.557</td>
</tr>
<tr>
<td>ID</td>
<td>0.567</td>
<td>NJ</td>
<td>0.808</td>
<td>WV</td>
<td>1.165</td>
</tr>
<tr>
<td>IL</td>
<td>1.076</td>
<td>NM</td>
<td>0.930</td>
<td>WI</td>
<td>0.832</td>
</tr>
<tr>
<td>IN</td>
<td>0.738</td>
<td>NY</td>
<td>1.349</td>
<td>WY</td>
<td>0.784</td>
</tr>
<tr>
<td>IA</td>
<td>0.707</td>
<td>NC</td>
<td>0.962</td>
<td>PR</td>
<td>0.535</td>
</tr>
<tr>
<td>KS</td>
<td>0.783</td>
<td>ND</td>
<td>0.862</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KY</td>
<td>1.603</td>
<td>OH</td>
<td>1.067</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Not all of the construction costs associated with a new project are incurred at the same time. The various construction cost elements developed or obtained by the analyst must be dated for proper treatment in the benefit-cost calculation framework. The expectation of this manual is that annual data are being used in the analysis, so this means associating each expenditure category with the year in which the expenditure occurs.

The Cost of Right-of-Way

A very important element of highway project costs, especially in urban settings, is the cost of the right-of-way—the incremental land needed to develop the transportation improvement. Many highway departments find estimation of the right-of-way costs of projects to be the most difficult aspect of the cost estimation process. In recent decades, the value of land, in many jurisdictions, has grown at rates that far outstripped general inflation. Since the price of land varies greatly with the economic setting, no general guidelines for the price of land can be provided in this manual. Guidance as to how to properly value land, and how to estimate its likely appreciation rate, can be provided.

Measuring the Current Value of Undeveloped Land

Undeveloped land should be valued currently at the price that others in the economy would be willing to pay for the land. In many property tax jurisdictions, increasingly sophisticated land valuation is performed by the tax assessor (using a technique called mass appraisal). Using mass appraisal, the value of a particular site is computed by attributing the implicit values paid in other property transactions for the individual characteristics of the site. Thus, even if the property is unique in its combination of characteristics (soil, slope, location, presence of timber, etc.) a fair value can be derived from transactions involving other properties using a so-called hedonic price regression.
that allocates individual price values to different property attributes and is at the heart of mass appraisal.

Private appraisal firms have access to the property sales data necessary to perform mass appraisal and hedonic price analysis, and can perform this task for highway authorities. This is a much superior technique to the older, comparable-sales technique. This method involves finding land value data from sales of matched properties. The ability to exactly match the features of the properties is poor, and almost always erroneous.

**Measuring the Future Value of Undeveloped Land**

In recent years, the value of undeveloped land has grown more rapidly than general inflation in many jurisdictions. This has frustrated highway planners who must evaluate and prioritize highway projects many years in advance.

Economic theory offers some general guidance. Theory suggests that site values in a region in which there is fixed land supply bear a relationship to the amount of economic activity located in the region. The reason is that economic rent is believed, by many economists to be “capitalized” into the value of the scarce productive asset, i.e., land. Thus, over long periods of time, the value of land is expected to appreciate at the general inflation rate plus the rate of real increase in regional income. Historically, this latter factor has been three to four percent for the nation as a whole. Thus, land should appreciate at approximately a three to four percent real rate.

If the market believes that regional income will grow more rapidly in the future (because of larger population, higher per capita incomes or both), site values can appreciate abruptly as land values are bid up by buyers expecting future growth. In regions in which land supply is more elastic, the appreciation rate will be lower or zero. Equation 6-22 displays a typical land value forecasting model that exploits this perspective, and the range of coefficients that one typically observes. Ideally, this relationship would be reexamined in the relevant local and general inflation context.

**Equation 6-22: Typical Land Value Forecasting Model**

\[
\frac{\Delta P_L}{P_L} \approx a_0 + a_1 \left( \frac{\Delta Y}{Y} - \frac{\Delta A}{A} \right)
\]

where:

- \(\frac{\Delta P_L}{P_L}\) = percent change in the price of land per annum
- \(\frac{\Delta Y}{Y}\) = percent change in regional income per annum
- \(\frac{\Delta A}{A}\) = percent change in available acres of land per annum

\(a_0 = 0.0\) to 0.09

\(a_1 = 0.8\) to 1.1
Measuring the Current and Future Value of Developed Land

Many highway projects involve ROW acquisition in settings in which there are already structures or other infrastructure on the land. Developed land is generally more costly to acquire than undeveloped land because of three main factors:

- **Existing structures or infrastructure.** Structures have productive value to others in the economy and developed sites (even sites without structures) usually have already-developed access to utilities, etc., that raw land does not have. The highway authority desirous of the underlying land will have to pay others to compensate them for value of the lost structures and development rights.

- **Demolition costs.** If the existing structures cannot be moved and resold, the highway authority must bear the cost of demolishing the structures.

- **Relocation costs.** In some political settings, highway authorities are required to underwrite, to varying degrees, the relocation of displaced residences and businesses in addition to paying of the cost of acquiring existing structures.

In summary, therefore, the value of developed land for the purpose of ROW acquisition will be as in Equation 6-23.

**Equation 6-23: The Cost of Acquiring Developed Land for ROW**

\[
P_L^D = P_L^{ui} + (P_S - P_S^M) + R
\]

where:

- \(P_L^D\) = value of developed land, per acre
- \(P_L^{ui}\) = value of undeveloped land, per acre
- \(P_S\) = value of structures (includes utility access and development rights), per acre
- \(P_S^M\) = proceeds from sale of structures, net of costs of sale, per acre
- \(R\) = relocation cost obligations of the highway authority, per acre

**Valuing ROW Already Owned**

In some cases, the highway authority already owns the right-of-way. The temptation is to treat the cost of this ROW as zero because it has already been paid for (perhaps as part of a previous project). However, unless the ROW cannot practically be sold to another party, or used for some other public purpose (such as a transit line, say), it should be valued at its opportunity cost. The opportunity cost is the value that someone else would pay to acquire it, and represents revenue foregone if the land is used in the current project.

The analyst should be cautious about assuming that existing ROW has zero value in other uses. In some countries with scarce land, the land in clover-leaf interchanges, in median strips, etc. are leased to farmers. Clearly, even such seemingly tied-up pieces of highway property have opportunity cost. Even if the highway authority chooses currently not to exploit this value, the potential is not permanently sacrificed by using the land for ROW.
Maintenance and Other Operating Costs
In addition to construction costs, highway projects impose maintenance and operating cost burdens on the agencies that are responsible for providing highway services. In economic analyses of highways, only certain types of costs should be included in the accounting of maintenance and operating costs.

Specifically, the only costs that should be included in the benefit-cost analysis are costs that are expended in order for the facility to be usable at its designed configuration. This is limited to costs that are borne:

- To offset the effects of use,
- To offset the effects of exposure to the elements,
- To offset the effects of the passage of time, or
- To facilitate access to the facility.

The basic notion is that for benefit-cost analysis purposes, only costs that allow the facility to continue to operate in its designed fashion over its life should be included in the maintenance and operating cost calculations. Costs associated with rehabilitating or enhancing the performance of the facility over time should not be included; actions taken to rehabilitate or enhance a roadway, in fact, are projects in the parlance of this manual.

Maintenance and operating costs from the perspective of this manual include a variety of costs, some of which are not considered maintenance in the engineering taxonomy:

- Cleaning debris from the road and shoulders,
- Resurfacing,
- Roadbed rehabilitation,
- Storm damage remediation,
- Maintenance of roadway shoulders,
- Maintenance and operation of wayside facilities, such as rest stops,
- Snow removal,
- Restriping,
- Maintenance and operation of toll booths and electronic toll collection facilities,
- The cost of providing electronic toll collection transponders, and etc.

