

OPERATIONS BENEFIT/COST ANALYSIS DESK REFERENCE

Providing Guidance to Practitioners in the Analysis of Benefits and Costs of Management and Operations Projects



U.S. Department of Transportation
Federal Highway Administration

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Chapter 1. Introduction

Project Background and Purpose

Due to an increasingly competitive fiscal environment, state, regional, and local transportation planning organizations around the country are being asked more than ever to justify their programs and expenditures. Transportation System Management and Operations (TSM&O) programs have not escaped this scrutiny and are routinely asked to rank their projects against traditional expansion projects, as well as conduct other “value”-related exercises.

This requirement can put TSM&O projects at a disadvantage since many specialists in this arena have limited experience in performing benefit/cost analysis; and often, many of the established tools and data available for conducting benefit/cost analysis for traditional infrastructure projects are poorly suited to analyzing the specific performance measures, project timelines, benefits, and life-cycle costs associated with operational improvements.

In response to the needs of system operators to conduct these analyses, a number of initiatives have been undertaken in recent years at the national, state, and regional levels to develop enhanced analysis tools, methodologies and information sources to support the conduct of benefit/cost analysis for many specific TSM&O strategies. It often remains difficult, however, for practitioners to weed through the multiple information and guidance sources in order to understand and apply an appropriate methodology for meeting their own specific analysis needs.

The FHWA Operations Benefit/Cost Analysis *Desk Reference* Project

The Federal Highway Administration (FHWA) Office of Operations initiated this project in recognition of practitioners’ need for relevant and practical guidance on how to effectively conduct benefit/cost analysis for a wide spectrum of transportation system management and operations strategies. The *Operations Benefit/Cost Analysis Desk Reference* project is intended to provide practitioners with relevant guidance on how to effectively and reliably estimate the benefits and costs of operations strategies.

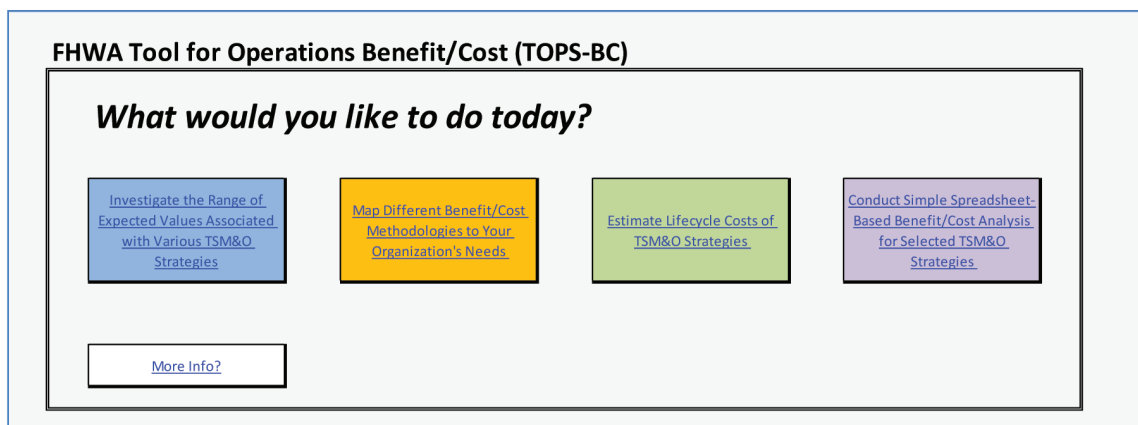
This *Desk Reference* is intended to meet the needs of a wide range of practitioners looking to conduct benefit/cost analysis of operations strategies. The guidance provided in the *Desk Reference* includes basic background information on benefit/cost analysis, including basic terminology and concepts, intended to support the needs of practitioners just getting started with B/C analysis, who may be unfamiliar with the general process. Building off this primer base, the *Desk Reference* also describes some of the more complex analytical concepts and latest research in order to support more advanced analysts in conducting their analysis. Some of the more advanced topics include capturing the impacts of travel time reliability; assessing the synergistic effects of combining different strategies; and capturing the benefits and costs of supporting infrastructure, such as traffic surveillance and communications.

This *Desk Reference* is supported by an Operations B/C decision support tool, called the *Tool for Operations Benefit/Cost (TOPS-BC)*. This spreadsheet-based tool is designed to assist practitioners in conducting benefit/cost analysis by providing four key capabilities, including the following:

- The ability for users to investigate the expected range of impacts associated with previous deployments and analyses of many TSM&O strategies;
- A screening mechanism to help users identify appropriate tools and methodologies for conducting a B/C analysis based on their analysis needs;
- A framework and default cost data to estimate the life-cycle costs of various TSM&O strategies, including capital, replacement, and continuing operations and maintenance (O&M) costs; and
- A framework and suggested impact values for conducting simple B/C analysis for selected TSM&O strategies.

Figure 1-1 shows the opening screen of *TOPS-BC*, which provides navigation to these capabilities within the support tool. The *TOPS-BC* application is supported by a separate, stand-alone *User's Manual* providing instruction on its proper set up and use.

Figure 1-1. Capabilities Provided by *TOPS-BC*



Operations Strategies Covered

Together the *Desk Reference* and the *TOPS-BC* tool are intended to support the analysis of a wide range of the available TSM&O strategies. These “strategies” include the direct application of technologies and infrastructure to roadside application (e.g., deployment of freeway service patrol vehicles), as well as many harder-to-define, nonphysical strategies (e.g., interagency coordination). While it is not possible to comprehensively provide guidance on every type and variation in application of all the many diverse TSM&O strategies (especially in light of the fact that new strategies and technologies are constantly emerging), TSM&O strategies covered in the *TOPS-BC* tool and/or the *Desk Reference* document include strategies from the following categories (see Chapter 3 for a more complete description of the TSM&O strategies and substrategies that comprise each category):

Physical Strategies, such as:

1. **Arterial Signal Coordination** – Improves the coordination of traffic signal timing to improve flow and reduce delay.
2. **Arterial Transit Signal Priority** – Provides the capability to expand or accelerate the green time allotted to traffic signals when the transit vehicle is detected approaching the intersection.
3. **Transit Automatic Vehicle Location** – Uses transponder and Global Positioning System (GPS) technologies to track the real-time location of transit vehicles. Compiled information is typically used to better manage the transit assets or provide traveler information to passengers.
4. **Ramp Metering** – Applies signals to on-ramp or freeway-to-freeway ramp locations to control and manage the flow of vehicles into the merge area.
5. **Incident Management** – Various combinations of incident detection, location verification, communication/coordination, and response strategies designed to lessen the time required to respond and clear traffic incidents.
6. **Pretrip Traveler Information** – Traveler information provided through several different available channels (e.g., telephone, web-based, broadcast-media, social-media) intended to reach individuals prior to the initiation of their trip so that they may make informed decisions on destination, mode, route, time of travel, and even whether to forego the trip.
7. **En-route Traveler Information** – Traveler information intended to reach the recipients while they are traveling. The information may be provided through several different channels, including telephone, in-vehicle system, roadside Dynamic Message Signs (DMS) or Highway Advisory Radio (HAR), or broadcast-media.
8. **Work Zone Management** – Lessens the congestion, delay, and safety issues associated with construction or maintenance work zones.
9. **High-Occupancy Toll (HOT) Lanes** – Allows single-occupancy vehicles (SOV) to pay a toll to use underutilized high-occupancy vehicle (HOV) lane capacity. The tolls charged may vary according to time-of-day schedules, or may be dynamically assessed in response to traffic conditions and available HOV lane capacity.
10. **Speed Harmonization** – Involves the implementation of variable speed limits and the communication of those limits through roadside signs. The speed limits are modified according to congestion levels to lessen stop-and-go conditions and lower the speed of vehicles as they approach downstream bottlenecks.
11. **Hard Shoulder Running** – Involves allowing vehicles to travel on the shoulder facilities of roadways, often for isolated sections of roadway or limited times of operation. The availability of the shoulder for use is often communicated through the use of overhead gantries or roadside DMS.
12. **Travel Demand Management** – Includes a number of strategies that may be employed to lessen travel demand (number of trips). These may include physical strategies (e.g., employer-based vanpools), as well as nonphysical, policy-based strategies (e.g., alternative work hours).

Supporting Strategies, such as:

1. **Traffic Surveillance** – Seeks to collect, compile, and analyze traffic data.
2. **Traffic Management Centers** – Physical- or virtually-based centers designed to provide the backbone management and operations capability to monitor and operate the deployed systems and technologies.
3. **Communications** – Landline- and mobile-based systems designed to provide communication between different roadside components, and provide communication between the components and any centralized management structure.

Nonphysical Strategies, such as:

1. **Active Transportation and Demand Management (ATDM)** – The dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Through the use of available tools and assets, traffic flow is managed and traveler behavior is influenced in real time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety, reducing emissions, or maximizing system efficiency. Under an ATDM approach, the transportation system is continuously monitored. Using archived data and or/predictive methods, actions are performed in real time to achieve or maintain system performance.
2. **System Integration** – Involves the coordination and integration of two or more strategies to allow for the sharing of data or capabilities to provide for the betterment of the combined system.
3. **Interagency Coordination** – The integration of efforts, resources, knowledge, or technologies across various agencies, departments, or entities to improve the coordinated management and operation of the transportation system.
4. **Regional Concepts for Transportation Operations** – Involves the coordination of various stakeholders responsible for operating one or more components or jurisdictions in order to develop sets of policies, procedures, and operating parameters that may be implemented according to specific identified conditions to improve the efficiency and effectiveness of operational strategies during those conditions.

Chapter 3 of this document provides expanded discussion of these various strategies, as well as substrategies and variations in application within the general categories. Chapter 3 also identifies the typical benefits and impact measures associated with the deployment of the strategies.

Table 1-1 below summarizes the TSM&O strategies above and identifies if specific guidance in their analysis is provided in this *Desk Reference*, the *TOPS-BC* tool, or both.

Table 1-1. Summary of Guidance on Various TSM&O Strategies

TSM&O Strategy	Discussed in <i>Desk Reference</i>	<i>TOPS-BC</i> Analysis Capability
Physical Strategies		
Arterial Signal Coordination	O	O
Arterial Transit Signal Priority	O	O
Transit Automatic Vehicle Location	O	O
Ramp Metering	O	O
Incident Management	O	O
Pretrip Traveler Information	O	O
En-route Traveler Information	O	O
Work Zone Management	O	O
HOT Lanes	O	O
Speed Harmonization	O	O
Hard Shoulder Running	O	
Travel Demand Management	O	O
Supporting Strategies		
Traffic Surveillance	O	\$
Traffic Management Centers	O	\$
Communications	O	\$
Nonphysical Strategies		
ATDM	O	
System Integration	O	
Interagency Coordination	O	
Regional Concepts for Transportation Operations	O	

O – Guidance or analysis capability provided.

\$ – Life-cycle cost estimation capability only.

Expert Review Panel

The development of the *Desk Reference* and *TOPS-BC* was greatly aided by an Expert Review Panel that was formed to provide input and guidance to the project. This Expert Review Panel was comprised of individuals representing Federal, state, regional, and local transportation agencies, as well as research organizations. The Expert Panel has been invaluable in identifying areas of the greatest need for guidance on particular strategies, performance measures and other issues, and in reviewing the guidance materials and the *TOPS-BC* application.

Project Workshops

In order to inform practitioners on the availability of the guidance materials, as well as provide an opportunity for additional testing and vetting of the material in a real-world analysis situations, the FHWA, as part of the Planning for Operations initiative, has technical workshop opportunities available. These workshops cover both the guidance available in this *Desk Reference*, as well as an overview of the proper set up and application of the *TOPS-BC* decision-support capabilities.

How to Use the *Desk Reference* and *TOPS-BC* Decision Support Tool

As discussed previously, the guidance in this *Desk Reference* is intended to be appropriate to a broad audience – from the novice to the more seasoned benefit/cost analyst. The first several sections of the *Desk Reference* are intended to serve as an overview primer for practitioners that may be unfamiliar with either benefit/cost analysis or the often unique characteristics and benefits of operations strategies. Subsequent sections build on this basic information to provide more detailed, often step-by-step guidance on particular aspects of conducting B/C analysis for operations planning. In overview, the remainder of the *Desk Reference* is organized into the following chapters:

- **Chapter 2, Overview of B/C Analysis for Operations** provides an overview of B/C analysis, its role in the planning process, basic terminology and concepts, and identification of general challenges and limitations.
- **Chapter 3, Operations Strategies and Their Impacts** summarizes the basic definitions of the types of TSM&O strategies covered in this project and maps these strategies to their likely impacts/benefits.
- **Chapter 4, Existing B/C Tools and Methods** summarizes the capabilities along with the strengths and limitations of many existing B/C tools and methods to aid practitioners in identifying appropriate situations in which to apply these tools. This discussion also includes information that details how to obtain more information on the tools, and provides a comparison discussion of the level of effort needed to set up and apply the tools.
- **Chapter 5, Conduct B/C Analysis for Operations** provides more detailed, step-by-step guidance on how to successfully conduct B/C analysis for operations strategies, identify considerations that need to be made, and highlight challenges that may be encountered, as well as propose methods to mitigate those challenges.

In parallel with the development of this *Desk Reference*, the *TOPS-BC* spreadsheet application was developed to provide additional decision-support and analysis structure. A separate, stand-alone User's Manual was specifically developed to guide interested practitioners in the proper set up and application of the *TOPS-BC* spreadsheet tool. It should be noted that capabilities within *TOPS-BC* are often referenced within this *Desk Reference* document, along with discussions of many other applicable analysis tools, when appropriate, but the *TOPS-BC User's Manual* focuses exclusively on *TOPS-BC* operation and is the devoted source of information for that resource.

Common Questions and Where to Locate More Information

As summarized above, the *Desk Reference* is structured to provide basic introductory information on the general principles and concepts of B/C analysis in the opening sections, appropriate as a

reference resource for beginning and intermediate B/C analysts. The following represents some common overview questions along with a guide on where more information may be found on the particular topic:

- What is B/C analysis? (See Chapter 2)
- What is the role of B/C analysis in the planning process? (See Chapter 2)
- How does B/C analysis differ from economic impact analysis? (See page 15 and Table 2-3 for a comparative discussion.)

Other users more seasoned with the basic concepts of B/C analysis may have more focused questions on the uniqueness of B/C analysis as it is applied to specific TSM&O strategies; for example:

- What are the appropriate measures to consider for particular strategies (See Chapter 3 for a description of the TSM&O strategies and for a discussion of common measures of effectiveness (MOE), and Figure 5-5 for a mapping of strategies to likely impacts); and how can these outputs be quantified and monetized? (See Chapter 5)
- What is the appropriate time horizon that should be used? (See Chapter 5 for a discussion of time horizons and the impact of the time value of money.)
- How can life-cycle costs be estimated? (See Chapter 5 for a discussion of life-cycle costs and methodologies for estimating these costs.)

Other more complex questions related to emerging performance measures or the analysis of other nonphysical strategies with less apparent benefits are provided in the later sections of the *Desk Reference*. The following are some of the questions related to more difficult to quantify benefits related to TSM&O covered in this guidance:

- What are appropriate ways to estimate travel time reliability impacts? (See Chapter 3 for a discussion of the importance of this measure in operations analysis and an overview of available methods for quantifying reliability; and Chapter 5 for a more detailed discussion of reliability (nonrecurring congestion) analysis methodologies).
- How can the benefits of nonphysical strategies such as improved interagency coordination be assessed? (See nonphysical strategy discussion in Chapter 5)

The *TOPS-BC* spreadsheet tool is intended to support this *Desk Reference* by serving as a decision-support tool to the document. The *TOPS-BC* tool is referenced throughout this *Desk Reference* where appropriate; and often, the reader may be directed to specific information or a specific capability within the tool. A more detailed discussion of the proper set up and application of the *TOPS-BC* tool is provided in the separate, stand-alone *User's Manual* that is distributed with the tool.

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Chapter 2. Overview of B/C Analysis for Operations

What is B/C Analysis?

Benefit/Cost (B/C) Analysis is defined as a systematic process for calculating and comparing benefits and costs of a project for two purposes:

1. To determine if it is a sound investment (justification/feasibility); and
2. To see how it compares with alternate projects (ranking/priority assignment).¹

Benefit/Cost analysis is also commonly referred to as Cost-Benefit Analysis, CBA, Benefit/Cost Analysis, and BCA. The analysis is identical despite the naming differences. Benefit/costs analysis is one type of economic valuation – an analysis that assesses the relative value of a project in monetized estimates. As the name implies, benefit/cost analysis determines the value of a project by dividing the incremental monetized benefits related to a project by the incremental costs of that project. The result is called the **Benefit/Cost Ratio** and is often the primary output of the analysis process. This output may either be expressed as a ratio (2:1) or a resultant value (2). For example, a project producing \$150,000 in benefits and costing \$100,000 would result in a B/C ratio of 1.5:1 or 1.5 (\$150,000 benefits/\$100,000 costs). Projects determined to have B/C ratios greater than one are said to be **Efficient** investments; in that, each dollar invested in the project returns more than \$1.00 in benefits. Projects determined to have a B/C ratio less than one are **Inefficient** investments since the costs of the project are greater than incremental benefits created by the project. Projects with a B/C ratio of exactly one – benefits are determined to be exactly the same as costs – are said to be **At Cost Efficiency**.²

Benefit/cost ratios can be used to compare the relative value of different projects. Various projects may be prioritized (in terms of economic efficiency), assessing each project individually and calculating the B/C ratio for each project. In comparing the various projects, those projects with the highest B/C ratio would be ranked as the most efficient.

A second common output measure from B/C analysis is a project **Net Benefit**. Net Benefit is determined by summing all benefits and subtracting the sum of all costs of a project. This output provides an absolute measure of benefits (total dollars), rather than the relative measures provided by B/C ratio. Net benefit can be useful in ranking projects with similar B/C ratios. Table 2-1 presents a hypothetical comparison of three projects showing the project monetized benefits, costs, B/C ratio, and net benefit. Based on B/C ratio in this example, Project 1 (having a B/C ratio of 4.0) would be ranked

¹ National Academies Transportation Research Board (TRB) Economics Committee, <http://bca.transportationeconomics.org/>.

² B/C ratios are nearly always positive, ranging from zero to 15 or higher for some TSM&O strategies. B/C ratios may be negative; however. A negative value indicates that the project is expected to generate greater disbenefits than actual benefits; meaning that on a net basis, the project would make conditions worse rather than better.

above Project 2 (B/C ratio of 1.5) and Project 3 (B/C ratio of 2.0). Although the relative comparison of B/C ratios shows that Project 1 is more efficient than Project 3, the absolute measure of net benefit is much higher for Project 3. Depending on the goals of the analysis (e.g., maximizing the efficiency of the investment or maximizing the total amount of the benefit), Project 1 or Project 3 could be ranked the highest.

Table 2-1. Comparison of Projects Using B/C Ratio and Net Benefit

	Project 1	Project 2	Project 3
Benefits	\$200,000	\$150,000	\$400,000
Costs	\$50,000	\$100,000	\$200,000
B/C Ratio (Benefits/Costs)	4.0	1.5	2.0
Net Benefit (Benefits – Costs)	\$150,000	\$50,000	\$200,000

Benefits in a B/C analysis are calculated by estimating the incremental change in various **MOEs** and then applying an established value to the identified amount of change to monetize the benefit. MOEs can include a wide range of metrics depending on the anticipated impacts of the various projects being analyzed. The MOEs should be identified during the analysis set up, and should be sufficiently comprehensive to capture the full benefits (positive impacts) and disbenefits (negative impacts) of the identified projects. Chapter 3.0 provides additional detail on many of the traditional and nontraditional MOEs used in transportation operations benefit/cost analysis; however, typical measures often include:

- Travel time (and the reliability of travel time);
- Crashes;
- Fuel use;
- Nonfuel vehicle operating costs;
- Emissions/air quality; and
- Agency efficiency.

For many projects, there are often tradeoffs between positive impacts to some MOEs weighed against negative impacts to other MOEs. Both the benefits and disbenefits should be calculated and the total benefit for the project should represent the net effect. For example, a proposal to increase the speed limit on a roadway could result in a decrease in travel time for users (a benefit), but simultaneously could result in an increased crash risk (a disbenefit). The total benefit for the project should weigh both these impacts to fully capture the total project benefits.

Similarly, an individual MOE may be both positively and negatively impacted by a single project or strategy. For example, a project to implement a ramp metering systems along a corridor may be predicted to improve travel time along the mainline roadway; however, the travel times may be worsened on the actual on-ramp facilities due to the addition of the impedance of the ramp signal. The travel time benefit calculated for this project needs to take into account the net change in travel time between these off-setting impacts. Practitioners need to be careful in setting up their analysis to

identify and fully capture all the network facilities impacted by the project in order to avoid overstating or understating benefits.

In selecting which MOEs to employ in an analysis, practitioners need to strive to capture the comprehensive impacts of their strategy; however, caution should also be applied to avoid double-counting particular benefits. The MOEs selected should be mutually exclusive. For example, if a project was predicted to reduce emissions, the analyst would not want to include both the benefit of the reduced emissions and the benefit of increased health for residents as a result of the emissions reduction. Presumably, the emissions benefits would already account for this health benefit; thus including both benefit measures would be double-counting.

Benefit/cost analysis for transportation projects is most typically forward looking, attempting to forecast the future changes in MOEs related to a potential project or collection of potential projects. Similar to many transportation-planning efforts, data needed to drive the future predictions of benefits are often obtained from travel demand or simulation models, or a variety of analysis tools capable of modeling changes in traffic performance. (Chapter 4 provides detailed discussion of many of the existing B/C analysis tools and methods currently in use.)

Although most typically predictive in nature, B/C analysis may also be backwards looking to quantify the benefits accruing from existing deployments. This evaluative B/C analysis is most often performed to estimate the relative benefit achieved through a prior deployment, often to provide additional justification for the value of continuing or expanding the project. These evaluations of existing projects typically rely on real-world data on the incremental impacts of the project, based on “before and after” comparisons of traffic performance both “with and without” the project, when available. Where empirical data is unavailable or unreliable, these evaluation B/C analyses may also rely on modeled data to fill critical information gaps. Chapter 5 provides additional discussion of the data needs and potential data sources related to B/C analysis of transportation operations projects.

Finally, depending on the particular needs of the assessment, B/C analysis may be conducted using a snapshot of traffic performance and project costs to estimate average annual benefits and costs. This average annual B/C is best used in situations where the relative benefits and costs are anticipated to be relatively stable over time. Other analysis may require the calculation of **Net Present Value** (NPV), which represents the sum of the stream of expected benefits and costs over a selected time horizon (e.g., 20 years). The stream of benefits and costs is discounted in future years to reflect the time cost of money (i.e., spending a dollar today is not the equivalent of spending a dollar five years from today). Chapter 5 presents an expanded discussion on the implications of the time horizon and of the time cost of money in generating NPV.

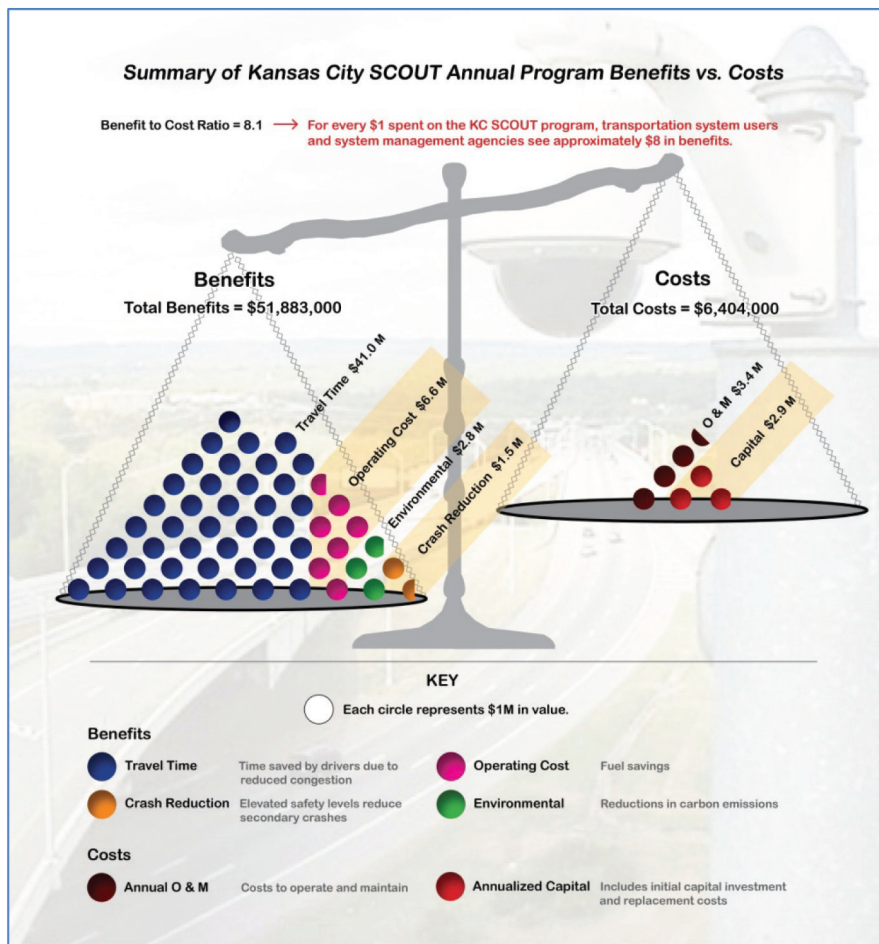
Once a B/C analysis is complete, the results may be displayed in many innovative ways. The format, structure, and content of the output display are determined by a number of factors, including the following:

- The purpose of the analysis (e.g., comparison of multiple projects or benefits estimation of a single project);
- The robustness of the analysis performed;
- The MOEs included;

- The desired output information;
- The intended audience (e.g., technical staff, policy-makers, public, media); and
- The needs of the project to be sensitive to other nonquantifiable benefits and issues.

Figure 2-1 presents a sample display from a benefit/cost analysis conducted on the *KC Scout* program, which is the traffic operations system for the Kansas City metropolitan region. The display effectively presents the strong outcome of the analysis showing a B/C ratio of more than eight (or more than \$8.00 in benefits for each \$1.00 invested).

Figure 2-1. Sample Display of B/C Analysis Output



Subsequent discussions in this overview section provide additional introduction to benefit/cost analysis, including the following:

- Common terminology;
- How does B/C analysis differ from other economic impact analyses?
- What are considered “benefits”/what are considered “costs”?
- Who are the various stakeholders in B/C analysis?

Table 2-2. Common Terminology Used in the Desk Reference

Term	Definition
At Cost Efficiency	A project determined to have exactly equal benefits and costs (B/C ratio equals precisely one).
Benefit/Cost (B/C) Analysis (Also known as Cost-Benefit Analysis, CBA, Benefit-Cost Analysis, or BCA)	A systematic process for calculating and comparing benefits and costs of a project.
Benefit/Cost Ratio	Measure calculated by dividing the incremental monetized benefits related to a project by the incremental costs of that project. May either be expressed as a ratio (2:1) or a resultant value (2). B/C ratios greater than one indicate that a project is efficient (benefits exceed costs). B/C ratios less than one indicate that a project is inefficient (costs exceed benefits).
Capital Costs	The upfront costs of implementing a project or improvement, including planning, design, construction/installation, and equipment costs.
Constant Dollars (also known as Real Dollars)	Presenting dollar value estimates of future costs and benefits that are expressed in terms of today's (or a selected base year) prices. Constant dollars remove the effects of inflation over time to express constant prices compared with the selected base year.
Current Dollars (also known as Nominal Dollars)	Presenting dollar value estimates of future costs and benefits in the year they will actually be incurred or received. Current year dollars will reflect price changes due to inflation over time.
Direct Benefits	Those measurable benefits that may be directly attributed to the project investment.
Discount Rate	The rate at which predicted cash expenditures (costs) or inflows (benefits) are reduced in future years to reflect the time cost of money. The purpose of the discount rate is to convert future values to present value.
Economic Impact Analysis	The analysis of the comprehensive regional economic impact related to a project. More broadly considers multiplicative productivity, jobs, and income benefits caused by changes in transportation performance than considered in B/C analysis.
Efficient	Projects determined to have benefits greater than their costs (B/C ratio greater than one).
End of Project Costs	Costs necessary to close down temporary projects or any residual or salvage value of equipment at the end of the time horizon of the analysis.
Indirect Benefits	Represent those regional production, employment, and income benefits attributable to the change in transportation system performance related to the project (considered in Economic Impact Analysis/not considered in B/C analysis).
Induced Benefits	Represent those regional economic impacts related to increased regional income being re-spent in the local economy (considered in Economic Impact Analysis/not considered in B/C analysis).
Inefficient	Projects determined to have benefits less than their costs (B/C ratio less than one).
Measure of Effectiveness (MOE)	Metric used to evaluate the level of impact of a project.

Term	Definition
Net Benefit	The sum of a project benefits minus the sum of the project costs.
Net Present Value	The sum of the discounted stream of expected benefits and costs over a selected time horizon.
Operations and Maintenance (O&M) Costs	The continuing costs necessary to keep the project performing as planned, including items, such as power, communications, labor, and routine maintenance.
Replacement Costs	The cost of replacing equipment that reaches the end of its useful life during the time horizon of the analysis.
Time Cost of Money	The impact of time on the value of future benefits and costs. Money spent or earned today is more valuable than the same amount of money promised in a future year since the money earned today can be invested and earn additional revenue in the interim years. Therefore, benefits and costs accruing in later years of an analysis are often valued at a discounted rate.
Transfers	Occur if one group or segment of the population enjoys a new benefit, but does so at the expense of a new disbenefit or additional cost accruing to another group.

How does B/C Analysis Differ from Economic Impact Analyses?

Benefit/cost analysis is often confused with Economic Impact Analysis, which serves to identify and monetize the full potential regional or national level economic benefits of a project, including changes in regional productivity, employment, and income. B/C analysis is defined differently, however, as the benefits and MOEs selected for any given analysis should represent the benefits accruing to users of the project as well as benefits to society at large. The real difference between these types of analyses has to do with the measures on which they focus. B/C analysis focuses on a summary measure of net benefit to society. Economic Impact analysis focuses on measures of impact on economic indicators, such as aggregate employment or real GDP, none of which serve as a summary measure of societal benefit.

Direct benefits, considered in B/C analysis are those measurable benefits that may be directly attributed to the project investment. B/C analysis does not consider broader indirect and induced benefits to the regional or national economy. **Indirect Benefits** represent those regional production, employment, and income benefits attributable to the change in the direct impact. **Induced Impacts** are related to the multiplicative affects of the re-spending of new income within the region, resulting from increased regional production or employment. Indirect and induced impacts are considered in economic impact analysis, which considers these broader regional economic impacts as shown in Table 2-3.

Table 2-3. Comparing B/C Analysis with Economic Impact Analysis

Type of Benefit	Direct Benefit	Indirect Benefit	Induced Benefit
Example of Benefit	Reduction in corridor travel times.	New businesses are attracted to the corridor by the improved corridor performance.	Employees of the new businesses spend their incomes at other regional businesses.
Considered in B/C Analysis	Yes	No	No
Considered in Economic Impact Analysis	Yes	Yes	Yes

The subsequent section provides additional detail on the benefits and costs used in B/C analysis.

What are Considered “Benefits”/What are Considered “Costs”?

Benefits

Within B/C analysis of transportation Operations projects, the “benefits” represent the monetized estimates of the changes in the MOEs identified for the project that are directly attributable to the project investment. These benefits may accrue to the transportation system users (e.g., travel time savings, reduction in crash risk, decreased operating costs); the deploying agency (increased agency efficiency); or society at large (reductions in emissions). The benefits may be either positive (e.g., a net decrease in travel time) or negative (a net increase in travel time) in value. Negative benefits are known as disbenefits.

Some B/C analysts improperly assign negative benefits (e.g., an increase in the amount of emissions) to the cost half of the B/C equation (denominator); however, as discussed below, the cost measure should exclusively represent the investment necessary to implement and operate the improvement. All changes in MOEs should be valued and accounted for in the benefit (numerator) portion of the equation. This may include changes in agency efficiency (measured in reduced agency costs) or productivity as well. For example, if a transit agency deploys a transit vehicle Automatic Vehicle Location (AVL) system to track and record the real-time location of buses, the agency may predict an efficiency gain because it will no longer have the need to conduct some manual data collection activities. The cost savings associated with the elimination of the manual data collection should properly be treated as a change in benefits; not a change in costs, as it is a direct result of the project. Chapter 3 provides an expanded discussion of MOEs and benefits used in assessing transportation Operations projects.

