Transportation Systems Management and Operations Benefit-Cost Analysis Compendium

U.S. Department of Transportation
Federal Highway Administration

July 2015

Notice

Quality Assurance Statement

Source for top left image on cover: PATH
Source for top right image on cover: Washington State Department of Transportation

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-HOP-14-032		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
Transportation Systems Management and Operations Benefit-Cost Analysis Compendium	5. Report Date: July 2015 6. Performing Organization Code
7. Author(s) Michael Lawrence, Paul Nguyen, Jonathan Skolnick (Jack Faucett Associates) Jennifer Symoun (Leidos), Jim Hunt, Roemer Alfelor (FHWA)	**8. Performing Organization Report No.** N/A
9. Performing Organization Name and Address Leidos 11251 Roger Bacon Drive Reston, Virginia 20190 Jack Faucett Associates 4915 St. Elmo Ave, Suite 205 Bethesda, Maryland 20814	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH61-12-D-00050
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Highway Administration Office of Operations 1200 New Jersey Avenue, SE Washington, DC 20590	**13. Type of Report and Period Covered** Compendium **14. Sponsoring Agency Code** HOP

15. Supplementary Notes

FHWA COTM, James Hunt

16. Abstract

The Transportation Systems Management and Operations (TSMO) Benefit Cost Compendium is a continuation of the series of reference documents and tools developed by the Federal Highway Administration (FHWA) Office of Operations designed to assist planners and operations professionals in evaluating the benefits and costs of Transportation Systems Management and Operations (TSMO) strategies and technologies. The TSMO Compendium is a collection of cases from across the country where benefit-cost analysis (BCA) has been applied to a specific TSMO technology/strategy or group. These actual project evaluations demonstrate the use of custom spreadsheet analysis developed by the agency or its contractors or the application of available software tools to conduct the BCA. The Compendium also includes hypothetical cases designed to demonstrate how BCA can be used for a specific TSMO technology/strategy or group. FHWA has developed a sketch planning BCA tool, called the Tool for Operations Benefit-Cost Analysis (TOPS-BC), for application to TSMO projects. For the hypothetical cases TOPS-BC is used to assist in the measurement of benefits and costs and in the calculation of the benefit-cost ratio. Each case demonstrates how planners have or could in the future conduct a BCA on one or more TSMO technologies or strategies. There are over two dozen cases presented in the Compendium and they cover a wide range of TSMO technologies and strategies where each case addresses one or more specific issues or procedures.

17. Key Words	18. Distribution Statement
TSMO, transportation systems management and operations, transportation operations, strategies, benefit-cost analysis, TOPS-BC, Tool for Operations Benefit-Cost Analysis, economic analysis tools	No restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	232	N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized.**

FOREWORD

The Federal Highway Administration (FHWA) Office of Operations is pleased to present this publication titled *Transportation Systems Management and Operations (TSMO) Benefit Cost Analysis (BCA) Compendium*. The TSMO BCA)Compendium is a continuation in the series of reference documents and tools developed by the FHWA Office of Operations designed to assist planners and operations professionals in evaluating the benefits and costs of Transportation Systems Management and Operations (TSMO) strategies and technologies. In 2012, FHWA released the *Benefit/Cost Analysis Desk Reference* (available at: http://www.ops.fhwa.dot.gov/publications/fhwahop12028/index.htm) to provide practitioners with the fundamental concepts and guidance for conducting BCA for a wide range of transportation system management and operations (TSM&O) strategies. This TSMO BCA Compendium builds on the BCA Desk Reference by presenting a collection of cases from across the country where benefit cost analyses have been applied to evaluate specific TSMO technologies or strategies. These evaluations demonstrate the use of custom manual or spreadsheet analyses developed by the agency or its contractors or the application of available software tools to conduct the BCA. The Compendium also includes hypothetical cases designed to demonstrate how BCA can be used for specific TSMO technologies or strategies. Several of the hypothetical cases illustrate the use of TOPS-BC (http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm), an FHWA developed sketch-level planning BCA spreadsheet tool. This TSMO BCA Compendium is a companion piece to similar publication focused on road-weather applications titled "The Road Weather Benefit Cost Analysis Compendium," which is available at: http://www.ops.fhwa.dot.gov/publications/fhwahop14033/index.htm.

The FHWA Office of Operations is supporting this compendium through workshops and related technical assistance. If you have any comments on this material, seek further assistance with a TSMO BCA, or wish to discuss opportunities for hosting a workshop, please contact Jim Hunt at jim.hunt@dot.gov, 717-221-4422 or Ralph Volpe at ralph.volpe@dot.gov, 404-562-3637.

Robert Arnold
Director Office of Transportation Management
Office of Operations, FHWA

TABLE OF CONTENTS

List of Tables

List of Figures

List of Acronyms

Acronym	Definition
AADT	average annual daily traffic
AASHTO	American Association of State Highway and Transportation Officials
AB	annual benefit
ALPRS	automated license plate recognition system
APC	automatic passenger counter
ARTIMIS	Advanced Regional Traffic Interactive Management and Information System
ATDM	Active Transportation and Demand Management
ATMS	automated traffic management system
ATSAC	Automated Traffic Surveillance and Control (center)
AVL	automatic vehicle location
AVI	Automatic Vehicle Identification
AVO	average vehicle occupancy
AWWS	Automated Wind Warning System
BCA	benefit-cost analysis
BCMOT	British Columbia Ministry of Transportation
BCR	benefit-cost ratio
BDS	automated bus dispatching system
CAFE	Corporate Average Fuel Economy
Caltrans	California Department of Transportation
CCTV	closed circuit television
CHART	Coordinated Highways Action Response Team
CMV	commercial motor vehicles
COATS	California / Oregon Advanced Transportation Systems
CPI	Consumer Price Index
CRD	Congestion Reduction Demonstrations
CUTR	Center for Urban Transportation Research (University of South Florida)
DMS	dynamic message signs
DRCOG	Denver Regional Council of Governments'
EUAC	Equivalent Uniform Annual Cost
ESS	environmental sensor station
FHWA	Federal Highway Administration
FITSEval	Florida ITS Evaluation
FSPE	Freeway Service Patrol Evaluation
GPS	global positioning system
GLTS	Green Light Transportation System
HAR	highway advisory radio
HCM	Highway Capacity Manual
HERS-ST	Highway Economic Requirements System
HOV/HOT	high occupancy vehicle/high occupancy toll (lane)

Acronym	Definition
HPMS	Highway Performance Monitoring System
IDAS	Intelligent Transportation Systems Deployment Analysis System
IIHS	Insurance Institute for Highway Safety
ITS	Intelligent Transportation Systems
LADOT	Los Angeles Department of Transportation
LOS	level of service
MAARS	Maryland Automatic Accident Reporting System
MATOC	Metropolitan Area Transportation Operations Coordination Program
MBCA	Multimodal Benefit-Cost Analysis
MDSHA	Maryland State Highway Administration
MDSS	Maintenance Decision-Support System
MOE	measures of effectiveness
MPO	metropolitan planning organizations
MTA	Metropolitan Transportation Authority
MUL	managed use lanes
MWCOG	Metropolitan Washington Council of Governments
NCR	National Capital Region
NEPA	National Environmental Policy Act
NPV	net present value
O&M	operations and maintenance
OKI	Ohio-Kentucky-Indiana
OMB	Office of Management and Budget
P4O	planning for operations
PWOB	present worth of benefits
PWOC	divided by the present worth of costs
PBC TED	Palm Beach County Traffic Engineering Department
PDO	Property damage only (crash)
RITIS	Regional Integrated Transportation Information System
RTMC	Regional Traffic Management Center
RWM	road weather management
RWMIS	road weather management information systems
SCRITS	Screening Tool for ITS
SHRP 2	Strategic Highway Research Program 2
SMART	System Management for Advanced Roadway Technologies
SOC	Statewide Operations Center
STEAM	Surface Transportation Efficiency Analysis Model
TIGER	Transportation Investment Generating Economic Recovery
TOC	transportation operations center
TOPS-BC	Tool for Operations Benefit-Cost Analysis
TREDIS	Transportation Economic Development Impact System
TRIMMS	Trip Reduction Impacts of Mobility Management Strategies

Acronym	Definition
TSP	Traffic Signal Priority
TSMO	transportation systems management and operations
UPA	Urban Partnership Agreements
USDOT	United States Department of Transportation
V/C	volume to capacity (ratio)
VMT	vehicle miles traveled
VOC	volatile organic compounds
WIM	weigh-in-motion
YOE	year of expenditure (dollars)

CHAPTER 1. INTRODUCTION

The *Transportation Systems Management and Operations Benefit Cost Analysis Compendium* (Compendium) is a continuation of the series of reference documents and tools developed by the Federal Highway Administration (FHWA) Office of Operations designed to assist planners and operations professionals in evaluating the benefits and costs of transportation systems management and operations (TSMO)[1] strategies and technologies. This body of work is part of a larger initiative in the Office of Operations referred to as Planning for Operations and designed to better integrate planning and operations activities.

For more information on FHWA's Planning for Operations program, visit http://www.ops.fhwa.dot.gov/plan4ops/

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. TSMO programs have not escaped this scrutiny, and project managers are routinely asked to rank their projects against traditional expansion and other TSMO projects, as well as conduct other "value-related" exercises.

This requirement can put TSMO projects at a disadvantage since many specialists in this arena have limited experience in performing benefit cost analyses (BCA); and often, many of the established tools and data available for conducting BCA 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 BCAs for many specific road weather management (RWM) 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 specific analysis needs.

The *Transportation Systems Management and Operations Compendium*

This Compendium is a collection of cases from across the country where BCAs have been applied to one or more TSMO technologies/strategies. The actual project evaluations involve the use of custom spreadsheets developed by the agency or its contractors, or the application of available software tools to the BCA. The Compendium also includes hypothetical cases designed to demonstrate how BCA can be used for one or more TSMO technologies/strategies. FHWA has developed a sketch planning BCA tool, called the Tool for Operations Benefit Cost Analysis (TOPS-BC), for application to TSMO projects. For the hypothetical cases TOPS-BC is used to assist in the measurement of benefits and costs and in the calculation of the benefit-cost ratio. More information about TOPS-BC can be found at http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

Each case demonstrates how planners have or could in the future conduct a BCA on one or more TSMO technologies or strategies. There are over two dozen cases presented in the Compendium and they cover a wide range of TSMO technologies and strategies where each case addresses one or more specific issues or procedures. Readers should become familiar with the *Operations Benefit/Cost Analysis Desk Reference* (Desk Reference), which is described below, and use it in conjunction with the Compendium. The technologies included in the Compendium are discussed in more detail in the Desk Reference.