All of these cost elements are logically includable in the accounting of highway maintenance and operating costs. This level of spending is one that preserves the design capacity of the roadway over time. If any other approach to operating and maintenance costs is taken, the user benefit calculations must be adjusted accordingly. For example, the HERS program and manual provide estimates of maintenance that implicitly contemplate the facility’s effective capacity deteriorating over time. That is, from the HERS manual perspective, the programming of rehabilitation of deteriorated road
surfaces is not part of maintenance calculations. Consequently, using only the maintenance calculations derived in HERS results in gradual deterioration of the road over its life. This deterioration will be manifested operationally in the reduction of the effective design speed or other changes that result in a reduction in effective capacity. In addition, user operating costs are higher over time on such a facility. If the analyst chooses to take this perspective on maintenance and operation expenses, such changes need to be incorporated in the user benefit analysis in the later years of the facility’s life.

Creating Operating Cost Estimates
When the analyst does not have specific estimates of highway maintenance and operating costs, the costs can be estimated. The level of accuracy is suitable for sketch planning, but not final project evaluation. HERS and other such sources can provide information useful as a starting point in calculating maintenance and operating costs. Figure 6-16 through Figure 6-19 are derived from HERS data by iteratively solving for the lowest operating cost envelope.
Figure 6-16: Operating Costs for Urban Highways (in 1997 Cents per Vehicle-Mile)

Urban Freeway or Expressway

Urban Other Principal Arterial
Figure 6-17: Operating Costs for Urban Highways (in 1997 Cents per Vehicle-Mile), cont.
Figure 6-18: Operating Costs for Rural Highways (in 1997 Cents per Vehicle-Mile)

Rural Interstate

Rural Other Principal Arterial
These figures provide estimates of maintenance and operating costs per average VMT at various ADT for facilities of various pavement designs. The estimates are intended to represent the costs incurred per VMT to maintain the facility’s design capacity. For sketch planning purposes, the analyst can use these estimates to provide operating cost information where it is otherwise not available. Special operating costs, such as toll facility operation, etc. are not included in these figures, and needs to be calculated for the specific configuration contemplated.
Annualizing Project Costs: The Role of Financing Costs

When the analyst has assembled the appropriate construction and operating cost data for the project, the data needs to be attributed to the individual, annual periods that comprise the life of project and the horizon of the benefit-cost analysis. This means that each cost element needs to be assigned to a particular year in the planning horizon. Since many projects are financed in a manner that spreads the cost burden over the life of the project, the analyst must decide how to treat financing costs in the benefit-cost analysis.

Construction Costs: To Amortize or Not to Amortize

The simplest situation for annualization of construction costs is the one where the highway authority spends out of a trust fund, earning market interest rates on idle portions of the fund. In this case, the date at which the trust fund is drawn down to pay for particular construction activities is the relevant date to assign to construction cost elements in the feasibility analysis.

Often, however, construction is paid for out of the revenues of bond issues. The bond indenture, in turn, establishes a claim on future highway revenues or grants or other revenues as the mechanism of repatriating this debt. In this manner, the cost of building the highway is spread out (“amortized”) over the life of the bond. In most cases, however, the fact that the construction is financed in this manner is irrelevant to the benefit-cost arithmetic. The reason is that the present value of the stream of payments resulting from the bond amortization generally should be the same as the principal value that is being amortized. This will always be the case if the discount rate used in the benefit-cost analysis is the same as the interest rate being used to amortize the bonded indebtedness.

Consequently, the only reason to amortize construction costs (i.e., rather than book them to the particular year in which they occur) is if the interest rate associated with the bond financing is different from the discount rate. If the bond rate is higher than the discount rate, amortization has the effect of elevating the present value of construction costs to reflect this financing burden. In general, however, if the market bond rate available for a project is higher than the discount rate, the analyst should reconsider the choice of discount rate. The higher rate suggests that the market may be applying a higher risk premium, and the market’s perceptions of risk may be correct.

Conversely, if the bond rate is lower than the discount rate, amortization reduces the measured present value of costs. Low financing rates are common for public projects because of the tax-favored treatment of public debt, and the fact that the debt may be (explicitly or implicitly) viewed by the market as enjoying the greater security of the taxing authority of the issuing government. From an economic welfare perspective, these rate advantages come at the expense of hidden public costs (losses in income tax revenue, etc.), and are illusory. From this perspective, construction costs should not be amortized at the special financing rate, but rather simply booked as lump-sum expenses in the year(s) in which they occur.

In most cases, therefore, the inclusion of the cost of financing highway construction through amortization of costs is not necessary or desirable.
An analogous financing issue arises in the treatment of annual operating costs. Operating and maintenance costs are naturally measured as a stream of annual costs, and no special accounting for financing costs is usually necessary. In practice, however, highway agencies may finance highway operating expenditures through the use of operating lines of credit or other such similar facilities. If this is the case, annualization of operating costs requires consideration of the effects of financing on these measures.

The treatment of such working capital costs is the same as for construction finance. That is, if the annual interest rate on working capital debt exceeds the discount rate used in the analysis, the incremental financing cost needs to be accounted for. Specifically, in the case of operating costs, the incremental interest costs should be added to the annual operating and maintenance cost estimates:

1. The incremental interest cost is calculated by multiplying the nominal operating cost figures by the difference between the financing rate and the discount rate.
2. This interest cost should be added to the annual operating cost estimates before calculating present values.

The same cautions as in the construction setting apply to using working capital interest rates that are different from the discount rate used in the benefit-cost analysis. Unless the market interest rates are purely arbitrary, they should be considered carefully as candidates for the estimate of the risk-adjusted discount rate.

PRESENT VALUE CALCULATIONS AND SENSITIVITY ANALYSIS

The final step in the user benefit analysis of highways is to determine the feasibility of the project, given the user benefits. All of the pieces of the analysis can be calculated following the guidance of earlier chapters in the manual. The purpose of this section of the manual is to provide guidance in drawing these elements together.

Assembling Module Information

If the analyst has used this manual effectively, data has been assembled that is in a form conducive to easy aggregation. For the purposes of this discussion, it is assumed that the project has numerous elements (a variety of affected segments or corridors, affected intersections, etc.). The manual has been set up in such a way that the resulting calculations are additive within an analysis year to derive total user benefits. It is assumed that project cost information can be developed on an annual basis.

User Benefit Calculations

The user benefit calculations have all resulted in the calculation of the User Benefit Formula (resulting in a user benefit per mile of affected segments or corridors), or using the recommended procedures for intersections and like facilities, a total user benefit per improvement element. In this discussion, therefore, we will distinguish between Segment-Based and Improvement-Based calculations.

Figure 6-20 illustrates how the modular user benefit information generated elsewhere in the manual is brought together. Note the different treatment of segment-based and improvement-based information.
Figure 6-20: Stylized Representation of User Benefit Aggregation and Extrapolation

- Vehicle-miles vs. Passenger-miles vs. Trips, etc.
- Define project type and units of analysis
- Segment (link, corridor, etc.) vs. improvement (intersection, etc.)
- Segment, facility, or corridor user benefit calculations by user class, study hour
- Perform user benefit analysis for peak or study hour
- Improvement-level user benefit calculations by user class, study hour
- Explicit expansion
- Choose method to expand hourly benefits to yearly
- Formulaic expansion
- Aggregate hourly benefits across user classes
- Expand to daily and monthly benefits
- Expand to yearly benefits
- Expand to daily and monthly benefits
- Expand to yearly benefits
- Aggregate hourly benefits across project segments and user classes
- Aggregate to the project level
- Aggregate across improvements
- Explicit iteration of other project years
- Extrapolate to other project years
- Formulaic extrapolation
- Segment and improvement-based user benefits, by project year
- Calculate present value of benefits
- Present value of benefits for the project

User Benefit Analysis for Highways
Present Value Calculations

Figure 6-21 shows how the user benefit information is merged with the project cost information, information about risk and uncertainty, project life, and the discount rate to yield the present value of user benefits and project costs and, finally, the project net benefits and the benefit-cost ratio. If net project benefits are positive, the project is said to be \textit{economically feasible at the given discount rate}. Such a project also will have a benefit-cost ratio greater than one. Calculating the benefit-cost ratio is helpful in selecting among a menu of projects under certain conditions.