Costs

For analyzing TSM&O projects, it is recommended that “Costs” or the denominator value in B/C analysis represents the life-cycle costs of implementing and operating the project. This is important for TSM&O projects since they typically incur a greater proportion of their costs in years after deployment to operate and maintain the system, and replace obsolete equipment, when compared to more traditional improvements. These life-cycle costs represent:

- The upfront **Capital Costs** of implementing the project or improvement, including planning, design, construction/installation, and equipment costs;
- The continuing **O&M Costs** necessary to keep the project operational, including items, such as power, communications, labor, and routine maintenance (excludes replacement costs);
- The **Replacement Cost** of equipment that reaches the end of its useful life during the time horizon of the analysis;
- The **End of Project Costs** necessary to close down temporary projects or any residual or salvage value of equipment at the end of the time horizon of the analysis.

These project life-cycle costs should include an accounting of all public-sector and private-sector costs, if applicable. Chapter 5 provides additional detail on identifying and estimating the costs associated with a project. In addition, the *TOPS-BC* application supporting this *Desk Reference* has the capability to estimate life-cycle costs associated with many types of TSM&O strategies. The use of these capabilities is discussed in the *TOPS-BC User's Manual*.

Who are the Various Stakeholders in B/C Analysis?

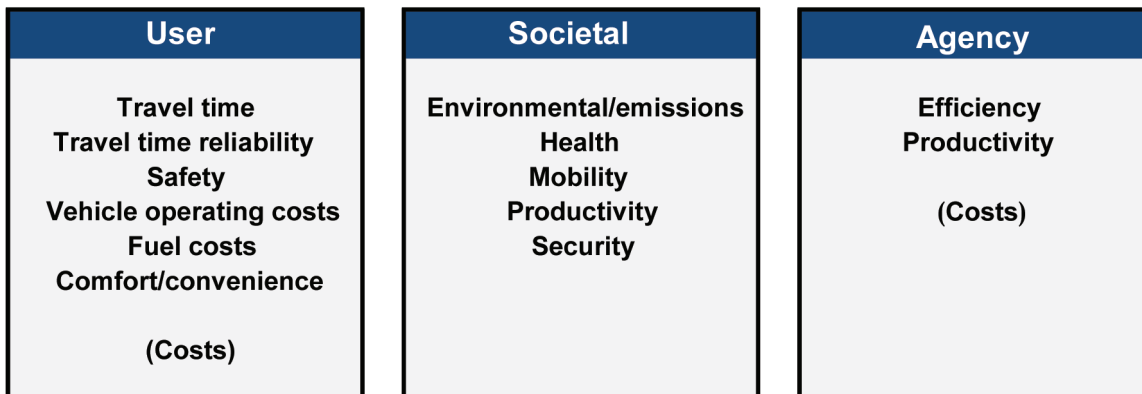
There are three general categories of stakeholders to which project benefits and/or costs may accrue in a B/C analysis. These include:

1. The direct users of the transportation system;
2. Society at large; and
3. The deploying agency or entity.

In many cases, benefits may impact more than one stakeholder group. For example, a project that results in a reduction in the number of fatality crashes would clearly be a benefit to the users of the project, as they would be able to directly reduce the risk of pain and suffering for themselves and their families. Society at large could also be expected to benefit, however, from the reduction in fatality crashes. Fatality crashes result in a loss of a productive member of the community; a loss of resources; and a loss of the community's investment in the crash victim (e.g., investments in the individual's public education). Therefore, there are broader societal benefits, in addition to the user benefit, that may accrue from a project that reduces the number of fatality crashes.

Project costs may also be shared by multiple stakeholder groups. For example, an automated toll payment collection system may require users to purchase an in-vehicle transponder in order to use the system. The private-sector cost of the transponder purchase may be included in the overall project cost value used in the B/C analysis.

Figure 2-2 presents a general summarization of the stakeholder groups and how the various benefits and costs most typically are distributed.

Figure 2-2. Typical Benefits and Costs Distribution among Stakeholder Groups

How is B/C Analysis Used in the Operations Planning Process?

B/C analysis provides several capabilities that are key in supporting different planning needs throughout the Operations planning process. B/C analysis is typically performed to provide one or both of the following capabilities:

- To determine if a project represents a sound investment (i.e., that the benefits of the project outweigh the costs – and to what degree); and
- To compare alternative projects to identify the most efficient projects for ranking/prioritization purposes.

These capabilities are invaluable in supporting planning activities throughout the entire cycle of the Operations planning process. As discussed in subsequent sections, the robustness of the B/C analysis may be scaled to fulfill different needs within the planning cycle. B/C analysis may be performed at a simple sketch-planning level to provide order of magnitude estimates of benefits and costs appropriate for early screening of projects, but also may be made much more rigorous to meet the more detailed analysis demands of later project prioritization or design activities.

Subsequent sections provide additional detail on the Operations Planning Process and the role of B/C analysis in supporting this process.

U.S. DOT Planning for Operations Initiative

Recently released guidance from the U.S. Department of Transportation (DOT), the FHWA Planning for Operations initiative introduces the Operations planning process as follows.³

“Planning for operations” is a joint effort between planners and operators to support improved regional transportation system management and operations. This term encompasses a variety

³ Advancing Metropolitan Planning for Operations: An Objectives-Driven, Performance-Based Approach – A Guidebook, 2010, http://www.ops.fhwa.dot.gov/publications/fhwahop10026/chap_1.htm#s12.

of activities that lead to improved transportation system operations, including the consideration of TSM&O strategies in the transportation planning process. Planning for operations also includes collaboration among transportation system operators, transit agencies, highway agencies, toll authorities, local governments, and others to facilitate improved transportation system operations and to ensure that transportation services are delivered in as safe, reliable, and secure a manner as possible. Often times, this collaboration is carried out in the context of a regional planning agency and is connected to the planning for operations process.

Planning for operations in the metropolitan transportation planning process means developing operations objectives to direct the consideration of operational performance during the planning process, and incorporating operations solutions into investment decisions that support the operations objectives. This approach ensures that operations needs are addressed in regional planning and investment decisions.

Operations managers are engaged in the planning process so that system performance concerns or challenges and potential operations strategies inform and influence the development of the metropolitan transportation plan. Operator involvement further ensures that operations informs and influences the planning process so that operations considerations are reflected in regional transportation plans. This results in a mix of operations and capital projects that optimizes transportation system performance.

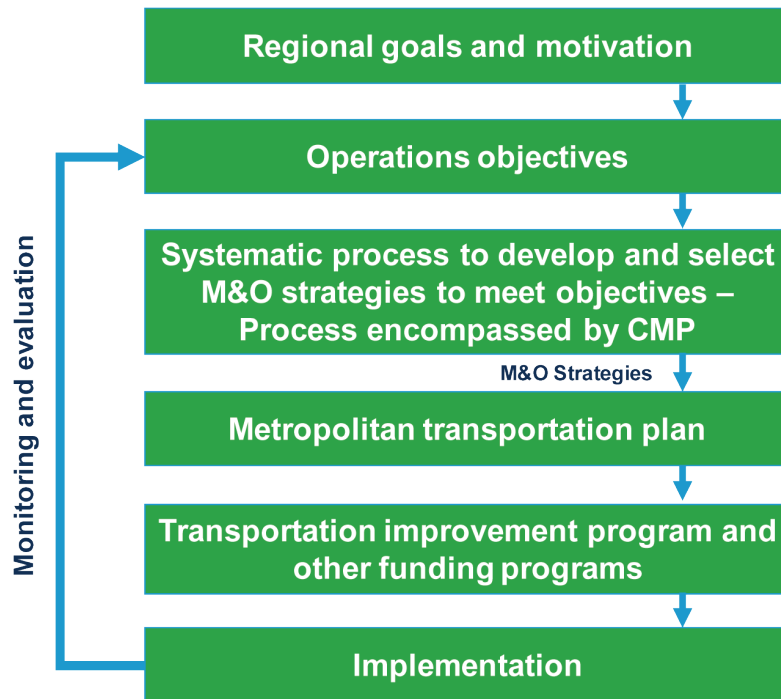
Relationship of B/C Analysis to Objectives-Driven, Performance-Based Approach to Planning for Operations

In order to develop a planning for operations process that is objectives driven and performance based, the approach should include the following elements:

- Developing one or more goals within the Metropolitan Transportation Plan (MTP) that focus on the efficient management and operation of the transportation system;
- Developing regional operations objectives for the MTP – specific, measurable statements of performance that will lead to accomplishing the goal or goals;
- Implementing a systematic approach to developing performance measures, analyzing transportation performance issues, and recommending TSM&O strategies;
- Selecting M&O strategies (within fiscal constraints and to meet operations objectives) for inclusion in the MTP and transportation improvement program (TIP);
- Implementing M&O strategies, which may include investments and collaborative activities; and
- Monitoring and evaluating the effectiveness of implemented strategies and tracking progress toward meeting regional operations objectives.

The approach is iterative with monitoring and evaluation used to refine and adjust operations objectives over time.⁴ Figure 2-3 presents this process graphically.

⁴ Advancing Metropolitan Planning for Operations: An Objectives-Driven, Performance-Based Approach – A Guidebook, 2010, <http://www.ops.fhwa.dot.gov/publications/fhwahop10026>.

Figure 2-3. Objectives-Driven Planning for Operations Approach

Source: Advancing Metropolitan Planning for Operations: An Objectives-Driven, Performance-Based Approach – A Guidebook, 2010, <http://www.ops.fhwa.dot.gov/publications/fhwahop10026>.

The capabilities of B/C analysis are critical in supporting many of the steps in this objectives-driven approach. Guidance provided in Chapter 3 of the *Desk Reference* on the benefits of operational strategies may be useful in identifying suitable regional objectives and performance measures that may be used to assess the degree in which strategies meet these objectives.

As previously mentioned, the robustness of the B/C analysis may be scaled to fulfill different needs within the planning approach. The early screening and identification of TSM&O projects that meet the identified objectives may be performed using a simple sketch-planning-level B/C analysis to provide:

- Order of magnitude estimates of benefits and costs appropriate for early screening of projects; and
- A systematic process to winnow out the most promising projects to carry forward in the planning and analysis process.

As the planning process continues into project prioritization phases to rank projects for inclusion in the MTP, the B/C analysis methods may be enhanced to provide greater confidence in the outputs and the ranking of evaluated projects. This analysis may additionally provide benefit and cost information that can be used as justification for funding the TSM&O project in the TIP. These analysis methodologies may be further enhanced, introducing rigorous analysis and data from detailed microsimulation models and/or real-time archived data systems to support the needs of practitioners, as the prioritized projects enter the design process and implementation steps.

Finally, B/C analysis can support the monitoring and feedback needs within the planning cycle by allowing for the assessment of deployed strategies in order to provide justification for expansion of promising applications, as well as supplying enhanced data on project benefits that may be fed back into the approach and used in future analysis of similar projects.

B/C Analysis can be Used to Compare Operations Projects One With Another, or Provide a Level Playing Field to Compare Operations Projects with Other Travel Demand Management or Capacity Projects

One of the greatest strengths of B/C analysis is that it provides a level playing field for comparing projects that may be very dissimilar. The systematic process of B/C analysis, when performed correctly, allows for widely varying projects that impact different MOEs to be compared head-to-head on an apples-to-apples basis. The monetization of the benefits, compared with the total project costs, provides a common basis that allows for this even comparison of the effectiveness.

The capability of B/C analysis to provide this level playing field comparison is what allows for the comparison of widely varying project types, such as a roadway widening, a new transit line, a signal timing project, and an employer-based travel demand management program; all within the same analysis structure. All of these projects would be expected to impact the transportation system in different ways – some would serve to increase capacity, others would lessen demand, some may promote a mode shift, others would serve to smooth traffic flow – therefore, it would be difficult to select a single evaluation metric (e.g., travel time, safety, emissions, fuel use, etc.) to effectively compare and rank the projects. The comprehensive evaluation structure of B/C analysis includes the full range of potential impacts for all projects; and allows for the cross-comparison of the differing projects by monetizing the benefits, in terms of the value of the combined benefits to society and the agency, thus, providing a common reference for prioritizing the potential investments based on the relative efficiency of each project.

Of course, B/C analysis can also be used to compare and rank very similar projects. For example, an agency may have the need to evaluate several traffic signal coordination projects in order to determine which particular corridors would provide the greatest benefit. In this case, a relatively simple B/C analysis could be conducted by identifying those key measures most likely impacted by this type of deployment (e.g., travel time, travel time reliability, fuel use, and emissions); and then collecting data or modeling scenarios to estimate the impact of the strategy on the individual corridors. The changes to the MOEs would then be monetized for the various corridors by applying an established value to the incremental change. The monetized benefit would then be compared with the cost for each corridor, allowing for the identification of the most efficient corridors (highest B/C ratio).

Comparing different projects with different likely impacts may often be more complicated than comparing similar projects with similar impacts. For example, comparing a roadway-widening project with a freeway service patrol – traffic incident management program would provide some analysis challenges due to the significant differences between the two strategies, for example:

- The roadway widening project would add base capacity to the roadway and presumably serve to improve average or recurring conditions, perhaps mitigating a bottleneck location. The additional capacity could result in additional traffic being attracted to the facility, possibly impacting (positively or negatively) the number of crashes, emissions, and fuel use in the corridor. The improvement in baseline capacity provided by the roadway widening project would be available on a 24/7 basis.

- Meanwhile, the traffic incident management program would have a much less substantial impact on recurring, everyday conditions, but could have significant impacts during nonrecurring incident conditions. This would likely result in a greater impact on the reliability of travel time in the corridor, as opposed to the impact on average recurring travel times. Likewise, the traffic incident management program would be less likely to directly impact the number of crashes occurring in the corridor (outside of the possible reduction in secondary crashes occurring in incident-related traffic queues), but may help to reduce the severity of some crashes due to faster response times. The benefits provided by the incident management would only accrue when the strategy was being operated (perhaps only during peak weekday commute hours), and when incidents had occurred.

The wide variation in the types of benefits of these two projects, combined with when the benefits are incurred (during everyday recurring conditions or during unique nonrecurring conditions) adds significant complexity to the analysis.

Due to the current transportation improvement funding environment, transportation planners and Operations personnel need to make these types of comparisons between more traditional infrastructure projects and Operations-oriented strategies, since these different projects are often competing for the same funds. Therefore, it is often increasingly necessary to prioritize and rank widely varying project types. Fortunately, B/C analysis provides a framework that may be adapted to the challenges of this analysis need. In setting up these analyses comparing differing project types, more care and effort are often required in setting up the analysis in order to:

- **Identify the comprehensive set of MOEs that may be impacted by the range of the varying projects.** Not all varying projects may impact all of the MOEs, but it is critical to identify the full range of benefits in order to provide a meaningfully comprehensive analysis. Likewise, the identification of MOEs should not only consider measures that are likely to be positively impacted (e.g., reduction in the number of crashes), but also those measures that may be negatively impacted (e.g., increase in fuel consumption).
- **Identify the sources of data necessary to support the estimation of impacts on the identified MOEs.** Analysts should strive to identify sources of data that are equally applicable to all the different project types, wherever possible.
- **Identify the analysis methods and/or modeling techniques/platforms that will be used to estimate the incremental impacts on the identified MOEs.** Some traffic modeling methods may be appropriate for analyzing some types of projects, but not others. For example, travel demand models are intended to evaluate changes in travel demand and system capacity. As such, a travel demand model would be ideal for evaluating the roadway widening project example above; however, since most travel demand model's analyses are based on an "average travel day" that is generally free of crashes and traffic incidents, it is less well suited to assess the impacts of the incident management program example. Whenever possible, a common analysis approach and tool should be utilized to avoid introducing bias caused by differing tool/methods.
- **Establish the values (dollar amounts) that will be applied to the incremental change in MOEs in order to monetize the benefit.** When using B/C to compare similar project types, it is less important to establish the values that are applied to the changes in MOEs, as all projects would be expected to impact the same MOEs, therefore, any change in a benefit

valuation would create a relatively equal change in all the project analysis outcomes. When evaluating widely varying types of projects, however, it is much more critical to establish accurate and justified benefit valuations, since not all projects will impact all the different MOEs; thus, an over- or underestimation in one benefit valuation could greatly skew the output results for one or a few projects relative to others in the analysis.

All of these analysis requirements need to be carefully considered in order to provide an accurate comparison and avoid introducing bias into the B/C analysis. Subsequent sections of this *Desk Reference* provide additional detail to be considered when making these analysis set-up decisions. Chapter 3 provides a discussion of the impacts and MOEs associated with various types of TSM&O strategies. Chapter 4 provides an expanded discussion and comparison of various types of existing analysis tools and methods. Chapter 5 provides an expanded discussion of the benefit valuations that may be used in conducting B/C analysis for TSM&O strategies.

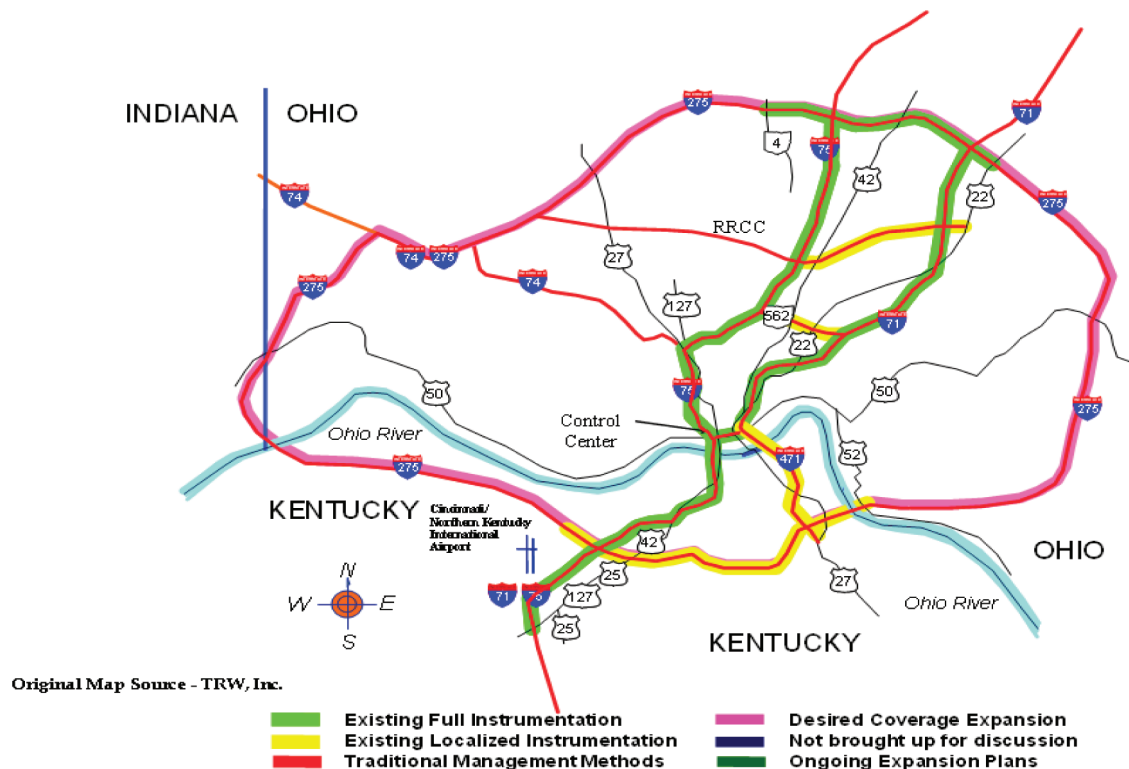
Case Study – Cincinnati Region ARTIMIS Study

The Ohio-Kentucky-Indiana (OKI) Regional Council of Governments, the Metropolitan Planning Organization (MPO) for the Cincinnati, Ohio region, recently had the need to assess the benefits of their regional traffic management and traveler information program, known as ARTIMIS. The ARTIMIS program is responsible for deploying and operating a number of TSM&O strategies in the region, including the following:

- Regional Traffic Operations Center;
- Traffic Surveillance (camera and loop detection);
- Incident Management and Freeway Service Patrols;
- Traveler Information (Regional 511); and
- DMS and HAR, among other applications.

Many ARTIMIS applications had been successfully applied to many of the key freeway corridors located within the region's suburban beltway network by the earlier 2000's; however, there was an increasing need to expand these capabilities' key sections of the beltway and to remaining radial freeways. Figure 2-4 shows the ARTIMIS expansion plans. In order to complete this expansion, the ARTIMIS program would need to compete directly for scarce funding with many more traditional roadway capacity enhancement projects, and would need to provide additional justification to decision-makers on the benefits of the program in order to secure the necessary support and funds in the regional transportation plan (RTP) and TIP.

Figure 2-4. ARTIMIS Program Expansion Plans



In response to this need, OKI launched an evaluation project to estimate the benefits and costs of the ARTIMIS program; and to compare these relative to other more traditional capacity improvement projects proposed for the region. In order to provide comparable benefits and costs within the analysis, OKI carefully selected key MOEs to fully capture the benefits of the traditional and Operational projects. These measures included:

- Mobility (travel time and travel time reliability);
- Safety;
- Fuel Use; and
- Emissions.

The next step was to select the appropriate analysis tools and methods. OKI weighed several alternative methods, but eventually selected a combination of their regional travel demand model merged with the *Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS)* software. The linking of these methods provided the needed:

- Analysis consistency, since the basis for the analysis of both the traditional projects and Operations strategies was the traffic conditions data from the regional travel demand model; and
- Analysis rigor, since the IDAS tool enabled the estimation of additional MOEs (particularly travel time reliability and crashes) not available directly from their travel demand model.

The analysts next reviewed the default parameters used in the analysis for consistency with their local conditions. In particular, OKI made several adjustments in the model assumptions regarding:

- The projected reduction in incident clearance time was modified based on data gathered during a previous evaluation of the ARTIMIS incident management system;
- The assumed market penetration rates for their traveler information system were modified based on internal marketing surveys;
- The benefit valuations were modified to be consistent with standard values typically used for B/C analysis in the region; and
- Estimated costs in the model were replaced with actual costs based on procurement records.

The results of the B/C analysis showed the existing ARTIMIS program to be an extremely efficient investment returning a B/C ratio of 12:1, meaning that the program was generating \$12 in benefits for every dollar invested. This finding itself provided strong justification for the regional investment in the program. The evaluation further compared the ARTIMIS program with several more traditional capacity expansion projects in order to provide a relative ranking of the projects. Table 2-4 shows selected measures, benefits, and costs of expanding the ARTIMIS program compared with a single corridor roadway widening project.

Table 2-4. Comparison of ARTIMIS Operational Projects with a Traditional Roadway Widening Project

Selected Measure	ARTIMIS	Added Lane Project
Miles of improvements	88	10
Fatality accidents	-3.2%	+0.3%
Mobility (time savings)	500 Hours	800 Hours
Travel time reliability saving	6,900 Hours	5,800 Hours
Emissions	-3.6% to -4.5%	+0.3% to +1.4%
Estimated <i>Annual</i> Benefit	\$53 Million	\$35 Million
Total Project Cost	\$40 Million	\$800 Million
Benefit/Cost Ratio	12:1	1.1:1

The benefit/cost information and project prioritization provided by the analysis were presented to decision-makers and the public through an outreach campaign. The results, made more relevant by the fact that they were generated through a valid and systematic process, were extremely valuable in making the case for investment in ARTIMIS in the region. The ARTIMIS expansion and enhancement project was identified as a high-priority project in the transportation plan and provided funding through the TIP process.

How can B/C Analysis for Operations Strategies be Integrated with B/C Analysis for Other More Traditional Strategies

B/C analysis has long been applied in the planning process to evaluate and prioritize investment in traditional capacity enhancing strategies, whether it be investments in highways, bus transit, rail transit, or other infrastructure element (e.g., bridges). More recently, the use of B/C analysis has been expanded at many agencies to examine the effectiveness of other less capital investment types of strategies, such as maintenance levels, replacement cycles, and various transportation programs and policies.

The use of B/C analysis for assessing TSM&O strategies is also a more recent addition as increased competition for funding and the accompanying need to provide greater justification for projects have driven the call for systematic processes that can be used to objectively weigh the relative benefits and costs of various projects, as well as provide meaningful analysis of projects that may differ greatly in their scope, intended outcomes, impacts on the transportation system, and costs.

Due to the long-time use of B/C analysis for more traditional infrastructure project assessment, many regions and states already have established procedures for conducting B/C analysis. These procedures may range from simple guidance on which MOEs to use, to detailed analysis frameworks, specified performance measures, and standardized benefit valuations to be applied. Therefore, except in situations where the analyst is only attempting to compare different TSM&O strategies with each other, care should be taken to be as consistent as possible with the established B/C analysis guidelines and procedures in order to provide for meaningful comparability of results. This consistency will ensure that the TSM&O strategies may be effectively and accurately compared and prioritized alongside more traditional infrastructure investments without risking the overstating or understating of benefits due to the analysis methodology itself.

The issue with maintaining this consistency with established B/C procedures designed for analysis of more traditional infrastructure projects is that the existing procedures may not be entirely appropriate for analysis of TSM&O projects. Analysts should be aware that existing agency procedures or guidelines may serve to limit the full, comprehensive assessment of the benefits of TSM&O strategies in one or more of the following ways:

- **Existing MOEs may not be sensitive to the unique benefits of TSM&O strategies** – Many established B/C frameworks, designed for more traditional capacity infrastructure projects, may not include assessment of some of the key benefit areas often provided by TSM&O strategies, such as improvements in travel time reliability or improved agency efficiency.
- **Specified analysis data may be inappropriate for assessment of TSM&O benefits** – Existing guidelines or procedures requiring the use of particular datasets (e.g., Highway Performance Monitoring System (HPMS) data, traffic counts, etc.) as inputs to the analysis may result in a bias against TSM&O strategies, unless the data is appropriate to the strategy being analyzed. For example, many traditional traffic count datasets only represent time periods free of incidents and inclement weather. Using this data as the basis for assessing the impacts of an incident management system or a weather information system would likely result in the severe underestimation of true benefits.

- **Required analysis methods, tools, or models may not be capable of capturing the full benefits of the TSM&O strategies** – For example, some regional B/C guidelines may specify that the established regional travel demand model be used as the basis for the traffic impact analysis. However, many regional travel demand models are focused on average traffic conditions, and may be inadequate for assessing TSM&O strategies focused on incident, construction work zone, or inclement weather conditions; or may not be sufficiently sensitive to travel costs to assess pricing options.
- **Cost estimation parameters and framework may be inadequate** – Many traditional infrastructure projects have large upfront capital costs required for construction and implementation, and then much smaller continuing O&M costs spread over a long project life (e.g., 30 years). Many TSM&O strategies, on the other hand, have much smaller capital outlays required for implementation, but proportionately higher continuing O&M costs. TSM&O strategies also typically utilize equipment with much shorter useful life cycles (e.g., sometimes as short as two to five years) than traditional infrastructure projects. The cost estimation framework in existing B/C analysis procedures designed around long-term capacity enhancements may not be sensitive to the quick equipment replacement cycles and continuing O&M costs associated with many TSM&O strategies.

While many regions and agencies have made significant efforts to enhance their existing regional B/C guidelines and policies in recent years to be more compatible with TSM&O analysis needs – including the incorporation of new MOEs (e.g., travel time reliability); updates to modeling and analysis tool capabilities; and the inclusion of automated archived data – Operations analysts should still be aware of these potential constraints of utilizing existing frameworks, datasets, modeling tools, and cost parameters.

The following are advantages of using the existing B/C analysis structure:

- Consistency with established procedures;
- Promotes the comparability of results; and
- Uses a vetted process that is familiar to planning staff and decision-makers.

Therefore, analysts looking to estimate the benefits and costs of TSM&O strategies should attempt to work within the existing structure and policies to the degree possible, but should remain flexible, when necessary, to avoid the understatement of TSM&O benefits due to an inadequate analysis structure. When these situations are encountered, the TSM&O analysts and managers should seek resolution through possible efforts, such as:

- Encouraging the regional adoption of objectives and performance measures that are sensitive to the unique benefits of TSM&O strategies.
- Identifying or developing new traffic datasets, or the development of systems to capture those data (e.g., archived data systems), that provide the needed input required for TSM&O strategies.
- Encouraging or developing enhancements to the existing regional modeling capabilities to better allow the analysis of the specific traffic impacts of TSM&O strategies, or encouraging the adoption of new modeling platforms and techniques to provide this analysis capability.
- Promoting changes to the existing regional analysis framework, parameters, and benefit valuations to be more applicable to TSM&O strategies; and improving the consistency

and comparability of analysis results between TSM&O and more traditional infrastructure investment projects.

The sections below provide discussions of several specific phases of the planning process, where opportunities for comparing and prioritizing TSM&O strategies alongside more traditional strategies most often exist; and explore issues that the TSM&O analyst should be aware of when conducting these activities.

Project Screening

Project screening provides the initial assessment of the viability of various projects. Usually, this process is performed at an order of magnitude assessment level, not to specifically rank projects in any absolute order, but instead to provide a general categorization of projects (e.g., high, medium, or low priority) or winnow out projects likely to not be efficient, so that scarce planning resources can be focused in later phases on those projects more likely to provide the greatest benefit.

This analysis for TSM&O projects is often performed using sketch-planning analysis tools or readily available methods and data. The *TOPS-BC* tool, developed to support this *Desk Reference*, maintains the ability to conduct screening-level B/C analysis for many Operations strategies, and is described in the tool's *User's Manual*. Chapter 4 presents additional discussion of other sketch-planning tools and methods appropriate to the project screening task.

Analysts should take care in evaluating TSM&O strategies alongside more traditional improvements to ensure that the MOEs used in the analysis are appropriate to the strategy (see Chapter 3 for more information on the likely impacts of TSM&O strategies); and are consistent to the degree possible for the traditional and the TSM&O strategy. The input data and the tool/method used for analysis should also be made as consistent as possible to avoid introducing bias to the analysis.

Project Prioritization

The project prioritization process often requires more robust analysis than required during the preliminary project screening process. As such, project prioritization is more likely to include the analysis of project impacts using more rigorous and complex analysis tools and methods. Analysis of traditional infrastructure projects is often conducted using the regionally accepted travel demand model. As discussed above, however, regional travel demand models may present challenges to the assessment of any strategies designed to have greater impact during periods of incidents, inclement weather, or construction activity. Therefore, it is critical to be aware of these limitations and modify the travel demand model analysis to better incorporate these impacts (see Chapter 5 for additional discussion), or consider other compatible methods or combinations of methods that may better support the analysis. The analysis tools used will likely provide the majority of the data input into the actual B/C analysis framework for monetization of benefits and the comparison with project costs, so it is critical that the base analysis tools and methods used are compatible with the unique impacts of TSM&O strategies.

Similar to project screening, it is also critical that the MOEs selected and the data identified for input into the analysis are consistent with the needs of TSM&O analysis. Failure to properly consider these issues could result in an understatement of TSM&O strategies in comparison to more traditional capacity improvements.

Congestion Management Process

The congestion management process (CMP) is a systematic approach applied in a metropolitan region to identify congestion and its causes, propose mitigation strategies, and evaluate the effectiveness of implemented strategies. The CMP then recommends projects and strategies for the plan and transportation improvement program (TIP). In many metropolitan areas, the CMP is one of the primary avenues for planning for operations. In the CMP, system performance issues are systematically examined and management and operations strategies are often included in the set of solutions recommended to address congestion. The CMP, guided by specific objectives and integrated into the planning process, is an example of this systematic approach. In some regions, the objectives-driven, performance-based approach for integrating operations into the plan may be performed within the CMP.⁵

For many regions, the CMP is the focus of activities designed to fully consider and integrate TSM&O strategies alongside more traditional transportation capacity projects. The TSM&O analysts and managers should strongly coordinate with the CMP process to ensure that TSM&O sensitive MOEs are considered, and that any analysis structure established within the CMP to assess and compare the relative effectiveness and efficiency of various strategies in mitigating the identified regional deficiencies.

Additionally, many times within the CMP process, the opportunity exists to move beyond the analysis of individual strategies and evaluate various combinations of strategies and their effectiveness in mitigating deficiencies and providing efficient management and operations of the transportation system. This opportunity may require the analysis of combinations of different types of TSM&O strategies, as well as the combination of TSM&O and more traditional strategies, to provide a synergistic effect. The combinations of strategies may present analysis complexities. While many traditional capacity enhancing strategies have been in use for years and their impacts are well documented, many TSM&O strategies have only been more recently deployed, and often have been deployed in limited applications. Therefore, it can be difficult to identify the likely impacts of combining different TSM&O strategies, particularly those that still represent emerging technologies.