The Operations Benefit/Cost Analysis Desk Reference

The FHWA Office of Operations developed the *Operations Benefit/Cost Analysis Desk Reference* in recognition of practitioners' need for relevant and practical guidance on how to effectively conduct a BCA for a wide spectrum of transportation system management and operations strategies. The Desk Reference provides practitioners with relevant guidance on how to effectively and reliably estimate the benefits and costs of TSMO strategies.

The Operations Benefit/Cost Analysis Desk Reference is available at http://www.ops.fhwa.dot.gov/publications/fhwahop12028/index.htm

The Desk Reference meets the needs of a wide range of practitioners looking to conduct a BCA of operations strategies. The guidance provided in the Desk Reference includes basic background information on conducting a BCA, such as basic terminology and concepts intended to support the needs of practitioners just getting started with a BCA who may be unfamiliar with the general process. Building from this base, the Desk Reference also describes some of the more complex analytical concepts and latest research in order to support more advanced analyses. 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.

Management and Operations Strategies

Together, the Desk Reference and this Compendium are intended to support the analysis of a wide range of the available TSMO 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 the many diverse TSMO strategies (especially in light of the fact that new strategies and technologies are constantly emerging), TSMO strategies covered in the Compendium and/or the Desk Reference include the physical strategies listed below (see Chapter 3 of the Desk Reference for a more complete description of the TSMO strategies and sub-strategies that comprise each category):

1. **Arterial Signal Coordination** – Improves the coordination of traffic signal timing to improve traffic flow and reduce delay.
2. **Arterial Transit Signal Priority** – Provides the capability to expand or accelerate the green time allotted to traffic signals when a 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. **Traveler Information**
    a. **Pre-trip** – 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.
    b. **En-route** – 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.
7. **Work Zone Management** – Lessens the congestion, delay, and safety issues associated with construction or maintenance work zones.
8. **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.
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.

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. **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).

This Compendium provides brief summaries of the BCAs of TSMO technologies undertaken by transportation agencies, educational institutions, and other organizations. These examples evaluate the benefits and costs of TSMO deployments and identify the lessons that can be learned from the BCA. Hypotheticals examples have been drawn from actual deployments, in part or whole, to demonstrate how the TOPS-BC model or alternative tools such as the ITS Deployment Analysis System (IDAS) can be used and modified to support a TSMO BCA.

Following this introduction, Chapter 2 provides a brief summary of the fundamentals of the BCA as applied to transportation projects in general and to TSMO projects in particular. Chapter 3 introduces several BCA tools developed by FHWA and others for transportation applications and TSMO projects. The final chapters of this Compendium contain a number of case studies illustrating how agencies have applied BCA to TSMO projects.

CHAPTER 2. FUNDAMENTALS OF BENEFIT-COST ANALYSIS

This chapter explains the basic approach to economic analysis as applied to transportation decision making and how it is useful for understanding and evaluating transportation systems management and operations (TSMO) projects. This is not intended to replace more extensive documents on economic analysis and benefit-cost analysis (BCA) available from FHWA and other sources (see box at right). This section addresses some of the fundamental concepts required for the economic analysis of projects (e.g. inflation and discounting) and then describes the fundamental components of BCA. These methods are demonstrated in the subsequent sections of this Compendium in a series of BCA studies conducted around the country on TSMO projects. Note that this chapter provides a summary of portions of the *FHWA Economic Analysis Primer,* which is available at http://www.webpages.uidaho.edu/~mlowry/Teaching/EngineeringEconomy/Supplemental/USDOT_Economic_Analysis_Primer.pdf.

FHWA BCA References

Economic Analysis Primer - *http://www.webpages.uidaho.edu/~mlowry/Teaching/EngineeringEconomy/Supplemental/USDOT_Economic_Analysis_Primer.pdf*

Operations Benefit/Cost Analysis Desk Reference – http://ops.fhwa.dot.gov/publications/fhwahop12028/index.htm

TIGER BCA Resource Guide – http://www.dot.gov/policy-initiatives/tiger/tiger-bca-resource-guide

Economic analysis is a critical component of a comprehensive project or program evaluation methodology that considers all key quantitative and qualitative impacts of TSMO investments. It allows highway agencies to identify, quantify, and assign a value to the economic benefits and costs of highway projects and programs over a multi-year timeframe. With this information, highway agencies are able both to allocate scarce resources to maximize public benefits as well as to show a rational basis for their decisions.

Economic analysis can inform many different phases of the transportation decision-making process. It can assist engineers in the development of more cost-effective designs once a decision has been made to go forward with a TSMO project. In planning, it can be applied to basic cost and performance data to screen a large number of potential project alternatives, assisting in the development of program budgets and areas of program emphasis. Similarly, economic analysis can play a critical role in screening alternatives to accomplish a specific project and provide information for the environmental assessment process.

The application of economic analysis to highway investments is not a new concept. The American Association of State Highway and Transportation Officials (AASHTO) published information on road-user-benefit analysis in 1952, showing that economic methods and procedures for transportation project evaluation were well understood and described 60 years ago. Of course, significant progress has been made since that time in areas as diverse as modeling future traffic flows, estimating the consequences of highway projects on safety, and the application of computer technologies to support improved economic methods.

Today, many States and metropolitan planning organizations (MPO) and some local governments use economic tools in some capacity. There is, however, much diversity in application. Most agencies will occasionally quantify the life-cycle costs or net benefits of projects or investigate their economic impacts on communities. Only a minority of agencies, however, regularly measure project net benefits in monetary terms. Also, most agencies do not consider the full range of costs and benefits when conducting their analyses. In general, there is significant potential for the broader application of economic methods to TSMO decision making.

FHWA has a long tradition of promoting the application of economic analysis to project planning, design, construction, preservation, and operation. FHWA has strongly encouraged the use of life-cycle cost applications as part of its pavement design and preservation initiatives as well as in the Value Engineering program. It has also published the *Operations Benefit/Cost Analysis Desk Reference* cited above. In addition, the United States Department of Transportation (U.S. DOT) requires a BCA to accompany all applications for Transportation Investment Generating Economic Recovery (TIGER) funding.

Benefits of Using of Economic Analysis for TSMO Projects

Among the beneficial applications of economic analysis to TSMO projects are the following:

Cost Effective Design and Deployment. Economic analysis can inform highway agencies as to which of several project designs can be implemented at the lowest life-cycle cost to the agency and the lowest user cost to the traveler. It can also identify the best affordable balance between these costs.

Best Return on Investment: Economic analysis can help in planning and implementing transportation programs with the best rate of return for any given budget, or it can be used to help determine an optimal program budget.

Understanding Complex Projects. In a time of growing public scrutiny of new and costly road projects, highway agencies and other decision makers need to understand the true benefits of these projects, how transportation system management and operations contribute to road performance, and the effects that such projects will have on regional economies. This information is often very helpful for informing the environmental assessment process.

Documentation of Decision Process. The discipline of quantifying and valuing the benefits and costs of highway projects also provides excellent documentation to explain the decision process to legislatures and the public.

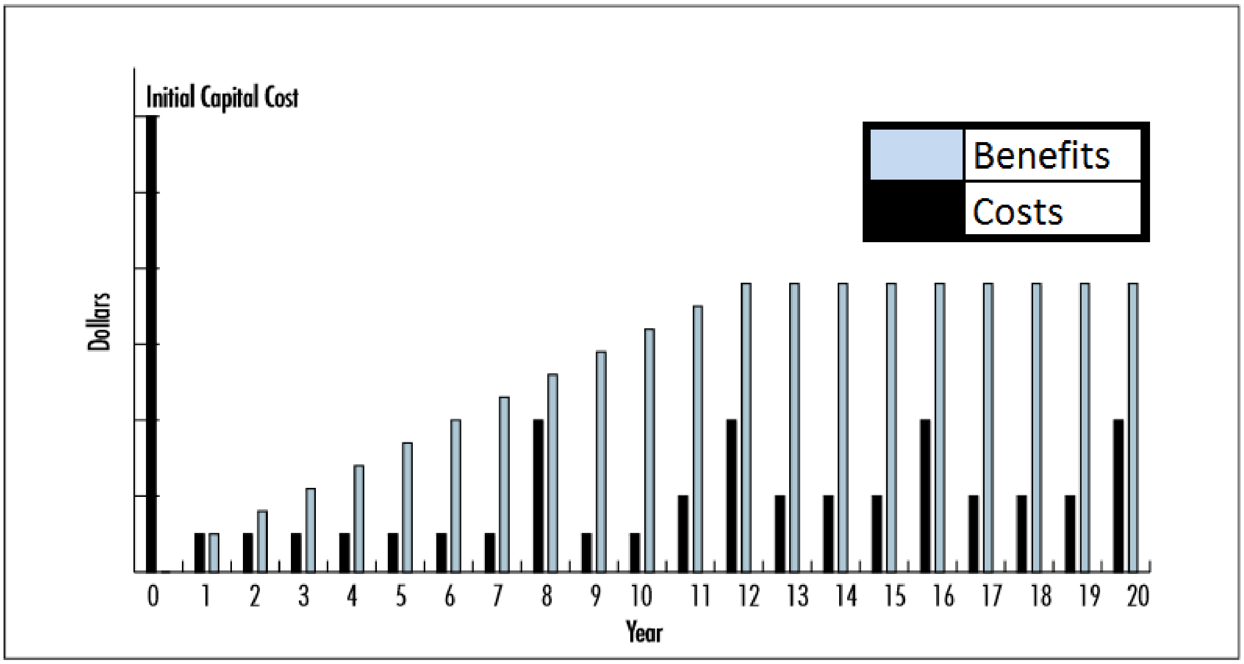
As part of its long-term commitment to improving operations investment and management practices, FHWA will continue to develop and advance economic tools and guidance. This Compendium of BCAs is part of an FHWA Office of Operations initiative referred to as "Planning for Operations" (P4O). The use of an economic analysis to compare costs and benefits in dollar terms over multiyear periods provides vital information about TSMO and other comprehensive infrastructure management strategies.