**Figure 6-21: Stylized Representation of Present Value Calculations**

\begin{itemize}
  \item Sum of segment and improvement-based user benefits data, by project year
  \item Sum of operating costs, by project year
  \item Sum of capital costs, by project year
  \item Sum of operating costs, by project year
  \item Present value calculation
  \item Terminal value estimate
  \item Present value of benefits (B)
  \item Present value of costs (C)
  \item Benefit-Cost Ratio (B/C)
  \item Net Benefits (B-C)
\end{itemize}
IDENTIFYING FEASIBLE PROJECTS

Benefit-cost analysis is used to reach decisions based on the proper balancing of benefit and cost considerations. The proper use of benefit and cost information depends upon the decision context.

Efficient investing in highway projects is fundamentally a search for projects with positive net benefits. If the discount rate is properly chosen—and user benefits are the only necessary perspective—projects with positive net benefits are worth building. In economic parlance, such projects are said to be economically feasible. Whether such projects actually will be built depends upon considerations of budget constraints and financial feasibility.

The Role of Budget Constraints

If budgets for building roadways were not constrained all economically feasible road projects should be built. That is, all projects with positive net benefits—benefits in excess of costs—should be built. To do otherwise would be economically wasteful, and injurious to the economy by definition. Road projects do not have to be balanced against other, non-road projects; this is done automatically by the choice of the appropriate discount rate which measures the opportunity cost of funds used in road projects.

For a variety of reasons, the budgets of highway departments are sometimes constrained in practice. That is, there may be more economically feasible projects than can be developed from the department’s budget. The budget may rely, for example, on certain tax or user fee sources that are poorly configured or arbitrary. If these constraints impose a serious limitation on the number of economically feasible projects that may be built, of course, removal of these constraints should be seriously considered. Nevertheless, as a practical matter, highway development budgets are often constrained by such considerations, and benefit-cost analysis has to be accommodated to it.

Constrained Budgets: The Use of Benefit-Cost Ratios

The calculation of benefit-cost ratios facilitates project selection under circumstances of constrained budgets. The project selection process under these circumstances proceeds as follows:

- **Calculate benefit-cost ratios for all economically feasible projects.** It is important that the denominator of this ratio, the project cost, has been defined so that it represents the budgetary cost to the highway agency. It is also important that the projects be independent, or non-mutually exclusive—that is, they do not affect the feasibility of one another.

- **Rank projects in descending order of benefit-cost ratios.** Note that this ranking is done independently of the size of the net benefits of the respective projects. It just uses the ratio of benefits to cost to rank projects.

- **Select projects for construction until the budget is exhausted.** This is the project selection criterion under conditions of a constrained budget.

Choosing projects in this manner guarantees that net benefits generated by the fixed budget are maximized.
Project Interdependence: Handling Mutual Exclusivity

A complicating factor in selecting among candidate projects is that the projects are often not independent. That is, the feasibility of Project A may depend upon whether or not Project B has been implemented.

The most obvious example of this situation is when there are several engineering solutions to the same transportation problem on the same road segment or corridor. The building of one project, therefore, obviates building the others. These projects are also mutually exclusive, as the net benefits from one project are completely independent from the other projects. In this simple setting, where projects are exactly mutually exclusive, and budgets are unconstrained, net benefits are maximized by doing the following:

- **Group mutually exclusive projects.** This isolates projects that are, in essence, candidates for solving the same transportation problem.
- **Select the project from each group that maximizes net benefits.** Following the principles outlined above, this ensures that net benefits are maximized.

In practice, however, projects may be partially mutually exclusive; that is, the net benefits of building two projects may exceed (or be somewhat less than) the total of their individual net benefits. In addition, there may be constrained budgets. Implementing efficient project selection in a setting of partial project interdependence and constrained budgets can be complicated. Many different combinations of projects may need to be considered and, thus, there may be multiple versions of the candidate project list to compare. The goal, however, remains the same—i.e., to maximize total net benefits that can be enjoyed from the given budget. The analyst simply needs to be sure that all relevant combinations of projects are considered, and that project interdependence has been measured accurately.

Fungibility of Funds: Handling Constraints on the Use of Funds

In many cases, highway improvement projects may be funded from sources that impose constraints on how the funds may be spent, or that require “matching funds” at some ratio from other sources. Funds may, for example, be limited to certain types of improvements, to certain facilities, or require concurrent spending on facilities for pedestrians or transit. The presence of these constraints may yield an optimal investment strategy that differs from the one that would result in the absence of the constraints.

To fully identify the optimal investment strategy under fungibility constraints would require both extremely complicated dynamic programming analysis and an accurate understanding of how fungibility constraints will change in the future. While asset-management tools that blend dynamic programming to schedule maintenance activities could be extended to cover investment analysis, such tools are not currently available to most agencies for investment analysis.

A more practical method for taking fungibility into account is similar to the approach for mutually exclusive projects. One first defines pools of funds representing different levels of fungibility. Note that spending from one pool may reduce the size of another because of matching requirements. Projects (or bundles of projects if concurrent spending on other types of investments is required) that meet the requirements of the pool are evaluated and ranked within the pool. Some projects will appear on the lists of every
pool, while others will appear only on the lists of the least-constrained pools. Projects are then selected starting with the highest benefit-cost ratio. When a project is chosen, its funds are removed from the most-constrained pool whose list it appears in and that has sufficient funds available, and matching funds, if required are removed from less-constrained pools. The project is then removed from all lists in which it appears. Projects are selected until all pools are depleted or no projects remain with benefits in excess of costs. This approach provides a reasonable optimization given both constraints on the types of projects that may be funded and requirements for matching funds and concurrent spending.

In general, mutual exclusivity should be handled before fungibility of funds, with only the most feasible project from each group of mutually exclusive projects included in the funding pools. The exception would be a case where the mutually exclusive projects do not appear in the same pools. In that case, when the first of the mutually exclusive projects is selected, the others would be removed from all pools in which they appear.

**Performing Sensitivity Analysis**

Sensitivity analysis is an important adjunct to benefit-cost analysis when the analysis yields a single expected value for the present value of benefits and the present value of project costs. In such instances, the benefit-cost analysis appears more precise than it actually is in practice. Sensitivity analysis is a way to formally recognize the uncertainty of key factors, and to experiment with alternative values in an organized fashion. Operationally, sensitivity analysis involves re-calculating project benefits and/or costs under different scenarios or combinations of the key factors. In this sense, sensitivity analysis is closely related to the earlier discussion of risk analysis. Sensitivity analysis, however, is appropriate even when all of the underlying factors are known with a high degree of certainty. That is, sensitivity analysis allows the analyst to determine how the final results are influenced by certain key parameters and assumptions made regarding the values for these parameters.

**Selecting Parameters for the Sensitivity Analysis**

The process of generating the information necessary to do feasibility analysis of highways, in particular, is complex and implicitly assumption laden. Project horizons and facility lives are long, and it is hard to forecast accurately over such long time periods. Modeling the response of traffic to the effects of the improvement requires adoption of behavioral parameters that are usually not known with great accuracy. The value of travelers’ time is not known precisely, etc. Other factors, however, are reasonably well known, such as the effect of engineering improvements on the effective capacity of the roadway.

To reduce the cumbersomeness of the sensitivity analysis, the analyst needs to focus on the factors that are both (a) key to the analysis, (b) not known with a high level of certainty and (c) not already modeled directly using Monte Carlo procedures. In addition, the analyst should not construct logically-inconsistent combinations of variables on which to perform sensitivity analysis. For example, the analyst might be uncertain about inflation (believing, for example that it might range between 3.0 percent and 6.0 percent), and also uncertain about the nominal discount rate (believing it could be as low as 3.5 percent and as high as 6.0 percent. Performing the benefit-cost analysis using an inflation
rate of 3.0 and a discount rate of 6.0, however, might be inconsistent, since inflation expectations is one of the factors affecting market interest rates. Thus, if the analyst wishes to have a logically-consistent sensitivity model, he or she would select inflation and discount rate parameters from the same end of their ranges.

In practice, in highway user analysis, certain factors that almost always demand inclusion in sensitivity analysis because of their intimate effect on measured user benefits and costs are as follows:

- **Traffic growth rates.** The performance of most highway facilities changes non-linearly as traffic grows. The benefit that capacity enhancement offers to users in a corridor, consequently, is sensitive to the assumed rate of traffic growth in the base case and in the improvement case. In addition, project improvements can themselves affect traffic growth rates, usually in a way that is not known well *ex ante*. Traffic growth rates should almost always be a dimension of sensitivity analysis. Unfortunately, because of the cost and time involved in re-specifying the travel demand models that generate this information (especially for a complex network), this is seldom done.