Challenges and Limitations of B/C Analysis

Although B/C analysis provides a robust and comprehensive framework for comparing the relative efficiency of different projects, there are many challenges and limitations to its overall use, as well as specific challenges in assessing TSM&O projects. These challenges and limitations include:

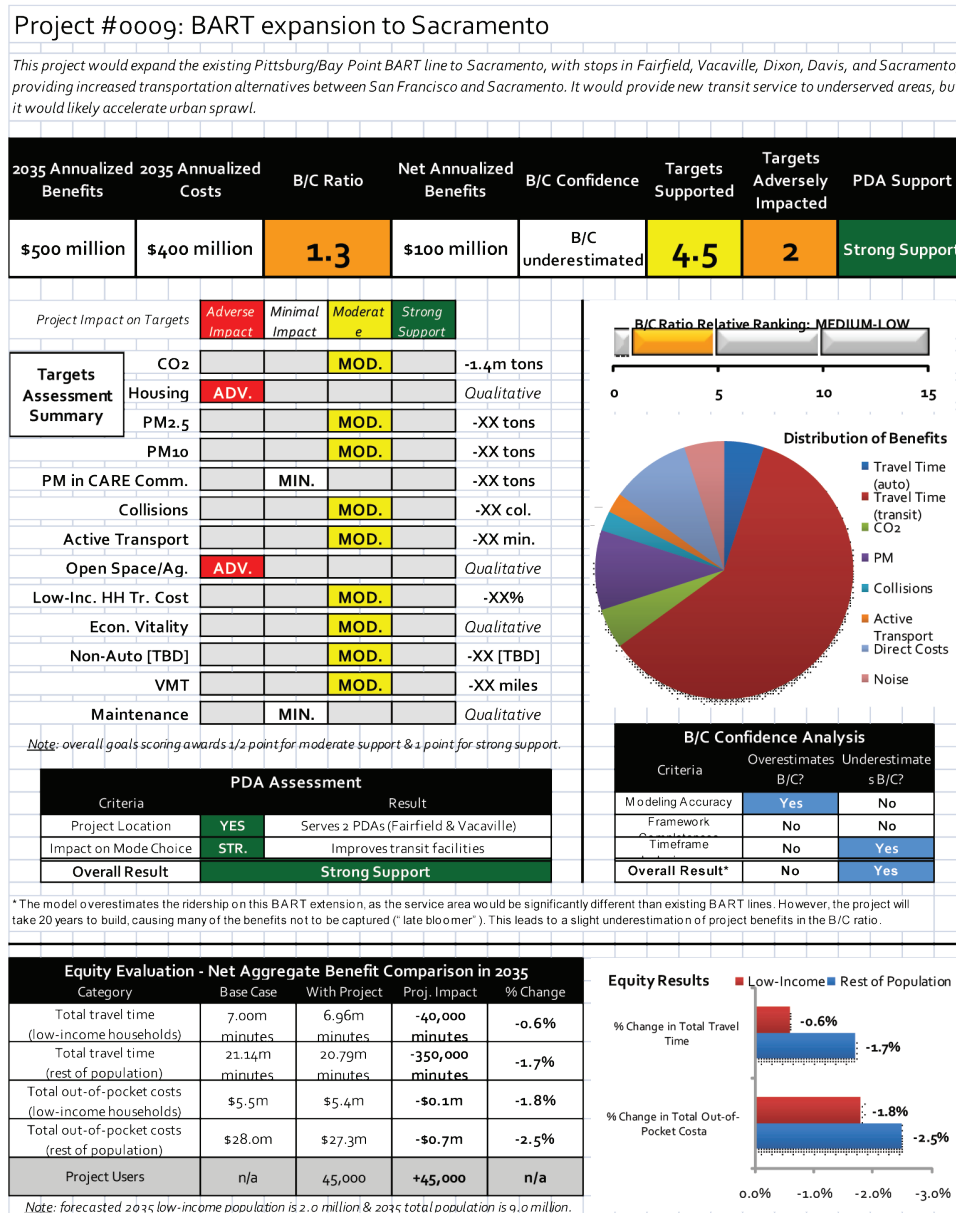
- **B/C analysis provides a key piece of information that may be used in analyzing and prioritizing projects, but it is not the only information that should be considered.** The B/C ratio and net benefit information is a powerful element in the comparison of different investment opportunities; however, as discussed below, there are limitations to the analysis and many project considerations that may not be able to be captured within a B/C analysis. Hard-to-capture benefits, such as improvements in community livability, changes in housing

⁵ Advancing Metropolitan Planning for Operations: An Objectives-Driven, Performance-Based Approach – A Guidebook, 2010, <http://www.ops.fhwa.dot.gov/publications/fhwahop10026>.

values, or impacts to disadvantaged communities, may be difficult to fully assess in the analysis. Further, other project prioritization considerations such as political will and public acceptability will not be captured in the analysis, yet may still play a role in determining the eventual prioritization of the projects being considered for investment. Therefore, it is critical that the results of the B/C analysis be carefully combined with other nonquantifiable inputs in making final decisions regarding the relative effectiveness of various projects. Figure 2-5 shows a hypothetical analysis framework being used in an assessment of regional transportation projects in the San Francisco Bay Area as part of the Metropolitan Transportation Commission (MTC) update of their 2035 Transportation Plan. As can be noted in the figure, the B/C ratio makes up a critical, but only one of many eventual inputs to the investment decision-making process.

- **Many TSM&O strategies have only been recently deployed or include emerging technologies, making it difficult to estimate the true impact of the strategies.** While many traditional capacity-enhancing strategies have been in use for years and their impacts are well documented, many TSM&O strategies have only been more recently deployed, and often have been deployed in limited applications. Therefore, estimates of the likely impact TSM&O strategies, particularly those that still represent emerging technologies, may need to be based on limited empirical data of the actual benefits of the strategy within the analysis. Chapter 3 contains additional information about the impacts and benefits of various Operations strategies. Additionally, the *TOPS-BC* application maintains a number of look-up tables on the observed impacts of many TSM&O strategies related to a number of MOEs, as highlighted in Figure 2-6.
- **Maintaining consistency in the analysis of TSM&O strategies and traditional capacity projects is frequently complex** due to varying analysis tools and methods, different MOEs, different analysis data inputs and sources, and different cost structures that are typically used to assess the various projects. As discussed further in Chapter 2, the analysis of varying strategies needs to be carefully planned in order to provide comparable and consistent results.
- **The quantification of benefits needs to be carefully planned and structured to avoid the double-counting of benefits.** Double-counting can occur in situations where there are overlaps in different benefits, or when a change to one benefit results in a direct change to another benefit. For example, a project to replace or upgrade traditional traffic signals to more efficient light emitting diodes (LED) signal lighting may be expected to result in a cost savings of \$150,000 in electricity costs to an agency. In conducting a benefit/cost analysis of this project, the analyst should be cautious in not accounting for this impact, both as a benefit (a \$150,000 gain to the agency), as well as a cost (a reduction of \$150,000 in operating costs). This would result in a doubling of the actual benefit.

Figure 2-5. Hypothetical Project Comparison Data – MTC San Francisco Bay Area 2035 Transportation Plan



Note: Figure 2-5 shows the sample results from an analysis of a completely hypothetical project. The estimated B/C ratio for this project is projected to be approximately 1.3. The pie chart displays the amount that different benefit categories comprise of the total benefit estimate. This display also presents information on the projects projected ability to impact various regional targets, such as reducing carbon dioxide (CO₂) emissions, or improving housing availability. Many of these target assessments are qualitative yet still included in the B/C analysis structure. The display also includes an assessment of the equity of the benefits (i.e., which groups of residents receive the greatest benefits/disbenefits) from the project. Again, these equity issues are not assessed in the B/C ratio, but are an important additional consideration for the agency conducting the study.

Figure 2-6. Sample View of *TOPS-BC* Impact Lookup Function

FHWA Tool for Operations Benefit/Cost (TOPS-BC)

Investigate the Range of Impact Values Associated with Various TSM&O Strategies

Navigation Screen [Return to OPENING SCREEN](#)

Instructions: Please select the "TSM&O Strategy" and the "Impact Category" you are interested from the pull down list below. If sufficient data is available, a range of expected impacts will be shown below. Click on the hyperlink to be taken to a table displaying the datapoints comprising the range.

TSMO Strategy Selected:

Impact Category:

Noted Impacts

[Expect 5% to 30% capacity reduction on ramps and 7% to 20% capacity increase on freeway.](#)
[Expected increases in volume between 5% and 30%](#)

Typical Range of Expected Impacts

- **There may be difficulty in assessing hard-to-quantify impacts within the analysis.** Although B/C analysis should strive to be as comprehensive as possible in the MOEs and benefits quantified in the analysis, there are often some measures and benefits that prove extremely hard to quantify. In some cases, these hard-to-quantify benefits may include emerging measures, where a firm consensus has yet to be reached regarding the relationship between a change in transportation system performance and the long-term monetized benefit amount. Many agencies struggling to include better assessment of global climate change within their B/C analysis have faced this challenge. In other cases, the measure or benefit may be somewhat esoteric, complicating efforts to place a value on the benefit. As a result, many times the B/C analysis is supported by a more qualitative analysis of other impacts seen as benefits or disbenefits in the region, such as impacts on community livability or urban sprawl.
- **There are often challenges in weighing the analysis comprehensiveness against the available analysis resources.** Like many other types of analyses, there are substantial tradeoffs between the comprehensiveness of the analysis with the resources necessary to achieve that comprehensiveness. Likewise, achieving a higher level of confidence in the accuracy of the results often requires additional resources be made available for the analysis. The analyst must make decisions early in the design and set up of the analysis to balance these competing needs. For preliminary screening purposes, it may be acceptable to simply consider a few key MOEs – presumably those measures likely to be most significantly impacted by the projects being compared – and assessed at an order of magnitude scale. For more detailed prioritization and design considerations, the analysis may need to be much more rigorous, involving multiple tools to support the assessment of many varying MOEs, and providing a high level of confidence in the analysis results. Chapter 4 of the *Desk Reference* provides a discussion of the tools and methods available for conducting B/C analysis, and previews the level of resources needed to conduct analysis using these methods.

- **TSM&O strategies that are targeted at mitigating unique, nonrecurring conditions may require additional analysis beyond the “average day” analysis typically used for recurring congestion projects.** TSM&O strategies, such as incident management systems, weather systems, evacuation strategies, and other strategies focused on nonrecurring or special events, may require special treatment in the analysis to assess the strategy’s impact during these conditions and the likely frequency in which those conditions will be observed in order to quantify the benefits of the strategy. This is a major departure from analysis of more traditional capacity projects that are generally assessed during a “typical” day or peak period, and the results are anticipated to be identical on all other days. Chapter 5 provides an enhanced discussion of how these strategies impacting nonrecurring conditions may be evaluated.
- **It can be difficult in developing the B/C analysis framework to decide if particular impacts represent a new benefit (to users, society or the agency), or if the impacts represent a transfer of benefits from one group to another.** In a B/C analysis, transfers can occur if one group or segment of the population enjoys a new benefit, but does so at the expense of a new disbenefit or additional cost accruing to another group. For example, a deployment of a HOT lane on a corridor could likely increase the amount of revenue that an agency receives. This should not be treated as a benefit in the B/C analysis, however, since the added revenue to the agency is directly offset by the additional cost paid by the HOT lane users. This impact would be considered a transfer; and since the impacts of the increased revenue and the increased costs cancel the other out in the analysis, they should not be included in the B/C framework.

Chapter 3. Operations Strategies and their Impacts (Agency, User, and Societal Benefits)

Definitions of Operations Strategies Covered in this Reference

This *Desk Reference* and the supporting *TOPS-BC* application provide guidance regarding a wide range of TSM&O strategies. Additionally, in many cases, the guidance provided can equally be applied to nonoperational strategies; however, the focus of this guidance is specifically on TSM&O strategies.

The TSM&O strategies covered in this guidance represent a mix of long established, as well as recently emerging technologies. The strategies include investments requiring the deployment of physical systems and hardware, as well as nonphysical improvements, such as enhancing interagency coordination. In general, the strategies are categorized into three groups.

1. **Operations Strategies** – These strategies involve the deployment of physical infrastructure to the roadside or transit assets, and are intended to provide direct impact on transportation system performance through their operation. These strategies are often highly visible to the traveling public and include a wide range of deployments, such as traffic signal coordination, freeway service patrols, 511 traveler information systems, HOT lanes, and DMS, among many others.
2. **Supporting Infrastructure** – Supporting infrastructure includes those backbone capabilities that serve to support and enhance the functioning of the roadside Operations strategies. This backbone infrastructure includes items, such as traffic detection and surveillance, communications, and traffic management centers. Often, by themselves, these strategies have no direct intrinsic benefits. The benefits derived from these strategies are the improved performance of the roadside Operations strategies enabled by their deployment. For example, a traffic surveillance camera by itself has little direct benefit. The benefit is derived from the manner in which the information is used (i.e., when the surveillance from the camera is used by operators to implement different signal timing patterns, or detect and respond to an incident faster). Therefore, the measure of benefit of these supporting infrastructure components is often measured by estimating the improved efficiency of the roadside components supported by the backbone infrastructure, rather than attempting to directly estimate the benefits of the supporting infrastructure itself.
3. **Nonphysical Strategies** – These strategies represent items intended to improve the efficiency and effectiveness of the TSM&O systems and includes strategies, such as improved interagency coordination; the development of advanced operational plans (e.g., evacuation plans); or system integration. While there certainly can be benefits of these activities and there are often costs, there typically is little or no new physical equipment or roadside components.

Similar to the supporting deployments, the benefits derived from these strategies are typically estimated by assessing the improvement in effectiveness of the existing roadside components provided by the strategy or activity.

These categories and the strategies belonging to the various groupings are discussed in the following sections.

Operations Strategies

The following are operations strategies discussed in this *Desk Reference* and included in the *TOPS-BC* guidance:

1. **Arterial Signal Coordination** – This strategy involves the coordination of traffic signal timing patterns and algorithms to smooth traffic flows – reducing stops and delays and improving travel times. This strategy can be implemented on a small corridor, a limited grid, or regionwide in aggressive deployments. The sophistication of the timing coordination can also vary from simple preset timing programs to more advanced traffic actuated corridor systems, to fully centrally controlled applications.
2. **Arterial Transit Signal Priority** – This strategy involves installing transponders on transit vehicles to communicate with the traffic signal systems. Traffic signal timing patterns are adjusted when a transit vehicle is detected approaching the intersection – either providing an early green phase or extending an existing green phase – to allow the transit vehicle to reduce stop delays through the corridor, improving travel times and travel time reliability (maintaining schedules).
3. **Transit AVL** – This strategy involves equipping transit vehicles with transponders and communication capabilities to allow for the real-time tracking of the vehicles by the transit agency. This information is used to better manage the fleet and improve schedule maintenance, thus improving travel time reliability for users and asset use efficiency for the agency. The information generated by the AVL is also often used to support real-time transit traveler information for users.
4. **Ramp Metering** – This strategy involves the placement of a traffic signal on freeway on-ramps to meter the flow of traffic entering the mainline facility and smoothing the flow of traffic in the merge area. Ramp metering may be implemented with minimal cycle lengths designed to simply break up platoons of vehicles entering the facility to smooth the merge operations, or may be operated more aggressively with longer cycle lengths designed to hold traffic on the on-ramp to maintain lower volumes and higher speeds on the mainline facility. Ramp meters may be deployed at single isolated locations, or may be deployed regionwide and are intended to improve merge operations and reduce bottlenecks at on-ramp locations, thus improving corridor travel times and safety. Similar to arterial signal systems, the sophistication of the timing patterns may be determined according to preset, traffic actuated, or centrally-controlled patterns.
5. **Traffic Incident Management (TIM)** – These strategies are often divided into several substrategies that may be combined to create a coordinated system. The benefits of these systems include a reduction in incident related delay (and associated fuel use and emissions impacts), and can include safety benefits by allowing for the faster dispatch and response of emergency personnel and assets to injury accidents. The TIM substrategies include the following:

- a. **Incident Detection and Verification** – Involves the implementation of surveillance, detection, communications, and algorithms to enhance the monitoring of the transportation system to more quickly detect the occurrence of incidents and provide more information to system operators to verify the location and severity of the incident, so that an appropriate response plan may be developed and implemented.
 - b. **Incident Response** – Involves the improved development, communication, and implementation of response plans through coordinated response strategies and computer-aided dispatch (CAD) systems.
 - c. **Freeway Service Patrols (FSP)** – Involves prepositioned or roving “highway helper” vehicles designed to quickly respond to system incidents and mitigate the situation. These vehicles may also provide first responder capabilities for more serious crashes or incidents until more appropriate emergency assets and personnel arrive on scene.
6. **Pretrip Traveler Information** – These strategies provide single mode or multimodal information to travelers prior to the initiation of their trip enabling the user to make better informed decisions on the route, mode, and timing of their travel. Often developed as regional 511 programs, these systems may deliver the information content via telephone, Internet, kiosks, or mobile devices. The enhanced information provided by these systems may also be distributed by existing media outlets (e.g., television or radio).
 7. **In-route Traveler Information** – These strategies may provide a variety of information (e.g., travel times, mode change opportunities, construction work zone information, incident warnings, and alternative route recommendations) to travelers already using the system, allowing the travelers to make more informed decisions on travel route and mode choice. Traditionally provided through DMS or changeable message signs (CMS), HAR, and through distribution by traditional media outlets (radio), the channels for distribution have been expanded in recent years to increasingly include in-vehicle and mobile devices.
 8. **HOT Lanes** – Allows SOVs to pay a toll to use underutilized HOV lane capacity. These systems most often utilize an in-vehicle transponder to determine lane usage and assess tolls. The tolls charged may vary according to time-of-day schedules, or may be dynamically assessed in response to traffic conditions and available HOV lane capacity.
 9. **Speed Harmonization** – Involves the implementation of variable speed limits and the communication of those limits through roadside signs. The speed limits are modified according to congestion levels to lessen stop-and-go conditions and lower the speed of vehicles as they approach downstream bottlenecks. The primary benefit of these emerging systems is improved safety.
 10. **Hard Shoulder Running** – Involves allowing vehicles to travel on the shoulder facilities of roadways often for isolated sections of roadway or limited times of operation. The availability of the shoulder for use is often communicated through the use of overhead gantries or roadside DMS.
 11. **Work Zone Management** – Involves the coordinated implementation and use of pretrip (e.g., 511 web-based applications) and en-route (e.g., DMS and HAR) traveler information, along with construction traffic management and alternative construction work hours planning to mitigate the congestion related to construction work zones.
 12. **Travel Demand Management** – Includes a number of strategies that may be employed to lessen travel demand (number of trips) associated with work commuting traffic. These strategies may include employee-based subsidies for alternative mode use or alternative work hours, or employer-based investment in vanpools or alternative work campuses to lessen the number of trips made by their employees.

Supporting Infrastructure

Supporting infrastructure includes those strategies that provide the backbone infrastructure that enables the effective operation of the roadside components. The benefits from these supporting infrastructure implementations are often measured by estimating the effectiveness and efficiency gains to the roadside components directly supported by the strategy. Supporting infrastructure discussed in this *Desk Reference* includes:⁶

1. **Traffic Detection and Surveillance** – Involves the implementation of traffic detection (e.g., loop detectors, radar detectors, acoustic detectors) and/or camera surveillance systems; and the development of associated data and analysis systems to provide the ability to monitor real-time conditions on the transportation system. This data is often used to support and enhance the capabilities of many Operations Strategies, including traffic signal coordination, ramp metering, incident management and Active Traffic Management (ATM), and traveler information systems.
2. **Traffic Management Centers** – Include the regional traffic and transit management centers, as well as the smaller subregional centers, required to monitor, coordinate, and operate the deployed Operations Strategies.
3. **Communications** – Include the landline and wireless communication networks required to coordinate and operate the Operations Strategies implemented in a region.

Nonphysical Strategies

Nonphysical Strategies are intended to improve the efficiency and effectiveness of the deployed TSM&O systems. The FHWA Integrated Corridor Management (ICM) initiative is an example of a project that heavily leverages many nonphysical strategies. This category includes strategies such as:

1. **ATDM** – The dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Through the use of available tools and assets, traffic flow is managed and traveler behavior is influenced in real time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety, reducing emissions, or maximizing system efficiency. Under an ATDM approach, the transportation system is continuously monitored. Using archived data and or/predictive methods, actions are performed in real time to achieve or maintain system performance.
2. **System Integration** – Involves the integration of two or more systems to allow for the improved exchange of data between the systems and/or the coordinated operation of the systems. For example, a traffic signal coordination system could be integrated with a traffic incident management system to provide additional capacity on parallel diversion routes when incidents occur on a freeway facility.
3. **Interagency Coordination** – Involves the exchange of information and/or agreements allowing for the joint operation of various strategies across different agencies or jurisdictions.
4. **Regional Concepts for Transportation Operations (RCTO)** – The development of regional concepts of transportation operations involves the coordination of the various stakeholders

⁶ Since many of the Supporting Infrastructure components have no direct benefits – their benefits are estimated through the roadside Operations Strategies supported by their implementation – they are not included as strategies available for benefit estimation in the *TOPS-BC* application. However, the ability to estimate the life-cycle costs of these components is provided within *TOPS-BC*. Section 5 of this *Desk Reference* provides additional detail on structuring the estimation of benefits of these Supporting Infrastructure strategies within a benefit/cost analysis framework.

responsible for operating one or more components in order to develop sets of policies, procedures, and operating parameters that may be implemented according to specific identified conditions to improve the efficiency and effectiveness of Operational Strategies during those conditions. The development of a coordinated strategy for operating strategies during a regional evacuation would be an example of a regional concept of transportation operations that might be analyzed using benefit/cost analysis. The FHWA Integrated Corridor Management (ICM) initiative serves as another example as the Concepts of Operations developed in support of this initiative represent RCTOs.

What are the Impacts and Benefits of Operations Strategies?

The operations strategies, discussed in Chapter 3 above, all impact the transportation system, traveler behaviors, and agency operations in different ways. For example, implementation and operation of different strategies could promote changes in the following:

- Roadway volumes (throughput);
- Roadway speeds;
- The duration of incidents;
- Traveler route choice;
- Traveler mode choice;
- Number of trips made by travelers;
- Number of crashes;
- Severity of crashes; or
- Day-to-day agency procedures, among many other possible changes.

These changes represent the direct *impacts* of the strategies; however, these changes do not necessarily represent the *benefits* of the strategy. For example, a change in travel mode promoted by a strategy does not necessarily represent a benefit. The benefit of the change in mode is estimated by measuring the effect that the change in mode has on other more quantifiable metrics, which can be more appropriately valued in monetized terms. Therefore, the *impact* of the change in mode is measured by the resulting change in several *MOEs*, such as vehicle operating costs, fuel use, emissions, crash risk exposure, and other measures that may result.

In benefit/cost analysis, the direct and measurable *impacts* of strategies are often important in that they are used as a means of estimating changes to various *MOEs*; however, within the benefit valuation framework of the analysis, the impacts are not valued, but are merely an input to the calculations. The sections below provide additional discussion of various *MOEs* that may be used in assessing TSM&O strategies in a benefit/cost analysis. These are segmented according to:

- Traditionally recognized *MOEs*;
- Emerging *MOEs*; and
- Hard-to-quantify *MOEs*.

Traditionally Recognized MOEs

There are a number of MOEs that are often used in assessing TSM&O strategies. In large part, these MOEs are derived from and consistent with many of the measures used in assessing more traditional capacity related transportation improvements. This is fortunate since the consistency in many of these measures promotes and allows the comparison of the relative benefits across different types of strategies. Additionally, the long-term use of many of these measures has often resulted in a greater consensus regarding the established valuations that may be applied to monetize the benefit.

The most typically applied benefit/cost MOEs include:

- User travel time savings;
- User vehicle operating costs;
- Crashes; and
- Emissions.

These typically used MOEs are summarized in the discussions below. Chapter 4 of this *Desk Reference* identifies various existing tools and analysis methods that may be used to estimate these measures; and additionally, Chapter 5 of this *Desk Reference* provides specific guidance in estimating these MOEs using the various analysis tools and methods.

User Travel Time Savings⁷

User travel time is the most often used MOE for a wide range of transportation improvements, including both TSM&O and more traditional capacity-enhancing projects. At its simplest level, user travel time represents the net change in the sum of all person hours of travel (PHT), resulting from implementation of the strategy within the defined geographic scope of the analysis. The travel time, as measured by PHT, may be differentiated by:

- **In-vehicle travel time** – PHT incurred in the mode of choice of the individual; and
- **Out-of-vehicle travel time** – PHT necessary to access the mode of choice.

This differentiation is more often used in analyses involving transit modes and is used to represent the time necessary to walk to the transit stop, wait for the transit vehicle, and wait at any transfer locations, but may also be used with auto modes to represent the time necessary to access (walk to) the vehicle in locations where parking is not immediately adjacent to the desired destination.

Depending on the analysis, the PHT may be estimated separately for different modes. This may be done simply to provide an estimate of benefits by mode, or because different benefit valuations will be applied to travel time incurred in different modes. Most typically, truck travel time is differentiated from auto and transit travel time due to the higher costs associated with truck travel time (costs of the driver salary and the carrying costs of the vehicle cargo).

Figure 3-1 shows an example analysis of the daily and annual incremental change in user travel time between a baseline and alternative scenario, where the measure of user travel time was broken out

⁷ Note: The use of consumer surplus and travel time reliability in the measure of travel time-related benefits are discussed in a subsequent section on “Emerging Measures of Effectiveness”.

separately for auto, truck, and transit modes. Further, the transit PHTs were also broken out by in-vehicle and out-of-vehicle travel time.

Figure 3-1. Example Display of User Travel Time MOE

Benefit/Cost	Baseline	Alternative	Difference	Annual Difference
Auto Vehicle Miles of Travel (VMT)	170,177,633	170,204,412	26,779	6,694,695
Truck VMT	18,128,820	18,136,463	7,643	1,910,870
Average Vehicle Occupancy	1.42			
Person Hours of Travel (Auto)	5,923,262	5,922,600	(663)	(165,631)
Vehicle Hours of Travel (Truck)	462,006	462,006	-	-
Person Hours of In-vehicle Travel (Transit)	40,679,986	40,649,288	(30,698)	(7,674,482)
Person Hours of Out-of-vehicle Travel (Transit)	33,925,318	33,935,621	10,303	2,575,640

Source: San Francisco Bay Area MTC, *2035 Long-Range Transportation Plan Project Performance Analysis*, 2011.

Also depending on the benefit valuation scheme to be applied and the rigor of the analysis, the net change in PHT may be segmented by trip purpose. The most typical categorization includes:

- **On-the-clock travel** – Represents those business people traveling to a meeting during work hours (e.g., a plumber traveling to the next work site);⁸
- **Commuter travel** – Represents those individuals traveling between their homes and their business locations; and
- **Nonwork travel** – Represents individuals making trips for shopping, school, recreation, or other purposes.

The reason for differentiating these trip purposes is to apply a different value of travel time based on the nature of the trip. Travel time incurred during on-the-clock trip purposes may often be valued at a higher rate than nonwork travel in an analysis due to more the greater direct costs incurred in any delay in this type of travel.

Although the user travel time measure is commonly used in benefit/cost analysis, there are limitations to using the measure in average, recurring travel time to assess TSM&O strategies. Many TSM&O strategies are targeted specifically at reducing nonrecurring travel time – due to incidents, inclement weather, excessive demand (special events), and construction activity – therefore, only using measurement of recurring travel time will result in the severe understatement of benefits due to TSM&O strategies. In recognition of this limitation of using average, recurring travel time, the measure of nonrecurring travel time or travel time reliability (variability) has become an important emerging trend in benefit/cost analysis. The travel time reliability measure is discussed in a subsequent section on emerging MOEs.

Source of Measure Estimation in the Analysis. The method of estimating the net change in user travel time in the analysis can range from simple, nearly back-of-envelope type estimations of change to complex analysis involving detailed data and models to calculate the expected changes in

⁸ Generally, all truck mode travel time is considered “on-the-clock” travel time, unless valued separately.

transportation system demand and performance. The method and tool used to estimate this MOE should be appropriately scaled to the needed rigor of the analysis. Chapter 4 and the *TOPS-BC* tool both provide additional guidance on selecting and applying appropriate analysis tools and methods.

At the simplest level, the change in user travel time may be estimated by applying a factor representing the anticipated impact of the strategy to a baseline measure (representing either a current or a future forecast of travel times without the strategy). Many of the sketch-planning tools described in Chapter 4 provide a slightly advanced application of this methodology.

If greater confidence in the accuracy of the analysis results is called for by the needs of the analysis, the estimates of the net change in user travel time may be obtained from more advanced modeling techniques, such as travel demand models or simulation models. These models are also often capable of estimating the change in travel time by mode and/or by trip purpose, if the analysis requires that level of categorization. For detailed evaluation of existing strategies, archived data sources may also be used to generate the input data (with improvement and without improvement) needed to estimate the net travel time change. Chapter 4 of this *Desk Reference* provides additional information on the available tools and methods for analyzing user travel time. Chapter 5 provides additional guidance on applying these techniques.

User Vehicle Operating Costs

The use of changes in net vehicle operating costs in benefit/cost analysis of TSM&O strategies is common practice. This MOE is typically broken out into fuel use and nonfuel use categories; although in simple analysis, they may be combined as a single measure. Nonfuel costs typically include measures of maintenance, insurance, and depreciation costs, but do not include vehicle registration and taxes, as these are often considered transfers in benefit/cost analysis.

Similar to the use of user travel time, measures of vehicle operating costs are also often used in assessments of non-TSM&O strategies, increasing the comparability of benefit/cost results across a variety of project types.

Source of Measure Estimation in the Analysis. Estimation of vehicle operating costs is usually relatively easy to estimate, and is often based on simple valuations applied directly to vehicle miles of travel (VMT). For simple analysis, a static rate of average fuel use (gallons per VMT) is applied to any net change in VMT to estimate the net change in fuel use. A benefit value (cost per gallon of fuel exclusive of fuel taxes) is then applied to the change in the number of gallons of fuel consumed. Note that since estimated fuel use rates can differ substantially based upon the year of analysis (future year vehicle fleets are anticipated to have greatly improved fuel use rates), practitioners are encouraged to use rates appropriate to the year of analysis. The U.S. Environmental Protection Agency (EPA) provides data on the past and future anticipated vehicle fleet fuel usage rates.⁹

Although an average fuel use rate may be applied for simple analyses, a fuel use rate sensitive to actual travel speeds may be appropriate for more rigorous analyses, since fuel use is directly associated with travel speeds. For these analyses, a look-up function needs to be applied to link the appropriate fuel use rate to a facility based on the average speed noted for the roadway. The appropriate fuel use rate (in gallons per VMT) may then be applied to the roadway VMT. Different rates are applied to freeway and arterial facilities for any given speed range.

⁹ <http://www.epa.gov/fueleconomy/>.

In these analyses, any net change in total VMT or roadway speed attributable to the TSM&O strategy will affect a change in fuel use. Fuel use rates supplied by the U.S. EPA and other sources are applied according to speed and vehicle type (e.g., auto, gas truck, diesel truck) to obtain total fuel use. Table 3-1 presents a sample of year 2010 fuel use rates as specified by U.S. EPA.

Table 3-1. Sample EPA Fuel Use Rates by Average Speed for Year 2010
(in Gallons per VMT)

Facility type	Speed	Auto	Truck Gas	Truck Diesel
Freeway	0	0.540	0.650	0.450
	5	0.182	0.310	0.696
	10	0.123	0.181	0.489
	15	0.089	0.135	0.297
	20	0.068	0.118	0.185
	25	0.054	0.120	0.131
	30	0.044	0.133	0.110
	35	0.037	0.156	0.112
	40	0.034	0.185	0.122
	45	0.033	0.223	0.136
	50	0.033	0.264	0.153
	55	0.034	0.310	0.170
	60	0.037	0.374	0.187
	65	0.043	0.439	0.204
70	0.052	0.511	0.221	
Arterial	5	0.144	0.275	0.383
	10	0.091	0.174	0.241
	15	0.073	0.140	0.194
	20	0.064	0.123	0.171
	25	0.059	0.113	0.157
	30	0.056	0.106	0.147
	35	0.053	0.101	0.140
	40	0.051	0.097	0.135

Source: <http://www.epa.gov/fueleconomy/>.

For nonfuel operating costs, an established value in these costs per VMT are directly applied to the change in VMT to estimate the benefit value. Similar to fuel use rates, the per VMT value may be sensitive to the forecast year of analysis; however, the valuation is usually not sensitive to differences in operating conditions (travel speeds, etc.).

Crashes

The assessment of safety impacts, particularly the risk of exposure to crashes, is typically a critical part of any transportation benefit/cost analysis. Many TSM&O strategies have proven to have significant benefits in the reduction of the number and/or severity of vehicle crashes. Strategies that serve

to smooth the flow of traffic at difficult merge points, such as ramp metering systems, have been observed to directly reduce the risk of crash exposure at those locations. Meanwhile, applications such as traffic incident management that serve to improve the emergency response to crashes have been demonstrated to reduce the severity of crashes by quickening the response times and better ensuring the appropriate emergency responder assets are directed to the scene when crashes occur.