Economic Fundamentals

The most basic economic questions that people face in their day-to-day personal and business lives involve the tradeoffs between dollars earned, spent, or invested today and those dollars they hope to earn, spend, or invest in the future. Such tradeoffs must also be considered when evaluating TSMO investments. Project life cycle evaluation is important for TSMO projects as these activities can be long lived and require initial and periodic capital investments as well as ongoing materials and maintenance expenditures. A typical distribution of costs and benefits over time is presented in Figure 1.

Comparison of benefits to costs over the project life cycle would be a simple issue of summation except for one problem: the value of a dollar changes over time. In particular, a dollar that an individual or agency will spend or earn in the future is almost always worth less to them today than a dollar they spend or earn now. This changing value of the dollar must be understood and quantified to enable meaningful comparisons of multiyear dollar streams.

Two separate and distinct factors account for why the value of a dollar, as seen from the present, diminishes over time. These factors are inflation and the time value of resources.



Source: FHWA Economic Analysis Primer

Figure 1. Graph. Time Series of Costs and Benefits

Inflation

Inflation is a continuous rise in prices. This is distinct from changes in relative prices that might be caused by changes in supply or demand for specific products or services. Furthermore, technological advances and consumer preferences change over time impacting market prices.

Economists usually measure inflation by comparing the price of groupings or "market baskets" of goods and services from year to year. The prices of some goods and services in the grouping will go up while the prices of others may go down. It is the overall price level of the grouping that captures the effect of inflation. A price or inflation index is constructed by dividing the price of the grouping in each year by its price in a fixed base year and multiplying the result by 100. The change in the index value from year to year reveals the trend and scale of inflation. The Consumer Price Index (CPI) is probably the best-known price or inflation index to most Americans, but there are many others.

Dollars from one year can be converted into equivalent dollars of another year (as measured by purchasing power) by using price indices to add or remove the effects of inflation. Dollars from which the inflation component has been removed are known as "real," "constant," or "base year" dollars. A real dollar is able to buy the same amount of goods and services in a future year as in the base year of the analysis. Dollars that include the effects of inflation are known as "nominal," "current," or "data year" dollars. A nominal dollar will typically buy a different amount of goods and services in each year of the analysis period.

In the case of economic analysis of investments by a public agency, it is best practice to forecast life-cycle costs and benefits of a project without inflation (i.e., in real or base year dollars). Inflation is very hard to predict, particularly more than a few years into the future. More importantly, if inflation is added to benefits and costs projected for future years, it will only have to be removed again before these benefits and costs can be compared in the form of dollars of any given base year.

Time Value of Resources

Most people have a day-to-day familiarity with inflation. They are less familiar, however, with the separate and distinct concept of the time value of resources. The time value of resources is also referred to as the time value of money or the opportunity cost (or value) of resources. It reflects the fact that there is a cost associated with diverting the resources needed for an investment from other productive uses or planned consumption within the economy. This cost is equal to the economic return that could be earned on the invested resources (or the dollars used to buy them) in their next best alternative use. Equivalently, the time value of resources can be interpreted as the amount of compensation that must be paid to people to induce them not to consume their resources in the current year, but rather to make them available for future investment.

The Role of the Discount Rate

The time value of resources is measured by an annual percentage factor known as the discount rate.

If an analyst knows the appropriate discount rate, he or she can calculate the "present value" of any sum of resources or money to be spent or received in the future. The application of the discount rate to future sums to calculate their present value is known as "discounting" (see example on page 10). Through discounting, different investment alternatives can be objectively compared based on their respective present values, even though each has a different stream of future benefits and costs.

Formula for Discounting

The standard formula for discounting is as follows:

$$PV = \left(\frac{1}{(1+r)^t}\right) A_t$$

Figure 2. Equation. Formula for Discounting.

where:

PV = present value at time zero (the base year);

r = discount rate;

t = time (year); and

A = amount of benefit or cost in year t.

The formula above is the most basic calculation of present value. The term

$$\frac{1}{(1+r)^t}$$

Figure 3. Equation. Present Value.

which incorporates the discount rate "r" is called the discount factor. Multiplying a future sum by the appropriate discount factor for that future year will yield the present value of that sum at time zero (e.g., the year in which the analysis is being done).

Of course, most TSMO projects generate costs and benefits over their entire life-cycles. This entire series of costs and benefits must be discounted to the present by multiple applications of the PV formula for each applicable year of the life-cycle (see formula below). These discounted values are then summed together (as represented by Σ) for each year of the life-cycle analysis period ("N") to yield an overall present value. The formula for doing this is as follows:

$$PV = \sum_{t=1}^{N} \left(\frac{1}{(1+r)^t}\right) A_t$$

Figure 4. Equation. Overall Present Value.

The present value of a series of numbers is often described as the "net present value," reflecting the fact that the discounted amount often reflects the net value of benefits after costs are subtracted from them.

Source: FHWA Economic Analysis Primer

Selecting a Discount Rate

As a rule of best practice, economic analysis should be performed in real terms; i.e., using dollars and discount rates that do not include the effects of inflation. A real discount rate can be estimated by removing the rate of inflation (as measured by a general price index such as the CPI) from a market (or nominal) interest rate for government borrowing. The selected market rate for government borrowing should be based on government bonds with maturities comparable in length to the analysis period used for the economic analysis. Real discount rates calculated in this manner have historically ranged from just below 0 percent to 5 percent - the rates most often used by States for discounting highway investments. The U.S. Office of Management and Budget (OMB) currently requires U.S. Federal agencies to use a 7 percent real discount rate to evaluate public investments and regulations. For more information, see http://www.whitehouse.gov/omb/circulars_a094/.

Benefit-Cost Analysis

A benefit-cost analysis, or BCA, attempts to capture all benefits and costs accruing to society from a project or course of action, regardless of which particular party realizes the benefits or costs, or the form these benefits and costs take. Used properly, a BCA reveals the most economically efficient investment alternative; i.e., the one that maximizes the net benefits to the public from an allocation of resources.

Useful Applications of Benefit Cost Analyses

A BCA considers the changes in benefits and costs that would be caused by a potential improvement to the status quo facility. In highway and TSMO decision-making, BCA may be used to help determine the following:

Whether or not a project should be undertaken at all (i.e., whether the project's life-cycle benefits will exceed its costs).

When a project should be undertaken. A BCA may reveal that the project does not pass economic muster now, but would be worth pursuing 10 years from now due to projected regional traffic growth. If so, it would be prudent to take steps now to preserve the future project's right-of-way.

Which among many competing alternatives and projects should be funded given a limited budget. A BCA can be used to select from among design alternatives that yield different benefits.

After a project is implemented, BCA can be used to evaluate the project performance. A BCA can be used to evaluate implemented projects to verify BCA ratios for future performance.

The Benefit-Cost Analysis Process

In conducting a BCA, the analyst applies a discount rate to the benefits and costs incurred in each year of the project's life cycle. This exercise yields one or more alternative measures of a project's economic merit.

Major Steps in the Benefit-Cost Analysis Process

1. Establish objectives
2. Identify constraints and specify assumptions
3. Define the base case and identify alternatives
4. Set the analysis period
5. Define the level of effort for screening alternatives
6. Analyze the traffic effects
7. Estimate benefits and costs relative to base case
8. Evaluate risks
9. Compare net benefits and rank alternatives
10. Make recommendations

The BCA process begins with the establishment of objectives for an improvement to the operation and management of transportation assets. A clear statement of the objective(s) is essential to reducing the number of alternatives considered. The next step is to identify constraints (policy, legal, natural, or other) on potential agency options and specify assumptions about the future, such as expected regional traffic growth and vehicle mixes over the projected lifespan of the improvement.

Having identified objectives and assumptions, the analyst (or analytical team) then develops a full set of reasonable improvement alternatives to meet the objectives. This process begins with the development of a "do minimal" option, known as the base case. The base case represents the continued operation of the current facility under good management practices but without the TSMO improvements anticipated. Under these "do minimal" conditions, the condition and performance of the base case would be expected to decline over time. Reasonable improvement alternatives to the base case can include a range of TSMO options under consideration.

To ensure that the alternatives can be compared fairly, the analyst specifies a multiyear analysis period over which the life-cycle costs and benefits of all alternatives will be measured. The analysis period selected is long enough to include at least one major rehabilitation activity for each alternative.

Ideally, the level of effort allocated to quantifying benefits and costs in the BCA is proportional to the expense, complexity, and controversy of the project. Also, to reduce effort, the analyst should initially screen the alternatives to ensure that the greatest share of analytical effort is allocated to the most promising scenarios. Detailed analysis of all alternatives is usually not necessary.

When an alternative is expected to generate significant net benefits to users, particularly in the form of congestion relief, the analyst evaluates the effect that the alternative would have on the future traffic levels and patterns projected for the base case. Changes in future traffic flows in response to an alternative will affect the calculation of project benefits and costs.

The investment costs, hours of delay, crash rates, and other effects of each alternative are measured using engineering methods and then compared to those of the base case, and the differences relative to the base case are quantified by year for each alternative. The analyst assigns dollar values to the different effects (e.g., the fewer hours of delay associated with an alternative relative to the base case are multiplied by a dollar value per hour) and discounts them to a present value amount. Risk associated with uncertain costs, traffic levels, and economic values also is assessed.

Any alternative where the value of discounted benefits exceeds the value of discounted costs is worth pursuing from an economic standpoint. For any given project, however, only one design alternative can be selected. Usually, this alternative will be the economically efficient one, for which benefits exceed costs by the largest amount.

Based on the results of the BCA and associated risk analysis, the analyst prepares a recommendation concerning the best alternative from an economic standpoint. It is good practice to document the recommendation with a summary of the analysis process conducted.

Benefit and Cost Elements to Include

Table 1 lists the benefit and cost categories and elements that are generally included in a BCA.