- **Values of time.** The values assigned to travel time are worthy of sensitivity analysis in most cases because travel time savings typically constitute the majority of the measured user benefits. If the wrong value of time is applied to these savings, benefits are going to be affected directly.

There are other factors that are more or less important depending upon the project being evaluated:

- **Accident rates.** Benefits from projects that provide most of their benefits in the form of reduced accident rates are vulnerable to miscalculation. The reaction of accident rates to ameliorative improvements is not known accurately. In these cases, the assumed impact of the project on accident rates should be subject to sensitivity analysis. It is less important to do this when travel time savings, for example, dominate the feasibility analysis.

- **Discount rates.** As discussed earlier, the proper choice of the discount rate should be known to analysts who have carefully considered the analytical perspective of their feasibility study. However, because the mathematics of discounting is non-linear, the level of the discount rate has a significant effect on the present value of a long-lived stream of benefits or costs. In those cases where the analyst is uncertain about the appropriate level of the discount rate, sensitivity analysis may be justified. One such instance is where the analyst has incorporated a risk premium in the discount rate as a means of addressing uncertainty. It may be appropriate to test the implications of different, assumed levels of uncertainty.

- **Project costs.** The cost of the project is an important variable because construction costs, in particular, are incurred early in the life of the project. Their value is largely undiscounted, and thus weighs significantly in the overall benefit-cost estimate.
Finally, there are a myriad of other factors that may be more or less important depending upon the nature of the project or are typically able to be estimated with reasonable accuracy, but may not be in certain circumstances:

- **Expansion factors.** If the analyst does not enjoy the benefit of detailed traffic data, it may be necessary to use rules of thumb or expansion factors to extrapolate from well-known information. If such approximation schemes have been used widely to characterize benefits, it is important to analyze the sensitivity of the results to the factors used.

- **User and project operating costs.** Operating costs are usually straightforward to estimate, and trend in a predictable fashion relative to general inflation and other factors. In cases where savings in user operating costs is the central dimension of benefits, however, it may be important to test alternative operating cost scenarios. In the case of operating and maintenance costs associated with the project itself, the same prescription holds true.

- **Mode choice.** Mode choice assumptions are not central to most highway feasibility studies. The reason is that most highway projects do not affect this dimension of travel in a significant or unpredictable way. The exceptions are those special highway projects whose design and primary purpose emphasize influence over mode choice. Projects such as carpool or HOV lanes, HOT lanes, and congestion pricing cannot be analyzed accurately without consideration of the sensitivity of the results to the mode choice assumptions.

- **Traffic behavior.** The effect of some engineering enhancements is dependent upon the reaction of traffic behavior in the network.

With judicious selection of the reasonable ranges of the factors of the sensitivity analysis, the analyst can raise the confidence of the investment decision makers.

**APPLICATION: EXPANSION AND EXTRAPOLATION OF TIME-SAVINGS BENEFITS**

In this example, we will calculate the value of time-savings benefits for a simple capacity-enhancing improvement (an additional lane), expand those benefits to the day, month, and year, and then extrapolate the annual benefits to future years.

If the analyst has available, from a travel-demand model, hourly traffic volumes, by class, with and without the proposed improvement, Worksheet 6-1 may be used to calculate the value of travel-time benefits by class for each hour. Worksheet 6-1 also expands daily benefits to annual benefits, by class. If information is available by hour, but not by class, Worksheet 6-1 still may be used. Simply put all traffic into one aggregate class.

If the analyst has only data for the peak hour, along with a K-factor for the peak hour, Worksheet 6-2A or 6-2B may be used to calculate peak-hour benefits and expand them to daily and annual benefits. Worksheet 6-2A takes peak-hour volume after the improvement as an input. Worksheet 6-2B takes the elasticity of travel demand with respect to delay as an input and estimates peak-hour volume after the improvement simultaneously with delay.

Worksheet 6-3 takes annual travel-time benefits calculated for one particular year and extrapolates them to each year of a project’s life, given a BPR exponent (b), a base-year
K-factor, and constant rates of growth for traffic and real value of time. It then discounts each year’s benefits to present value (for the specified evaluation year).

Worksheet 6-1 through Worksheet 6-3 should be implemented using the electronic versions provided with this manual. The computations are too numerous and too complex to be feasibly implemented with a hand calculator.

The input page for Worksheet 6-1 describes the example being evaluated. It is followed by a second page showing the delay calculation results for each hour, and a third page showing the calculated benefits by hour, day, week, and year by class.
Worksheet 6-1: Calculation of Time-Savings Benefits When Hourly Volumes Are Known

<table>
<thead>
<tr>
<th>Hourly Capacity (PCE) without Project</th>
<th>Hourly Capacity (PCE) with Project</th>
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<td>Volume in Hour 1 (PCE) without Project</td>
<td>Volume in Hour 1 (PCE) with Project</td>
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<td>Volume in Hour 12 (PCE) with Project</td>
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<td>Volume in Hour 13 (PCE) without Project</td>
<td>Volume in Hour 13 (PCE) with Project</td>
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<tr>
<td>Volume in Hour 24 (PCE) without Project</td>
<td>Volume in Hour 24 (PCE) with Project</td>
</tr>
</tbody>
</table>

### General Information
- Name: [Name]
- Agency/Company: [Agency/Company]
- Project: [Project]
- Room: [Room]
- Date Performed: [Date Performed]

### Site Information
- Facility: [Facility]
- Segment: [Segment]
- Analysis Year: [Analysis Year]

### Inputs
- Name of Vehicle Class
- BPR Function exponent (b)
- BPR Function coefficient (a)
- Freeflow speed (mph)
- Segment Length (miles)
- Hourly Capacity (PCE) without Project
- Hourly Capacity (PCE) with Project

### Outputs
- All VC
- VC1
- VC2
- VC3
- VC4
- VC5
- VC6

### Value of time (dollars per hour)

### General Information
- Agency/Company: [Agency/Company]
- Project: [Project]
- Room: [Room]
- Date Performed: [Date Performed]

### Site Information
- Facility: [Facility]
- Segment: [Segment]
- Analysis Year: [Analysis Year]

### Inputs
- Name of Vehicle Class
- BPR Function exponent (b)
- BPR Function coefficient (a)
- Freeflow speed (mph)
- Segment Length (miles)
- Hourly Capacity (PCE) without Project
- Hourly Capacity (PCE) with Project

### Outputs
- All VC
- VC1
- VC2
- VC3
- VC4
- VC5
- VC6

### Value of time (dollars per hour)
Worksheet 6-1 (continued)

<table>
<thead>
<tr>
<th>Delays</th>
<th>Minutes/PCE-Mile</th>
<th>MPH</th>
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<tr>
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<tr>
<td>Delay without Project in Hour 2</td>
<td>1.09</td>
<td>55.00</td>
</tr>
<tr>
<td>Delay without Project in Hour 3</td>
<td>1.09</td>
<td>55.00</td>
</tr>
<tr>
<td>Delay without Project in Hour 4</td>
<td>1.09</td>
<td>55.00</td>
</tr>
<tr>
<td>Delay without Project in Hour 5</td>
<td>1.09</td>
<td>55.00</td>
</tr>
<tr>
<td>Delay without Project in Hour 6</td>
<td>1.09</td>
<td>55.00</td>
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<tr>
<td>Delay without Project in Hour 7</td>
<td>1.11</td>
<td>54.22</td>
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<td>Delay without Project in Hour 8</td>
<td>1.58</td>
<td>38.06</td>
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<td>Delay without Project in Hour 9</td>
<td>1.12</td>
<td>53.61</td>
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<td>1.09</td>
<td>55.00</td>
</tr>
<tr>
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<td>55.00</td>
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<td>1.09</td>
<td>54.99</td>
</tr>
<tr>
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<td>1.10</td>
<td>54.59</td>
</tr>
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<td>55.00</td>
</tr>
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<td>1.09</td>
<td>55.00</td>
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<td>53.95</td>
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<td>55.00</td>
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<table>
<thead>
<tr>
<th>Travel-Time Savings</th>
<th>Minutes/PCE-Mile</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>Savings in Hour 2</td>
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<tr>
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<td>0.0000</td>
</tr>
<tr>
<td>Savings in Hour 24</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Delays are calculated using the BPR volume-delay function (Equation 3-1): Savings are calculated by subtracting:
Savings = Delay Without - Delay With
Worksheet 6-1 (continued)