The benefit valuations typically applied to a reduction in the number of crashes are often substantial, particularly in the case of fatality and injury crashes, ranging into multiple millions of dollars. Often, these valuations are based on a two-tiered structure to fully capture the benefits of a reduction in the number or severity of a crash. Typical crash reduction benefit valuations are based on a combination of the following valuation methods:

- **Actual costs** – This valuation methodology is intended to capture the actual accountable costs of the crash. For example, in the case of a fatality crash, these costs would include the costs of medical treatment of the victims, the loss of the victim’s wages for the family, and any property damage.
- **Cost to avoid** – Most crash valuations additionally include a measure of the additional cost to avoid; or in other words, an estimate of the value that individuals would likely pay to avoid being involved in a crash of this severity. This valuation additionally accounts for the potential pain and suffering experienced by the crash victim(s) and their families.

Source of Measure Estimation in the Analysis. To estimate the change in the number of crashes attributable to a TSM&O strategies, crash rates (typically expressed as crash occurrence per million VMT) are applied to the change in VMT in the network or for a particular facility type (freeways versus arterials). Different crash rates are also usually applied for different severities of crashes, most generally defined as:

- Fatality crash;
- Injury crash; and
- Property damage only crash.

However, many different agencies use different categorization schemes for crashes; often breaking injury crashes into more discrete severity categories (minor injury versus severe injuries). Many agencies also maintain their own crash rates that are based on local crash records, and are typically the best source of rates for use in any TSM&O benefit/cost analysis since they are locally derived and consistent with analysis performed for other non-TSM&O strategies.

At the simplest analysis level, a single static rate (for each crash severity) may be applied to the total change in VMT for all vehicle categories estimated from the application of the TSM&O strategies. For more rigorous analysis, more segmented and dynamic rates may be researched and applied. These enhanced rates may be categorized or sensitive to:

- Vehicle types (autos versus trucks);
- Facility types;
- Roadway configuration and geometrics;

- Existing roadway safety installations;
- Facility speeds;
- Facility congestion levels (most often facility volume/capacity ratio); and/or
- Even applied to individual links based on actual historical crash occurrence.

The level of sensitivity of the crash rates to be applied in any given analysis is typically based on the following factors:

- The locally prescribed crash analysis rate;
- The need to maintain consistency with other local analysis;
- The analysis rigor (level of confidence required in the analysis results);
- The type of TSM&O strategy being analyzed (i.e., some TSM&O strategies may be anticipated to have more direct crash savings benefits, and thus may require additional analysis rigor to quantify these benefits);
- Availability of enhanced rates; and
- Availability of appropriately structured input data (e.g., VMT by facility type and vehicle type) to support the crash analysis structure.

Beyond the analysis of crash occurrence based on estimated changes in VMT, many TSM&O strategies additionally may influence the actual crash rate that should be applied. For example, ramp metering applications serve to smooth traffic merging at the confluence of traffic at the end of the on-ramp lane. This smoothing of the merge has been observed to result in a meaningful decrease in the crash rate (particularly for sideswipe, rear end, and run-off-road accident types that are common in merge areas). Previous ramp meter applications deployed nationwide have been observed to reduce crashes in the merge area by approximately 7 to 25 percent. This crash rate reduction is in addition to any change in the number of crashes resulting from changes in the underlying VMT. Similarly, strategies such as speed harmonization applications are intended to smooth the flow of traffic and reduce the amount of stop-and-go movements. These applications would likely reduce the risk of crashes without any change in the underlying VMT at that location.

In these situations, where the TSM&O strategy has a direct linkage to reduced crashes, the crash rate that is applied at locations influenced by the TSM&O strategy should be reduced prior to application to the VMT observed for the applicable facility. Using the ramp metering example above, the applicable crash rate would reasonably be reduced by 7 to 25 percent prior to application to the VMT estimated in the merge area following the application of ramp metering.

Emissions

Emissions are another commonly used MOE for TSM&O strategies, as well as traditional infrastructure projects. The inclusion of emissions estimates in the benefit/cost analysis is particularly important when projects are being prioritized in competition for several types of funding (e.g., Congestion Mitigation and Air Quality (CMAQ) funds); or the project is being considered in an air quality nonattainment area.

Emissions categories considered in benefit/cost analysis most often include one or more of the following emissions categories, and typically include those emissions categories of most concern in the local region:

- Hydrocarbons (HC)/Reactive Organic Gases (ROG);
- Nitrous Oxide (NO_x);
- Carbon Monoxide (CO);
- Carbon Dioxide (CO₂);
- Particulate Matter (PM₁₀) or Fine Particulate Matter (PM_{2.5}); and
- Sulfur Dioxide (SO₂).

Emissions may represent one of the most complex to estimate MOEs used in many B/C analyses. This is due to the many variables that determine the appropriate emission rates. Most emissions estimations are based on an application of an emissions rate on a per VMT basis. Depending on the emissions category, the appropriate emissions rate to apply may be sensitive to numerous factors, including the following:

- Year of the analysis – Future year vehicle fleets are anticipated to produce fewer emissions in many categories;
- The mix of gasoline and diesel vehicles in the regional fleet;
- Vehicle speeds;
- The number of cold starts;
- The mix of vehicles in the regional vehicle mix (e.g., autos, light trucks, medium-duty trucks, heavy-duty trucks, etc.); and
- Regional weather patterns/climate and other considerations.

Given these many variables impacting emissions rate, the rates for most analysis need to be obtained from existing emissions analysis tools specifically configured to the individual region, or derived from previously conducted regional analysis. Therefore, caution should be applied in using rates derived from other regions or based on averages between different regions.

Source of Measure Estimation in the Analysis. Many urban areas, particularly those in nonattainment areas, maintain robust emissions estimation and analysis models and tools. These are most typically based on the U.S. EPA tools, including MOBILE or MOVES, for most of the country. In California, emissions analysis is based on tools and guidance developed by the California Air Resources Board (CARB). These customized and configured tools are typically the best source of analysis of emissions impacts, when available. These tools and analyses are typically linked to analysis conducted in the regional travel demand model; and in many cases, the emissions analysis is performed as a post-processing of the travel model data outputs, or may also be performed as an iterative feedback loop with the travel demand model.

In areas when an appropriate regional air quality model is unavailable or situations where running the full analysis model is impractical given the time and budget resources available for the analysis,

more simplified analysis may be necessary. Simplified emissions analysis may be conducted using emissions rate tables derived from the regional emissions analysis process combined with a look-up function to ascertain the appropriate rate (based on vehicle class and speed) to apply. Several sketch-planning and post-processing analysis tool (discussed in more detail in Chapter 4) use this simplified approach for their own internal emissions analysis. Practitioners using this simplified method need to use caution in selecting rate tables that are appropriate for the region and time periods being analyzed.

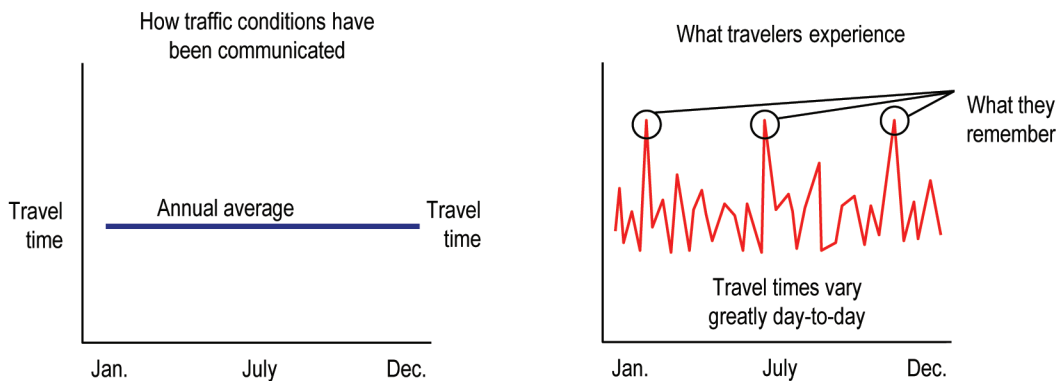
Emerging MOEs

In recent years, several new MOEs have been introduced into many B/C analyses, including measures of travel time reliability (variability), consumer surplus, and measures of global climate change. These measures can often provide more justification for TSM&O projects as these measures, particularly travel time variability, are precisely the focus of many Operations deployments.

Travel Time Reliability

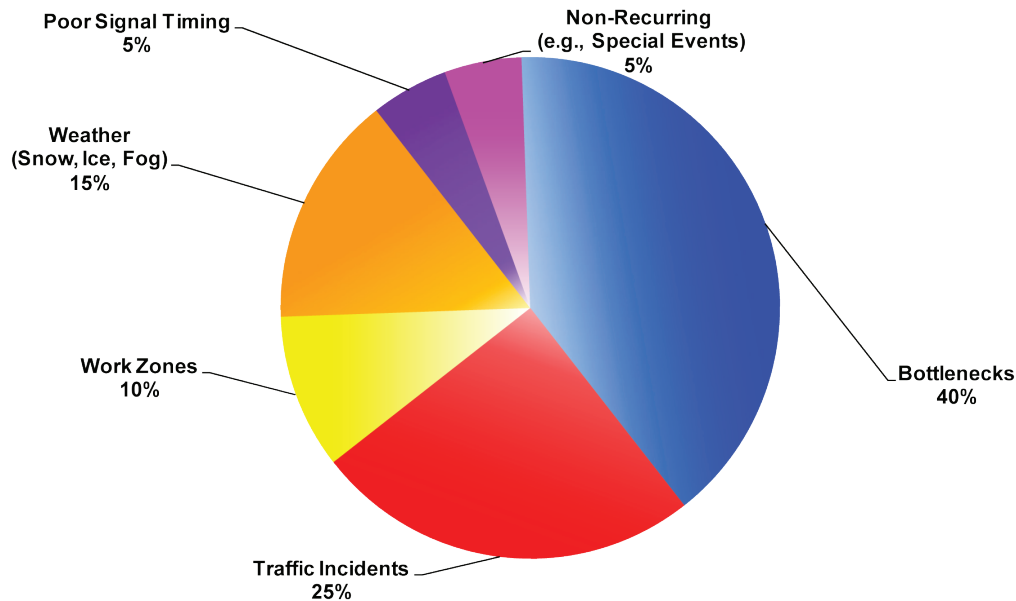
Practitioners and researchers have increasingly been assessing the importance of travel time reliability when evaluating transportation projects. Historically, average travel time was the primary measure most often used for B/C analysis of transportation projects. However, use of this average measure often only captures the change in recurring travel time, due to the nature of the measure itself and the methods that were often used to assess the measure. As shown in Figure 3-2, use of the average travel time may not realistically represent actual traveler's experiences.

Figure 3-2. Use of Recurring Travel Time Measurement versus Actual Traveler Experience



Source: http://ops.fhwa.dot.gov/freight/freight_analysis/perform_meas/fpmtraveltime/traveltimebrochure.pdf.

More recently, significant research and analysis have been performed on the effects of nonrecurring travel time delay – travel time delays caused by factors, such as incidents, special events, weather, construction work zones, and poorly timed traffic signal systems, among other causes. Research completed as part of the Transportation Research Board's (TRB) Strategic Highway Research Program (SHRP 2) and other numerous Federal and state efforts have shown the amount of delay caused by nonrecurring congestion is substantial; and leaving this measure out of transportation B/C analysis risks severely understating the potential benefits of many improvements. Figure 3-3 presents a breakdown of the typical causes of congestion, as estimated from national sources; and shows that nonrecurring sources of congestion account for more than one-half of the total delay in a typical urban network.

Figure 3-3. National Summary of the Sources of Congestion

Source: Cambridge Systematics, Inc., and Texas Transportation Institute, *Traffic Congestion and Reliability: Linking Solutions to Problems*, July 19, 2004, http://ops.fhwa.dot.gov/congestion_report_04/executive_summary.htm.

Travel time reliability measurement seeks to quantify the variability in travel times caused by nonrecurring, as well as recurring, congestion sources in order to better estimate the full distribution of travel times experienced by the system users. A number of performance measures and indices have been developed to help quantify these impacts, as shown in Table 3-2.¹⁰ Many of these measures are based on an analysis of the distribution of travel times for a particular segment or facility.

¹⁰ Note: Although many of these performance measures are useful in assessing system reliability, they are not appropriate as MOEs to be used in B/C analysis since they provide relative comparisons of reliability levels that are not immediately able to be valued (monetized).

Table 3-2. Reliability Performance Measures

Reliability Performance Metric	Definition	Units
Planning-Time Index	<ul style="list-style-type: none"> 95th percentile Travel Time Index (95th percentile travel-time divided by the free-flow travel time), normalized by the average travel time 	None
Buffer Index (BI)	<ul style="list-style-type: none"> The difference between the 95th percentile travel time and the median travel time, normalized by the median travel time The difference between the 95th percentile travel time and the average travel time, normalized by the average travel-time The difference between the 95th percentile travel time and the median travel time, normalized by the median travel-time 	Percent
Failure/On-Time Measures	<ul style="list-style-type: none"> Percent of trips with travel-times less than 1.1 * Median Travel Time or 1.25 * Median Travel Time Percent of trips with space mean speed less than 50 mph, 45 mph, or 30 mph 	Percent
80 th Percentile Travel-Time Index	<ul style="list-style-type: none"> 80th percentile travel time divided by the free-flow travel time 	None
Skew Statistic	<ul style="list-style-type: none"> The ratio of (90th percentile travel time minus the median) divided by (the median minus the 10th percentile) 	None
Misery Index (Modified)	<ul style="list-style-type: none"> The average of the highest five percent of travel times divided by the free-flow travel time 	None

Source: SHRP 2 Project L03 Final Report: Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies.

In addition to the research work completed on improved measures and analytical methods for assessing travel time reliability in a network, many parallel efforts have been undertaken to demonstrate the impact that many different types of transportation strategies have in improving travel time reliability. Both traditional types of capacity expansion projects and TSM&O strategies have been shown to improve reliability. Although most typically focused on recurring congestion issues, traditional capacity increasing projects may improve reliability since roadways and transit facilities with more available capacity are more easily able to handle unusual spikes in demand or weather the impacts of an incident. TSM&O strategies are often more directly targeted at the underlying causes of nonrecurring congestion – incidents, weather, construction work zones, special events, and poor operations – and can have substantial success in mitigating the delay caused by these sources. Therefore, it is important that travel time reliability be considered for traditional capacity projects; however, it is often even more critical that this measure be considered for B/C analysis of TSM&O strategies, since a much higher proportion of the anticipated overall benefit is expected to be derived from these strategies' impacts on reducing nonrecurring congestion.¹¹

Source of Measure Estimation in the Analysis. To meet the need to be able to better consider valuation of travel time reliability benefits within a benefit/cost analysis structure, many new and

¹¹ SHRP 2 L03 Final Report: Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies, 2010.

enhanced methods for quantifying this measure have been proposed, developed, and tested. However, as much of this research is still evolving, there are frequently limitations in applying many of the techniques. Additional research is ongoing to refine and enhance the approaches; some of which are detailed below.

Measurement of standard deviation. For existing deployments where sufficient “before and after” data is available, the impact on travel time reliability may be estimated by comparing the distributions of travel time prior to application of the strategy (the “before” or “without” scenario) with the distribution following the application (the “after” or “with” scenario). The net change in the standard deviation in minutes of travel time may be calculated from the distributions and multiplied with the number of facility users to estimate a temporal measure of travel time reliability savings. A value may be applied to this measure to monetize the benefit for use in the B/C analysis. This type of analysis assumes, however, that an evaluation of an existing deployment is being performed – the method is not as useful as a predictive tool – and that sufficient data is available to support the estimation of the travel time distributions.¹² Data required to identify the travel time distributions may be obtained from long-term data archive systems, multiple manual data collection/monitoring activities, or modeling efforts using multiple scenarios representing varying expected traffic conditions (see Chapter 5 for an expanded discussion of structuring modeling analysis to consider impacts during varying traffic conditions). Regardless of the data source, the analyst needs to ensure that the dataset used to estimate the distribution of travel times is sufficiently robust to fully capture travel times during a representative sampling of travel time conditions. This may require six months to multiple years’ worth of constant data in some situations, where a high level of confidence in analysis results is required.

Measurement of total recurring and nonrecurring delay. The development of the SHRP 2 L03 Report, *Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies*, resulted in the refinement of an approach to estimate total delay (combining both recurring and nonrecurring delay), based on the mean recurring travel time and assuming a normal distribution of travel times. The developed analysis method and equation are intended for application in “data poor” situations, where the robustness of either the archived historic traffic data or the modeled predicted traffic data was insufficient to provide meaningful analysis of nonrecurring congestion delay. The function below, which is intended to be applied to freeway facilities, was estimated by statistically examining the relationship between the total mean travel time delay and the mean recurring travel time estimate (as based on long-term data collected and analyzed from multiple regions throughout the nation); and allows an adjustment of the mean recurring travel time estimate to include the addition of an estimate of nonrecurring travel time.¹³

$$\text{MeanTT} = 1.0274 * \text{RecurringMeanTT} + 1.2204$$

The above equation provides a reasonable approximation of the relationship between overall congestion and recurring congestion. The method does produce a measure of total recurring and nonrecurring delay that may be summed for all facilities and users, compared for a baseline and alternative scenario to identify a net change in the measure, and monetized to provide an estimate of travel time reliability in the B/C analysis. However, its application in B/C analysis for TSM&O strategies

¹² Modeling of multiple scenarios representing varying traffic conditions may be used to make this analysis methodology more applicable for predictive use. See Section 5.0 for a discussion of the required analysis structure.

¹³ SHRP 2 L03 Final Report, *Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies*, 2010.

is limited, primarily due to the inability to effectively break out recurring travel time from nonrecurring travel time (travel time reliability), and the difficulty in assessing the specific impact that particular TSM&O strategies may have on reducing specific causes of nonrecurring congestion since any change in total mean travel time is only based on changes in mean recurring travel time.

Additional work is currently underway as part of a subsequent SHRP 2 project to allow for more effective breakout of the nonrecurring congestion by source; and to develop additional analysis methods to estimate the impacts of various TSM&O strategies on the source causes of congestion, thus allowing broader application of this methodology.¹⁴

Incident related delay. As shown previously in Figure 3-3, traffic incidents account for approximately 25 percent of all congestion delay and the most substantial proportion of nonrecurring (nonbottleneck related) delay sources in most urban areas. As a result, several analysis methods have been specifically developed to estimate incident-related delay.

The most prevalent example of these methods is the analysis originally developed and implemented as part of the analysis capabilities of the FHWA's IDAS sketch-planning tool.¹⁵ The IDAS incident delay analysis involves the use of look-up rate tables containing estimates of the amount of incident-related delay likely to be experienced for a facility on a per VMT basis. These rates were predicted based upon long-term monitoring and analysis of annual incident delay experience on a number of national freeway corridors. These rates are sensitive to several key input factors, including the following:

- **The number of facility lanes** – The incident-related delay rate for freeways with a greater number of lanes is less than for facilities with fewer lanes, assuming other factors are also equal. This is due to the more substantial blockage of capacity caused by similar incidents on roadways with fewer lanes. For example, identical incidents blocking a single lane would reduce capacity by one-half of the available lanes on a two-lane facility, but only reduce capacity by one-quarter of the available lanes on a four-lane facility.
- **The facility volume-to-capacity (V/C) ratio** – The level of base congestion (prior to the occurrence of the incident) is represented by the V/C ratio. Facilities with a higher V/C ratio will have higher incident-related rates associated with them, as it would be expected that incidents on these more congested facilities would cause a quicker breakdown in conditions and a longer time required to allow the incident-related queue to dissipate once the incident was cleared.

Different rates are also estimated based on the length of the analysis period (one-hour, two-hour, three-hour, four-hour, or daily). Table 3-3 presents an example of the travel time reliability rates used in IDAS. These tables may be employed using a look-up function in an analysis to identify the appropriate rate to the VMT estimated for the facility. This estimation would be performed for the baseline scenario (without the improvement) and for an alternative scenario (with the improvement). The amount of incident-related delay would be expected to change if there are any changes in roadway volumes, capacities, or number of lanes as a result of the improvement in the alternative scenario as compared to the baseline scenario.

¹⁴ SHRP 2 L05 Draft Interim Report, *Incorporating Reliability in the Transportation Planning Process*, 2011.

¹⁵ www.idas.camsys.com.

Table 3-3. Sample IDAS-Derived Travel Time Reliability – Rates for One-Hour Peak
(Vehicle Hours of Incident Delay per Vehicle Mile)

Volume/1-Hour Level of Service Capacity	Number of Lanes		
	2	3	4
0.05	3.44E-08	1.44E-09	4.39E-12
0.1	5.24E-07	4.63E-08	5.82E-10
0.15	2.58E-06	3.53E-07	1.01E-08
0.2	7.99E-06	1.49E-06	7.71E-08
0.25	1.92E-05	4.57E-06	3.72E-07
0.3	3.93E-05	1.14E-05	1.34E-06
0.35	7.20E-05	2.46E-05	3.99E-06
0.4	0.000122	4.81E-05	1.02E-05
0.45	0.000193	8.68E-05	2.34E-05
0.5	0.000293	0.000147	4.93E-05
0.55	0.000426	0.000237	9.65E-05
0.6	0.0006	0.000367	0.000178
0.65	0.000825	0.000548	0.000313
0.7	0.001117	0.000798	0.000528
0.75	0.001511	0.001142	0.00086
0.8	0.002093	0.001637	0.00136
0.85	0.003092	0.002438	0.002115
0.9	0.005095	0.004008	0.003348
0.95	0.009547	0.007712	0.005922
1	0.01986	0.01744	0.01368

Source: IDAS User's Manual – Appendix A, 2008.

In addition to changes in incident-related delay forecast due to predicted changes in volume, capacity, or number of lanes, some TSM&O strategies have been observed to lessen the frequency of incidents or reduce their duration. Strategies such as traffic incident management systems have been observed to reduce incident-related delay by up to 40 percent due to the improved and faster response provided by the enhanced incident detection, verification, and coordinated response.¹⁶ In this analysis situation, the hours of incident-related delay for the facility would first be calculated for the baseline and the alternative using the look-up analysis described in the paragraph above. Then, the resulting estimation of hours of incident-related delay for the alternative scenario would be further reduced by 40 percent (or another factor more appropriate to the local conditions) prior to comparison with the baseline and valuation in the B/C analysis. Further description of how this analysis may be performed is provided in Chapter 5.

¹⁶ www.idas.camsys.com.

The methodology used in IDAS for estimating incident-related delay has been adopted for use in the *TOPS-BC* tool that supports this *Desk Reference*. A description of how this analysis is applied is described in the *TOPS-BC* User's Manual.

Induced Travel/Consumer Surplus

The concept of consumer surplus has increasingly been applied in many recent B/C analyses of transportation projects. Consumer surplus is an economic concept intended to enhance the analysis of travel time and costs. It is based on the principle of weighing the willingness of individuals to pay (in time and money) for a particular trip with the actual cost of the trip, and is capable of more accurately assessing the benefits of any *induced travel* resulting from the improvement.

Each user of the transportation facility is willing to pay a certain price (in terms of time, accident risk, vehicle operating costs, tolls, etc.) to travel on that facility. This amount will differ from user to user. However, every user typically incurs the same travel time costs. The difference between what a group of users is willing to pay in terms of travel costs (travel time, etc.) and what they actually pay is called consumer surplus. In a benefit cost analysis, we are concerned with the change in consumer surplus attributable to a transportation improvement.

Measurement of consumer surplus is most often used in the assessment of travel time savings in place of simple measures of the total change in facility travel time observed between the baseline and alternative scenarios. An example of why consumer surplus may be a more accurate picture of travel time benefits, as opposed to using an approach that only considers the total change in travel time, is provided here. A section of roadway in the baseline scenario carries 6,000 vehicles during a peak period and maintains an average travel time of 20 minutes, resulting in 2,000 hours of vehicle travel time. In an alternative scenario, the segment travel time is reduced to 18 minutes as a result of a deployment; however, this improvement in travel time promotes an additional 800 travelers, who previously chose to forego their trips, to now travel, resulting in 6,800 trips on the facility. This would result in a total of 2,040 hours of travel time in the alternative scenario. If only total travel time was used to estimate the benefits of the improvement scenario, the analysis would indicate that the transportation improvement resulted in a disbenefit, since there would be 40 more hours of travel time incurred in the alternative scenario as compared with the baseline scenario.

The estimation of a travel time disbenefit in the above example is counterintuitive since all the existing travelers incur less travel time to traverse the segment; and the new induced travelers must also be benefiting from using the facility, or they would not have chosen to change their behavior. When consumer surplus is estimated, the impacts of new, induced travel are treated separately to account for this effect. Typically, a linear relationship is assumed in the elasticity of individuals' sensitivity to travel in response to costs, therefore, allowing new traveler benefits to be estimated as one-half (50 percent) of the benefits of existing users. The following two formulas would be used to estimate consumer surplus benefits for existing and new users of a transportation facility:

Where:

V1 = Baseline volume

V2 = Alternative volume

P1 = Baseline price (travel time)

P2 = Alternative price (travel time)

$$\begin{aligned}\text{Existing users} &= V1 * (P1 - P2) \\ \text{New users} &= 0.5(V2 - V1)(P1 - P2)\end{aligned}$$

Using the hypothetical example provided above, this consumer surplus would be calculated as follows:

$$\begin{aligned}\text{Consumer Surplus Existing Users} &= 6,000 * (20 \text{ min} - 18 \text{ min}) = 200 \text{ hours} \\ \text{Consumer Surplus New Users} &= 0.5 * (6,800 - 6,000) * (20 \text{ min} - 18 \text{ min}) = 13.3 \text{ hours}\end{aligned}$$

The sum of these two values represents the estimated change in consumer surplus due to the transportation improvement, or:

$$\text{Total Consumer Surplus} = 200 \text{ hours} + 13.3 \text{ hours} = 213.3 \text{ hours saved}$$

Thus, the use of consumer surplus in place of standard total travel time benefit in this analysis results in a more accurate depiction of the improvement as having positive travel time benefits. Since the measurement of consumer surplus is closely linked with induced travel, it is most often used in analyses that are anticipated to result in significant numbers of induced trips being made.¹⁷ If only a small number or no new trips are expected to be made as a result of the improvements being analyzed, there is little advantage in using consumer surplus, since the estimation of benefits will not vary significantly from the benefits estimated using total travel time.

Note: “New” trips in the analysis are only intended to represent those travelers who previously did not make a trip, but were induced to travel by the lowered cost of making the trip. Increased volumes of trips resulting from route changes from parallel roadways or mode shifts from other forms of transportation should not be treated as induced travel in this analysis method.

Difficult to Quantify MOEs

Beyond the more traditional and emerging MOEs discussed above, a number of additional potential benefits of TSM&O strategies have been identified and studied. Meaningful estimation of many of these MOEs within the confines of a B/C analysis framework has often proven difficult, however. Barriers to developing accurate quantification of these barriers often include:

- Few existing estimation/analysis methods;
- Little established consensus on the appropriate valuation to place on the change estimated for the MOE;
- Potential overlap with existing measures (increasing the likelihood of double-counting of benefits);
- Quantification of the measures is not supported by generally used transportation analysis tools; and
- Little empirical evidence establishing a link between TSM&O strategies and quantifiable changes in the measures.

¹⁷ Although the discussion in this section focuses on the effects of induced trips, consumer surplus can be equally applied to capture the disbenefits of individuals deciding to forego travel in response to an increase in travel time or the cost of travel.

Several examples of these difficult to quantify MOEs include:

- **Community livability** – Improvements to the desirability of a community to residents due to the more efficient and effective operation of the transportation system. Inclusion of these benefits in analysis of TSM&O strategies is often hampered by the lack of a clear consensus of how TSM&O strategies affect livability in a community, as well as appropriate methods for estimating and valuing this measure.
- **Customer satisfaction** – Many TSM&O strategies have been shown to have a strong linkage to improving customer (traveler) satisfaction. Surveys and customer comments related to improvements, such as freeway service patrols and traveler information systems, are often highly positive and supportive of these types of improvements; however, there often remain significant barriers to establishing appropriate valuations of these benefits in a B/C analysis.
- **Traveler feelings of safety and security** – Some TSM&O strategies have been shown to enhance travelers' feelings regarding the safety and security of travel. For example, surveys and system user comments have revealed that travelers highly appreciate the availability of freeway service patrols (FSP). Even travelers who have never had to use the services first-hand often feel more secure in their travels knowing that they are less likely to be stranded in an uncomfortable or dangerous situation given the presence of the FSP. Likewise, strategies that serve to smooth the flow of traffic and reduce crash risk exposure (e.g., an application of ramp meters at a difficult merge location) may also serve to reduce the anxiety of users traveling through the improvement location. This benefit is typically not captured in the valuation of crash occurrence, mostly due to difficulties in valuing (e.g., assigning a dollar value) to the benefit.

Given the difficulties in quantitatively assessing many of these MOEs, these benefits are more often analyzed using more qualitative assessment external to the B/C analysis. As more information is gathered on these measures and the linkage of TSM&O strategies to these measures, more enhanced quantitative analysis may be possible in the future.

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Chapter 4. Existing B/C Tools and Methods

Overview of Existing Tools and Methods for B/C Analysis of Operations

Dozens of individual analysis tools and methodologies designed for conducting B/C analysis of one or more TSM&O strategies have been identified to date. These include tools developed by regional, state, and Federal agencies, as well as proprietary tools developed by many private-sector enterprises; and range from simple methods intended for one-time analysis to more complex tools that are continually maintained and updated that form a continuing standardized framework for conducting B/C analysis for various agencies. Additionally, several emerging tools/methods are currently undergoing development as part of parallel efforts by U.S. DOT, American Association of State Highway and Transportation Officials (AASHTO), individual states and regions, and research organizations.¹⁸

Some of the most widely distributed and applied tools used for conducting B/C analysis of TSM&O strategies include those summarized (in alphabetical order) in Table 4-1. This listing summarizes those major tools developed by Federal, state, or regional transportation agencies (or affiliated research organizations) that are available within the public realm. This listing does not include proprietary offerings of private-sector vendors. Specific descriptions of the various tools follow Table 4-1.

The following sections provide a brief introductory description of the tools and methods presented in Table 4-1.

- **BCA.Net** – BCA.Net is the FHWA’s web-based benefit/cost analysis tool to support the highway project decision-making process, which is supported by the FHWA Asset Management Evaluation and Economic Investment Team. The BCA.Net system enables users to manage the data for an analysis, select from a wide array of sample data values, develop cases corresponding to alternative strategies for improving and managing highway facilities, evaluate and compare the benefits and costs of the alternative strategies, and provide summary metrics to inform investment decisions.

¹⁸ Note: Although classified as Benefit/Cost tools, few of the evaluated tools were capable of estimating the costs of TSM&O strategies. Most tools required the costs to be estimated off-model and entered as a line item in the analysis assumptions.

Table 4-1. Summary of Existing B/C Tools and Methods for TSM&O

Tool/Method	Developed by	Web Site
BCA.Net	FHWA	http://www.fhwa.dot.gov/infrastructure/asstmgmt/bcanet.cfm
CAL-BC	Caltrans	http://www.dot.ca.gov/hq/tpp/offices/eab/LCBC_Analysis_Model.html
COMMUTER Model	U.S. EPA	http://www.epa.gov/oms/stateresources/policy/pag_transp.htm
EMFITS	New York State DOT	https://www.nysdot.gov/divisions/engineering/design/dqab/dqab-repository/pdmapp6.pdf
The Florida ITS Evaluation (FITSEval) Tool	Florida DOT	N/A
Highway Economic Requirements System – State Version (HERS-ST)	FHWA	http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersindex.cfm
IDAS	FHWA	http://idas.camsys.com
IMPACTS	FHWA	http://www.fhwa.dot.gov/steam/impacts.htm
Screening Tool for ITS (SCRITS)	FHWA	http://www.fhwa.dot.gov/steam/scrirts.htm
Surface Transportation Efficiency Analysis Model (STEAM)	FHWA	http://www.fhwa.dot.gov/steam/index.htm
Tool for Operations Benefit/Cost (TOPS-BC)	FHWA	N/A
Trip Reduction Impacts of Mobility Management Strategies (TRIMMS)	Center for Urban Transportation Research (CUTR) at the University of South Florida	http://www.nctr.usf.edu/abstracts/abs77805.htm

- **CAL-BC** – Excel spreadsheet-based tool developed by Caltrans. Originally designed to conduct benefit/cost analysis of traditional highway improvements, Cal-B/C has been subsequently enhanced to be used to analyze many types of highway construction and operational improvement projects, as well as some ITS and transit projects. Several agencies outside Caltrans have also adapted Cal-BC as the basis for their own tools. Cal-BC has been developed in separate versions supporting corridor- and network-wide benefits.
- **COMMUTER Model** – Spreadsheet-based analysis developed by the U.S. EPA to estimate emissions benefits related to a number of employer-based travel demand management strategies.
- **EMFITS** – Benefit/cost analysis methodology developed for New York State DOT and incorporated in New York State DOT ITS Scoping Guidance (Project Development Manual).
- **FITSEval** – The Florida ITS Evaluation (FITSEval) tool is currently under development by the Florida DOT. The tool is a travel demand model post-processor designed to estimate B/C of ITS from the State’s standardized FSUTMS model structure.