Table 1. Benefit and Cost Categories and Elements

Agency Benefits/Costs	User Benefits/Costs Associated With TSMO Projects	Externalities (non-user impacts, if applicable)
• Design and engineering • Land acquisition • Construction • Reconstruction/rehabilitation • Preservation • Routine maintenance • Mitigation (e.g., noise barriers)	• Travel time and delay • Reliability • Crashes • Vehicle operating costs	• Emissions • Noise • Other societal impacts

Source: FHWA Economic Analysis Primer and JFA.

The impacts of a particular alternative do not always fall neatly into benefit or cost categories. An alternative may reduce agency costs, which is a benefit. Similarly an alternative may reduce crash rates (a benefit) relative to the base case while another alternative may increase crash rates (a cost, also called a negative benefit or disbenefit) relative to the base case. Care must be taken to ensure that all costs and benefits of each alternative are fully and accurately accounted for.

Note that toll receipts and other user fees are not listed as benefits or costs in Table 1. Rather, they represent transfers of some of a project's benefits from users to the agency operating the project.

Many people are puzzled about how economists assign monetary values to highway project benefits and costs. For instance, how does one value an hour of travel time, or a crash? The valuation of each of the major elements listed in Table 1 is described below.

Agency costs. The assignment of monetary values to the design and construction of a project is perhaps the easiest valuation concept to understand. Engineers estimate these costs based on past experience, bid prices, design specifications, materials costs, and other information. Care must be taken to make a complete capital cost estimation, including contingencies and administrative expenses such as internal staff planning and overhead costs. A common error in economic analysis and budgeting is the underestimation of project construction and development costs. Particular care should be used when costing large or complicated projects.

Expenses associated with a project's financing, such as depreciation and interest payments, are not included in the BCA. The equivalent value of such expenses is already captured in the BCA through the application of the discount rate to the agency cost of the project. Adding depreciation or interest expenses to agency costs in a BCA in most cases would lead to double counting costs.

Travel time, delay, and reliability. An hour of travel associated with a business trip or commerce is usually valued at the average traveler's wage plus overhead—representing the cost to the traveler's employer. Personal travel time (either for commuting or leisure) is usually valued as a percentage of average personal wage or through estimates of what travelers would be willing to pay to reduce travel time. Recently researchers have identified another important benefit: travel time reliability. Due to uncertainty in travel time, travelers add "buffer time" to their trips to ensure they arrive at their destination on time. Some TSMO projects reduce travel time, some reduce buffer time, and some reduce both. Both are benefits.

Treatment of Revenues, Tolls, Taxes, and Other Transfers in Benefit Cost Analysis

Tolls, taxes, and other user charges for transportation projects constitute important potential revenue sources to State agencies for financing transportation projects. However, these revenue sources are not "benefits" of a project as measured by economic analysis such as BCA. Rather, these charges represent a means by which some of the benefits to the users of the transportation project (as measured by their implicit willingness to pay for reduced travel time or improved safety) can be transferred in whole or in part (in the form of cash payments by the users) to the State or private agency that operates the facility. Adding toll or tax revenues to the value of travel time, safety, and vehicle operating cost benefits already included in the BCA would be double-counting benefits.

Crashes. The assignment of monetary values to changes in crash rates or severities can provoke controversy because crashes often involve injury or loss of life. The use of reasonable crash values is critical, however, to avoid underinvesting in highway safety. Economists often use the dollar amounts that travelers are willing to pay to reduce their risk of injury or death to estimate monetary values for fatalities and injuries associated with crashes. Medical, property, legal, and other crash-related costs are also calculated and added to these amounts. U.S. DOT offers extensive guidance on this subject in the current TIGER funding application guidance. (See also "Revision of Departmental Guidance on Treatment of the Value of Life and Injuries,"[2] and "The Economic Impact of Motor Vehicle Crashes."[3])

Vehicle operating costs. The cost of owning and operating vehicles can be affected by a project due to the changes that it causes in highway speeds, traffic congestion, pavement surface, and other conditions that affect vehicle fuel consumption and wear and tear. Accurate calculations of a project's effects on vehicle operating costs require good information on the relationship of vehicle performance to highway conditions and clear assumptions about future vehicle fleet fuel efficiency and performance. U.S. DOT does not provide official guidance on estimating vehicle operating costs, but useful information on the valuation of vehicle operating costs (and other BCA elements) is provided in AASHTO's 2010 "User and Non-User Benefit Analysis for Highways" and in the "Highway Economic Requirements System Volume IV: Technical Report" (FHWA-PL-00-028), Chapter 7. Benefits attributable to lower VOC are usually not a major component of a project's benefit stream.

Externalities. One of the more challenging areas of BCA is the treatment and valuation of the "externalities" of transportation projects. In economics, an externality is the uncompensated impact of one person's actions on the well-being of a bystander. In the case of transportation investments, "bystanders" are the nonusers of the project. When the impact benefits the nonuser, this is called a positive externality. When the impact is adverse, this is called a negative externality.

Often, when there is talk about externalities of highways, the focus is on negative externalities. Negative externalities include the undesirable effects of a project on air and water quality, noise and construction disruptions, and various community and aesthetic impacts. Positive externalities, however, also exist. A project may serve to reduce air or noise pollution from previously existing or projected levels.

Several methods exist for including externalities in a BCA. In some cases, scientific and economic studies have revealed per-unit costs for air pollutants, for example, that can be incorporated directly into the BCA. Much uncertainty surrounds these valuations, however. Values can vary from project to project due to location, climate, and pre-existing environmental conditions. Risk analysis techniques can yield helpful information about the sensitivity of results to these uncertain values.

Externalities are specifically dealt with in environmental assessments required by the National Environmental Policy Act (NEPA). Where adverse impacts are identified, mitigation is required to avoid, minimize, or compensate for them. Required mitigation is part of the environmental decision, and the costs of mitigation will become "internalized" in the project's cost in the BCA. The BCA effort should be coordinated closely with the NEPA assessment.

When an externality cannot be put into dollar terms, it can often be dealt with on a qualitative basis relative to other, monetized components of the BCA. If the measurable net benefits of a project are highly positive, the presence of minor unquantified externalities can be tolerated from an economic standpoint even if they are perceived to be negative. On the other hand, if the net benefits are very low, then the existence of significant unquantified negative externalities may tip the economic balance against the project.

Externalities Versus Indirect Effects

Externalities considered in a BCA are the uncompensated *direct* impacts of the project on nonusers of the project. These effects are additive to other direct costs and benefits (such as the value of time saving or reduced crashes and saved lives) measured in the BCA. Direct effects, however, usually lead to indirect effects on the regional economy through the actions of the marketplace. Indirect impacts of a transportation project could include local changes in employment or land use. The value of indirect effects is *not* additional to that of direct effects measured in BCA; rather, indirect effects are a restatement or transfer to other parties of the value of direct effects.

Comparing Benefits to Costs

Once the analyst has calculated all benefits and costs of the project alternatives and discounted them, there are several measures to compare benefits to costs in the BCA. The two most widely used measures are described below.

- *Net present value (NPV)*: NPV is perhaps the most straightforward BCA measure. All benefits and costs over an alternative's life cycle are discounted to the present, and the costs are subtracted from the benefits to yield an NPV. If benefits exceed costs, the NPV is positive and the project is worth pursuing. Where two or more alternatives for a project exist, the one with the highest NPV over an equivalent analysis period should usually be pursued. Policy issues, perceived risk, and funding availability, however, may lead to the selection of an alternative with a lower positive NPV.
- *Benefit-cost ratio (BCR):* The BCR is frequently used to select among projects when funding restrictions apply. In this measure, the present value of benefits (including negative benefits) is placed in the numerator of the ratio and the present value of the initial agency investment cost is placed in the denominator. The ratio is usually expressed as a quotient (e.g., $2.2 million/$1.1 million = 2.0). For any given budget, the projects with the highest BCRs can be selected to form a package of projects that yields the greatest multiple of benefits to costs.

FHWA recommends the use of either the NPV or BCR measures for most economic evaluations. Other BCA measures are available and may be used, however, depending on agency preference. For example, the equivalent uniform annual value approach converts the NPV measure into an annuity amount. The internal rate of return measure represents the discount rate necessary to yield an NPV of zero from a project's multiyear benefit and cost stream.

Appropriate Use of the Benefit-Cost Ratio

The benefit-cost ratio (BCR) is often used to select among competing projects when an agency is operating under budget constraints. In particular, use of the BCR can identify a collection of projects that yields the greatest multiple of benefits to costs where the ability to incur costs is limited by available funds. However, care must be taken when relying on the BCR as the primary BCA measure.

The FHWA recommends that only the initial agency investment cost be included in the denominator of the ratio. All other BCA values, including periodic rehabilitation costs or user costs, such as delay associated with construction, should be included in the ratio's numerator as positive or negative benefits. Adherence to this guidance facilitates consistent project comparisons. Use of specialized procedures such as incremental BCA, in which the increments in benefits and costs of one alternative relative to another are compared in ratio format and prioritized subject to budget constraints, can minimize the risk of selecting inferior alternatives using BCRs. A good description of the incremental BCA approach is provided in Chapter 7 of the *HERS-ST 2.0 Highway Economic Requirements System-State Version Overview* by FHWA, which is available at: http://isddc.dot.gov/OLPFiles/FHWA/010617.pdf.

Misunderstandings

The BCA is a powerful, informative tool available to assist planners, engineers, and decision makers. Agencies often avoid or underutilize the BCA due to misconceptions about it.

In some cases, agency personnel are skeptical about the accuracy of a BCA due to perceived uncertainties in measuring or valuing costs and benefits. In reality, there is much more substance to economic analysis techniques and values than is generally understood. Where uncertainty does exist, it can usually be measured and managed. It is helpful to remember that sound economic analysis reduces uncertainty. Not performing the analysis only serves to hide uncertainty from decision makers.

Another concern is that the workload involved in conducting a BCA may be excessive relative to agency resources. Once the engineering and economic capabilities are in place, however, BCA workloads diminish markedly. The level of effort to conduct a BCA should also reflect project cost, complexity, and controversy; routine projects may be analyzed with minimal effort.