| Benefits in Hour 1 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 2 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 3 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 4 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 5 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 6 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 7 | $132 | $98 | $19 | 4 | 2 | 8 |
| Benefits in Hour 8 | $6,405 | $4,287 | $1,102 | $7 | $4 | $29 |
| Benefits in Hour 9 | $268 | $177 | $16 | $35 | $7 | $29 |
| Benefits in Hour 10 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 11 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 12 | $65 | $4 | $50 | $2 | $1 | $8 |
| Benefits in Hour 13 | $1 | $0 | $1 | $0 | $0 | $0 |
| Benefits in Hour 14 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 15 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 16 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 17 | $188 | $106 | $52 | $5 | $5 | $22 |
| Benefits in Hour 18 | $32,679 | $20,576 | $9,938 | $5,226 | $348 | $502 | $1,089 |
| Benefits in Hour 19 | $4,785 | $2,789 | $228 | $1,489 | $66 | $63 | $155 |
| Benefits in Hour 20 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 21 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 22 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 23 | $0 | $0 | $0 | $0 | $0 | $0 |
| Benefits in Hour 24 | $0 | $0 | $0 | $0 | $0 | $0 |

| Weekday Benefits | $44,525 | $28,038 | $6,285 | $7,451 | $510 | $688 | $1,559 |
| Weekly Benefits  | $224,851 | $131,590 | $31,737 | $37,629 | $2,576 | $3,976 | $7,885 |
| Monthly Benefits  | $977,031 | $615,291 | $137,906 | $163,506 | $10,195 | $15,094 | $30,090 |
| Annual Benefits   | $7,592,403 | $4,780,972 | $1,071,650 | $1,270,585 | $86,996 | $117,282 | $264,906 |

| Percent of Benefits | 63.0% | 19.1% | 16.7% | 1.1% | 1.5% | 3.5% |
| Percent of PCE-VMT  | 43.1% | 2.3% | 40.9% | 7.9% | 0.9% | 5.8% |
| Percent of VMT     | 45.5% | 2.4% | 43.1% | 2.6% | 0.2% | 6.1% |
| Percent of Person-Miles | 35.1% | 4.1% | 50.3% | 2.0% | 2.2% | 6.0% |

Actual Peak-Hour to Weekday Expansion Factor: 1.36
Predicted Expansion Factor (from Formula in Equation 6-6): 1.24
Peak Hour Volume/Weekday Volume: 0.12

Hourly benefits are calculated using Equation 6-3:
Daily benefits are the sum of 24 hourly benefits.
Weekly benefits are daily benefits times the day-to-week expansion factor specified on the inputs page.
Peak month benefits are calculated as weekly benefits times (365/12)/7.
Annual benefits are calculated using Equation 6-8:
In this example, the capacity of the segment before the improvement was 4,000 PCE/hour (two lanes). The improvement consisted of adding a lane, bringing the capacity to 6,000 PCE/hour. The analyst specified a BPR volume-delay function with a coefficient of 0.10 and an exponent of 10. The facility has a free-flow speed of 55 MPH. The value of time varies by vehicle class, ranging from $10.00 per hour for shopping and other auto to $25 per hour for trucks. PCEs per vehicle and occupants per vehicle also vary by vehicle class. PCEs per vehicle range from 1.0 for cars to 3.0 for trucks, averaging 1.05 overall. Occupants per vehicle range from 1.0 for drive-alone commute to 12.0 for buses, averaging 1.30 overall.

In the peak hour (Hour 18 or 5-6PM), there are 6,144 PCE on the segment without the improvement. The reduced delay resulting from the improvement draws an additional 404 PCE to the segment with the improvement. The ratio of peak-hour PCEs to daily PCEs (K-factor) is 0.13.

This information can be used without hourly detail to estimate daily and annual benefits using Worksheet 6-2. Worksheet 6-2 requires a single, per-hour value of time that represents a weighted average of the values of time for all the vehicle classes. In this example, the analyst used $13.75. There are two variants of Worksheet 6-2. Worksheet 6-2A requires that the analyst specify the peak-hour volumes with and without the improvement. Worksheet 6-2B allows the analyst to specify an elasticity of travel demand with respect to delay and solves for the volume after the improvement.
# Worksheet 6-2A: Formulaic Calculation of Time-Savings Benefits

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## Site Information

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## Inputs

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<tbody>
<tr>
<td>Hourly Capacity (PCE) without Project</td>
<td>4,000</td>
</tr>
<tr>
<td>Hourly Capacity (PCE) with Project</td>
<td>6,000</td>
</tr>
<tr>
<td>Volume in Peak Hour of Peak Month (PCE) without Project</td>
<td>5,394</td>
</tr>
<tr>
<td>Volume in Peak Hour of Peak Month (PCE) with Project</td>
<td>5,809</td>
</tr>
<tr>
<td>Peak-Hour Volume/Weekday Volume (in Peak Month)</td>
<td>0.12</td>
</tr>
<tr>
<td>BPR Function exponent (b)</td>
<td>10.00</td>
</tr>
<tr>
<td>BPR Function coefficient (a)</td>
<td>0.10</td>
</tr>
<tr>
<td>Freeflow speed (mph)</td>
<td>55.00</td>
</tr>
<tr>
<td>Segment Length (miles)</td>
<td>10.00</td>
</tr>
<tr>
<td>Weekday-to-Week Expansion Factor</td>
<td>5.05</td>
</tr>
<tr>
<td>Peak Month ADT/AADT</td>
<td>1.05</td>
</tr>
<tr>
<td>Value of time (dollars per hour)</td>
<td>$15.00</td>
</tr>
<tr>
<td>PCEs per Vehicle</td>
<td>1.06</td>
</tr>
<tr>
<td>Occupants per Vehicle</td>
<td>1.29</td>
</tr>
</tbody>
</table>

## Delay Calculations

<table>
<thead>
<tr>
<th>Delay</th>
<th>MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay without Project (minutes per PCE mile)</td>
<td>3.26</td>
</tr>
<tr>
<td>Delay with Project (minutes per PCE mile)</td>
<td>1.17</td>
</tr>
</tbody>
</table>

## Benefits Calculations

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Time (Dollars per PCE)</td>
<td>$18.37</td>
</tr>
<tr>
<td>Peak-hour benefits (dollars)</td>
<td>$35,848</td>
</tr>
<tr>
<td>Weekday benefits (dollars)</td>
<td>$44,446</td>
</tr>
<tr>
<td>Weekly Benefits (dollars)</td>
<td>$224,454</td>
</tr>
<tr>
<td>Annual Benefits</td>
<td>$7,578,996</td>
</tr>
</tbody>
</table>

Peak Hour Benefits x 2 x 250 = $17,923,925
(for comparison only—do not use)
### General Information

<table>
<thead>
<tr>
<th>Analyst</th>
<th>Me</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency/Company</td>
<td>My Agency</td>
</tr>
<tr>
<td>Project</td>
<td>Demo</td>
</tr>
<tr>
<td>Date Performed</td>
<td>1/1/2002</td>
</tr>
</tbody>
</table>

### Site Information

<table>
<thead>
<tr>
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<th>Facility 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>Segment 1</td>
</tr>
<tr>
<td>Analysis Year</td>
<td>2005</td>
</tr>
</tbody>
</table>