- **HERS-ST** – Highway Economic Requirements System – State Version (HERS-ST) was developed by the FHWA. Originally designed for assessing the impacts of traditional capacity improvements, HERS-ST was updated in 2004 to include analysis of selected management and operations strategies through the use of a data preprocessor. The Operations Preprocessor modifies the basic characteristics of the HPMS data used by HERS (capacity, delay, crash relationships, and incident characteristics). HERS then estimates the impacts based on the revised characteristics. The I-95 Corridor Coalition recently used HERS-ST to assess impacts of investment in multistate corridors.
- **IDAS** – The IDAS tools was initially developed by the FHWA in 2001 and has undergone multiple updates since. IDAS, a sketch-planning tool operating as a travel demand model post-processor, implements the modal split and traffic assignment steps associated with the traditional traffic demand forecasting planning model. IDAS estimates changes in modal, route, and temporal decisions of travelers resulting from more than 60 types of ITS technologies. There are more than 30 state and metropolitan planning organizations (MPO) applications of IDAS. Although many of the public sector-developed tools and methods presented in this section are available free of charge, IDAS is only available for purchase through the McTrans Center at the University of Florida at a costs of \$795 per seat license.
- **IMPACTS** – IMPACTS is a series of spreadsheets, related to the STEAM model, developed to help screening-level evaluation of multimodal corridor alternatives, including highway expansion, bus system expansion, light-rail transit investment, HOV lanes, conversion of an existing highway facility to a toll facility, employer-based travel demand management, and bicycle lanes. Inputs are travel demand estimates by mode for each alternative.
- **SCRITS** – Screening Tool for ITS (SCRITS) was developed by the FHWA. The tool is a spreadsheet application for estimating user benefits of ITS at the sketch-planning level. SCRITS provides a highly approximate subset of the capabilities found in *TOPS-BC*.
- **STEAM** – Surface Transportation Efficiency Analysis Model (STEAM) uses information developed through the travel demand modeling process to compute the net value of mobility and safety benefits attributable to regionally important transportation projects. Developed by the FHWA, STEAM uses information developed through the travel demand modeling process to compute the net value of mobility and safety benefits attributable to regionally important transportation projects.
- **TOPS-BC** – The Tool for Operations Benefit/Cost (*TOPS-BC*) was developed in parallel with this *Desk Reference* and is intended to support the guidance provided in this document by providing four key capabilities: 1) allows users to look up the expected range of TSM&O strategy impacts based on a database of observed impacts in other areas; 2) provides guidance and a selection tool for users to identify appropriate B/C methods and tools based on the input needs of their analysis; 3) provides the ability to estimate life-cycle costs of a wide range of TSM&O strategies; and 4) allows for the estimation of benefits using a spreadsheet-based sketch-planning approach and the comparison with estimated strategy costs. The capabilities of *TOPS-BC* are highlighted throughout this *Desk Reference*.
- **TRIMMS** – Trip Reduction Impacts of Mobility Management Strategies (TRIMMS) model developed by the CUTR at the University of South Florida. TRIMMS© allows quantifying the net social benefits of a wide range of transportation demand management (TDM) initiatives in terms of emission reductions, accident reductions, congestion reductions, excess fuel consumption, and adverse global climate change impacts. The model also provides program cost-effectiveness assessment to meet the FHWA’s CMAQ Improvement Program requirements for program effectiveness assessment and benchmarking.

In addition to these existing tools, several pieces of ongoing research are anticipated to result in the development of tools and analysis methodologies related to operations strategies. Where available and appropriate, preliminary findings and methods from these studies have been integrated into this *Desk Reference* and utilized in the *TOPS-BC* application. Several of these more noteworthy efforts include:

- The FHWA pooled funds study of the impacts of managed lanes;
- I-95 Corridor and FHWA study on Traffic Incident Management (TIM) and benefit/cost analysis;
- The FHWA-sponsored project conducted by the University of Texas to develop a Project Evaluation Toolkit and Guidebook;
- The FHWA study on developing Highway Capacity Manual (HCM) methods for analyzing ATDM strategies; and
- SHRP 2 Project L05, *Incorporating Reliability in the Transportation Planning Process*.

The above tools and research efforts represent a sampling of the available methods that may be used for supporting and conducting B/C analysis of TSM&O strategies. The capabilities of many of these tools and the findings of the research efforts have been weaved into this guidance document, and also often forms the basis for the benefit and cost estimation capabilities developed in the supporting *TOPS-BC* tool.

In addition to these established tools, there are many customized methods that have been developed to support an individual agency's needs, or modified from an analysis method to meet the needs of a specific analysis. These tools and methods can generally be segmented into three broad categories, including the following:

1. **Sketch-planning methods** – These analysis methods provide simple, quick, and low-cost estimation of TSM&O strategy benefits and costs. Often based in a spreadsheet format, these methods often rely on generally available input data and static default relationships between the strategies and their impact on a limited number of MOEs to estimate the benefits of the strategy. A number of established B/C tools, including *TOPS-BC*, *SCRITS*, and *Cal-BC*, are classified as sketch-planning methods; however, this category also includes scores of individually developed and customized spreadsheet and simple database methods configured to support various analyses by single agencies.
2. **Post-processing methods** – These methods are often more robust than sketch-planning methods, as they seek to more directly link the B/C analysis with the travel demand, network data, and performance measure outputs from regional travel demand or simulation models. Several established tools, including *IDAS* and the *FITSEval* application, have been designed to directly accept detailed model data as inputs to the analysis. The tools then provide additional analysis within their framework to assess impacts to MOEs outside the capabilities of typical travel demand models. Outside of these more established tools, these post-processing methods also include customized applications, algorithms, and routines that may be applied directly within a region's existing modeling framework to produce the required MOEs. These methods are often more capable of assessing the impacts of route, mode, or temporal shifts than compared to sketch-planning methods.
3. **Multiresolution/multiscenario methods** – These analysis methods are often the most complex of the methods and are typically applied when a high level of confidence in the

accuracy of the results is required. These methods are most often applied during the final rounds of alternatives analysis or during the design phases when detailed information is required to prioritize and optimize the proposed strategies. Multiresolution methods depend on the integration of various analysis tools (e.g., linking a travel demand model and a simulation model) to provide meaningful analysis of the full range of impacts of a TSM&O strategy – capturing both the long-term impacts on travel demand, along with the more immediate impacts on traffic performance. Meanwhile, multiscenario methods seek to assess strategy performance during varying underlying traffic conditions. In this analysis, the impact of a particular strategy may be tested under a variety of conditions (e.g., incident versus no-incident, good weather versus rain conditions versus snow conditions) in order to fully capture the benefits under all the likely operating conditions. This type of analysis often requires that the analysis model be run multiple times to capture these effects. For complex analysis requiring a high degree of confidence in the results, multiresolution and multiscenario analysis may be performed in concert within an analysis framework.

The general categories listed above largely encompass the range of available analysis methods; however, there are often methods and tools that may not fit neatly within single categories. These hybrid approaches are often applied when a single method does not completely meet the needs of a particular analysis. The subsequent sections provide additional discussion of the method categories, and provide examples of tools and analysis utilizing those methods.

Note: The *TOPS-BC* tool developed in parallel with this *Desk Reference* document contains a decision-support tool designed to aid practitioners in identifying an appropriate method for conducting B/C analysis based on various input criteria. This capability is described further in Chapter 5.

Sketch-Planning Methods

These methods/tools are typically conducted in spreadsheets or simply structured databases, and are intended to provide relatively easy and fast analysis of the TSM&O strategy. They represent most commonly applied tool category. The methods often require relatively limited input data (e.g., basic aggregated volume and speed data); and produce order of magnitude results appropriate for early evaluation, screening, and prioritization of various strategies. Benefit analysis is typically based on generally linear assumptions regarding the impact of various strategies. These methods are also often limited; in that, they are incapable of assessing the impacts of various TSM&O strategies deployed in combination with each other (i.e., the tools typically cannot analyze the synergistic effects of integrating various systems). These methods are often developed and configured by agencies for individual analysis, although a number of existing tools has been developed to serve as ongoing templates for conducting analysis, including the *TOPS-BC* tool developed in parallel to this *Desk Reference*, FHWA's *SCRITS* tool (shown as Figure 4-1 below), and Caltrans' *CAL-BC* tool (shown as Figure 4-2 below), among many others.

Figure 4-1. Example View of Sketch-Planning B/C Analysis Method (SCRITS) Data Inputs

	User Input	Calculated Value
ANALYSIS OF VARIABLE MESSAGE SIGN ANALYSIS		
3 Date of analysis	9/24/1998	
4 Scenario	Alternative 3	
5 Analyst	Smith	
6 Description of improvement	VMS on facility X from Y to Z	
NON-RECURRING DELAY ANALYSIS		
9 Number of signs to be installed at strategic points on freeway	2	
10 Average volume (VPH) past sign	4000	
11 Number of times/day each sign provides incident information	0.5	
12 Time (hrs.) sign active for each incident	4	
13 Percent of drivers (vehicles) passing sign that save time	20.0%	
14 Amount of time (min.) saved by each vehicle passing sign	3	
15 Vehicle hours saved per sign, per day		80
16 Total vehicle hours per day saved		160
17 Percent of non-recurring delay saved		2.3%
18 Hours of delay saved per year on weekdays		40,000
ACCIDENT REDUCTION		
20 Percent reduction in secondary accidents		2.3%
21 Number of secondary accidents per day on affected freeways		0.12
22 Accidents reduced per weekday on affected freeways		0.003
23 Accidents reduced per year on affected freeways on weekdays		0.7
COSTS AND BENEFITS		
25 Time savings (\$) per year on weekdays		\$572,000
26 Accident savings (\$) per year on weekdays		\$10,177
27 Total annual dollar benefit for weekdays only		\$582,177
28 Total annual dollar benefit for full week		\$790,163

Figure 4-2. Example View of Caltrans' CAL-BC Analysis Tool Data Outputs

District: 4 Project #
PROJECT: US 101 HOV Lanes - Narrows Phase A (SR 37 to Atherton Ave) EA:
PPND:

INVESTMENT ANALYSIS
SUMMARY RESULTS

		Average	Total Over
		Annual	20 Years
Life-Cycle Costs (mil. \$)	\$76.2		
Life-Cycle Benefits (mil. \$)	\$236.1		
Net Present Value (mil. \$)	\$159.9		
Benefit / Cost Ratio:	3.1		
Rate of Return on Investment:	18.8%		
Payback Period:	5 years		
ITEMIZED BENEFITS (mil. \$)			
Travel Time Savings		\$13.2	\$264.4
Veh. Op. Cost Savings		-\$1.4	-\$28.3
Accident Cost Savings		\$0.0	\$0.0
Emission Cost Savings		\$0.0	\$0.0
TOTAL BENEFITS		\$11.8	\$236.1
Person Hours of Delay Saved		2,104,087	42,081,737

Should results include:

1) Induced Travel? (y/n)
Default = Y

2) Vehicle Emissions? (y/n)
Default = N

MTC PRIORITIZATION RESULTS (first year only)

		Peak	Non-Peak
DVHD Reduction*	3,778		
DVHD/Escalated Cost (in \$M)	48		
DPHD Reduction	5,003.2		
Peak Period VIC – Before	0.84		
Peak Period VIC – After	0.63		
FREEWAY TRAVEL TIME (min.)			
Before		11.3	5.1
After		4.3	4.3
Savings		6.9	0.8

Notes: 1) DVHD is difference in travel time for existing vehicles, 2) need to calculate twice for bypass and intersection projects

Sketch-Planning Method Advantages

The following summarize the general advantages of using sketch-planning analysis:

- **Easy to use** – Many of the sketch-planning methods may be researched and mastered very quickly, limiting the amount of staff resources needed to conduct the analysis.
- **Limited data requirements** – Sketch-planning methods typically require generally available data (e.g., facility volumes, speeds) as inputs to the framework. These data may be obtained from real-world counts, model data, or other sources.
- **Quick set up and analysis times** – Assuming the input data is easily available, the analysis times are generally very fast, often allowing multiple alternatives to be analyzed in the period of a single hour.
- **Low cost** – Due to the ease of use, limited data requirements, and quick analysis times, sketch-planning methods may often be applied at little resource cost to the performing agency.

Additionally, many of the established sketch-planning tools are distributed at no or very limited procurement cost.

- **Ability to customize** – Since many sketch-planning methods are developed in a spreadsheet format, it is typically easy to both review and make adjustments to the default parameters, assumptions and formulas used in the tools. This allows for the better configuration of established tools to the local environment and conditions.

Sketch-Planning Method Challenges

The following represent some of the identified challenges of using sketch-planning methods:

- **Order of magnitude outputs** – Sketch-planning methods often lack the rigor of more advanced analysis methods; therefore, the outputs are most appropriate for preliminary planning and screening of alternatives when a low or moderate level of confidence in the analysis results is appropriate to the analysis phase.
- **Limited MOEs** – Many sketch-planning methods focus only on a limited set of output MOEs, reducing the comprehensiveness of the B/C analysis.
- **Linear (Nondynamic) assumptions of user behaviors** – Most sketch-planning methods assume static, linear reactions of travelers to deployed strategies. Behavioral changes, such as route change, mode shift, temporal change, or longer-term changes in travel demand, may not be captured in the simplified analysis.

Appropriate Applications for Sketch-Planning Methods

Given the capabilities of sketch-planning methods, as reflected in the advantages and challenges presented above, these methods are often most appropriately applied during the early stages of the planning process, when there is a large number of potential projects that must be preliminarily analyzed in order to prioritize projects that are most deserving of additional, more detailed analysis in subsequent planning phases. Sketch-planning methods are also appropriate for use in estimating high-level benefits of existing strategies for use in justifying the continued deployment funding or expansion of an existing initiative.

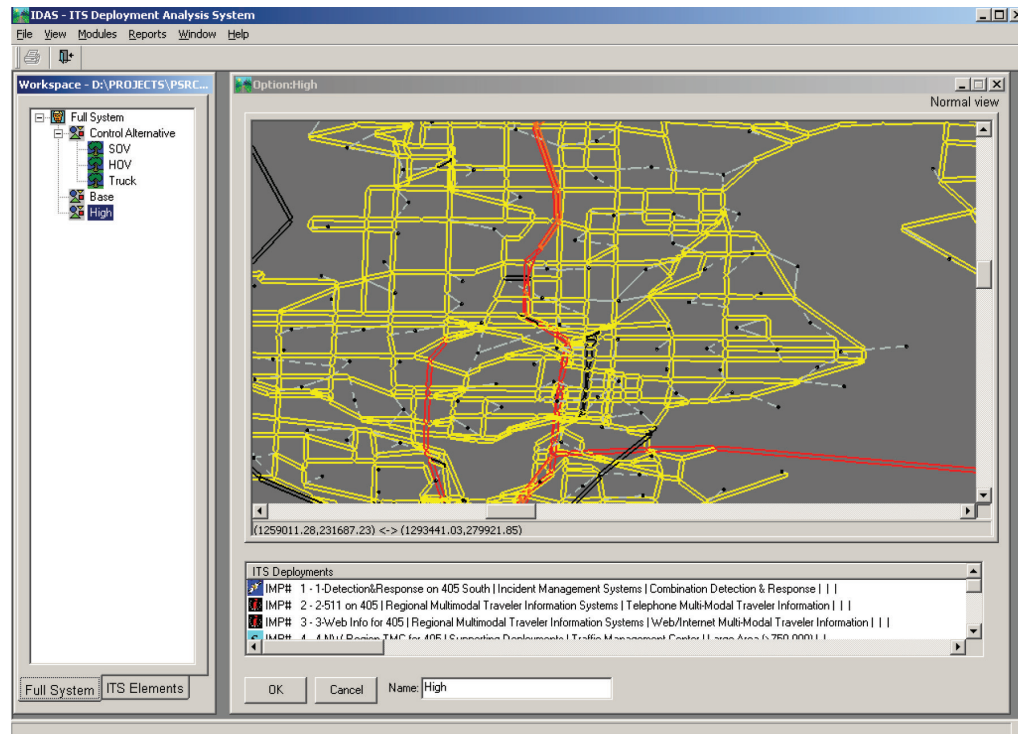
Post-Processing Methods

These more complex methods and tools generally include customized user interfaces and analysis processes, and are intended to be linked (either directly or indirectly) with traditional transportation analysis tools, such as travel demand models, simulation models, or HPMS databases. These tools may be developed in various programming languages; and some, such as the FHWA's *BCA Net*, are available directly through on-line portals. The customized functionality of these tools often provides additional analysis capabilities and additional accuracy of estimated impacts, due to the customization and configurability provided beyond simple spreadsheet capabilities. Additionally, some of these tools work by modifying the existing analysis capabilities available in their host tools to be more sensitive to the specific impacts of TSM&O strategies.

These tools may, however, require more specific data and additional effort to configure and operate, and the analysis processes may not be as transparent as some spreadsheet-based tools. The additional analysis configurability often allows for the closer inspection of specific impacts related to

specific MOEs and improves the confidence in the output results, making these tools valuable for prioritizing limited lists of potential deployments. Other examples of these types of tools include the FHWA's *IDAS* software (shown as Figure 4-3 below) and the Florida DOT's *FITSEval* toolset.

Figure 4-3. Example of Post-Processing B/C Analysis Method (IDAS)



In addition to these established post-processing tools designed to be applied by multiple agency, this category also includes model modifications by individual agencies intended to develop routines, algorithms, and processes to improve the ability to generate better estimates of TSM&O-related performance measures (e.g., travel time reliability), or otherwise improve the assessment of TSM&O within their existing travel demand or simulation model framework.

Post-Processing Method Advantages

The following summarize the general advantages of using post-processing B/C analysis methods:

- **Assessment of traveler behaviors** – Since these methods are based on existing models calibrated to regional travel conditions, there is often the capability to better assess a wider range of potential traveler behaviors, such as route change, mode shifts, temporal shifts, and long-term changes in travel demand, thus, providing more adaptive (less linear) reactions to strategies than provided in the sketch-planning methods.
- **Data availability** – Since most urban regions have existing calibrated travel demand models, the analysis data and structure necessary to conduct this type of analysis already exists. This limits the amount of additional data collection and analysis that may need to be performed to support the analysis.

- **Consistency with the regional planning process** – Most planning agencies are familiar and comfortable with using the regional travel demand model outputs in their planning studies. Consistency with the existing processes promotes better understanding and buy-in with the results of the analysis.
- **Development of a reusable process** – Once post-processing methods have been initially set up and tested, they may be repeatedly used to provide consistent and low-cost analysis of multiple alternatives. The initial set-up process for this method may be onerous, however, as discussed below.

Post-Processing Method Challenges

The following represent some of the identified challenges of using post-processing methods:

- **Analysis effort** – Post-processing methods most typically require either the linkage of an existing regional model with an available post-processing tool (e.g., IDAS); or the individual development of customized model routines, algorithms, and procedures within the model structure. Either way, the complexity of modern travel demand or simulation models means that a significant effort will be required to develop, apply, test, and validate these methods. Often, a majority of this total analysis effort is required in the early set up and calibration of the method.
- **Compatibility of tools/methods** – Many different modeling platforms from a variety of vendors are in use today; and there is often little standardization in their input/export data, modeling routines, and assumptions. Likewise, the developed post-processing tools also have many limitations on the types and format of data that may be used in the analysis. Prior to attempting these methods, research is recommended to assess the compatibility of the proposed tools to better ensure success in linking their capabilities.

Appropriate Applications for Post-Processing Methods

Given the capabilities of post-processing methods, as reflected in the advantages and challenges presented above, these methods are often most appropriately applied during the middle to late stages of the alternative analysis/prioritization planning processes. The higher costs (greater analysis resources required) associated with post-processing methods mean that a smaller number of alternatives be considered in the analysis, as compared with lower-cost sketch-planning methods. These methods may also be appropriately used in the evaluation of existing deployments, as highlighted in the Cincinnati region case study presented in Chapter 2.

Multiresolution/Multiscenario Methods

These methods/tools are the most complex of the analysis approaches and are typically only used in situations where a limited number of alternatives need to be evaluated, but highly accurate results are desired. These methods require the use and integration of multiple analysis tools (e.g., combining the analysis capabilities of a travel demand model with a traffic simulation model) to assess the potential impacts of the TSM&O strategy. The combination of the modeling capabilities is intended to combine the strengths of various transportation analysis models to assess both the short-term impacts (e.g., impacts on travel speed under particular travel conditions) and the long-term impacts (e.g., changes in travel demand over time) of TSM&O strategies.

Likewise, multiscenario methods seek to assess strategy performance during variations in underlying traffic conditions. In this analysis, the impact of a particular strategy may be tested under a variety of conditions (e.g., incident versus no-incident, good weather versus rain conditions versus snow conditions) in order to fully capture the benefits under all the likely operating conditions. This type of analysis often requires that the analysis model(s) be run multiple times to capture these effects. The data required to identify and develop appropriate analysis scenarios (e.g., frequency and location of incidents; distribution of fair, rain, snow weather days) are often obtained using archived data systems, adding another tool to the integrated analysis approach.

For complex analysis requiring a high degree of confidence in the results, multiresolution and multiscenario analysis may be performed in concert within an analysis framework. One of the most prominent recent examples of multiresolution/multiscenario methods for B/C analysis is the FHWA's ICM Initiative analysis effort.¹⁹ Figure 4-4 presents an overview of the multiresolution analysis process that was developed in the B/C analysis effort of the ICM initiative, showing the linkage of regional travel demand models (which were used to assess the long-term impacts on travel demand of the considered strategies) and a refined simulation model (used to identify the more immediate operational performance impacts of the strategies). The ICM analysis process was completed for multiple iterations to estimate the variation in performance under different operating scenarios (e.g., incidents versus nonincident days). Thus, this method represents a combined multiple resolution and multiple scenario approach.

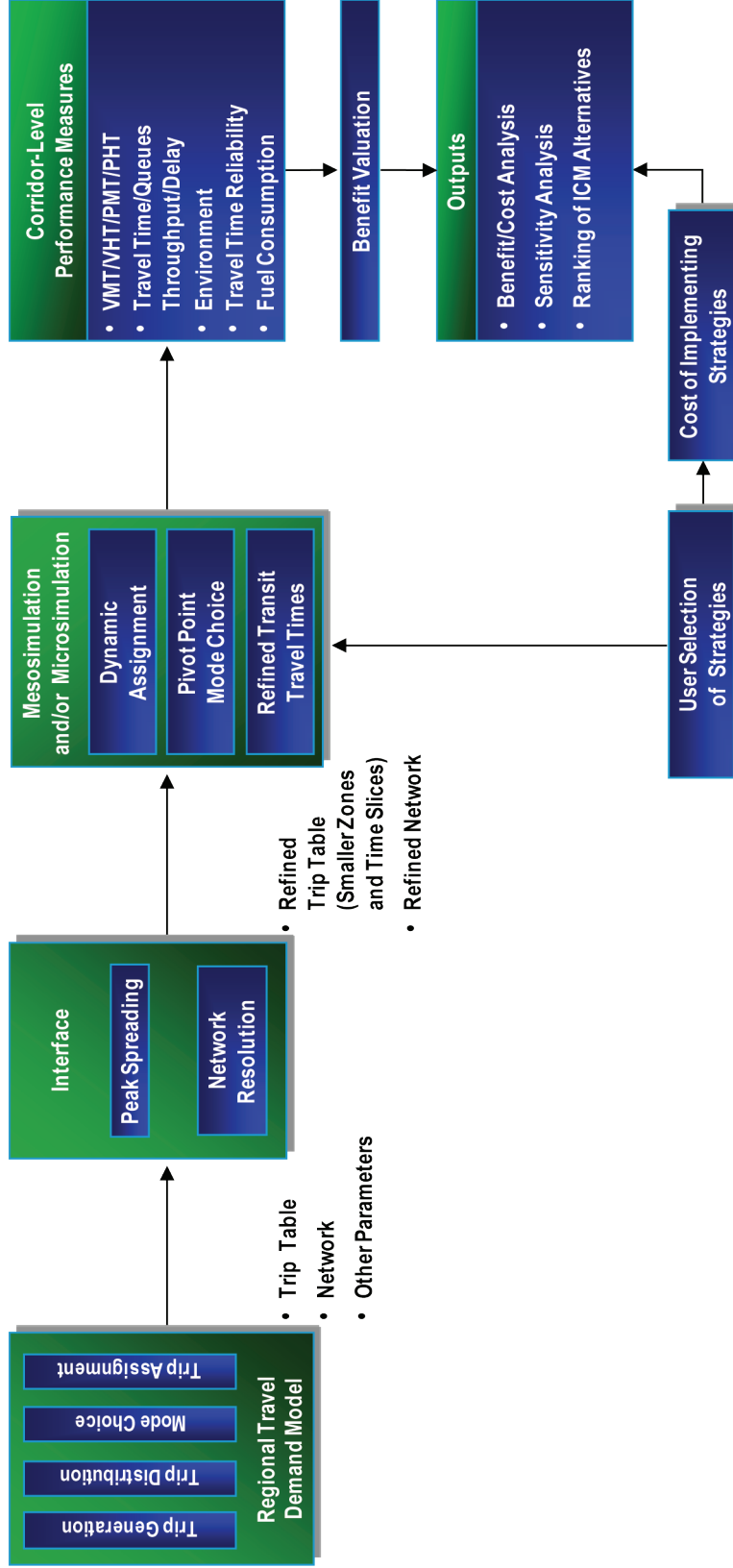
Multiresolution/Multiscenario Method Advantages

The following summarize the general advantages of using multiresolution/multiscenario B/C analysis methods:

- **Assessment of short- and long-term traveler behaviors** – Travel demand models have a strong capability of assessing long-term impacts of travel demand and analyzing traffic during “typical” conditions, while simulation models’ strength is often the dynamic assessment of operational performance during discrete time slices and during varying nonrecurring traffic conditions. Combining the strengths of these two models provides the ability to assess both the short-term, immediate impacts of a TSM&O strategy, but also the longer-term demand (change in the number of trips) impacts that may occur as travelers adjust to the changed transportation environment. These tools often represent the best solution for fully considering the multifaceted impacts of many strategies for both operations and planning purposes.

¹⁹ FHWA ICM – *Analysis, Modeling, and Simulation Guide*, Draft Report, April 2011.

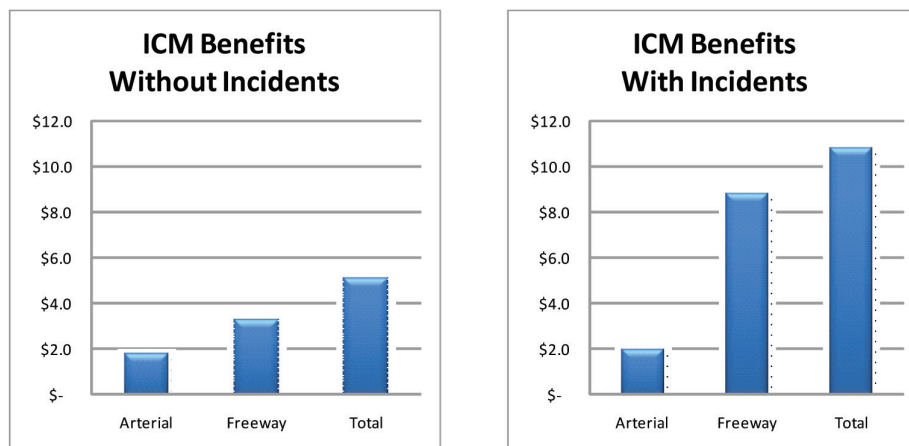
Figure 4-4. Multiple-Resolution Approach Developed for the ICM Initiative Analysis



Source: FHWA ICM – Analysis, Modeling and Simulation Guide, Draft Report, April 2011.

- Assessment of nonrecurring conditions** – This method, particularly when multiscenario analysis is applied, is capable of dynamically modeling conditions representing nonrecurring situations that would likely to occur. Assessing this full range of conditions provides the ability to capture benefits of many TSM&O strategies that otherwise would have been understated if only “typical” day conditions had been included in the analysis. Figure 4-5 presents a comparison of two analyses performed as part of the ICM initiative analysis. The figure on the left represents an estimate of the benefits for a San Diego deployment of ICM that only considers “typical” days that are void of incident conditions. The figure on the right represents an estimate of benefits that would accrue as a result of the improvements when both “typical” and incident days are considered. Clearly, the inclusion of the analysis of benefits on incident days boosts the benefits (more than double) and illustrates that failure to consider these nonrecurring conditions will often result in a severe understatement of benefits for many TSM&O strategies.

Figure 4-5. Comparison of ICM Benefit Estimates between Nonincident Scenarios and Incident Scenarios
(San Diego I-405 Analysis – in Millions of Annual Dollars)



Source: FHWA ICM – *Analysis, Modeling, and Simulation Guide*, Draft Report, April 2011.

- Detail of analysis** – Multiresolution/multiscenario analysis has the capability to produce very detailed analysis results. The ability of this method to examine many MOEs, particularly travel time reliability, is far superior to existing sketch-planning or post-processing methods. When set up and calibrated correctly, this method allows a high level of confidence to be placed on the accuracy of the output results of the analysis activity.
- Flexibility of the analysis** – The highly customizable analysis routines, provided by this method, allow practitioners to evaluate the widest range of TSM&O strategies of any of the methods, and further provide the capability to look at many MOEs at a level of detail not provided by other tools/methods.

Multiresolution/Multiscenario Method Challenges

The following represent some of the identified challenges of using multiresolution/multiscenario B/C analysis methods:

- **Model development and analysis effort** – The complexity of this analysis process requires that a significant effort be undertaken to develop the analysis process. Linking various model platforms often requires a substantial amount of staff, expertise, computing, schedule, and budget resources. It is critical that the linkage process be carefully planned, and that the model processes undergo a rigorous calibration and validation process to ensure the accuracy of the results. The model calibration process can be the most time- and budget-consuming process in the entire analysis. For complex analyses, practitioners can expect six months to one year be required to develop the analysis capabilities.²⁰ However, once the model is established, the analysis may be repeated for multiple alternatives on a relatively quick basis, allowing the initial cost of developing the method to be amortized over multiple operations and planning analysis. Further, ongoing research and application of these methods by FHWA and other practitioners is yielding new methods and process guidance that is reducing the cost of these efforts.
- **Compatibility of tools/methods** – The linkage of different modeling platforms and tools requires careful planning and research prior to undertaking this ambitious effort. Many tools are not easily combined, and thus, may require significant effort to manually interface the models and data. Again, ongoing research, as well as efforts by individual tool developers are reducing this barrier as these methods become more mainstreamed.
- **Complexity limits on analysis scope** – The large amount of resources required to develop the model processes often limits the scope of the analysis that may be performed using this methodology. This may represent a geographic limitation – the simulation analysis is often limited to a single corridor or small subarea, instead of the entire network – or an alternative limitation – the number of alternatives that may be run through the process is likely to be limited to a small number given the resources required to analyze each scenario.

Appropriate Applications for Multiresolution/Multiscenario Methods

Given the capabilities of multiresolution/multiscenario methods, as reflected in the advantages and challenges presented above, these methods are often most appropriately applied during the final stages of the alternative analysis/prioritization planning processes, and during phases where the actual operating parameters of the strategy are being refined (design phase). These stages of the planning process often require the high level of detail and strong confidence in result accuracy provided by this method. The resources required to develop and calibrate the modeling capabilities, as well as the effort required to run individual scenarios, often limit the geographic scope of the analysis – more likely a corridor analysis than a regionwide assessment – or the number of alternatives that may be analyzed, so it is recommended that this method be applied after previous prioritization processes have already condensed the number of scenarios to be analyzed.

²⁰ FHWA *Traffic Analysis Toolbox – Volume II*, 2004.

Operations Strategies Available for Analysis in the Tools/Methods

Many of the different tools and methods discussed in Chapter 4 were designed to analyze one or more TSM&O strategies. Only multiresolution/multiscenario analysis methods maintain the flexibility to currently analyze all of the generally recognized TSM&O strategies. Figure 4-6 summarizes the strategies that may be analyzed by many of these widely distributed available tools.

Figure 4-6. Available Tools/Methods Mapped to Strategies Analyzed

Tool/Methodology	Travel Demand Management	Public Transit Systems	Arterial Traffic Mgmt	CVO	HOT Lanes	Freeway Management Systems	Incident Management Systems	Regional Multimodal Traveler Info	Work Zone Mgmt
BCA.Net			●			●			
Cal-B/C		○	●		●	●	●	●	
COMMUTER Model	●								
EMFITS			●			●	●	●	○
FITSEval			●			●	●	●	
HERS-ST (Preprocessor)			●			●	○		
IDAS	●	○	●	●	●	●	●	●	●
IMPACTS	○		○		○				
Multiresolution/Multiscenario Methods	●	●	●	●	●	●	●	●	●
NET_BC									
SCRITS			●		●	●	●	●	
STEAM			●			●	●	●	
TOPS-BC	○	○	●	○	●	●	●	●	●
TRIMMS	●	●							

● – Addresses most elements of strategy

○ – Addresses some elements of strategy

MOEs Generated

Most of the analysis tools and methods introduced in Chapter 4 provide varying capabilities of analyzing the impact of TSM&O strategies on different MOEs. Few existing tools are fully capable

of estimating the impacts to the comprehensive range of measures that may be impacted by TSM&O strategies. Only multiresolution/multiscenario methods come closest to this comprehensive capability, and the ability of these methods to produce the full range of benefits is not intrinsic to the method itself, but is instead a product of the flexibility of the approach. The user of multiresolution/multiscenario methods would need to carefully plan and implement their modeling approach to produce the desired MOEs. Figure 4-7 summarizes the MOEs that may be analyzed by many of the currently available tools.