Finally, some agencies are concerned that the results of BCA could conflict with preferred or mandated outcomes. In any situation, an objective and independent assessment of a project's economic consequences can contribute valuable information to the decision process. There are, however, valid reasons why decision makers may choose to override or constrain economic information. For example, if there are concerns that BCA results would disproportionately favor projects in urban areas, policy makers can initially apportion funds between urban and rural areas based on equity considerations. Urban projects would then compete based on their economic merits for the urban funds; rural projects would similarly compete for the rural funds.

Avoiding Pitfalls

As with any analytic method, the BCA can give erroneous results if it is misused. Perhaps the foremost cause of error in a BCA is the selection of an unrealistic base case. The base case must be founded on intelligent use and management of each TSMO alternative under consideration during the analysis period. For instance, allowances should be made for traffic diversion and changing peak periods as congestion builds in the base case. Failure to factor in these elements can lead to overly pessimistic estimates of delay levels in the base case, by comparison to which any alternative would look attractive. BCA results can also be biased by the comparison of only one design alternative to the base case, even though less costly alternatives exist. A correctly conducted BCA considers a full range of reasonable alternatives.

Another common hurdle involves the evaluation of a "project" that is actually a combination of two or more independent or separable projects. This is very common in TSMO projects, where maximum benefits are often achieved by the joint deployment of multiple synergistic technologies or strategies. In such cases, the net benefits of one project may hide the net costs of the other, or vice versa. Both of the projects would either be built or rejected if incorrectly considered individually, when in fact both should be built as a result of their synergy.

BCA results can be erroneous if they do not include the correct cost or benefit elements or amounts associated with a project. This occurs most often when user costs or major externalities (if present) are omitted. In some cases, an agency may focus only on local costs and benefits, failing to include those that accrue outside its jurisdiction. Care must also be taken not to include "benefits" that are simply restatements of other benefits (or costs) measured elsewhere in the BCA. This latter error, a form of double counting, can occur when employment, business, or land use effects that are measured using an economic impact analysis are added to the benefits of travel-time saving, safety, and vehicle operating cost reductions.

Presenting the Results of a BCA

The BCA provides information for decision makers that demonstrate whether or not a particular project is efficient and how that project compares to other projects. The analysis can be performed for a new project or for an already deployed project. The results of the BCA inform the decision maker, who considers these results along with other investment alternatives, available budgets, and other information to decide if the project will move forward. This may mean that further research is needed to refine the estimates or that the project is ready for deployment.

As discussed above, findings from a BCA can include the dollar value of costs and benefits, the estimated the BCR, the net benefits, and the return on investment. There may also be comparisons of these values for project alternatives. Most BCA software tools provide a tabular summary of the results as standard tool output. Figures 5 and 6 provide example tabular displays of the BCA results from TOPS-BC and the Clear Roads BCA Toolkit.

Choose the active strategies:

- [x] Generic Link Analysis
- [x] Signal Coordination: Central Control
- [x] Ramp Metering: Preset Timing
- [x] Traffic Incident Management
- [x] Dynamic Message Sign
- [x] Highway Advisory Radio
- [x] Pre Trip Traveler Information
- [x] HOT Lanes
- [x] Hard Shoulder Running
- [x] Speed Harmonization
- [x] Road Weather Management
- [x] Work Zone Systems
- [x] Traffic Management Center
- [x] Loop Detection
- [x] CCTV

Benefit/Cost Summary

		Generic Link Analysis	Signal Coordination: Central Control
Annual Benefits			
Travel Time	$	36,561	121,654
Travel Time Reliability	$	31,023	106,602
Energy	$	21,004	23,412
Safety	$	19,200	98,464
Other	$	0	0
User Entered	$	0	0
Total Annual Benefits	**$**	107,788	350,132
Annual Costs	**$**	62,521	166,580
Benefit/Cost Comparison			
Net Benefit	**$**	45,267	183,552
Benefit Cost Ratio		1.72	2.10

Stream of Net Benefits

Source: FHWA TOPS-BC

Figure 5. Screenshot. Partial the Tabular Display of Benefit-Cost Analysis Results from the Tool for Operations Benefit-Cost Analysis.

Agency Costs – Initial	Iowa
Material Spreader ($800)	$720,000
Flow Controller ($2389)	$2,150,100
Agency Costs – Annual	
Material Costs ($30/ton)	$4,536,000
Production Costs ($14.42)	$0
Equipment Maintenance ($14.42)	$192,780
Corrosion/Environmental Costs ($0/ton)	$0
Total Costs – Summary	
Annualized Cost	$8,137,418
Present Value	$57,153,817
Present Value	$9,042
User Benefits	
General Savings	$0
User Benefits	
Crash and Travel Time Savings	$54,732,240
Total Benefits – Summary	
Annualized Benefit	$54,732,240
Present Value	$384,416,351
Annualized Benefit/Truck	$60,814
Cost-Benefit-Ratios	
Agency	0.0
Total	6.7

Source: Clear Roads BCA Toolkit

Figure 6. Chart. Clear Roads Tabular Display of Benefit-Cost Analysis Results.

In addition to spreadsheet tools developed for specific projects or with modifications to TOPS-BC and the Clear Roads BCA Toolkit, these tabular displays can provide the summary data to demonstrate how results vary across selected project assumptions. Table 2 was developed by the New Jersey Department of Transportation (NJDOT) to evaluate the benefits and costs of their Incident Management System. NJDOT was planning to request Federal funding for an Incident Management Program. In their summary of the BCA results, they chose to compare the BCA results that could be achieved with a 15-minute verses a 30-minute reduction in incident duration.

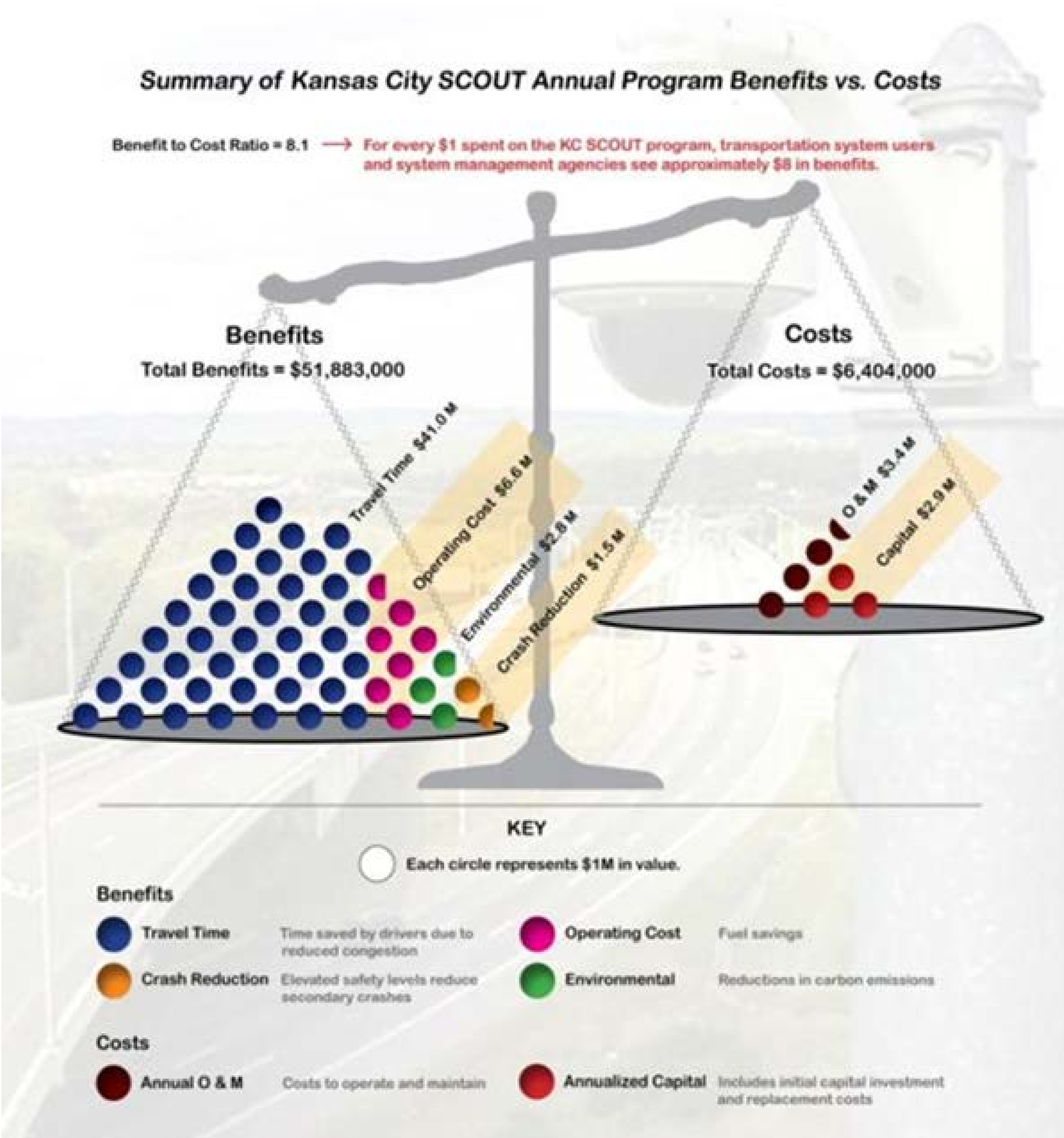
Table 2. New Jersey Department of Transportation Comparison of Savings for the Assumed Reduction in Duration of Each Incident.

Savings Category	15 Minute Reduction	30 Minute Reduction
Reduced Travel Delay	$10,097,678	$18,562,284
Reduced Vehicle Emissions	$745,747	$1,370,763
Reduced Fuel Consumption	$1,288,295	$2,365,928
Reduction in Secondary Incidents	$39,297	$74,257
TOTAL Cost Savings	$12,171,017	$22,373,232
Total Annual Program Cost	$510,000.00	$510,000.00
B/C Ratio	23.87	43.87

Source: New Jersey DOT

This tabular output may be all that is needed by the decision maker. However, graphic displays often provide a visually informative display of results that assists decision makers, public officials, and the public to understand the results. This is particularly true where the project or analysis is complex and the tabular display is hard to interpret. Several such graphic displays are discussed and displayed below.