### Inputs

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Capacity (PCE) without Project</td>
<td>4,000</td>
</tr>
<tr>
<td>Hourly Capacity (PCE) with Project</td>
<td>6,000</td>
</tr>
<tr>
<td>Volume in Peak Hour of Peak Month (PCE) without Project</td>
<td>5,394</td>
</tr>
<tr>
<td>Volume in Peak Hour of Peak Month (PCE) with Project</td>
<td>5,809</td>
</tr>
<tr>
<td>Elasticity of Volume with respect to Delay</td>
<td>-0.12</td>
</tr>
<tr>
<td>Peak-Hour Volume/Weekday Volume (in Peak Month)</td>
<td>0.12</td>
</tr>
<tr>
<td>BPR Function exponent (b)</td>
<td>10.00</td>
</tr>
<tr>
<td>BPR Function coefficient (a)</td>
<td>0.10</td>
</tr>
<tr>
<td>Freeflow speed (mph)</td>
<td>55.00</td>
</tr>
<tr>
<td>Segment Length (miles)</td>
<td>10.00</td>
</tr>
<tr>
<td>Weekday-to-Week Expansion Factor (use 5.0 if unknown)</td>
<td>5.05</td>
</tr>
<tr>
<td>Peak Month ADT/AADT</td>
<td>1.05</td>
</tr>
<tr>
<td>Value of time (dollars per hour)</td>
<td>15.00</td>
</tr>
<tr>
<td>PCEs per Vehicle</td>
<td>1.06</td>
</tr>
<tr>
<td>Occupants per Vehicle</td>
<td>1.29</td>
</tr>
</tbody>
</table>

### Delay Calculations

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay without Project (minutes per PCE mile)</td>
<td>3.26</td>
</tr>
<tr>
<td>Delay with Project (minutes per PCE mile)</td>
<td>1.17</td>
</tr>
</tbody>
</table>

### Benefits Calculations

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Time (Dollars per PCE)</td>
<td>$18.37</td>
</tr>
<tr>
<td>Peak-hour benefits (dollars)</td>
<td>$35,848</td>
</tr>
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<td>Weekday benefits (dollars)</td>
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<td>Weekly Benefits (dollars)</td>
<td>$224,454</td>
</tr>
<tr>
<td>Annual Benefits</td>
<td>$7,578,998</td>
</tr>
</tbody>
</table>

Peak Hour Benefits x 2 x 250 $17,923,930 (for comparison only--do not use)
Having completed Worksheet 6-1 or Worksheet 6-2A or 6-2B, the analyst now has estimates of travel-time savings benefits for one year. In this case, that year is 2000, the year for which data were available. But the project will not be built until 2004, and the analyst needs estimates of travel-time benefits for each of 30 years of operation. The analyst also needs to discount the stream of benefits to the year 2002. Worksheet 6-3 performs all of these calculations. It calculates a separate growth rate for benefits from each year to the next (taking into account growth in traffic, growth in the real value of time, and negative growth in the K-factor as congestion increases), starting in the data year, and compounds them. It then uses the compounded growth rates to convert the data-year benefits into operating-year benefits, and discounts each operating year’s benefits back to the evaluation year.

Worksheet 6-3: Extrapolation and Present Valuation of Benefits from a Capacity-Improvement Project

<table>
<thead>
<tr>
<th>General Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
</tr>
<tr>
<td>Agency/Company</td>
</tr>
<tr>
<td>Project</td>
</tr>
<tr>
<td>Date Performed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility</td>
</tr>
<tr>
<td>Segment</td>
</tr>
<tr>
<td>Segment Length (miles)</td>
</tr>
<tr>
<td>Analysis Year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of Growth in ADT (PCEs)</td>
</tr>
<tr>
<td>Rate of Growth in Real Value of Time</td>
</tr>
<tr>
<td>BPR Exponent (b)</td>
</tr>
<tr>
<td>Elasticity of K-factor WRT ADT (z)</td>
</tr>
<tr>
<td>Real Discount Rate</td>
</tr>
<tr>
<td>Benefit Calculation Data Year</td>
</tr>
<tr>
<td>Evaluation Year</td>
</tr>
<tr>
<td>First Year of Operation</td>
</tr>
<tr>
<td>Project Lifetime (years)</td>
</tr>
</tbody>
</table>

| Annual Travel Time Benefits | $7,592,403 |
| (in Benefit Calculation Data Year dollars) |

| K-factor | 0.12 |
| (Peak-Hour Volume/Daily Volume in Benefit Calculation Year) |

| Present Value of Benefits | $424,929,451 |
| (in Evaluation Year dollars) |
The present value of travel-time savings benefits still must be combined with other benefits and costs. One can say, however, that if the proposed improvement in this example costs more than $42.5 million per lane mile to build, it is unlikely to have positive net benefits.
Chapter 7. Survey of Available Software Tools

OVERVIEW

This manual has focused on the calculation methods associated with determining changes in values of time, operating costs, and accident costs associated with a wide range of highway improvement projects. As shown in the various calculations included in these chapters and in other resources such as the HCM 2000, these calculations can be quite complex and require a significant amount of data to be inputted by the analyst. For these reasons, many DOTs and other planning organizations often forego conducting formal benefit-cost analyses and rely on more informal techniques to evaluate projects.

To address these concerns, a review of available software tools was conducted in support of this guidebook. There is a wide range of computer tools and models available to assist with evaluating highway projects. It is important to note that not all the computer tools reviewed were designed specifically to conduct benefit analysis. For example, some models are designed to only focus the potential safety benefits of proposed projects. Nevertheless, the models do provide a valuable resource and significantly reduce the complexity of estimating the components included in the User Benefit Equation.

These computer tools also vary by the level of detail covered by the model estimates. In some situations, a more comprehensive level of information is needed, with detailed analysis of traffic delays and impacts on user costs. Other situations call for a simplified sketch planning analysis. Sketch planning calculations provide less detailed information but are useful to conduct a quick estimation of the likely net benefits of a project. As this suggests, the computer tools can be categorized by the types of projects they are capable of analyzing, the level of analysis (detailed or sketch-planning) they are suited for, and the types of benefits and costs they consider. The available tools also vary considerably in the amount and types of input data required, the methods and assumptions used to estimate benefits, and the extent to which the analyst can override default data and assumptions.

These differences are discussed in this chapter for the most commonly used transportation software tools. While these models have been developed to address different issues and analysis areas, this chapter focuses on each model’s capability for estimating the user cost elements of the User Benefit Equation. A table providing a summary comparison of these models is included in the end of this chapter. In addition, a short survey of 20 state DOTs was conducted to determine the current level of use of these software tools. This information is also summarized at the end of this chapter.

TOOLS FOR PROJECT-LEVEL EVALUATION

Tools for project-level evaluation assess the benefits and costs of an individual improvement project. These tools evaluate the benefits and costs of an individual project without taking into account its effect on the rest of the highway network or its effect on other modes of travel. They are useful for evaluating projects on isolated rural roads and small projects with negligible effects on other roads, and for screening large numbers of projects for further consideration.
MicroBENCOST

MicroBENCOST was developed by the Texas Transportation Institute to implement the 1977 AASHTO Red Book. The program can evaluate a wide range of project types, including adding additional lanes, bypasses, intersections, interchanges, pavement and shoulder improvements, bridges, safety improvements, railroad crossings, and high-occupancy-vehicle lanes. It is able to estimate all of the components of user benefits addressed in this manual, including traffic delay times, user operating costs, user discomfort costs, accident costs, construction-related delays. MicroBENCOST also provides estimates for eight separate vehicle types (four are pre-defined) and 24 time periods, which can be hours of the day or user selected time periods that together account for all of the hours in a year.

MicroBENCOST does allow benefit calculations to change over time based on anticipated growth in traffic. This is incorporated into the model using a traffic growth rate or user-supplied traffic volumes for three years (base, intermediate, and forecast years).

<table>
<thead>
<tr>
<th>User Benefit Category</th>
<th>Model Calculates</th>
<th>User Must Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Delay</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Operating Costs</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Rates</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Costs</td>
<td>♦</td>
<td></td>
</tr>
</tbody>
</table>

**Table 7-1: Summary of User Benefit Calculations for MicroBENCOST**

<table>
<thead>
<tr>
<th>Traffic Specification</th>
<th>Allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly</td>
<td>♦</td>
</tr>
<tr>
<td>Annual</td>
<td>♦</td>
</tr>
</tbody>
</table>

HEEM III

A precursor to MicroBENCOST is HEEM III, which was also developed by the Texas Transportation Institute and released in 1992. Although this model is relatively new, MicroBENCOST has largely supplanted HEEM III in practice and consequently HEEM III is rarely used anymore.