Selecting the appropriate analysis tool or method is a critical step in the B/C analysis. The selected tool must be capable of evaluating the TSM&O strategies and MOEs of interest to the agency. The tool must also be appropriate to the scope of the analysis and be able to use with the resources available for the study. Chapter 5 provides additional detail on factors that need to be considered when developing an analysis approach. Additionally, the *TOPS-BC* application that supports this *Desk Reference* provides a decision-support tool intended to assist practitioners in prioritizing their analysis needs against the capabilities of the available tools. In this *TOPS-BC* screening process, users are asked to indicate their analysis needs in relation to a number of criteria, including the following:

- Geographic scope of the analysis;
- Desired level of confidence in the results;
- TSM&O strategies to be analyzed;
- Key MOEs;
- Travel modes to include;
- Level of resources to support the analysis; and
- Data/tools available to support the analysis.

Figure 4-8 presents a partial screen view of the *TOPS-BC* method selection application.

Figure 4-7. Available Tools/Methods Mapped to MOEs Analyzed

Tool/ Methodology	Mobility (Travel Time Savings)	Reliability (Total Delay)	Safety (Number and Severity of Crashes)	Environment (Emissions Reduction)	Energy (Fuel Use)	Productivity (Public Agency Costs/Efficiency)	Vehicle Operating Cost Savings	Notes
BCA.Net	●		●	●	●		●	
Cal-B/C	●		●	●			●	
EMFITS	●		●	●	●			Emissions: HC, CO, NO _x
Florida DOT's <i>FITSEval</i>	●		●	●	●		●	Final performance measures still under development
HERS-ST	●		●	●		●	●	HERS preprocessor
IDAS	●	●	●	●	●	●	●	Reliability estimates represent incident-related delay
IMPACTS	●			●	●		●	Induced demand, parking costs, revenue transfers
Multiresolution/ Multiscenario	●	●	●	●	●	●	●	
NET_BC	●		●				●	
SCRITS			●	●	●		●	VMT, Vehicle Hours Traveled (VHT), emissions (HC, CO, NO _x)
STEAM	●		●	●	●		●	Total transportation cost, accessibility to jobs, emissions (HC, CO, NO _x), noise and other external costs, revenue transfers
<i>TOPS-BC</i>	●	●	●	○	●	●	●	Reliability estimates represent incident related delay
TRIMMS	●			●	●			

● – Primary analysis capability

○ – Secondary analysis capability

Figure 4-8. TOPS-BC Analysis Method Selection Tool (Partial Screenview)

FHWA Tool for Operations Benefit/Cost (TOPS-BC)

Guidance on Appropriate Benefit/Cost Methods [Return to OPENING SCREEN](#)

Instructions: Please indicate the needs of your analysis associated with the following criteria then press "GO".
A list of appropriate methodologies will be displayed to the right and will change in response to your answers to the input analysis criteria.

INPUT CRITERIA	Go	Suggested Methodologies:
<p>1 What is the geographic scope of the analysis? (Select 1)</p> <p><input checked="" type="checkbox"/> No Preference</p> <p><input type="checkbox"/> Statewide</p> <p><input type="checkbox"/> Regional</p> <p><input type="checkbox"/> Corridor</p> <p><input type="checkbox"/> Isolated Location</p> <p><input type="checkbox"/> Other</p>	Go	<p>Recommended:</p> <p>Tools meeting ALL criteria</p> <p>TOPS-BC *</p> <p>BCA.net</p> <p>CAL-BC</p> <p>EMFITS</p> <p>FITSEval *</p> <p>HERS-ST</p> <p>IDAS</p> <p>MicroBENCOST</p> <p>Redbook Wizard *</p> <p>SCRITS</p> <p>SPASM *</p> <p>STEAM</p> <p>Travel Demand Model Methods *</p> <p>Simulation Methods *</p>
<p>2 What is the desired level of confidence of the analysis results? (Select 1)</p> <p><input checked="" type="checkbox"/> No Preference</p> <p><input type="checkbox"/> High (extremely accurate)</p> <p><input type="checkbox"/> Medium</p> <p><input type="checkbox"/> Low (order of magnitude)</p>		
<p>3 What TSM&O strategy(ies) do you want to analyze? (Choose Multiple)</p> <p><input checked="" type="checkbox"/> No Preference</p> <p><input type="checkbox"/> Arterial Corridor Traffic Signal Coordination Strategies</p> <p><input type="checkbox"/> Traffic Signal Priority Strategies</p> <p><input type="checkbox"/> Ramp Metering Strategies</p> <p><input type="checkbox"/> Traffic Incident Management Systems</p> <p><input type="checkbox"/> Transit AVL and Automated Scheduling</p> <p><input type="checkbox"/> Pre-Trip Traveler Information</p>		

Chapter 5. Conducting B/C Analysis for Operations

Selecting the Appropriate Methodology/Factors Influencing the Analysis Approach

The process of selecting an appropriate method or tool for use in the B/C analysis is a critical step in ensuring the eventual success of the effort. As discussed in Chapter 4, there is a wide variety of existing tools available for conducting B/C analysis of TSM&O strategies. Likewise, there is often great opportunity for practitioners to develop their own customized analysis approach if the available tools do not meet the exact needs of their analysis. Often, these custom approaches are built by borrowing capabilities from existing tools; and enhancing the process with customized methods configured to available data, existing regional analysis tools, and the specific needs of the analysis.

Prior to initiating any analysis, practitioners are encouraged to carefully weigh the factors influencing the analysis approach. Careful assessment of the analysis needs and mapping to an appropriate analysis method or tool will provide for a better use of scarce analysis resources, and help minimize the possibility of discovering that the selected analysis method is incapable of successfully completing the analysis when the evaluation is half-finished.

The sections below present expanded discussion of multiple factors that should be considered in selecting a methodology and customizing an analysis approach. These factors include:

- Geographic scope;
- Types of strategies;
- Need for/purpose of study;
- Desired MOEs;
- Required level of confidence in results;
- Available tools and data;
- Available analysis resources; and
- Other factors.

Geographic Scope

The geographic scope of the strategy to be analyzed plays a key role in developing the analysis approach. Some TSM&O strategies may be deployed and influence only a limited geographic area, such as an intersection, a freeway interchange, or a single corridor. Other strategies may be deployed on multiple corridors or even regionwide (e.g., 511 traveler information systems). The scope of the deployment(s) to be analyzed is a critical factor in determining the appropriate facilities to include in the analysis, as well as a determinant in selecting an appropriate analysis tool.

Another issue to consider when assessing the geographic scope to capture in the analysis is the effect of transfers from other regions. For example, an economic analysis may indicate a regional increase in jobs as a result of the increased regional productivity provided by an improvement. This would be seen as a benefit for the region gaining the jobs, but might be a disbenefit for the region where the jobs moved. If the analyst were conducting an analysis of the benefits that could be gained if the improvement were funded from 100-percent local funding, they may include these benefits as they represent a regional gain. If, however, the analysis were being completed for an improvement that was anticipated to be funded through state or national sources, these benefits would represent a transfer and should not be included. At the national scale, interstate and interregional transfers should not be included – only the net change on a national scale should be considered.

Prior to developing the analysis approach, practitioners should carefully assess the possible impacts of the TSM&O strategy to be analyzed, and determine the likely geographic extents of the impacts to various regional facilities. It is important that the analysis be designed to fully capture not only the impacts at facilities immediately adjacent to the proposed deployment, but also capture broader network impacts due to likely traveler changes in route mode or time of travel. For example, an analysis of a ramp metering deployment should not only attempt to assess the change in roadway performance within the immediate merge area, but also should attempt to include an assessment of conditions in the ramp queue, at adjacent intersections, and possibly on parallel arterials or freeway facilities, if they are likely to be impacted by the deployment. Failure to include all the likely facilities and modes likely to be impacted by a strategy risks understating or overstating the benefits of the strategy.

The anticipated geographic reach of impacts of a TSM&O strategy also plays a key role in the selection of an appropriate analysis method/tool. Different analysis methods and tools are typically more appropriately scaled to analysis at different geographic scopes. For example, analysis of a TSM&O strategy on a corridor level may be most appropriately assessed using a multiscenario simulation, model-based approach; however, if an assessment is required on a regionwide basis, the simulation approach may prove to be too resource demanding to be practical. Table 5-1 presents a general overview of the tool categories (presented in Chapter 4) and their appropriateness to various geographic scales. As a general rule, as shown in the table, increases in the complexity of the analysis methods typically results in a smaller appropriate geographic coverage, often due to the resources necessary to conduct a very robust analysis on a broad scale.

Table 5-1. Analysis Methods/Tools Mapped to Appropriate Geographic Scope

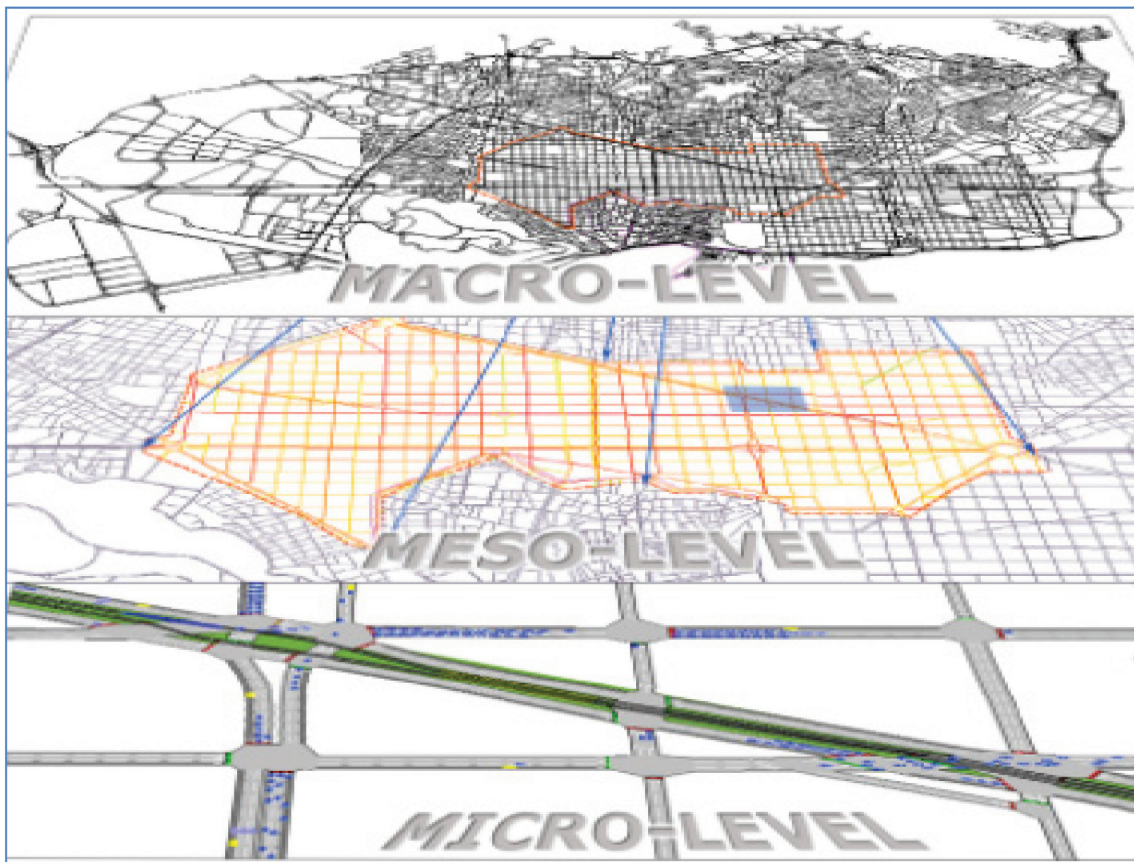
Analysis Method/Tool	Appropriate Geographic Scope
Sketch-Planning Methods	Isolated Location Corridor Subarea Regionwide ^a
Post-processing Methods	Corridor Subarea Regionwide ^b
Multiresolution/Multiscenario Methods	Corridor Subarea

^a Dependent on the specific analysis tool selected.

^b Assumes post-processing method is applied to the regional travel demand model.

In addition to helping determine the most appropriate tool category to apply, the intended geographic scope of the analysis may play a factor in identifying specific tools to be considered. For example, a multiresolution approach utilizing a simulation model may be proposed for a particular analysis; however, different simulation packages/platforms are available that can support analysis at different geographic scales. For example, macrosimulation models provide less detailed analysis, but can provide simulation over a wider regional scale. Mesoscopic simulation models provide more detailed analysis, but are often limited to a subregional geographic scale. Microsimulation models provide the most detailed analysis, but are often limited to analysis on a corridor scale, given the data and resource requirements necessary to develop these models. In designing the analysis, the practitioner must make decisions regarding the tradeoff between the detail available in the simulation model and the geographic coverage that will be possible, given the available resources for the analysis. Figure 5-1 provides an overview of the different types of simulation tools mapped to their typical geographic scales.

Figure 5-1. Different Simulation Analysis Tools are Appropriate to Different Geographic Scopes

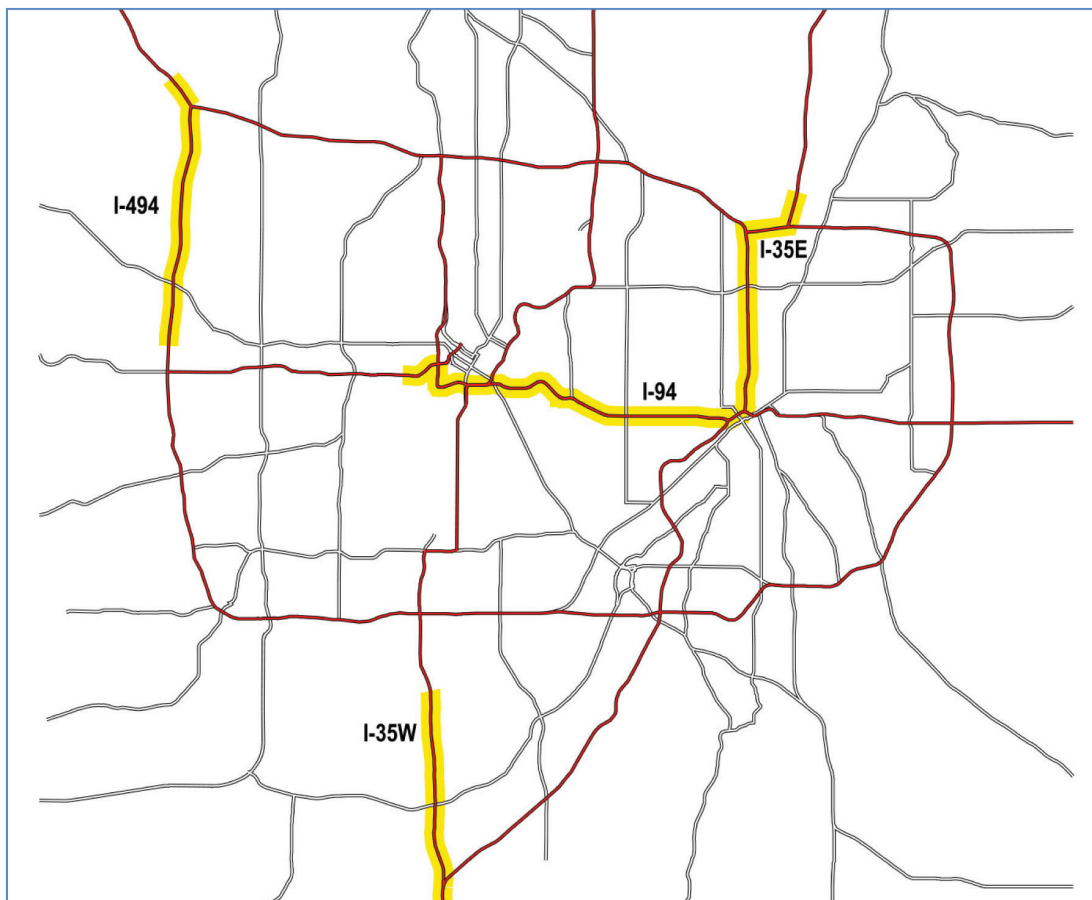


Source: FHWA Traffic Analysis Toolbox – Volume II, 2004.

In situations where a great amount of operational detail is required, but the analysis resources do not allow for full modeling or data collection on all the regional facilities impacted by the deployment, practitioners may want to consider the use of representative corridors for analysis. In this approach, one or more representative corridors are selected for detailed analysis, and the results are then extrapolated to other regional facilities. For example, in a well-known evaluation of the ramp metering

system in the Minneapolis/St. Paul metropolitan region, the benefits of metering were examined regionwide; however, the analysis resources did not allow for detailed data collection and analysis on all individual corridors in the region. Instead, the analyst carefully selected four representative freeway corridors in the region: 1) a downtown corridor, 2) a radial corridor inside the beltway, 3) a radial corridor outside the beltway, and 4) a section of the beltway corridor. Figure 5-2 shows the selected representative corridors in relation to the overall regional transportation system in the Twin Cities.

Figure 5-2. Use of Representative Corridors in an Analysis



Source: *Minnesota DOT Twin Cities Ramp Meter Evaluation, Final Report, 2001.*

Detailed data collection and analysis were performed on the four representative corridors, and then the analysis results, in terms of percentage changes in key MOEs, were extrapolated to all other corridors in the region based on the type of the corridor being analyzed. Performing the analysis in this way allowed for the required detailed analysis of specific benefits, but also allowed for the regional compilation of total benefits within the resource requirements of the study.

Types of Strategies

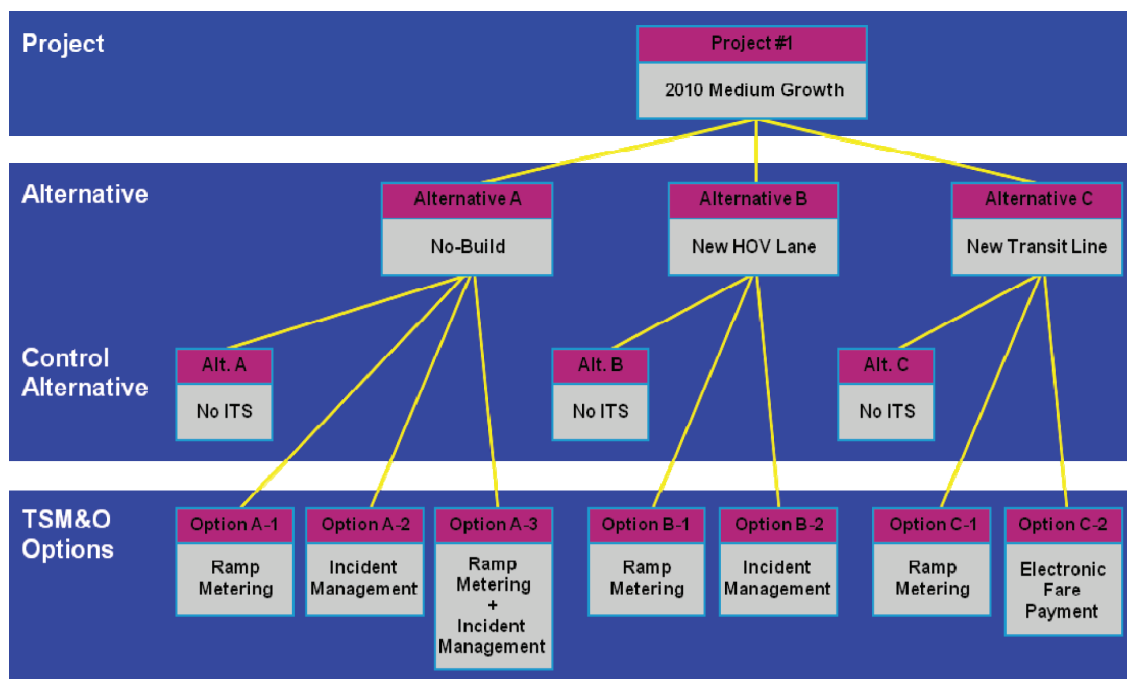
The type of strategy, or combinations of strategies, to be analyzed and compared within the B/C analysis is a key factor in determining the analysis approach. At the most basic level, the analyst should first determine if the analysis would need to:

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- Only evaluate and prioritize TSM&O strategies compared with each other;
- Compare TSM&O strategies alongside alternative scenarios with more traditional capacity enhancements; or
- Evaluate various alternative scenarios containing combinations of TSM&O and more traditional capacity enhancements.

A list of the strategies (TSM&O and traditional capacity projects) to be analyzed should be developed prior to the identification of the analysis approach. Many practitioners also find it useful to graphically map the strategies to be analyzed to individual analysis scenarios that will be analyzed. Figure 5-3 shows a sample mapping of strategies and scenarios that shows the breakout of strategies to be performed, as well as identifying those strategies that will be combined and analyzed together. This display is useful in identifying analysis that needs to be conducted on more traditional capacity enhancements (shown at the “Alternative” level in Figure 5-3), as well as scenarios that include only TSM&O strategies and combinations of TSM&O and more traditional strategies (shown as the “TSM&O Options” in Figure 5-3). This preliminary identification of analysis scenarios also is useful in identifying the number of individual analyses that will need to be performed.

Figure 5-3. Mapping of Strategies to Analysis Scenarios



Source: FHWA IDAS Training Course Participant Workbook, 2010.

This list of alternative strategies/scenarios should then be assessed to project the likely impacts of the strategies, including:

- What are the MOEs that may be affected?
- What are the facilities that will likely be impacted?

- Which modes will be impacted?
- What are the likely traveler behavior changes (e.g., route change, mode shift, temporal shift, etc.)?
- What are the time periods that likely will be impacted (i.e., are the strategies intended to be operated all day or only during peak periods or special conditions)?
- Will the timing of the strategy's implementation need to be considered (i.e., are all alternative strategies projected to be deployed on a similar time horizon or would the deployment of certain alternatives be delayed until future years [See discussions later in this Chapter on the Impacts of Selecting Different Time Horizons and the Impact of Time on Monetary Value]).

Answers to these questions will allow the analyst to begin formulating the analysis approach, including selecting an appropriate analysis tool(s), as well as identifying preliminary input data needs. The assessment of strategies to be analyzed should be weighed against the other factors presented in this section to formulate the final analysis approach.

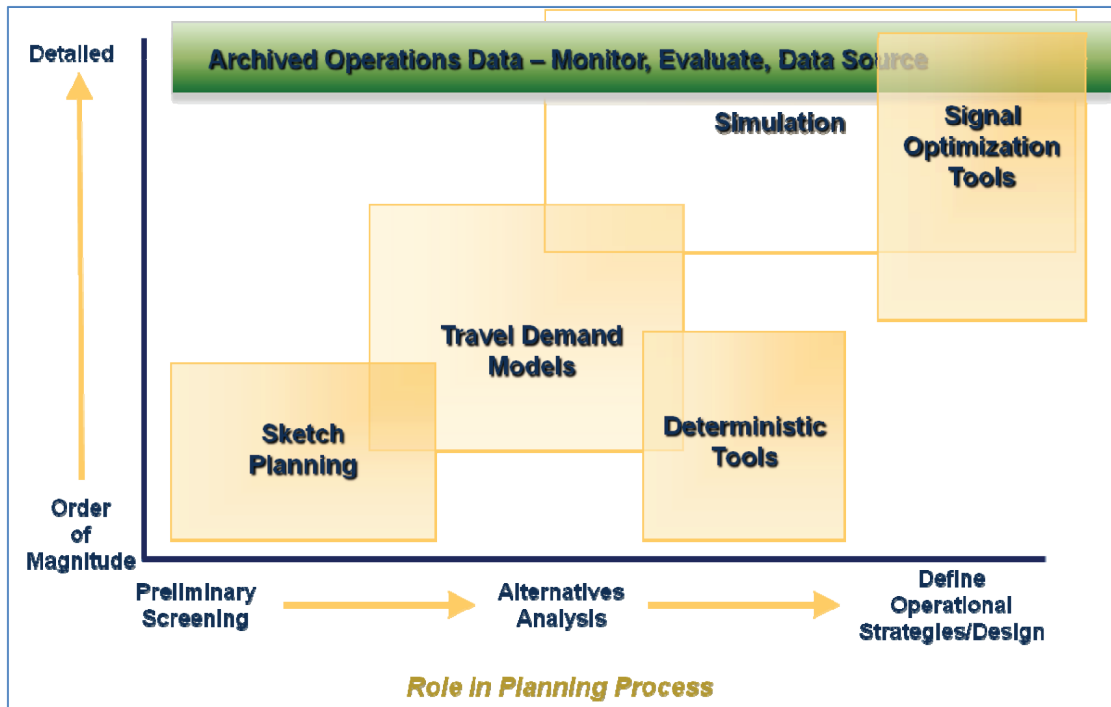
Need for/Purpose of Study

As discussed in Chapter 2, B/C analysis can play a role across a wide range of transportation planning processes and phases. The need for the analysis (or the planning objective that the analysis is intended to fulfill) is a key factor to consider in developing the analysis approach, and often helps to determine:

- The required level of confidence in the accuracy of the results;
- The number of alternatives to be analyzed; and
- The appropriate level of resources needed to conduct the analysis.

In early planning phases, for example the preliminary screening of alternatives, there is often a need to quickly conduct high-level, order-of-magnitude analysis of a large number of alternative scenarios. This analysis would likely require an approach that could be quickly implemented and repeated for a number of scenarios; however, the level of detail in the analysis may not be as critical. Alternatively, at the other end of the planning spectrum during the final alternative prioritization and design process, there may be the need to conduct very detailed analysis of a small number of scenarios. This analysis may require a substantially different analysis approach than used for preliminary screening needs. Figure 5-4 provides a comparison of different analysis tools mapped to different phases of the planning process, as well as the level of detail provided by the different analysis tool types, developed for an FHWA workshop series on *Applying Analysis Tools in Planning for Operations*. The figure shows how the proposed analysis method and/or tool may be influenced by the need for detail related to different phases of the planning process.

Figure 5-4. Comparison of Analysis Methods with Various Stages of the Planning Process and Need for Analysis Sensitivity



Source: FHWA Workshop Series – Applying Analysis Tools in Planning for Operations Participant Workbook, 2011.

Desired MOEs

Different TSM&O strategies often may have impacts on different MOEs. Likewise, different regions may place a higher priority on particular MOEs. For example, a region that is in noncompliance for a particular emissions category may have requirements that an assessment of that measure be included in all regional analysis. Therefore, the analyst should carefully consider the MOEs to be used in the analysis when setting up the approach and making decisions on applicable analysis tools.

Figure 5-5 presents an overview of TSM&O strategies and their primary and secondary impacts on various MOEs.

In addition, Figure 4-7, presented earlier, shows the capabilities of a wide range of analysis tools in examining particular performance measures. In planning for the analysis, practitioners should:

- Carefully identify the MOEs likely to be impacted by the strategies and projects they want to evaluate;
- Prioritize the MOEs to the needs of the analysis and the individual needs of the agency; and
- Select a tool or analysis method that best supports the analysis of the prioritized MOEs.

Figure 5-5. TSM&O Strategies Mapped to Likely Impacts on MOEs

TSM&O Strategy	Mobility (Travel Time Savings)	Reliability (Total Delay)	Safety (Number and Severity of Crashes)	Emissions	Energy (Fuel Use)	Vehicle Operating Cost Savings	Agency Efficiency
Arterial Corridor Signal Coordination							
Preset timing							
Traffic actuated timing	●	○	●	●	●	○	
Centrally-controlled timing							
Arterial transit vehicle signal priority							
Freeway Management Systems							
Ramp metering							
Preset timing	●	●	●	●	●	●	
Traffic actuated timing							
Centrally-controlled timing							
Advanced Public Transportation Systems							
Fixed-route systems Transit AVL							
Transit automated scheduling							
Paratransit systems	●	●	○	○	○	○	●
Transit AVL							
Transit automated scheduling							
Incident Management Systems							
Freeway/arterial service patrols	●	●	●	●	●	○	
Incident detection and verification							
Incident response management							
Pretrip Multimodal Traveler Information Systems							
Web-based 511 Traveler Information Systems	●	●	○	○	○		
Phone-based 511 Traveler Information Systems							
Kiosk-based Traveler Information Systems							
En-Route Multimodal Traveler Information Systems							
In-vehicle 511 Traveler Information Systems (PDA/Web based or Telephone based)	●	●	○	○	○		
HAR							
DMS							
Transit Station Traveler Information Systems							
Commercial Vehicle Operations							
Roadside Electronic Credential and Safety Screening	●		●	●	●	●	○
Traffic and Demand Management							
Congestion Pricing	●	●	○	○	○		
HOT Lanes							
Speed Harmonization	○	●	●	●	●		
Work Zone Management	●	●	●	●	●	●	●

● – Primary MOEs associated with the strategy.

○ – Secondary MOEs associated with the strategy.

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Required Level of Confidence in Results

The needs of different analyses often require different standards in terms of the level of confidence that is needed in the analysis outputs and results. Preliminary screening of projects may only require that order-of-magnitude results be generated to help categorize long lists of projects into high-, medium-, and low-priority levels. At the other end of the spectrum, very detailed and accurate results may be needed for finalizing design decisions or establishing strategy operating parameters. It is critical, therefore, that the level of confidence in the results required by the study needs be carefully considered in planning the analysis, and in selecting the appropriate analysis method/tool.

The required level of confidence in the results of the analysis often has a direct influence on the analysis resources that will be required. Typically, analysis requiring highly detailed and accurate results will demand the application of more robust analysis methods and tools that may necessitate a greater application of resources, including analysis budget, schedule, computing resources, and staff expertise. The tradeoffs between the required level of confidence and the level of resources need to be carefully weighed in order to avoid selecting an inappropriate analysis method. Inappropriate analysis methods can include both:

- “Underpowered” tools or methods that are not sufficiently robust to produce results with the desired level of confidence; and
- “Overpowered” tools or methods are overly detailed for the analysis need and may end up requiring more analysis resources than are available for the study.

Either of these above situations has the potential to negatively impact the integrity of the analysis and may result in the analysis being scrapped and started over using a more appropriately scaled tool or method, often at great cost.

While the level of confidence in the results is largely a product of the analysis tool or method selected, it is also related to the amount of effort put into customizing, calibrating, and validating the various tools. For very simple analysis requiring order-of-magnitude detail, practitioners may choose to simply apply parameters, impact measures, and benefit values based on national averages. As the need for greater confidence in the level of accuracy increases, practitioners will want to place greater effort on identifying and applying customized analysis parameters within the selected method/tool that more closely match the local experience and traffic conditions.

The level of confidence required for any individual analysis is determined individually for each analysis based on a number of factors, including:

1. The role fulfilled by the analysis in the planning process;
2. The intended audience for the analysis results;
3. The number of alternatives to be evaluated;
4. The availability and accuracy of underlying data and models; and
5. Subsequent analysis to be performed based on the analysis results.

Among these factors, the role that the analysis fulfills in the planning process often has the most substantial influence on the level of confidence and detail required. Figure 5-4, shown earlier in this section, showed that activities occurring earlier in the planning process, such as preliminary screening of alternatives, often require a lower level of detailed results, and confidence in the results,

while activities occurring during later stages of the planning process, such as final prioritization of alternatives or design work, may require highly detailed results that also require a high degree of confidence in the accuracy of the results. As shown in Figure 5-4, the need for detail and accuracy often drives decisions regarding the appropriateness of different tools and methods.

The level of confidence required in the analysis results is often the most substantial factor determining the analysis approach and the level of analysis resources that will be required to meet these needs. The following section provides additional discussion on the need to balance the analysis needs with the available resources.

Available Analysis Resources

Ideally, every B/C analysis would be conducted with the highest level of detail and rigor to provide:

- Comprehensive analysis of all the MOEs possibly impacted by the selected strategy;
- Analysis on a wide geographic scale to ensure the full capture of all regional benefits; and
- The highest level of confidence and detail of the analysis approach.

The reality of constrained budgets available for analysis, however, means that practitioners must often weigh the actual needs of the analysis against the available resources to balance the needs against the ability to support those needs.

Different analysis methods and tools often require substantially different levels of resources in order to successfully complete the analysis. The resources required for an analysis may include:

1. Budget resources;
2. Schedule;
3. Staff knowledge and expertise;
4. Computing resources;
5. Knowledge and data on local traffic conditions and operations;
6. Data availability and collection capabilities; and
7. Time and costs of utilizing supporting tools, models and analysis.