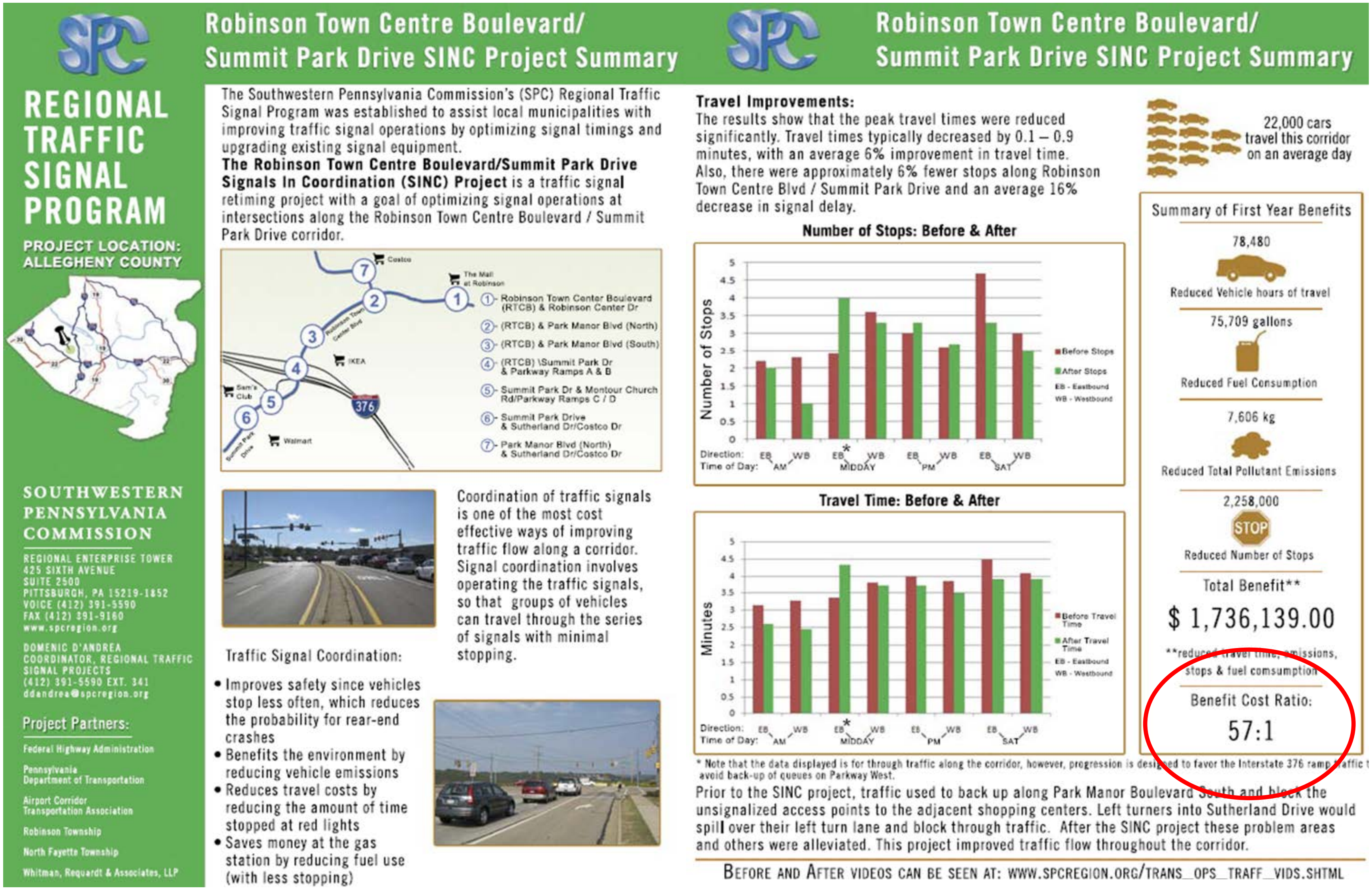
Figure 7 is from a Kansas City SCOUT program benefit-cost study. This graphic captures the fundamental goal of a BCA to provide a comparison of the benefits received from an expenditure of costs. It also allows for the presentation of the relative importance of benefit and cost components to the overall benefit-cost ratio.



Source: Kansas City Scout

Figure 7. Screenshot. Kansas City SCOUT Graphic Display of Benefit-Cost Analysis Results.

In another BCA, the Southwest Pennsylvania Regional Traffic Signal Program used a "newsletter" approach to highlight the results of their study. Figure 8 is an example of this BCA display technique.



Source: South West Pennsylvania Comission

Figure 8. Screenshot. Southwest Pennsylvania Regional Traffic Signal Program Graphic Display of Benefit-Cost Analysis Results.

Finally, graphic displays can seek to present a large amount of information in a single display. The Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area provided multi-modal BCA evaluation results where the magnitude of the BCA results and achieving stated planning goals were displayed concurrently (see Figure 9). Depending on the purpose of the presentation of the results, analysts can balance simplicity of tabular information with creative displays that present multiple dimensions of the analysis.

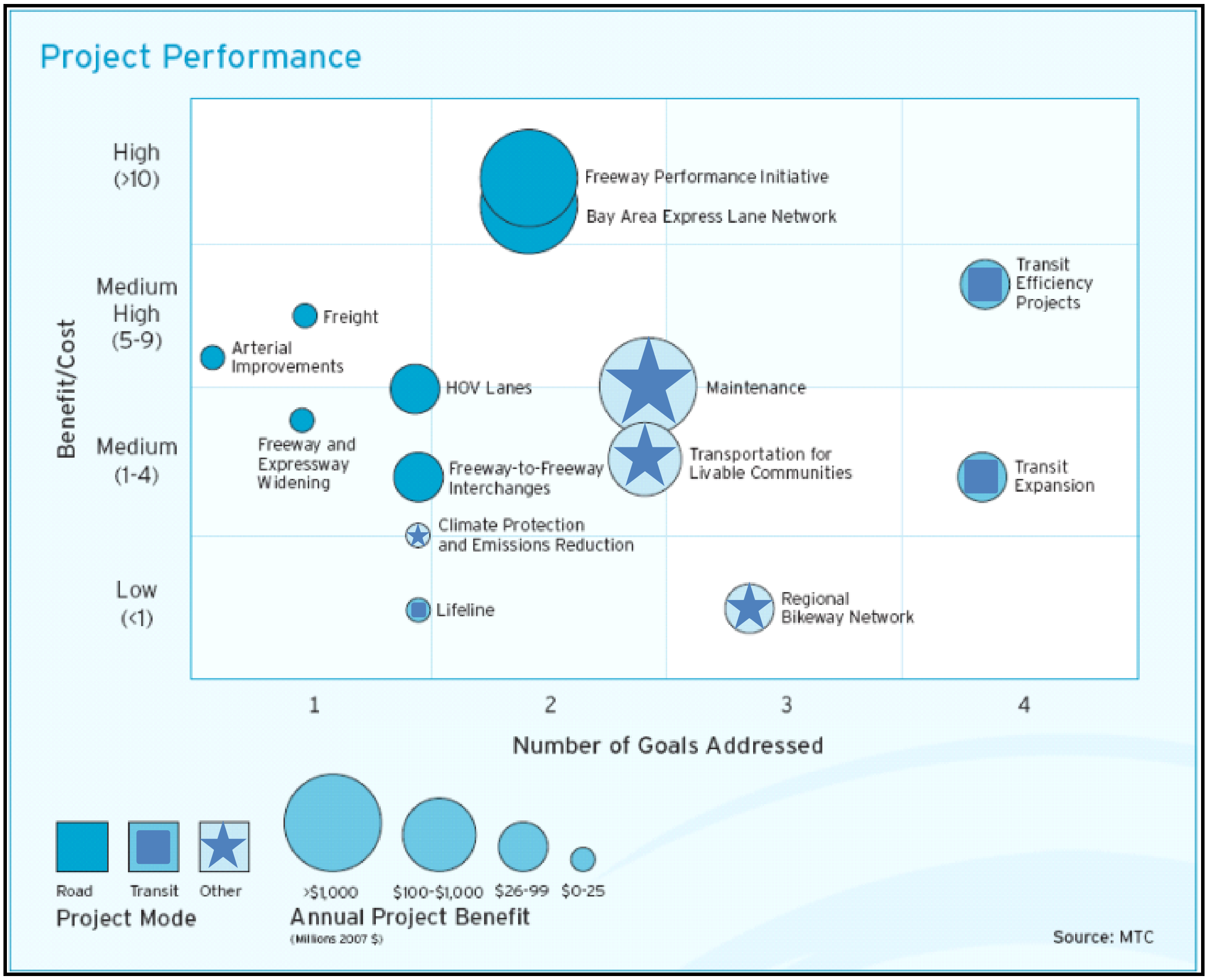


Figure 9. Diagram. Multidimensional Display from the Metropolitan Transportation Commission.

CHAPTER 3. USE OF DISCOUNTING, PRESENT VALUE, CONSTANT AND CURRENT DOLLARS IN BENEFIT-COST ANALYSIS

Benefit-cost analysis is a method and framework for collecting and evaluating project cost and benefit data and presenting the results of the analysis to decision makers. For the base project and project alternatives process benefit-cost analysis (BCA) involves:

- The listing of benefit categories.
- The identification of Measures of Effectiveness.
- The quantification of benefits in dollar values.
- The identification of costs.
- The quantification of costs in dollar values.
- Estimation of net present value of costs and benefits.
- The presentation of results Benefit-Cost Ratios and Net Benefits.

It is important to present benefit-cost analysis results in tabular and graphic format as well as narratives. Some policy analysts and the public often prefer such formats as it makes it easier to understand the relationships between project investments, alternatives, and benefits. For tips on BCA results visualization, see Chapter 3 for some good examples.

Benefits

BCA of transportation operations projects requires the estimation of benefits which represent the monetized estimates of the changes in the Measures of Effectiveness (MOE) 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 benefit cost analysts improperly assign negative benefits (e.g., an increase in the amount of emissions) to the cost component of the benefit cost equation (denominator); however, 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 benefit-cost ratio. 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 activity should properly be treated as a change in benefits rather than a cost reduction, as these savings are a direct result of the project.