WSDOT Benefit-Cost Software

The Washington State Department of Transportation, under legislative mandate to apply benefit-cost analysis to all mobility projects, contracted with Dowling Associates to develop a set of spreadsheet tools for project evaluation. The spreadsheet evaluates additional lanes, new interchanges, improvements to existing intersections, two-way left turn lanes, HOV lanes, park and ride lots, and safety improvements. It estimates user
benefits from reduced delay, but does not handle induced travel. It estimates the benefits associated with safety improvements, but does not estimate safety-related benefits for other types of improvements.

**Table 7-2: Summary of User Benefit Calculations for WSDOT Benefit-Cost Software**

<table>
<thead>
<tr>
<th>User Benefit Category</th>
<th>Model Calculates</th>
<th>User Must Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Delay</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Operating Costs</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Rates</td>
<td></td>
<td>♦</td>
</tr>
<tr>
<td>Accident Costs</td>
<td>♦</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic Specification</th>
<th>Allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly</td>
<td>(Must over-write default settings)</td>
</tr>
<tr>
<td>Annual</td>
<td>♦</td>
</tr>
</tbody>
</table>

**ROADSIDE**

ROADSIDE implements the AASHTO Roadside Design Guide and includes estimates of benefits and costs associated with roadside safety improvements. The primary advantage of the ROADSIDE model is that it estimates accident costs and accident rates based on both the design features of the road and the roadside. As discussed in other chapters, a primary limitation of other models and empirical work is that accident costs are often estimated based only on road features to the exclusion of roadside characteristics.

The estimation tools included in ROADSIDE are integrated with the design tools and provide a convenient evaluation of projects designed with the design guide. The primary focus of ROADSIDE is to estimate the safety benefits of improved roadside design. As a consequence, the model does not address the other user cost components of delay and operating costs.
Table 7-3: Summary of User Benefit Calculations for ROADSIDE

<table>
<thead>
<tr>
<th>User Benefit Category</th>
<th>Model Calculates</th>
<th>User Must Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Delay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accident Rates</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Costs</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Traffic Specification</td>
<td>Allowed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hourly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td></td>
</tr>
</tbody>
</table>

TOOLS FOR CORRIDOR- OR NETWORK-LEVEL EVALUATION

Models that address project impacts at the corridor or network level are designed to account for costs and benefits beyond the individual project. For example, an improvement to one segment may shift traffic from other segments, thereby impacting an entire corridor or network. The models addressed in this section estimate benefits based both on the impact on the individual project area as well as those external areas that will also be influenced by the improvement.

SPASM

SPASM is a sketch-planning tool for evaluating multiple transportation improvements at the corridor level. SPASM does not provide detailed analysis of specific projects, but instead uses built-in assumptions and relies on exogenous, rough estimates of project costs, travel demand, vehicle occupancy, etc. For example, all trips are assumed to be of the same length. The advantage of this is that the analyst can obtain a general idea of project benefits without conducting a detailed benefit-cost analysis.

SPASM is a simple to use spreadsheet model that estimates all of the user benefits discussed in this manual. In addition, SPASM provides estimates of costs to public agencies, emissions, and energy use associated with the project being evaluated.

SPASM can evaluate the following improvements individually or as a combined set of improvements: transit system improvements, highway capacity improvements, HOV lanes, and auto use disincentives. SPASM also has the advantage of accounting for induced travel on the corridor as a result of the improvements.

The primary disadvantage of SPASM is that it does not provide a way to incorporate directly the potential safety effects of highway project. Safety benefits must first be calculated by the analyst as either a per mile or per trip cost that is added as an input as an operating cost. This applies to safety benefits that will affect insurance rates as well as any additional safety effects that are not reflected as a change in insurance costs.
Table 7-4: Summary of User Benefit Calculations for SPASM

<table>
<thead>
<tr>
<th>User Benefit Category</th>
<th>Model Calculates</th>
<th>User Must Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Delay</td>
<td>✦</td>
<td></td>
</tr>
<tr>
<td>Operating Costs</td>
<td>✦</td>
<td></td>
</tr>
<tr>
<td>Accident Rates</td>
<td></td>
<td>✦</td>
</tr>
<tr>
<td>Accident Costs</td>
<td></td>
<td>✦</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic Specification</th>
<th>Allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly</td>
<td>✦</td>
</tr>
<tr>
<td>Annual</td>
<td>✦</td>
</tr>
</tbody>
</table>

STEAM

STEAM was developed as an enhanced version of SPASM, designed to enable more detailed analysis. STEAM uses traffic assignment data directly from a four-step transportation demand model to create speed estimates under congested conditions. STEAM also uses risk-analysis to identify the uncertainty surrounding its results and produces estimates of systemwide benefits and costs, as opposed to SPASM, which provides only corridor-level estimates.

Like SPASM, STEAM estimates user benefits, emissions, and energy use. It analyzes capital costs and revenue transfers separately, allowing agencies to assess fiscal impacts separately from the cost analysis. The fuel consumption analysis produces estimates of greenhouse gas production and also supplies the operating cost analysis with fuel use estimates. STEAM estimates both the user costs of accidents and the external, social costs associated with accidents. It also estimates other external costs, including those incurred during construction. In its analysis of user delay, STEAM automatically accounts for peak spreading and incidents.

By allowing the user to specify the upper and lower bounds for 90 percent confidence intervals around input assumptions, STEAM can calculate confidence intervals for all of its outputs.
Table 7-5: Summary of User Benefit Calculations for STEAM

<table>
<thead>
<tr>
<th>User Benefit Category</th>
<th>Model Calculates</th>
<th>User Must Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Delay</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Operating Costs</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Rates</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Costs</td>
<td>♦</td>
<td></td>
</tr>
</tbody>
</table>

Traffic Specification | Allowed |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly</td>
<td>Peak and off-peak</td>
</tr>
<tr>
<td>Annual</td>
<td>♦</td>
</tr>
</tbody>
</table>

HDM4

HDM4 was developed by the World Bank to provide a tool for cost benefit analysis of roadway improvements that can be applied around the world. It includes 16 types of motorized vehicles and eight types of non-motorized vehicles. It can evaluate asphalt, concrete, gravel, dirt, or sand roads. HDM4 is available in English, French, Spanish, and Russian, and its internal models can be calibrated to local conditions.

HDM4 provides estimates of each of the user delay costs, accident costs, and operating expenses. In addition, HDM4 also provides estimates of energy consumption, emissions, capital costs, and operating and maintenance costs for the facility.

Table 7-6: Summary of User Benefit Calculations for HDM4

<table>
<thead>
<tr>
<th>User Benefit Category</th>
<th>Model Calculates</th>
<th>User Must Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Delay</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Operating Costs</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Rates</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Costs</td>
<td>♦</td>
<td></td>
</tr>
</tbody>
</table>

Traffic Specification | Allowed |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly</td>
<td>♦</td>
</tr>
<tr>
<td>Annual</td>
<td>♦</td>
</tr>
</tbody>
</table>
**StratBENCOST**

StratBENCOST was developed by HLB for the NCHRP as a tool for strategic planning. Like SPASM, it is designed to be used at the sketch-planning level and incorporates risk analysis features like those include in STEAM. StratBENCOST can operate at either the network or segment level.

StratBENCOST includes a travel demand model for generating traffic forecasts and, therefore, does not rely on data from an external, four-step transportation demand model. It includes default value of time and operating cost data. It estimates accident-related costs, environmental effects, and construction-related costs. The model does not estimate the effects of a highway improvement on other modes.

**Table 7-7: Summary of User Benefit Calculations for StratBENCOST**

<table>
<thead>
<tr>
<th>User Benefit Category</th>
<th>Model Calculates</th>
<th>User Must Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Delay</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Operating Costs</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Rates</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Costs</td>
<td>♦</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic Specification</th>
<th>Allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly</td>
<td>♦</td>
</tr>
<tr>
<td>Annual</td>
<td>♦</td>
</tr>
</tbody>
</table>

**Net BC**

Net BC was developed by Bernardin, Lochmueller, and Associates to read loaded traffic assignment networks from four-step models such as TRANPLAN, MINUTP, TRANSCAD, and TMODEL3 (but not EMME/2). Net BC only calculates user benefits based on system-wide delay, no calculations are done for operating or for accident costs.