Some simple sketch-planning tools are designed to be applied at a low cost on a quick-timeframe basis. Utilizing the basic default parameters available in many of these tools, along with readily available data, a novice analyst could produce a basic B/C analysis in an afternoon. On the other hand, many analyses involving highly robust multiresolution/multiscenario methods may require six months to a year to complete at a cost of hundreds of thousands of dollars. Table 5-2 presents an overview of the general categories of analysis methods and tools compared with their approximate relative costs. Dollar budget costs presented in the table are approximate and represent the staff time required to complete an analysis (or the equivalent cost of a consultant).

Table 5-2. Analysis Tools and Methods Mapped to their General Resource Requirements^a

Method/Tool	Resources Required
Sketch planning	Budget – Low (\$1K to \$25K) Schedule – 1 week to 8 weeks Staff Expertise – Medium Data Availability – Low
Post-processing methods	Budget – Medium/High (\$5,000 to \$50,000) Schedule – 2 months to 1-year Staff Expertise – Medium/High Data Availability – Medium
Multiresolution/multiscenario	Budget – High (\$50,000 to \$1.5 million) Schedule – 3-months to 1.5-years Staff Expertise – High Data Availability – High

^a Estimates are provided for a “typical” analysis. Actual time and budget resources would be dependent on the number of alternatives, geographic scope, and effort required to compile the appropriate input data.

Available analysis resources should be identified early in the analysis planning process, along with the other factors discussed in this section. The analysts and their managers should then carefully weigh the needs of the analysis with the projected costs. The estimate of resources should also consider the contingency costs of conducting any additional analysis, or evaluating new alternatives that may arise during the project prioritization process. If, during this assessment, the project needs and the available resources are found to not be aligned, then the analysts and their managers need to seek a balanced resolution, but either cutting scope and/or requirements from the analysis (e.g., lessening the number of alternatives to be analyzed or reducing the complexity of the analysis); or by increasing the available resources to meet the needs of the analysis. Failure to do so will result in either a cost overrun, a poorly conducted analysis that does not meet its original intent, or both.

The *TOPS-BC* application, developed in parallel with this *Desk Reference*, provides a decision-support tool to aid practitioners in weighing the needs of the analysis with the resources that may be required. Additionally, the FHWA initiative on the Traffic Analysis Toolbox also provides guidance on the level of resources needed to perform different types of analysis (using different types of analysis tools).²¹

Other Factors

The factors presented above often comprise the most critical determinants in identifying and planning a successful analysis approach. As discussed, there is often the need to carefully balance the tradeoffs between the various factors (e.g., more robust analysis often requires additional resources to complete) in the final selection of an appropriate analysis approach.

In addition to these factors, several additional aspects of the analysis should be considered during the early planning and scoping effort in order to effectively establish a suitable analysis approach. These additional factors include:

²¹ FHWA *Traffic Analysis Toolbox – Volume II*, 2004.

- **Established B/C analysis procedures and framework** – Many regions and agencies have long used B/C analysis for assessing and prioritizing various transportation projects. This long-term use has often resulted in procedures, benefit valuations, and analysis frameworks being established. These established guidelines should be followed to the degree possible in order to remain consistent with the local planning process. If the established procedure has primarily been used to conduct B/C analysis of more traditional capacity-enhancing projects, some modification of the framework may be necessary to make it appropriately sensitive to the needs of MOEs used for analysis of TSM&O strategies. See Chapter 4 for an expanded discussion of these issues.
- **Available data to support the analysis** – In regions with rich sources of available data, such as a region equipped with a robust and reliable archived data system, some more advanced analysis methods may be pursued at substantially less cost than could be considered in other more “data poor” regions. The readily available data in the robust data region could be tapped to support more advanced analysis methods and tools than in the data poor region, where substantial resources may need to be applied to manual data collection efforts in order to establish the baseline dataset necessary to support the analysis effort, or calibrate and validate the needed analysis tools.
- **Available tools to support the analysis** – Many analysis tools commonly used to provide input data for B/C analyses were originally developed for other purposes. For example, if a detailed simulation model has been previously developed, calibrated, and validated for a regional corridor, a more advanced and detailed analysis method may be possible at a substantially lower cost than would be possible in a corridor, where an existing model did not exist. All existing and underdevelopment tools that may be available to support an analysis should be inventoried during the analysis planning phase, along with the data outputs available and the level of effort required to conduct analysis using the tool, and weighed along with the other critical factors in identifying the optimal analysis approach.

Determining the Appropriate Timeframe to Use

As opposed to many standard transportation analyses that examine the system performance related to a particular improvement alternative for a specific analysis year (e.g., current year 2011 baseline analysis, or future year 2030 analysis), many B/C analysis attempt to capture the comprehensive benefits that flow as a result of an improvement over the life cycle of the deployment or other another selected time stream (e.g., 10-, 20-, or 30-year time horizons). The purpose of this approach is to spread out both the benefits and costs over an appropriate timeframe to allow for a meaningful analysis. For example, a practitioner would not want to compare the total costs for a strategy with a single-year estimate of benefits.

Therefore, the selection of an appropriate timeframe or time horizon to use in the analysis can take on more importance than in other transportation analyses. The implications of selecting and using different timeframes for analysis are discussed in the following sections.

Impacts of Selecting Different Time Horizons

The practice of capturing benefits and costs over a defined time horizon in transportation-related analyses is common and is largely tied to the analysis of large-scale infrastructure projects, where a general useful life of the project is well known. For example, the costs (capital implementation costs plus continuing operations and maintenance costs) of a new bridge or roadway could historically be

relatively well estimated over the expected life (e.g., 30 years) of the infrastructure or pavement. The benefits often were relatively static over the analysis timeline as well, providing for an easy calculation and comparison of benefits and costs over the selected timeframe.

Applying this same traditional timeframe approach to TSM&O strategies can add complexity to the analysis due to the following factors:

- **Benefits of TSM&O strategies can be extremely variable** – For example, a TSM&O weather management system would be expected to have varying benefits year after year, depending on the number of inclement weather days. This differs from more traditional capacity improvements that would be expected to have nearly the identical benefits year after year.
- **TSM&O strategies often have shorter useful life of equipment and require more frequent replacement cycles** – Many major infrastructure projects, like adding a lane to a regional freeway facility, have a relatively long and predictable useful life (e.g., 20 to more than 30 years) before requiring complete replacement. Many TSM&O strategies, on the other hand, are technology based and some key components may need replacement on much faster cycles (e.g., every 2 to 5 years). As a result, it is more difficult to place an overall “useful life” on TSM&O strategies since they have equipment with much shorter useful lives, yet are often also assumed to be operated in perpetuity once they are deployed.
- **Costs of technology are changing over time** – Many TSM&O strategies rely heavily on emerging technology; and as the economies of scale of new strategies expand, the costs often decrease. Therefore, evaluating a pilot project based on the initial development and implementation costs may not be accurate, as the costs could be expected to decline significantly in future years as a result of technology improvements.

These factors, combined with the effects of inflation and the time value of money, which impact all B/C analyses performed over a time horizon (discussed in a subsequent section), make selecting a time horizon for the analysis a critical effort that potentially impacts the results.

Many agencies maintain their own procedures for conducting B/C analysis that specify the length of the analysis period that should be applied. This standard should be applied whenever consistency with the established B/C framework is required. Likewise, if a B/C analysis is required to fulfill part of a funding request, the funding mechanism may specify a specific time horizon be used. For example, the recent U.S. DOT TIGER Grant application process required that a 20-year time horizon be used in the B/C analysis. The analyst should research any existing agency practices and/or the specifications of any funding application prior to initiating the analysis to identify any requirements for a specific time horizon.

If no predetermined time horizon exists, the analyst may choose between several options for the time horizon for the analysis. If a stream of cost analysis is desired, the time horizon generally is scheduled to start with the first project expenditures, and extends through the useful life of the project or its most long-lived alternative, or some future time at which meaningful estimates of effects are no longer possible.²²

If the time horizon selected is shorter than the expected life of one of the analyzed projects, and/or a project will need to be redeployed within the time horizon, the analysis may need to consider the salvage

²² <http://bca.transportationeconomics.org/setup/time-period-of-analysis>.

value or residual value of the equipment or deployment that remains at the end of the time horizon. For example, if a 20-year time horizon is selected for a light-rail project, it is likely that the rail vehicles and rail infrastructure will still have substantial remaining useful life at the end of the analysis period. In this situation, the residual value of this remaining life would need to be determined and added back into the analysis. Residual or salvage values are often used less in analysis of TSM&O strategies as the faster equipment replacement cycles lessen the salvage value for many of technologies and equipment.

An alternative option to using an analysis with a set time horizon is to utilize a single estimate of average annual benefits and costs. This measure is most typically used in analysis that seeks to compare and prioritize various TSM&O strategies with each other. TSM&O strategies are often well suited for analysis using average annual benefits and costs since they have relatively short life cycles, and are anticipated to be repeatedly redeployed in future years. Use of average annual benefits is also useful if only a single-year snapshot view of performance is available for the analysis (e.g., only a single forecast year of data is available for analysis).

Many current B/C analysis tools use average annual benefits and costs in their analyses, including the IDAS tool and the *TOPS-BC* tool that supports this *Desk Reference*.²³ Average annual benefits are generally estimated based on a single forecast year, and are anticipated to be identical for all years. Average annual costs are estimated based on the capital cost of a piece of equipment divided by the anticipated useful life of the equipment. To this capital cost, an estimate of annual O&M cost is added to estimate the total average annual costs. For example, if a camera to be used in traffic surveillance strategy has:

- A total capital cost of \$10,000;
- An anticipated useful life of 10 years; and
- Annual O&M costs of \$2,000 per year, the average annual costs would be:

$$\text{Average Annual Cost} = (\$10,000 \text{ capital} / 10 \text{ years}) + \$2,000 \text{ O\&M} = \$3,000 \text{ per year}$$

Impacts of Time on Monetary Value (Inflation and Discount Rate)

Two competing influences on future dollar values need to be considered in B/C analysis: inflation and discounting.

1. **Inflation** is the increase in prices for goods and services over time. It implies a loss in the value of money over time, as it erodes the purchasing power of a currency. Benefit/cost analysis for public-sector projects generally controls for inflation, using estimates of future costs and benefits that are expressed in terms of today's (or some base year's) prices. These are referred to as "constant" or "real" dollars. Consistent with this approach, the discount rate used in benefit/cost analysis represents the time value of money after adjustment for inflation.²⁴
2. The **Discount Rate** is the recognition that a dollar today is worth more than a dollar five years from now, even if there is no inflation because today's dollar can be used productively in the ensuing five years, yielding a value greater than the initial dollar. Future benefits and costs are discounted to reflect this fact.

²³ *TOPS-BC* is capable of estimating average annual benefits and costs, or projecting the benefits and costs to a stream of costs that may be used with a time horizon selected by the user.

²⁴ <http://bca.transportationeconomics.org/calculation-issues/inflation>.

Benefit/cost analyses typically ignore inflation because the prediction of future prices introduces unnecessary uncertainty into the analysis. Therefore, discount rates are typically based on interest rates for borrowing with the inflation component removed, yielding the “real” interest rate. This rate is typically calculated by subtracting the rate of inflation (consumer price index) from the interest rate of an investment, such as a 10-year U.S. Treasury bill. For example, if the interest on a 10-Year Treasury bill is 5.5 percent and the inflation rate is 3 percent, then the discount rate would be 2.5 percent.²⁵

The discount rate for most projects is based on guidance provided by the U.S. Office of Management and Budget (OMB). The rate to be applied is related to the type of the project and the expected benefits and costs. If the project is anticipated to have benefits to the general public (societal benefits such as travel time savings or crash reductions), the OMB currently suggests a discount rate of 7 percent, which represents the real discount rate on private investment. If, however, the analysis includes benefits and costs exclusively related to the public agency, for example, an analysis of an investment that would bring about a cost savings to the agency, the OMB suggests using the real discount rate for public-sector investments, which is often lower due to the lower risk associated with government borrowing. The OMB publishes “real” interest rates on its web site http://www.whitehouse.gov/omb/circulars_a094_a94_appx-c/. Table 5-3 presents the real rates published on the site in July 2011. Generally, if there is a mix of societal and agency benefits within the same analysis, only the private-sector investment discount rate (7 percent) is used.

Table 5-3. Real Discount Rates 2011 (Public Investment)
(in Percentage)

Time Period	3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
Discount Rate (%)	0.0	0.4	0.8	1.3	2.1	2.3

Source: White House Office of Management and Budget, 2011.

Real discount rates, as shown in Table 5-3, represent rates in which inflation has been removed. These real rates are to be used in B/C analysis for discounting real (constant-dollar) flows.

Available Resources for Identifying the Benefits of Operations Strategies

Often, one of the most challenging aspects of conducting B/C analysis of TSM&O strategies is identifying the likely impact or benefit of the strategy. This is particularly true for emerging technologies or strategies, where few real-world deployments exist to provide empirical evidence on the likely impacts to various MOEs. Several options for researching the likely benefit levels that may be used in an analysis are discussed in this section.

The *TOPS-BC* application that supports this *Desk Reference* maintains a look-up database of likely impacts of various TSM&O strategies related to several MOEs. Figure 5-6 shows a view of the navigation screen for this capability in *TOPS-BC*. To research likely impact levels of TSM&O strategies, the user would select a “Strategy” and “Impact Category” from the pull-down menus. Based on this input, *TOPS-BC* would display a “Typical Range of Expected Impacts,” assuming there is sufficient data to formulate a range for the selected strategy and impact category.

²⁵ <http://bca.transportationeconomics.org/calculation-issues/discounting>.

Figure 5-6. Sample View of *TOPS-BC* TSM&O Impact Look-up Function

FHWA Tool for Operations Benefit/Cost (TOPS-BC)

Investigate the Range of Impact Values Associated with Various TSM&O Strategies

Navigation Screen [Return to OPENING SCREEN](#)

Instructions: Please select the "TSM&O Strategy" and the "Impact Category" you are interested from the pull down list below. If sufficient data is available, a range of expected impacts will be shown below. Click on the hyperlink to be taken to a table displaying the datapoints comprising the range.

TSMO Strategy Selected:

Freeway Management System : Ramp Metering : Traffic Actuated

Impact Category:

Throughput

Noted Impacts

[Expect 5% to 30% capacity reduction on ramps and 7% to 20% capacity increase on freeway.](#)
[Expected increases in volume between 5% and 30%](#)

Typical Range of Expected Impacts

Source: FHWA *TOPS-BC* model.

The range of expected impacts is based on a compilation of evaluations and studies that have gathered empirical evidence on the impact of these strategies in national and international locations. This range also often considers the predicted impacts used in various traffic and B/C analysis tools as the default impacts used in the calculation of benefits for the strategy, when available. The user may view these individual studies and model data on subsequent worksheets in the *TOPS-BC* application. Descriptions of the observed impacts are brief, but links are provided to the source documentation so the user may research further any interesting information.

Another valuable resource for researching the potential benefits of TSM&O strategies is the ITS Benefit Database maintained by U.S. DOT Research and Innovative Technology Administration's (RITA) ITS Joint Program Office at <http://www.benefitcost.its.dot.gov/its/benecost.nsf/BenefitsHome>. The database allows users to research benefits information by strategy area, provides a rich resource for identifying benefits, and maintains a robust library of studies documenting the benefits of many TSM&O strategies. Figure 5-7 presents a view of the navigation page for the database site.

Figure 5-7. Sample View of U.S. DOT ITS Benefits Database Web Site



Configuring B/C Analysis to Local Conditions

As discussed in Chapter 3, many existing B/C tools and analysis frameworks maintain default parameters representing the anticipated impact to various MOEs. These are often based on national averages of observed benefits gathered from empirical studies in the case of widely available tools. For analysis frameworks that were developed for a specific region, these parameters may be more individually customized for that specific region. For simple analysis, for example, a quick, first-cut screening of alternatives, analysts may choose to use one of these widely available tools or perhaps a framework that was developed for another agency or region, and apply the method locally with little or no changes to these default settings. As the level of required confidence in the analysis results increases, however, users should increasingly place greater scrutiny on the default parameters, and modify these inputs accordingly to better configure the analysis to local conditions.

Ideally, analysts will be able to identify and obtain data specific to the local region that may be applicable in supplementing or replacing the default analysis parameters based on national averages. This data may be obtained from previously conducted evaluations that were conducted in the region, review and analysis of archived data, or other local sources. For example, in the Cincinnati analysis

case study presented in Chapter 2, the OKI region analysts started the analysis with a thorough review of the analysis defaults. The defaults were scrutinized to assess if they were appropriate to the way the region operated its TSM&O strategies, and to identify any local sources of information that would be more appropriate. The analysts were able to identify a locally conducted evaluation of the reduction in incident duration caused by their FSPs, which they were able to use to replace the default parameter in the analysis. Likewise, some local survey results were used to refine the default amount of time saved by travelers as a result of DMS-provided information. These modifications substantially improved the overall analysis; in that, the parameters were better configured to local conditions. This configuration was performed for the local system costs and benefit valuation figures as well.

Where data is not available specifically representing conditions in the local area, the reference resources discussed in Chapter 5 may be used to assess the appropriateness of the default parameters and make adjustments to better configure the results to the local conditions. For example, an analyst working for a mid-sized region located in Midwest may want to review the individual studies highlighted in the *TOPS-BC* and the ITS JPO ITS Benefit Database to find individual studies conducted in similarly sized and located regions. If the results from these individual studies differ substantially from the national average default parameters, they may want to modify the parameters to be more representative of conditions in their region.

Finally, for more detailed multiscenario analysis, where the analysts may be attempting to individually model different scenarios representing various nonrecurring conditions, a preanalysis of existing conditions and the frequency of various nonrecurring factors may be warranted to develop meaningful analysis scenarios representing likely conditions. Robust data from archived data systems is often the best source for conducting this analysis for scenario development and identification. Table 5-4 presents an output of an analysis performed for the ICM Pioneer Site study conducted in Dallas. The analysis shows the frequency of occurrence of several factors related to congestion levels, and was used to identify likely analysis scenarios that most accurately represented the nonrecurring traffic conditions on the U.S. 75 corridor. By basing the test scenarios on the actual observed distribution of conditions, the analysis was better configured to local conditions.

Table 5-4. Distribution of Operating Conditions in U.S. 75 Dallas

Demand	Incident	Inclement Weather	Number of Hours	Percent
Med	No	No	247	33.9%
Low	No	No	136	18.7%
High	No	No	134	18.4%
Med	Minor	No	79	10.8%
High	Minor	No	55	7.5%
Low	Minor	No	55	7.5%
Low	No	Yes	9	1.2%
Med	No	Yes	5	0.7%
Med	Major	No	4	0.5%
Low	Major	No	2	0.3%
Low	Minor	Yes	2	0.3%
High	Major	No	1	0.1%
Med	Minor	Yes	0	0.0%
High	No	Yes	0	0.0%
High	Minor	Yes	0	0.0%
High	Major	Yes	0	0.0%
Med	Major	Yes	0	0.0%
Low	Major	Yes	0	0.0%

Source: *ICM System – Analysis, Modeling, and Simulation Guide*, Draft Final Report, 2011.

Estimating the Impacts (User and Societal Benefits) of the Operations Strategy

Estimating the benefits of various TSM&O strategies is tied to the type of project being evaluated. As detailed in Chapter 3, TSM&O strategies are often categorized into three groups:

1. **Physical operations strategies** – These strategies involve the deployment of physical infrastructure to the roadside or transit assets, and are intended to provide direct impact on transportation system performance through their operation. These strategies are often highly visible to the traveling public, and include a wide range of deployments, such as traffic signal coordination, freeway service patrols, 511 traveler information systems, HOT lanes, and DMS, among many others.
2. **Supporting infrastructure** – Supporting infrastructure includes those backbone capabilities that serve to support and enhance the functioning of the roadside Operations strategies. This backbone infrastructure includes items, such as traffic detection and surveillance, communications, and traffic management centers. Often, by themselves, these strategies have no direct intrinsic benefits. The benefits derived from these strategies are the improved performance of the roadside Operations strategies enabled by their deployment. For example, a traffic surveillance camera by itself has little direct benefit. The benefit is derived from the manner in which the information is use (i.e., when the surveillance from the camera is used by

operators to implement different signal timing patterns, or detect and respond to an incident faster). Therefore, the measure of benefit of these supporting infrastructure components is often measured by estimating the improved efficiency of the roadside components supported by the backbone infrastructure, rather than attempting to directly estimate the benefits of the supporting infrastructure itself.

3. **Nonphysical strategies** – These strategies represent items intended to improve the efficiency and effectiveness of the TSM&O systems; and includes strategies, such as improved interagency coordination, the development of advanced operational plans (e.g., evacuation plans), or system integration. While there certainly can be benefits of these activities and there are often costs, there typically is little or no new physical equipment or roadside components. Similar to the supporting deployments, the benefits derived from these strategies are typically estimated by assessing the improvement in effectiveness of the existing roadside components provided by the strategy or activity.

Methods for estimating the benefits of these types of strategies are discussed in the subsequent sections.

Estimating the Impacts of Physical Operations Strategies

Most of the physical operations strategies impact one or more of the common MOEs. Previously presented, Table 5-5 shows the primary and secondary MOEs impacted by the strategies. Primary measures are those most closely correlated to the strategy, while the secondary measures may be more trivially impacted by the strategy, or may only be impacted depending on how the particular strategy is implemented and operated.

The goal in evaluating these types of strategies is to isolate the incremental change in the MOEs related to the deployment. In a real-world B/C evaluation of an existing strategy, empirical data representing conditions without the strategy (before deployment) is compared to data representing conditions with the strategy (after deployment) to assess the incremental change.

In a forecasting study, the “with” and “without” conditions are estimated using models or other predictive approaches to assess a baseline (without strategy) and an alternative (with strategy) scenario. The difference between the scenarios’ performance represents the incremental change due to the implementation of the strategy. In using modeled data for TSM&O strategies, it is important that the period of analysis in the model closely approximates the temporal (i.e., time-of-day) operating parameters of the strategy. For example, in evaluating a HOT lane strategy that is only anticipated to be operational during peak periods, the model used should represent the peak period, as this is the only time that benefits would be generated by the strategy. Use of a daily model in this situation could result in the overstatement of benefits, as benefits would be estimated to be falsely accruing to the strategy during off-peak periods, where it would not be expected to be operational.

The real-world before and after data or the modeled baseline and alternative scenario data are often entered into a spreadsheet or entered into an existing B/C analysis tool to provide a framework for calculating and documenting the change in the various MOEs. If the data used in assessing the incremental change represents a daily or portion of a day analysis (e.g., three-hour peak-period analysis), the resulting incremental change in the MOE needs to be annualized by applying a factor representing how many of those periods would be expected in a given year. Similar to selecting the

appropriate time period for the analysis, it is critical that the analyst selects an annualization factor that accurately represents the operating parameters of the TSM&O strategy. For example, if the strategy were only operated on nonholiday weekdays, an annualization factor of 250 would be used to factor daily changes in MOEs to annual measures. For other strategies that are only operated during special events or other nonrecurring conditions, the annualization factor may be even less. Figure 5-8 shows a sample calculation of the daily change in various MOEs and the application of an annualization factor (250) to estimate the annual incremental change.

Figure 5-8. Example Calculations of Incremental Change MOEs

Benefit/Cost	Baseline	Alternative	Difference	Annual Difference
Auto Vehicle Miles of Travel (VMT)	170,177,633	170,204,412	26,779	6,694,695
Truck VMT	18,128,820	18,136,463	7,643	1,910,870
Average Vehicle Occupancy	1.42			
Person Hours of Travel (Auto)	5,923,262	5,922,600	(663)	(165,631)
Vehicle Hours of Travel (Truck)	462,006	462,006	-	-
Person Hours of In-vehicle Travel (Transit)	40,679,986	40,649,288	(30,698)	(7,674,482)
Person Hours of Out-of-vehicle Travel (Transit)	33,925,318	33,935,621	10,303	2,575,640

Source: San Francisco Bay Area MTC 2035 Long-Range Transportation Plan Project Performance Analysis, 2011.

The example shown in Figure 5-8 represents a relatively simple analysis, where a single-year forecast (2035 in this example) is used to represent the likely change in MOEs for all years. This assumes that the impacts and benefits of the deployed strategies remain fairly constant throughout the time horizon of the analysis. These incremental changes in MOEs may be expected to vary significantly, however, if the baseline (without the strategy) traffic conditions are expected to vary in future years. Depending on the underlying traffic conditions and the strategy selected, the benefits of the strategy could be expected to increase in future years – providing greater benefits as congestion increases – or decrease in future years – if the strategies incremental benefits are overwhelmed by increasing congestion.

Depending on the level of detail required by the analysis and the extent in which future conditions are expected to vary during the timeframe of the analysis, it may be necessary to add an analysis of one or more additional forecast years, and then interpolate the incremental change in MOEs between the analysis years to more fully capture these changing benefits.

For many typical MOEs (e.g., person hours of travel), the modeling method used as the source of the data (e.g., travel demand model, HCM analysis or simulation models) will be able to directly export the metric. Other MOEs, such as the number of crashes or amount of pollutant emissions, may be able to be directly estimated within the model structure (depending on the robustness of the regional modeling structure); or if not, may need to be assessed in a post-processing step. For example, many of the existing B/C analysis tools maintain the ability to estimate crashes and emissions based on simple outputs from the regional travel demand model.

For some of the emerging MOEs, such as travel time reliability, it is often necessary to employ a separate analysis method or structure (e.g., multiresolution- or multiscenario-based methods) to accurately assess

these benefits as these measures are typically not yet well integrated with many regional modeling frameworks. See Chapter 5 for an expanding discussion of the methods that may be used to meet the challenges of assessing nonrecurring conditions in the analysis of TSM&O strategies.

Once the desired MOEs have been estimated and assembled in the B/C analysis tool or customized framework, appropriate benefit valuations (discussed in a subsequent section) are applied on a per unit basis (e.g., per hour of travel time saved, per number of injury crashes reduce, per ton of emissions reduced) to estimate the monetized user or societal benefit generated by the incremental change in the MOE.

Estimating the Impacts of Supporting Infrastructure

Estimating the impacts of supporting infrastructure, such as traffic surveillance and detection systems, traffic management centers, or communications systems, is often not as straightforward as estimating the benefits related to a physical operations strategy. Many of these supporting infrastructure projects have no inherent benefits associated with them. The benefits of these strategies flow from their ability to improve the physical roadside operations strategies. For example, the deployment of a camera surveillance system by itself would not be anticipated to generate any incremental changes to the typical MOEs (e.g., travel time, safety, vehicle operating costs, etc.). The benefit of the camera surveillance would be the impact of the additional data on improving other physical operations strategies – the camera images could be used to enhance the incident detection and verification procedures of the incident management program, or used to monitor an arterial in order to select appropriate signal timing strategies. Thus, the benefit does not accrue simply from deploying the supporting infrastructure, but from the improvement in operations of the physical roadside strategies which it supports.

To estimate the impacts of supporting infrastructure, the analyst first needs to map the supporting infrastructure to the roadside physical strategies it supports. An assessment then needs to be made regarding the influence of the supporting infrastructure. This assessment should evaluate:

- The degree to which the roadside physical strategy is influenced or enabled by the supporting infrastructure;
- Which specific MOEs will be impacted by the improved operation of the roadside physical strategy;
- The expected amount of time that the supporting infrastructure will be used to enable the roadside strategy (e.g., on a day-to-day basis, or only during infrequent occasions); and
- The proportion of cost of the supporting infrastructure that should be reasonably allocated to operating the roadside component (for example, if a camera surveillance system is anticipated to equally support an incident management program and the corridor traffic signal coordination strategy, the cost of the cameras should be proportionately allocated to both roadside strategies).

Based on this assessment, the anticipated impact for the roadside physical strategy should be increased to a higher point in the expected range of impacts for those MOEs anticipated to be improved by the enhancement provided by the supporting infrastructure.

If the supporting infrastructure and the roadside physical operations strategy are deployed in parallel as part of an integrated system, the costs used in the B/C analysis should include the full cost of the physical operations strategy and the proportion of the supporting infrastructure that can be reasonably allocated to supporting the specific roadside component. If, however, the supporting infrastructure

serves to enhance an existing roadside strategy, the costs of that strategy should not be included in the analysis since they were paid for as part of another project. In these situations, only the cost of the supporting infrastructure that can be allocated to the enhancement of roadside component, and possibly any additional minor costs necessary to integrate the supporting infrastructure and the legacy roadside strategy should be considered.

Estimating the Impacts of Nonphysical Operations Strategies

Nonphysical strategies are intended to improve the efficiency and effectiveness of the deployed TSM&O systems, and involve their own challenges in assessment in a B/C analysis framework. The following represent some of the common nonphysical operations strategies, along with a description of an analysis approach.

1. **System integration** – Involves the integration of two or more systems to allow for the improved exchange of data between the systems and/or the coordinated operation of the systems. For example, a traffic signal coordination system could be integrated with a traffic incident management system to provide additional capacity on parallel diversion routes when incidents occur on a freeway facility. Similar to the analysis of supporting infrastructure deployments, analysts evaluating system integration strategies must carefully assess how and the degree which existing capabilities of the strategies to be integrated will be enhanced by the improved data availability or coordinated operations. The benefits would be estimated by modifying the expected impact on various MOEs to a higher level in the range of anticipated impacts to reflect this improvement. If the system integration involves the linkage of two or more existing legacy systems, the baseline scenario becomes the analysis of the physical operations strategies operated at their previous, nonintegrated impact level, and the alternative scenario would be the operations strategies operated at their enhanced impact level. The incremental benefit would be represented by the difference between these two scenarios. It is important if existing deployments are included in the analysis that the analyst not include the benefits already accruing due to the legacy components, but only include the incremental benefits of the enhanced operations due to integration.
2. **Interagency coordination** – Involves the exchange of information and/or agreements, allowing for the joint operation of various strategies across different agencies or jurisdictions. Similar to the approach for assessing system integration, the analyst and system operators will need to conduct an assessment of how and the degree to which the interagency coordination will improve existing or proposed physical operations strategies. An alternative analysis scenario should then be developed that increases the likely impacts on selected performance measures higher in the range of likely values. This alternative should then be run through the analysis process to estimate the change in MOEs, and should be compared with a baseline that represents the existing and proposed physical operations strategies operated at a lower level of impact (representing no interagency coordination).
3. **Regional concepts of transportation operations** – The development of regional concepts of transportation operations involves the coordination of the various stakeholders responsible for operating one or more components in order to develop sets of policies, procedures, and operating parameters that may be implemented according to specific identified conditions to improve the efficiency and effectiveness of Operational Strategies during those conditions. The development of a coordinated strategy for operating strategies during a regional evacuation would be an example of a regional concept of transportation operations that might be analyzed using benefit/cost analysis.

In the case where regional concepts of transportation operations are developed to simply improve day-to-day operations, their analysis may be conducted similar to system integration or interagency coordination strategies by estimating the influence the regional concept of transportation operations may have on the performance of physical operations strategies, and then testing the incremental effect on MOEs as an alternative scenario.

Evaluating the impacts of regional concepts of transportation operations is often made more challenging, however, in that the plans and strategies may be targeted at unique, nonrecurring events (such as incident-related road closures, severe weather events, hazardous materials (hazmat) spills, special events, or evacuations). In many cases, these unique conditions, in which regional concepts of transportation operations are applied, may also require aspects of the system to be operated in dramatically different ways than normal day-to-day operations. For example, an evacuation regional concept of transportation operations may allow for reversing the flow on particular roadways. There are generally three major steps in conducting a B/C analysis of a regional concept of transportation operations plan that must be completed in addition to the normal steps required for typical B/C analysis. These steps include:

- a. The regional concept of transportation operations plans need to be reviewed by the analysts and system operators to identify how and the degree to which the operation of the physical operations strategies will be modified by the application of the regional concept of transportation operations. This includes an assessment of which MOEs may be influenced, and making adjustments to default impact parameters to reflect these changes.
- b. The situations in which the regional concept of transportation operations will be applied needs to be evaluated by the analysts and system operators, and any underlying analysis models will need to be checked to confirm they are capable of analyzing any unique conditions. It is important to check that both the analysis of the baseline (without the regional concept of transportation operations application) and the alternative scenario (with the regional concept of transportation operations application) are able to be modeled within the analysis framework. Modifications to the model may be necessary to allow for these nontypical conditions. For example, in the case of a regional concept of transportation operations targeted at improving operations for a special event (e.g., a large sporting event), a baseline travel demand or simulation model may need to be adjusted to reflect the added trips destined to the stadium location. Other regional concepts of transportation operations applications may require more substantial modifications to the underlying model. For example, a hurricane evacuation regional concept of transportation operations evaluation may require significant changes to the underlying model, including a complete modification of normal trip origin and destination patterns, modifications to the road network to reflect road closures or reverse flow, and modification of transit system operations.
- c. Once the first two steps are complete, the analyst may run the models or the analysis techniques for both the baseline and the alternative scenarios to estimate the incremental change in MOEs. Since the conditions covered by many regional concepts of transportation operations are unique or nonrecurring events, the process of annualizing the benefits is made more complex. Data will need to be compiled and analyzed in order to estimate the frequency or likelihood of the conditions in which the regional concept of transportation operations is to be applied. For regional concepts of transportation operations designed around events or conditions that are anticipated to occur multiple times per year, for example sporting events at a stadium, the incremental

benefits identified for a single event are multiplied by the anticipated number of events or occurrences of those conditions during a year, or:

$$\text{Annual Benefit} = \text{Incremental Benefit per Event} * \text{Number of Events per Year}$$

- d. For regional concepts of transportation operations designed around less frequent events or conditions, such as hurricane evacuations, the identified benefit per occurrence or event is multiplied with a factor representing the overall likelihood that an event will occur in any given year. For example, if a region undergoes a major hurricane evacuation once every 25 years on average. If the same region conducts an analysis of the regional concept of transportation operations developed for guiding hurricane evaluations and finds the benefits of implementing the plan are \$3 million per event, the annual benefit would be calculated as follows:

$$\text{Annual Benefit} = \text{Incremental Benefit per Event} * \text{Likelihood of Event in Any Given Year}$$

$$\text{Annual Benefit} = \$3\text{M per Event} * (1/25 \text{ or } 0.04) = \$120,000$$

- e. In presenting and displaying the benefit results from evaluations of regional concepts of transportation operations, it is recommended that both the annual benefit and the benefit per event be used in order to avoid confusion among the reviewing audience.