Costs

The Costs or the denominator value in benefit-cost ratio for transportation systems management and operations (TSMO) projects represents the life-cycle costs of implementing and operating the project. This is important for TSMO 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 Operations & Maintenanc (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. The TOPS-BC has the capability to estimate life-cycle costs associated with many types of TSMO strategies. The use of these capabilities is also discussed in the TOPS-BC User's Manual.

The Monetization of Benefits and Costs

On aspect of benefit-cost analysis that can be challenging is the monetization of cost and benefits. In the analysis we seek to compare a potential project to a baseline condition or to an alternative solution. In order to analyze costs and benefits as well as alternative projects, it is necessary to have costs and benefits on a common unit basis. In order to explain this, we need to define a few terms. These include:

- ***Inflation*** is the increase in prices for goods and services over time. It implies a loss in the nominal 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.
- ***The Discount Rate*** is the recognition that a dollar today is worth more than a dollar 5 years from now, even if there is no inflation because today's dollar can be used productively in the ensuing 5 years, yielding a value greater than the initial dollar. Future benefits and costs are discounted to reflect this fact.

- ***Year of Expenditure Dollars (YOE***) are the current dollar in the year during which an expenditure is made or a benefit is realized. These are used in financial analysis, but not usually in BCA. YOE dollars are needed to know if agency revenues will be sufficient to meet agency outlays.

TSMO and other transportation projects usually entail a stream of expenditures and benefits over time. Initial capital cost may occur in the early project years with O&M costs continuing over the project life. Benefits usually occur over the full life of the project. TOPS-BC is designed to simplify these conversions between current and future dollars. TOPS-BC estimates average annual benefits and costs, or projects the benefits and costs to a stream of costs that may be used with a time horizon selected by the user. The user can also select the inflation rate and the discount rate.

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 or 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.

The discount rate for most projects in 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. However, if 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/. 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.

CHAPTER 4. INTRODUCTION TO BENEFIT-COST ANALYSIS TOOLS

Benefit-cost analysis (BCA) of one or more transportation systems management and operations (TSMO) strategies can be conducted with the support of several available software tools. Some of these tools are generic and support the analyst in organizing their data for BCA. Others are more focused on the needs of analysts examining TSMO strategies and options. These include tools developed by regional, state, and Federal agencies, as well as proprietary tools developed by many private sector enterprises. These software tools range from simple methods intended for one-time analysis to more complex tools that are continually maintained and updated. Additionally, several emerging tools/methods are currently undergoing development as part of parallel efforts by the U.S. Department of Transportation (USDOT), American Association of State Highway and Transportation Officials (AASHTO), the Strategic Highway Research Program 2 (SHRP2), individual states and regions, and research organizations.

Some of the most widely distributed and applied tools used for conducting benefit-cost analysis of TSMO strategies include those summarized (in alphabetical order) in Table 3. 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 3. Summary of Existing Benefit-Cost Analysis Tools and Methods for Transportation Systems Management and Operations Projects

Tool/Method	Developed by	Web Site
BCA.net	FHWA	https://fhwaapps.fhwa.dot.gov/bcap/BaseLogin/LoginReg.aspx
CAL-BC	Caltrans	http://www.dot.ca.gov/hq/tpp/offices/eab/LCBC_Analysis_Model.html
Clear Roads BC Toolkit	Montana State University under contract to Clear Roads Consortium	http://clearroads.org/cba-toolkit/
COMMUTER Model	U.S. EPA	http://www.epa.gov/oms/stateresources/policy/pag_transp.htm
EMFITS	New York State DOT	https://www.dot.ny.gov/divisions/engineering/design/dqab/dqab-repository/pdmapp6.pdf
The Florida ITS Evaluation (FITSEval) Tool	Florida DOT	Not Available
IDAS	FHWA	http://idas.camsys.com
IMPACTS	FHWA	Not Available
MBCA	TREDIS Software	http://www.tredis.com/mbca
Screening Tool for ITS (SCRITS)	FHWA	Not Available
Surface Transportation Efficiency Analysis Model (STEAM)	FHWA	Not Available
Tool for Operations Benefit Cost Analysis (*TOPS-BC*)	FHWA	http://plan4operations.dot.gov/topsbctool/index.htm.
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

Source: FHWA TOPS Manual and JFA

The following sections provide a brief introductory description of the tools and methods presented in Table 3. More detailed information can be accessed by following the links provided.

- 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.
- 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.
- Clear Roads – This toolkit is meant to be used not only to understand the expected costs and benefits of specific winter weather maintenance practices, equipment, or operations, but also to convey those expectations to decision-makers outside the maintenance community. It includes costs and benefits for new practices, equipment, and operations, as well as provides a means to be expandable in the future to include additional winter maintenance elements as needed. This toolkit was initially developed by the Western Transportation Institute at Montana State University and Current Transportation Solutions under contract to the Clear Roads Consortium and Wisconsin Department of Transportation
- 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.

- HOT-BC – The HOT-BC was developed by the Managed Lanes Pooled Fund Study to analyze societal benefits and costs associated with value pricing projects for managed lanes. HOT-BC is an Excel based tool designed to help planners address the concern of legislators, transportation engineers, and the public on the cost-effectiveness of the value priced lanes in congestion mitigation.
- 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.
- 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.
- MBCA – The Multimodal Benefit-Cost Analysis (MBCA) is a free, web-based calculation system for comparing the costs and user benefits of individual transportation projects. MBCA is unique in that it covers both passenger and freight transportation spanning all modes – road, rail, air and marine – and it also includes pedestrian and bicycle modes. It is designed to be consistent with USDOT guidelines, making it useful for multimodal project assessment, grant applications and education programs. MBCA is set up with standard US and Canadian values for user benefit, which are not tied to any specific study area.
- TOPS-BC – The Tool for Operations Benefit-Cost Analysis (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.

- SHRP L07 - Evaluation of Cost-Effectiveness of Highway Design Features - The overall objective of this project is to identify the full range of possible roadway design features used by transportation agencies on freeways and major arterials to improve travel time reliability, assess their costs, operational effectiveness, and safety, and provide recommendations for their use and eventual incorporation into appropriate design guides.
- SHRP C11 - Tools for Assessing Wider Economic Benefits - The Strategic Highway Research Program II funded the SHRP2 Project C11, "Development of Tools for Assessing Wider Economic Benefits of Transportation." The goal of this project was to develop a bridge between (A) the case study form of analysis provided by the TPICS web tool, and (B) more sophisticated simulation and forecasting models that are necessary to fully assess the wider economic impacts of proposed projects. This study provides four sets of spreadsheet tools that can aid in transportation project impact assessment. These tools enable measurement of project impacts on travel time reliability, intermodal connectivity and accessibility, and they are accompanied by an accounting system for incorporating them into economic benefit and impact analyses.

The above tools and research efforts represent a sampling of the available methods that may be used for supporting and conducting benefit cast analysis of TSMO strategies. The capabilities of many of these tools and the findings of the research efforts are more fully described in the *Operations Benefit/Cost Analysis Desk Reference* which is available at: http://ops.fhwa.dot.gov/publications/fhwahop12028/fhwahop12028.pdf

In addition, these developed tools and published research often form the basis for the benefit and cost estimation capabilities incorporated in the TOPS-BC tool.

TOPS-BC – A Tool for Benefit-Cost Analysis of TSMO Strategies

TOPS-BC provides an analysis framework and many default parameters that offer the capability to conduct simple sketch planning level benefit-cost analysis for selected TSMO strategies. This capability provides practitioners with the capability to conduct benefit-cost analysis quickly, simply and with generally available input data. A number of sketch planning tools and analysis frameworks described above allow analysts the ability to assess the benefits of a particular TSMO strategy or small sets of strategies. TOPS-BC leverages many of these existing tools to identify best practices, and synthesizes their capabilities into a more standardized format for analyzing a broader range of strategies within a single tool.

TOPS-BC also links the estimation of sketch level benefits with life-cycle cost estimates. This ability to directly estimate benefits and costs within a single tool is uncommon in existing tools. TOPS-BC provides the ability to assess the sketch planning level benefits of various TSMO strategies using minimal user data input. Changes in performance measures, such as throughput, speeds, and

Compendium users should familiarize themselves with TOPS-BC. This can be accomplished by:

1. Downloading and reviewing the Operations Benefit Cost Analysis Desk Reference at http://ops.fhwa.dot.gov/publications/fhwahop12028/fhwahop12028.pdf
2. Downloading and reviewing the TOPS-BC User Manual at http://www.ops.fhwa.dot.gov/publications/fhwahop13041/index.htm#toc
3. Downloading and reviewing TOPS-BC at http://www.plan4operations.dot.gov/topsbctool/index.htm

number of crashes are based on simple and established relationships used in numerous other models. With generally available data such as corridor speeds, volumes and capacities, TOPS-BC can produce an estimate of the change in performance resulting from the implementation of TSMO strategies. This change in performance can then be used to generate enhanced metrics, and the estimated benefits can be monetized within the tool and compared with estimated life-cycle costs for the strategy.

While the sketch planning level analysis provided by TOPS-BC may be suitable for many planning studies, TOPS-BC was not intended to serve as a single analysis tool to be used for all situations. The Desk Reference discusses benefit cost analyses of deployments requiring detailed output and high levels of confidence in the accuracy of the results and how these studies may require more advanced analysis capabilities than provided directly within TOPS-BC. Even in these situations, however, TOPS-BC may provide value in serving as a framework for monetizing benefits and comparing with costs. Outputs from more advanced simulation or dynamic traffic assignment tools may be used as inputs to TOPS-BC, overriding the performance impacts normally calculated within the tool.

TOPS-BC is intended to provide a framework for analysts that can be modified and configured to match the needs of their regions and the characteristics of the area being analyzed. Default data is provided for many impact parameters, performance relationships, and benefit valuations. Such default data are typically based on national averages or accepted values. However, opportunities are provided, and users are encouraged, to use locally configured or regionally relevant data where appropriate and desired.

The TOPS-BC life-cycle cost estimation capabilities and the benefit estimation capabilities provide a common instructional worksheet with links to individual strategies housed on separate worksheets. The outputs from the benefits estimation include the Average Annual Benefit and the Stream of Benefits time horizon (up to 50 years). The estimated benefits for all strategy sheets are rolled up in a summary sheet that estimates the cumulative benefit for all strategies deployed in the selected analysis.