**IDAS**

IDAS was developed by Cambridge Systematics to evaluate ITS improvement options. It can estimate benefits and costs for traffic-actuated signals, coordinated signals, ramp metering, incident management systems, electronic payment systems, traveler information systems, weigh-in-motion, traffic surveillance, and more. IDAS incorporates its own travel demand model and network representation.
### Table 7-8: Summary of User Benefit Calculations for IDAS

<table>
<thead>
<tr>
<th>User Benefit Category</th>
<th>Model Calculates</th>
<th>User Must Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Delay</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Operating Costs</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Rates</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Accident Costs</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Traffic Specification</td>
<td></td>
<td>Allowed</td>
</tr>
<tr>
<td>Hourly</td>
<td>♦</td>
<td></td>
</tr>
<tr>
<td>Annual</td>
<td>♦</td>
<td></td>
</tr>
</tbody>
</table>

**SUMMARY**

The software tools discussed in this chapter are the computer models most often used by analysts to estimate the benefits of highway improvement projects. Table 7-9 provides a summary of the features of the models discussed in this chapter, including the level of analysis, special features, and software limitations.
### Table 7-9: Comparison of Available Benefit-Cost Software

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Types of Projects</th>
<th>Level of Analysis</th>
<th>Special Features</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEEM III</td>
<td>TTI</td>
<td>additional lanes (including HOV), interchanges, grade</td>
<td>project-level</td>
<td>includes intersection and interchange delay calculations; calculates maintenance</td>
<td>no accounting for network effects or interaction between modes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>separations, bypasses</td>
<td></td>
<td>costs and pavement condition</td>
<td></td>
</tr>
<tr>
<td>SPA3M</td>
<td>FHWA</td>
<td>all, including TDM, transit, ITS, land use policies,</td>
<td>corridor-level</td>
<td>system-wide; accounts for diverted and induced trips; multimodal</td>
<td>no accounting for safety-related benefits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bikeways, etc.</td>
<td>sketch planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STEAM</td>
<td>FHWA</td>
<td>highway improvements, transit improvements, TDM, tolls,</td>
<td>system- or</td>
<td>accepts input from four-step models; separate analyses by trip purpose and</td>
<td>some costs must be estimated outside model; requires trip tables and network from external travel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>multimodal</td>
<td>corridor-level</td>
<td>modal emissions analysis; fuel consumption; revenue</td>
<td>demand model</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>detailed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>StratBENCOST</td>
<td>HLB</td>
<td>highway improvements</td>
<td>network-wide or</td>
<td>risk analysis, environmental effects, separate modules for network-wide or</td>
<td>no accounting for interaction between modes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>single-roadway</td>
<td>single-roadway analysis; includes construction delays</td>
<td></td>
</tr>
<tr>
<td>MicroBENCOST</td>
<td>TTI</td>
<td>highway improvements and safety projects</td>
<td>project-level</td>
<td>based on 1977 Redbook; includes intersection and interchange delay, bridges, RR</td>
<td>limited accounting for network effects; no accounting for interaction between modes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>crossings, HOVs, safety improvements; calculates emissions; calculates</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>construction-related delays; includes multiple vehicle classes; estimates</td>
<td></td>
</tr>
<tr>
<td>Roadside</td>
<td>AASHTO</td>
<td>roadside safety improvements</td>
<td>project-level</td>
<td>integrated with design tool</td>
<td>only accounts for safety-related benefits</td>
</tr>
<tr>
<td>HDM4</td>
<td>World Bank</td>
<td>highway improvements</td>
<td>network-wide or</td>
<td>suitable for use worldwide; includes 16 motorized and 8 non-motorized vehicle</td>
<td>no accounting for interaction between modes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>single-roadway</td>
<td>types; includes roadway deterioration model for asphalt, concrete, gravel, and</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>dirt roads; estimates emissions and energy consumption</td>
<td></td>
</tr>
<tr>
<td>iDAS</td>
<td>Cambridge</td>
<td>ITS improvements</td>
<td>project-level</td>
<td>estimates benefits and costs for traffic-actuated signals, coordinated signals,</td>
<td>evaluates ITS options only</td>
</tr>
<tr>
<td></td>
<td>Systematics</td>
<td></td>
<td></td>
<td>ramp metering, incident management systems, electronic payment systems, traveler</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>information systems, weigh-in-motion, traffic surveillance, and more</td>
<td></td>
</tr>
<tr>
<td>WSDOT</td>
<td>Washington</td>
<td>highway improvements</td>
<td>project screening,</td>
<td>designed to screen potential projects</td>
<td>no accounting for network effects, interaction between modes, or safety-related benefits</td>
</tr>
<tr>
<td>Benefit/Cost</td>
<td>DOT</td>
<td></td>
<td>segment-level only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NetBC</td>
<td>BLA</td>
<td>any project that changes network loading</td>
<td>network</td>
<td>estimates user benefits from output of 4-setp models</td>
<td>only estimates time-related benefits; only works with Tranplan, MiniUTP, Transcad, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TModel3 (not EMME2) and no accounting for interaction between modes</td>
</tr>
</tbody>
</table>
DOT SURVEY OF SOFTWARE TOOLS

In support of this review of currently available software tools, a survey of state DOTs was conducted. This survey asked analysts at 20 DOTs within the U. S which software tools and methods they used to estimate user benefits and conduct benefit-cost analysis for highway improvement projects. Respondents were asked which tools they used, what were the benefits and disadvantages of these tools, and if they had developed their own computer-based analysis tools in lieu of these other models. The results of this survey are summarized in Table 7-10.

Table 7-10: Summary of State DOT Software Survey Results

<table>
<thead>
<tr>
<th>Response</th>
<th>Number of States Responding (Total = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use a spreadsheet model</td>
<td>13</td>
</tr>
<tr>
<td>Use or have tried MicroBENCOST</td>
<td>5</td>
</tr>
<tr>
<td>Use other computer model</td>
<td>8</td>
</tr>
<tr>
<td>Do not do much formal benefit-cost analysis or else done at local (MPO, CGO) level</td>
<td>8</td>
</tr>
<tr>
<td>Tend to contract out benefit-cost analysis work</td>
<td>2</td>
</tr>
</tbody>
</table>

Most of the DOTs contacted relied on some sort of simple spreadsheet model to perform benefit-cost analysis. Some indicated that they had reviewed MicroBENCOST and had decided not to use it as because it required too much data. These two factors indicate a need and a desire for simple spreadsheet models to evaluate projects, similar to SPASM. Those DOTs that indicated they use other models were generally using these models to track costs and not to conduct formal a benefit-cost analysis.

Eight DOTs indicated that they did not do much benefit-cost analysis. Often in these instances the benefit-cost analysis was done at the local level for MPOs or COGs. Others also indicated that they would contract out to consultants to conduct more formal or comprehensive benefit-cost analyses. Some DOTs focused on tracking project costs and did not try to quantify project benefits.
Chapter 8. References


Cambridge Systematics, “The Value of Travel Time” (Section 8.2) in Revisions to HERS. Federal Highway Administration, Washington DC (1997).


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The AASHTO *User Benefit Analysis for Highways Manual* and this accompanying CD-ROM are intended to help state and local transportation planning authorities evaluate the user benefits of highway improvements. These products update, extend, and replace AASHTO’s 1977 *Redbook* (which analyzed both highway and transit improvements) and bring up to date both the theoretical and empirical bases of highway improvement evaluations. The findings of a separate project, sponsored by the Transit Cooperative Research Program (TCRP), are available in TCRP Report 78: *Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners*.

This CD-ROM contains the *User Benefit Analysis for Highways Manual* in Portable Document Format (PDF). It also contains (1) a computerized “wizard” that automates benefit-cost analysis for highways, (2) electronic calculation worksheets matching the worksheets in the Manual, (3) presentation templates and materials, and (4) reference materials.

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