Valuing the Benefits

The *TOPS-BC* application that supports this *Desk Reference* maintains a repository of many of the benefit valuations, along with identification of their source, that are typically applied in B/C analysis of TSM&O strategies. Figure 5-9 shows a sample of the benefit valuations maintained in the *TOPS-BC* repository. It is recommended that these benefit valuations be closely reviewed by the analyst prior to application in a study to ensure compatibility with local conditions. Where locally preferred valuations are prescribed by regional B/C analysis guidelines, the local figures should be applied to ensure consistency with those local guidelines and better allow the comparison of B/C analysis results from TSM&O strategies with non-TSM&O strategies. If the practitioner is developing the B/C analysis to support an application for funding, however, the analyst should check any requirements or restrictions on using different valuations other than any specified in the funding application instructions.

Figure 5-9. Sample View of Benefit Valuations Maintained in the TOPS-BC Repository

Benefit Valuations		
<i>Recurring Travel Time (per hour)</i>		
"On the Clock" Travel Time	\$	28.00
Other Auto Travel Time	\$	14.00
Truck Travel Time	\$	28.00
<i>Non-Recurring Travel Time (per hour)</i>		
"On the Clock" Travel Time	\$	28.00
Other Auto Travel Time	\$	14.00
Truck Travel Time	\$	28.00
<i>Crashes (per occurrence)</i>		
Fatality	\$	6,500,000
Injury	\$	67,000
Property Damage Only (PDO)	\$	2,300
<i>Fuel Use</i>		
Per Gallon (Excluding Taxes)	\$	3.67
<i>Non-fuel Operating Costs (per VMT)</i>		
Auto		0.25
Truck		0.37

Source: FHWA TOPS-BC, 2012.

Estimating the Life-Cycle Costs

Estimating the costs of TSM&O strategies is often complex. Compared to more traditional infrastructure improvements, TSM&O improvements typically incur a greater proportion of their costs as continuing O&M costs, as opposed to upfront capital costs. Much of the equipment associated with TSM&O strategies also typically has a much shorter anticipated useful life than many traditional improvements, and must be replaced as it reaches obsolescence. Further complicating the TSM&O cost estimation process is the fact that TSM&O deployment costs are greatly impacted by the degree in which equipment and resources are shared across different deployments and jurisdictions.

Despite these difficulties, it is critical that planners fully consider and account for all the costs of TSM&O strategies when evaluating and developing deployment and O&M plans. Failure to recognize and accurately forecast these costs may result in future funding or resource shortfalls, or worse, the inability to properly operate and maintain deployed TSM&O improvements. The cost estimation capability developed within the TOPS-BC support tool is intended to assist planners in estimating and predicting high-level cost and resource requirements of planned TSM&O strategies.

A good structure to follow for organizing these cost data includes:

- **Capital costs** – Include the upfront costs necessary to procure and install equipment related to the Operations strategy. These costs will be shown as a total (one-time) expenditure, and will include the capital equipment costs, as well as the soft costs required for design and installation of the equipment.
- **O&M costs** – Include those continuing costs necessary to operate and maintain the deployed strategy, including labor costs. While these costs do contain provisions for upkeep and replacement of minor components of the system, they do not contain provisions for wholesale replacement of the equipment when it reaches the end of its useful life. These O&M costs will be presented as annual estimates.
- **Replacement costs** – Include the periodic cost of replacing/redeploying system equipment as it becomes obsolete and reaches the end of its expected useful life in order to insure the continued operation of the strategy.
- **Annualized costs** – Represent the average annual expenditure that would be expected in order to deploy, operate, and maintain the Operations strategy; and replace (or redeploy) any equipment as it reaches the end of its useful life. Within this cost figure, the capital cost of the equipment will be amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual O&M cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of TSM&O deployments.

The complexity of many Operations deployments warrants that these cost figures be further segmented to ensure their usefulness. Within each of the capital, O&M, and annualized cost estimates, costs should be further disaggregated to show the infrastructure and incremental costs. These are defined as follows:

- **Infrastructure costs** – Include the basic “backbone” infrastructure equipment (including labor) necessary to enable the system. For example, in order to deploy a camera (closed-circuit television (CCTV)) surveillance system, certain infrastructure equipment must first be deployed at the traffic management center to support the roadside ITS elements. This may include costs, such as computer hardware/software, video monitors, and the labor to operate the system. Once this equipment is in place, however, multiple roadside elements may be integrated and linked to this backbone infrastructure without experiencing significant incremental costs (i.e., the equipment does not need to be redeployed every time a new camera is added to the system). These infrastructure costs typically include equipment and resources installed at the traffic management center, but may include some shared roadside elements as well.
- **Incremental Costs** – Include the costs necessary to add one additional roadside element to the deployment. For example, the incremental costs for the camera surveillance example include the costs of purchasing and installing one additional camera. Other deployments may include incremental costs for multiple units. For instance, an emergency vehicle signal priority system would include incremental unit costs for each additional intersection and for each additional emergency vehicle that would be equipped as part of the deployment.

Structuring the cost data in this framework provides the ability to readily scale the cost estimates to the size of potential deployments. Figure 5-10 provides a sample view of the cost data organized according to the defined structure in the *TOPS-BC* application. Infrastructure costs would be incurred

for any new technology deployment. Incremental costs would be multiplied with the appropriate unit (e.g., number of intersections equipped, number of ramps equipped, number of variable message sign locations, etc.); and added to the infrastructure costs to determine the total estimated cost of the deployment. Presenting the costs in this scalable format provides the opportunity to easily estimate the costs of expanding or contracting the size of the deployment, and allows the cost data to be reutilized for evaluating other corridors.

Figure 5-10. Example View of Cost Data Organization for a Ramp Meter System

FHWA Tool for Operations Benefit/Cost (TOPS-BC)					
PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies					
WORK AREA 1 - ESTIMATE AVERAGE ANNUAL COST					
Strategy: Ramp Metering -- Centrally Controlled					
Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	
Basic Infrastructure Equipment					
TMC Hardware for Freeway Control	5	\$ 22,500	\$ 2,000	\$ 6,500	
TMC Software/Integration	5	\$ 200,000	\$ -	\$ 40,000	
Labor		\$ -	\$ 250,000	\$ 250,000	
TOTAL Infrastructure Cost		\$ 222,500	\$ 252,000	\$ 296,500	
Incremental Deployment Equipment (Per Ramp Location)					
Ramp Meter (Signal, Controller)	25	\$ 88,000	\$ 2,000	\$ 5,520	
Loop Detectors (2)	25	\$ 11,000	\$ 500	\$ 940	
Communication Line	25	\$ 750	\$ 250	\$ 280	
TOTAL Incremental Cost		\$ 99,750	\$ 2,750	\$ 6,740	
INPUT	Enter Number of Infrastructure Deployments			<input type="text" value="1"/>	\$ 296,500
INPUT	Enter Number of Incremental Deployments (# of Ramps)			<input type="text" value="3"/>	\$ 20,220
INPUT	Enter Year of Deployment			<input type="text" value="2011"/>	
Average Annual Cost				\$ 316,720	

In the ramp meter example shown in Figure 5-10, the *Annualized Costs* for any individual piece of equipment equals the *Capital Costs* (which represents the total cost to deploy or redeploy that piece of equipment) and divided by the *Useful Life* (to amortize the cost of the equipment over the anticipated life), plus the annual cost of operating and maintaining the piece of equipment. This methodology

assumes that the piece of equipment is redeployed at the end of its useful life. For example, the Annualized Costs for the equipment called “TMC Hardware for Freeway Control” is calculated as:

$$\begin{aligned} \text{Annualized Costs} &= (\text{Capital Costs/Useful Life}) + \text{Annual O\&M Costs} \\ &\text{or} \\ \text{Annualized Costs} &= (\$22,500/5 \text{ years}) + \$2,000 = \$6,500 \end{aligned}$$

Some equipment does not have upfront Capital Costs, but only has recurring annual O&M Costs, as illustrated by the “Labor” costs in the Figure 5-10 example. In these situations, the annualized cost is simply the annual O&M Costs.

In the *TOPS-BC* application, users are able to enter the quantity of Infrastructure and Incremental equipment units they want to deploy, as shown in Figure 5-10; and the tool will calculate the total cost of the selected deployments based on these entries.²⁶ Average Annual Costs for the ramp metering example would be calculated as:

$$\begin{aligned} \text{Average Annual Costs} &= (\# \text{ of Infrastructure Deployments} * \text{Annualized Costs of Infrastructure} \\ &\text{Deployment}) + (\# \text{ of Incremental Deployments} * \text{Annualized Costs of Incremental Deployment}) \\ &\text{or} \\ \text{Average Annual Costs} &= (1 * \$296,500) + (10 * \$5,990) = \$356,400 \end{aligned}$$

Outputs from this process include the following:

- An **Average Annual Cost** – A single expected cost compiling upfront capital, ongoing O&M, and future equipment replacement costs in a single figure.
- A **Projected Stream of Costs** – An output showing year-by-year expected expenditures over the next 30-year timeframe. This stream of outputs will also have the capability to escalate future expenditures based on an inflation rate selected by the user. This output can be used to calculate Net Present Value (NPV) over any time horizon chosen by the user, if they chose to use NPV instead of average annual costs in their analysis.

Figure 5-11 shows a sample view of the Projected Stream of Costs generated for the ramp meter strategy illustrated in the earlier Figure 5-10. In this view, the Capital Costs are not amortized over the life of equipment, but appear in the year they are incurred. Upfront Capital Costs appear in the first year of deployment (as indicated by the user), and Replacement Costs are incurred in future years, as equipment needs to be replaced. In the case of the ramp metering example, the full Capital Cost of deployment is incurred in year 2010, but only a portion of the Capital Cost are incurred again in year 2015, since only a portion of the equipment involved in the deployment has reached the end of its useful life by this date. Space is provided to view costs up to a 50-year time horizon. The user may calculate the NPV of the costs by selecting a time horizon (in number of years) and an appropriate discount rate. Defaults are provided, but the user may override those defaults by entering their own values.

²⁶ For most TSM&O strategies, the number of “Infrastructure” deployments will be one, as only one deployment of this equipment is necessary to support multiple deployments of the “Incremental” units. However, the user has the opportunity to deploy more than one “Infrastructure” unit if their planned deployment is configured in a nontypical manner (e.g., managed from multiple Traffic Management Centers).

Figure 5-11. TOPS-BC Projected Stream of Costs Output

FHWA Tool for Operations Benefit/Cost (TOPS-BC)						
PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies						
WORK AREA 2 - PROJECT STREAM OF COSTS AND ESTIMATE NET PRESENT VALUE						
Strategy: Ramp Metering – Centrally Controlled						
Cost Item	2010	2011	2012	2013	2014	2015
Infrastructure Equipment Costs	\$ -	\$ 474,500	\$ 252,000	\$ 252,000	\$ 252,000	\$ 252,000
Incremental Deployment Equipment Costs	\$ -	\$ 307,500	\$ 8,250	\$ 8,250	\$ 8,250	\$ 8,250
Total Annual Cost	\$ -	\$ 782,000	\$ 260,250	\$ 260,250	\$ 260,250	\$ 260,250
<i>Cumulative Cost</i>	\$ -	\$ 782,000	\$ 1,042,250	\$ 1,302,500	\$ 1,562,750	\$ 1,823,000
INPUT	Enter Number of Years in the Analysis Time Horizon		20		Source: TIGER Grant Application	
INPUT	Enter the Beginning Year of the Analysis		2011			
INPUT	Enter Discount Rate		2.0%		Source: Office of Management and Enterprise Services	
NET PRESENT VALUE OF COSTS		\$5,456,374				
		2011	TO	2031		

Displaying and Communicating Results

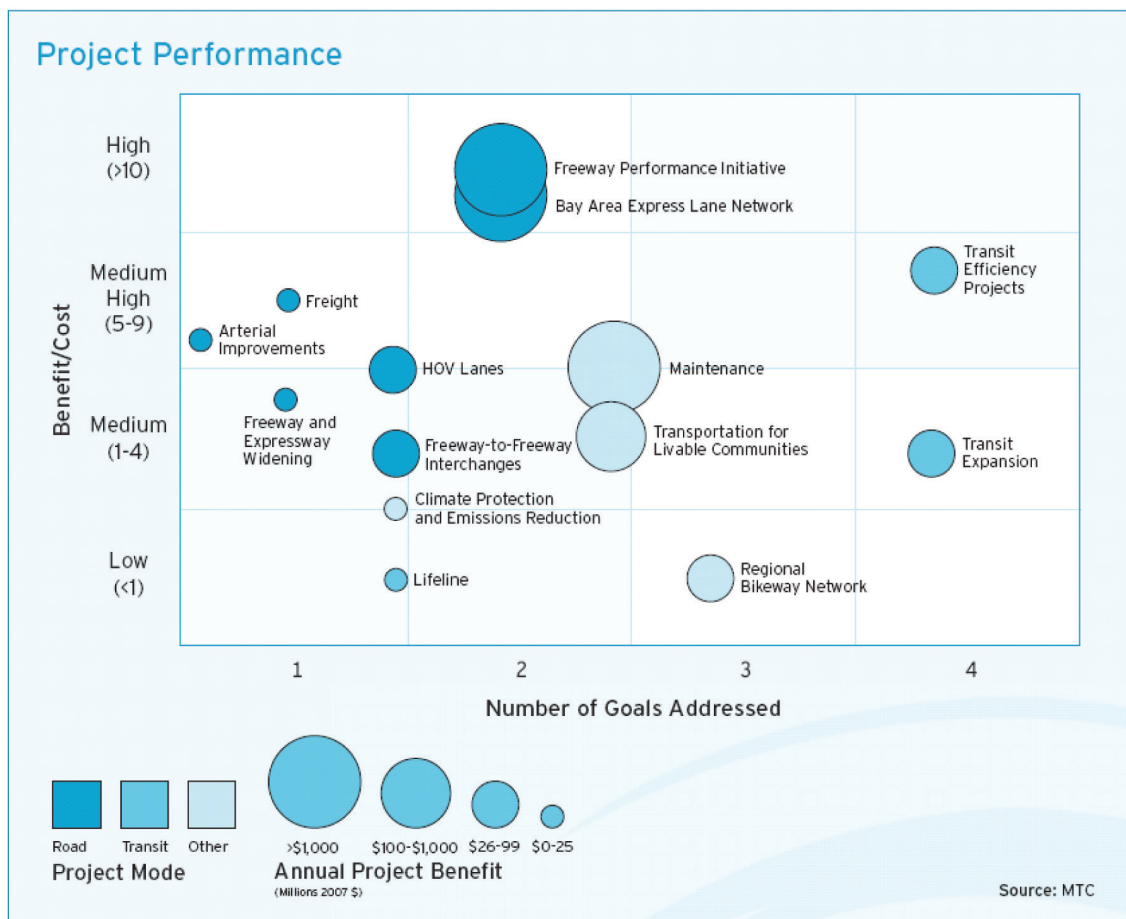
Although the primary output of a benefit/cost analysis is a relatively simple ratio (B/C ratio) and estimate of Net Benefits, there are typically many additional data regarding changes to various MOEs and costs that roll up into the B/C ratio that provide robust opportunities to present and explain the findings in order to promote better understanding and acceptance of the results. Prior to developing the presentation of findings, the analysts and project managers should carefully consider the following:

- **What is (are) the key audience(s) for the results?** If the primary audience is a technical one, the analysts should be prepared to present sufficient detail to allow the reviewers to map their own conclusions to the ones presented by the performing entity. If the audience is anticipated to comprise public or high-level decision-makers, the analyst may want to carefully craft a presentation of data to make effective use of graphics to display a high level of information in an easily digestible and understandable format. In many cases, the findings may need to be presented to differing audiences; and in these cases, different formats and data displays may be required.
- **What is the key information to present?** B/C analysis often results in significant amounts of data being generated regarding individual impacts to different MOEs. Attempting to present all this information can quickly result in overwhelming the audience and losing focus on the key issues. The analyst should attempt to identify the key issue or issues, appropriate to the intended audience, and focus the output display on those issues.
- **How can graphics and charts be best used to condense multiple data?** Charts and graphics can go far beyond simple pie charts and line graphs to effectively present information representing multiple data simultaneously in an easy to comprehend format – often times increasing the readers understanding of the relationship between multiple variables.

Figure 5-12 shows the innovative use of a graphic to simultaneously present multiple pieces of data comparing different projects. This graphic concurrently compares:

- The relative benefit/cost ratio estimated for the project (down the left axis);
- The relative size of the net benefit (by the size of the bubble);
- The number of qualitative goals met (across the bottom axis);
- The type of the project (by color); and
- The project name.

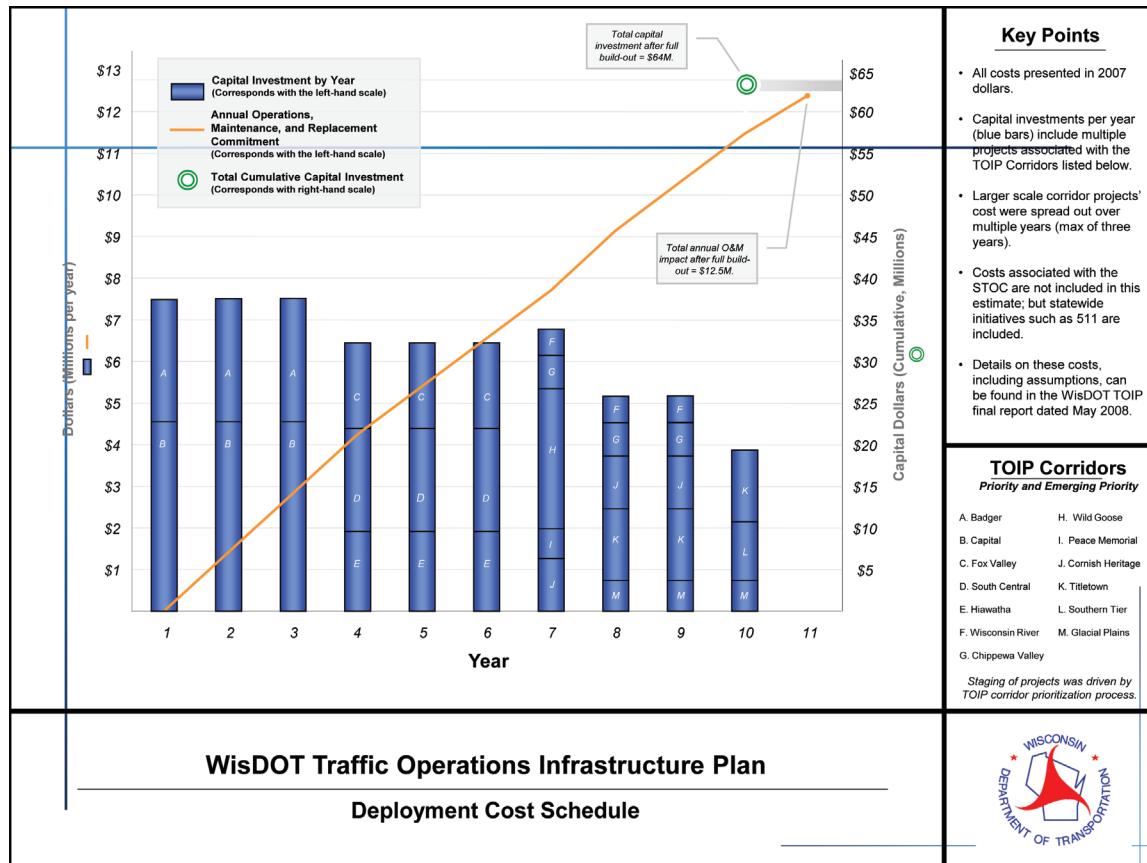
Figure 5-12. Innovative Use of Graphics to Display Multiple Data



Source: San Francisco Bay Area MTC 2030 Project Performance Assessment, 2007.

Graphics can also be effectively used to present data occurring over a timeline for those analyses using a defined time horizon. Figure 5-13 presents estimated costs, separated by upfront capital costs and ongoing O&M costs shown against the left axis, over an 11-year time horizon. This graphic effectively portrays the concept that, as more capital costs are expended to deploy more operations strategies, the annual O&M costs continue and increase as a result of more and expanded strategies to manage. The right-hand axis of the graphic displays the cumulative capital costs over the project time horizon.

Figure 5-13. Sample Graphic Presenting Results over an Analysis Timeline



Source: Wisconsin DOT Traffic Operations Infrastructure Plan, 2007.

Addressing Challenges of Applying B/C Analysis to TSM&O Strategies Targeted at Nonrecurring Conditions

The concepts of travel time reliability and addressing nonrecurring congestion have increasingly been receiving attention in recent years. This is particularly important in regards to many TSM&O strategies since many are targeted specifically at nonrecurring conditions (e.g., incidents, special events, work zones, and inclement weather). Many of the traditional tools designed to analyze transportation projects, however, have proved to be ill-suited to analyzing nonrecurring conditions. For example, traditional travel demand models, which have historically shouldered a large portion of alternative analysis needs for many agencies, are typically developed and calibrated to days with good weather,

no incidents, normal demand, and no work zone activity. This means that these traditional analysis methods do not consider the additional negative impacts (reduced capacity, speeds, increased crashes) related to these nonrecurring conditions; and as such, TSM&O strategies analyzed using these traditional methods may have their potential benefits severely understated.

As a result of the increasing focus on the significant portion of congestion caused by nonrecurring sources, and the ability of TSM&O strategies to effectively improve travel conditions during nonrecurring events, much improvement has recently been made in enhancing the analysis of nonrecurring conditions. Two national initiatives, in particular, have made significant advances in overcoming some of the analysis challenges related to identifying and quantifying nonrecurring congestion and the impacts of TSM&O strategies in mitigating the negative impacts. These initiatives include the FHWA ICM initiative, which includes the development of an *Analysis, Modeling, and Simulation (AMS) Guide* to aid practitioners at applying the developed analysis methods, and the ongoing FHWA development of a *Guidebook on Analysis of Active Transportation and Demand Management Using Highway Capacity Methods*.

These projects both are developing analysis methods related to multiresolution/multiscenario methods, which as discussed in Chapter 4, and represent the most complex methods best capable of assessing these types of impacts. Although much more complex in their actual application, these analyses follow several general steps, including:

1. The identification of the causes of nonrecurring congestion in a region;
2. The identification of the negative impacts of these nonrecurring conditions (e.g., reduced capacity caused by rainy conditions);
3. The modification of analysis models and routines to be able to model baseline nonrecurring scenarios;
4. The identification of TSM&O and traditional projects impact on these nonrecurring conditions;
5. The identification and incorporation of appropriate MOEs into the analysis that are capable of quantifying the benefits;
6. The adjustment and development of modeling tools and methods to support the analysis; and
7. The effective presentation and explanation of results.

Although more complex than many typical analysis that only consider recurring congestion, these enhanced analyses may be used to support B/C analysis of TSM&O strategies. The basic premise behind this method is to separately analyze recurring and various nonrecurring conditions as different scenarios, and then sum the results of all the scenarios, weighted to the frequency in which each individual scenario is anticipated to occur in a typical year. To accomplish this, the analyst will need to compile data on historic patterns for:

- Demand variability;
- Weather patterns;
- Incident occurrence; and
- Work zones.

In order to develop scenarios representing these nonrecurring conditions, the analyst will need to make modifications to the baseline parameters in the model used to reflect the capacity loss of

these nonrecurring conditions. As part of the development of the *Guidebook on Evaluation of Active Transportation and Demand Management Using Highway Capacity Methods*, a number of baseline capacity constraints has been mapped to various nonrecurring conditions based on data in the 2010 HCM. Table 5-5 presents the capacity reduction factors related to various inclement weather conditions. Table 5-6 presents capacity reduction factors related to various incident types. Table 5-7 presents capacity reduction factors related to various.

Table 5-5. Capacity Reduction Based on Nonrecurring Weather Types

Weather Type	Capacity Range (Percentage)
Rain	2-14
Snow	4-22
Low temp	1-9
High wind	1-2
Visibility	1-12

Source: FHWA Guidebook on Analysis of Active Transportation and Demand Management Using Highway Capacity Methods – Workshop Presentation, adapted from Exhibit 10-15, 2010 HCM.

Table 5-6. Capacity Reduction Based on Nonrecurring Incidents
(In Percentage)

Number of Lanes (1 Dir)	Shoulder Disablement	Shoulder Accident	One Lane Blocked	Two Lanes Blocked	Three Lanes Blocked
2	5	19	65	100	N/A
3	1	17	51	83	100
4	1	15	42	75	87
5	1	13	35	60	80
6	1	11	29	50	74
7	1	9	25	43	64
8	1	7	22	37	59

Source: FHWA Guidebook on Analysis of Active Transportation and Demand Management Using Highway Capacity Methods – Workshop Presentation, adapted from Exhibit 10-17, 2010 HCM.

Table 5-7. Capacity Reduction Related to Work Zones
(In Percentage)

Original Lanes	Work Lanes			
	1	2	3	4
1	?	N/A	N/A	N/A
2	67	?	N/A	N/A
3	77	54	?	N/A
4	84	65	46	?

Source: FHWA Guidebook on Analysis of Active Transportation and Demand Management Using Highway Capacity Methods – Workshop Presentation, adapted from Exhibit 10-14, 2010 HCM.

The capacity reduction factors, presented in the tables above, may be used to create various baseline scenarios that represent one or a combination of these various nonrecurring conditions. The development and analysis of additional scenarios representing different nonrecurring conditions needs to be carefully considered, however, as each additional scenario will require additional time and resources to create and run. In addition, it is important for the analyst to remember that, in order to conduct a B/C analysis of TSM&O strategies, each of the scenarios will need to be run twice, once as baseline without the strategy and once as an alternative scenario with the strategy deployed. Therefore, adding additional nonrecurring conditions scenarios can quickly multiply the number of model runs that are required.

It is recommended that the analyst review the data compiled on the frequency of nonrecurring events in order to develop a reasonable number of scenarios that may be modeled. Table 5-8 presents a sample comparison of the frequency of occurrence of various incident and bad weather conditions compared with varying levels of travel demand (presented as percentiles of the volume distribution), prepared for a sample section of the I-580 corridor in California as part of the development of the FHWA *Guidebook on Evaluation of Active Transportation and Demand Management Using Highway Capacity Methods*. These probabilities may be used to first assess the usefulness of analyzing particular scenarios – the used may decide to omit analyzing scenarios with very low likelihood of occurrence. Secondly, these probabilities may be used to weight the outcomes of individual scenarios – the analyst would apply a higher weight on those scenarios with a greater likelihood of occurrence.

Table 5-8. Sample Scenario Probabilities – I-580 Corridor

Capacity Reduction		5% Demand	20% Demand	50% Demand	80% Demand	95% Demand	Row Totals
No Incidents, Good Weather	0%	6.04%	15.10%	18.12%	15.10%	6.04%	60.40%
Single Lane Closure, Good Weather	42%	2.16%	5.40%	6.48%	5.40%	2.16%	21.60%
Dual+ Lane Closure, Good Weather	75%	0.07%	0.19%	0.22%	0.19%	0.07%	0.74%
No Incidents, Bad Weather	7%	1.26%	3.15%	3.78%	3.15%	1.26%	12.60%
Single Lane Closure, Bad Weather	49%	0.45%	1.13%	1.35%	1.13%	0.45%	4.50%
Dual+ Lane Closure, Bad Weather	82%	0.02%	0.04%	0.05%	0.04%	0.02%	0.16%
Column Totals		10.00%	25.00%	30.00%	25.00%	10.00%	100.00%

Source: FHWA Guidebook on Analysis of Active Transportation and Demand Management Using Highway Capacity Methods – Workshop Presentation, 2011.

The probabilities of various scenarios would be expected to vary depending on the region and even the individual corridor; therefore, it is recommended that analysts assemble and analyze the probabilities of nonrecurring conditions individually for each study. Once this data has been analyzed, the analyst can prioritize various scenarios to be developed and analyzed based on their probabilities. For example, if resources are not available to run all scenarios, the analyst may want to discard those strategies with very low probabilities.

Once all the scenarios have been analyzed for both the baseline and alternative scenarios, the incremental change in benefits for each scenario would be weighted according to its probability and summed to provide an estimate of benefits across all recurring and nonrecurring conditions.

Additional Resources and Support

The TRB Transportation Economics Committee recommends the following additional resources for supporting B/C analysis.²⁷

- Abley, S., P. Durdin, and M. Douglass, 2010, *Integrated Transport Assessment Guidelines*, Report 422, Land Transport New Zealand (www.nzta.govt.nz), at www.nzta.govt.nz/resources/research/reports/422.
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²⁷ <http://bca.transportationeconomics.org/published-guidance-and-references>.

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Appendix A. List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AMS	Analysis, Modeling, and Simulation
ATDM	Active Transportation and Demand Management
ATM	Active Traffic Management
AVL	Automatic Vehicle Location
B/C	Benefit/Cost
BI	Buffer Index
CAD	Computer-Aided Dispatch
CAL-BC	Caltrans Benefit/Cost Tool
CARB	California Air Resources Board
CBA	Cost-Benefit Analysis
CCTV	Closed-Caption Television
CMAQ	Congestion Mitigation and Air Quality
CMP	Congestion Management Process
CMS	Changeable Message Sign
CO	Carbon Monoxide
CO₂	Carbon Dioxide
CUTR	Center for Urban Transportation Research (CUTR) at the University of South Florida
DMS	Dynamic Message Signs
DOT	Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FITSEval	The Florida ITS Evaluation
FSP	Freeway Service Patrol
GPS	Global Positioning System
HAR	Highway Advisory Radio
HC	Hydrocarbons
HCM	Highway Capacity Manual
HERS	Highway Economic Requirements System
HERS-ST	Highway Economic Requirements System – State Version
HOT	High-Occupancy Toll
HOV	High-Occupancy Vehicle

HPMS	Highway Performance Monitoring System
ICM	Integrated Corridor Management
IDAS	ITS Deployment Analysis System
ITS	Intelligent Transportation Systems
LED	Light Emitting Diodes
M&O	Management and Operations
MOE	Measure of Effectiveness
MOVES	Motor Vehicle Emission Simulator
MPO	Metropolitan Planning Organization
MTC	Metropolitan Transportation Commission
MTP	Metropolitan Transportation Plan
NO_x	Nitrous Oxide
NPV	Net Present Value
O&M	Operations and Maintenance
OMB	Office of Management and Budget
OKI	Ohio-Kentucky-Indiana
PHT	Person Hours of Travel
PM_{2.5}	Fine Particulate Matter
PM₁₀	Particulate Matter
RCTO	Regional Concepts for Transportation Operations
RITA	Research and Innovative Technology Administration
ROG	Reactive Organic Gases
RTP	Regional Transportation Plan
SCRITS	Screening for ITS
SHRP	Strategic Highway Research Program
SO₂	Sulfur Dioxide
SOV	Single-Occupancy Vehicle
STEAM	Surface Transportation Efficiency Analysis Model
TDM	Travel Demand Management
TIGER	Transportation Investment Generating Economic Recovery
TIM	Traffic Incident Management
TIP	Transportation Improvement Program
TOPS-BC	Tool for Operations Benefit/Cost
TRB	Transportation Research Board
TSM&O	Transportation System Management and Operations

TRIMMS	Trip Reduction Impacts of Mobility Management Strategies
V/C	Volume-to-Capacity
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles of Travel



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