The cases provided in the compendium cover many of the strategies included in TOPS-BC. In some cases the strategies analyzed are evaluated with custom developed tools or with benefit-cost analysis software such as those identified above. In other cases, the strategy is evaluated with

TOPS-BC where model input and output data are provided. Still other cases offer examples setting up, modifying and running TOPS-BC for TSMO strategies.

Data Requirements

Current data is essential for conducting BCA of TSMO projects or combinations of projects. TOPS-BC provides an analysis framework and many default parameters in order to provide the capability to conduct simple sketch planning level BCA for selected TSMO strategies. This capability was provided in order to enable practitioners to conduct BCA quickly, simply and with generally available input data. A number of sketch planning tools and analysis frameworks currently exist to assess the benefits of particular TSMO strategies or small sets of strategies. TOPS-BC leverages many of these existing tools to identify best practices, and synthesizes their capabilities into a more standardized format for analyzing a broader range of strategies within a single tool.

TOPS-BC also links the estimation of sketch level benefits with life-cycle cost estimates developed elsewhere in the model. This ability to directly estimate benefits and costs within a single tool is uncommon in existing tools to date. The benefits estimation capability of TOPS-BC incorporated much of the latest research on the benefits of TSMO, particularly for many new and emerging strategies.

TOPS-BC provides the ability to assess the sketch planning level benefits of various TSMO strategies using minimal data input. Changes in performance measures, such as throughput, speeds, and number of crashes are based on simple and established relationships used in numerous other models. With generally available data such as corridor speeds, volumes and capacities, TOPS-BC can produce an estimate of the change in performance resulting from the implementation of TSMO strategies. This change in performance can then be used to generate enhanced metrics, and the estimated benefits can be monetized within the tool and compared with estimated life-cycle costs for the estimation of a benefit-cost ratio and net benefits.

There are two methods available to modify the values required for benefit calculation in TOPS-BC. For an individual technology evaluation, the user can input values into the green cells on the Benefits Estimation pages or the user can go to the Parameters page and make universal modifications that will be used in all future TOPS-BC calculations until changed again.

Updating the Parameters Page. TOPS-BC allows the user to rely heavily on data already contained in TOPS-BC. The user is also encouraged to update default values for individual TSMO benefit analysis with more recent data. In addition, information generated for the project by simulation modeling, travel demand modeling, surveys or other means can be input to TOPS-BC to replace default values. The user will always input some project/facility information such as the facility type, location, length, number of lanes, etc. Some default values contained in TOPS-BC are located on the Parameters Page. These data are used by many technologies and strategies to provide quantification and monetization. A partial screen shot of the TOPS-BC Version 1.0 Parameters page is provided in Figure 10.

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0 Restore

Estimate Benefits of TSM&O Strategies

Benefit Estimation Parameters

General Parameters

Year of Dollars Displayed	
Year of Dollar Display	2010
Inflation Rate	3%
Adjustment Factor	1.00
Annualization Factor	
Number of Periods per Year	250
Net Present Value Calculation	
Default Time Horizon (Years)	20
Traffic Mix	
Percentage Trucks	10%
Percentage "On-the-Clock" Travel Purpose (A	20%
Average Auto Occupancy	1.67
Discount Rate	
Discount Rate (for 20 year analysis)	7.0%
Analysis Time Horizon	
Years	20

Benefit Valuations

Recurring Travel Time (per hour)		
"On the Clock" Travel Time	$	28.00
Other Auto Travel Time	$	14.00
Truck Travel Time	$	28.00
Non-Recurring Travel Time (per hour)		
"On the Clock" Travel Time	$	28.00
Other Auto Travel Time	$	14.00
Truck Travel Time	$	28.00
Crashes (per occurance)		
Fatality	$	6,500,000
Injury	$	67,000
Property Damage Only (PDO)	$	2,300
Fuel Use		
Per Gallon (Excluding Taxes)	$	3.67
Non-fuel Operating Costs (per VMT)		
Auto		0.25
Truck		0.37
Emission Cost (per ton)		
CO	$	70
CO2	$	37
Nox	$	16,300
PM10	$	131,800
VOC	$	1,140
Noise (per VMT)		
Auto	$	0.0011
Truck	$	0.0330

Speed/Flow Relationsh

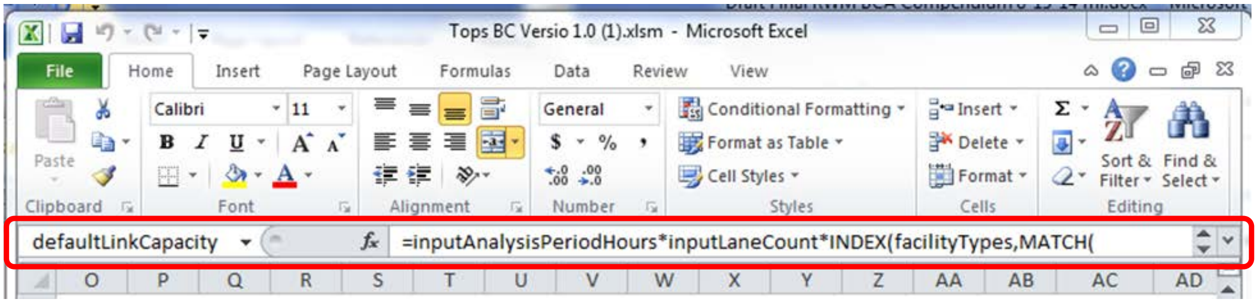
	V/C Ratio	l Factor
Freeways	0.2	0.9878
	0.3	0.9781
	0.5	0.9471
	0.7	0.890
	0.8	0.8442
	0.9	0.7825
	1	0.6984
	1.1	0.5838
	1.2	0.4276
	1.4	0.300
	1.6	0.123
	1.8	0.090
	2	0.084
	2.5	0.072
	3	0.043
	4	0.01
	5	0.008
	6	0.004
	12	0.001
Arterials	0.2	0.990
	0.3	0.9842
	0.5	0.9678
	0.7	0.9443
	0.8	0.929
	0.9	0.9108
	1	0.8889
	1.1	0.8627
	1.2	0.8314
	1.4	0.7492
	1.6	0.6315

Source: FHWA TOPS-BC

Figure 10. Screenshot. Portion of the Benefit Estimation Parameters Page from the Tool for Operations Benefit-Cost Analysis

The Parameter page also includes data on fuel economy for autos and trucks and incident delay factors by facility type, duration and congestion levels. Note that the gasoline price per gallon excludes all taxes. The user may want to modify some of these values to reflect more current or regionally specific information. Note the upper right hand corner where a *Restore* button allows the user to go back to the original default values on this page at any time. The first item to observe is the *Year of Dollar Display*, here 2010. If prices or values are changed on this page, they must be entered in the base year 2010 dollars. The Parameters page assumes a 3 percent annual inflation rate, but this value can be modified. If you change the *Year of Dollar Display* to the current year the page will recalculate most values on the page to that year dollars assuming a 3 percent annual inflation rate. These revised values will now be used in all TOPS-BC calculations that call for that value.

If you plan to change a value in the *Benefit Valuations* column, you should do this in the formula bar by editing the formula displayed, and not in the individual cell. The formula bar in Excel is located above the work area of the spreadsheet, shown in Figure 11. The formula bar displays the data or formula stored in the active cell. The formula bar can be used to enter or edit a formula, a function, or data in a cell. If you enter a new value directly in a cell, it will overwrite the cell formula. In this case, if you later change the *Year of Dollar Display,* the *Benefit Valuation* for the cell changed directly will not be updated to the new year dollars.



Source: Microsoft Inc. Excel Spreadsheet and FHWA TOPS-BC

Figure 11. Screenshot. Excel Formula Bar Outlined in Red

The user can also change the speed flow relationship or the delay factors. Be careful to make these adjustments in the same cells as are now displayed on the Parameters page as they may be referred to by another sheet in the model.

TOPS-BC Current Safety Impact Defaults

In the TOPS-BC methodology, the number of crashes is generally estimated by applying a crash rate based on crashes per vehicle miles traveled. The overall crash rates are based on crash rates from the FHWA's ITS Deployment Analysis System (IDAS) analysis tool. Different rates are provided by roadway type (freeway or arterial) and for three different crash severity levels (fatality, injury and property-damage-only (PDO)). For selected categories (freeway injury and PDO crashes) the rates are sensitive to the volume/capacity (V/C) ratio of the analyzed facility and increase at higher levels of congestion. Table 4 shows the safety rates uses for the different categories. Table 5 shows the V/C ratio-sensitive rates used for estimating the freeway injury and PDO crashes. These and other TOPS-BC defaults can be overridden if users have more accurate or accepted local values.

Table 4. Crash Rates per Million Vehicle Miles Traveled.

Severity	Freeway	Arterial
Fatality	.007	.018
Injury	Variable	1.699
PDO	Variable	2.474

Source: FHWA TOPS-BC

In TOPS-BC, the non-fatal crash rate assumed on freeways is based on the volume to capacity ratio or V/C. TOPS-BC uses a fixed crash rate for freeway crash rates for injury and PDO crashes where the V/C is less than 0.7 or greater then 1.0, TOPS-BC uses an increasing crash rate for injury and PDO crashes when V/C is between 0.7 and 1.0. The variable rates are shown in Table 4.

Table 5. Volume to Capacity Ratio-Sensitive Crash Rates per Million Vehicle Miles Traveled.

V/C Ratio	Freeway Injury Crashes	Freeway PDO Crashes
.1 to .7	.476	.617
.8	.532	.718
.9	.677	.836
1+	.706	.919

Source: FHWA TOPS-BC

Using this general methodology, the number of crashes is predicted to change for any strategy that results in a change in VMT, or strategies that result in a change to the volume/capacity level of freeway facilities.

In addition to this general estimation methodology, selected strategies available for deployment in TOPS-BC also have specific default safety impacts associated with them that are applied on top of any crash change resulting from a change in VMT or V/C ratio. Table 6 presents these default impacts currently used in the tool.

Table 6. Default Impact Assumptions Currently in the Tool for Operations Benefit-Cost Analysis.

Strategy	Default Impact Assumptions
Arterial Traffic Signal Coordination	10% reduction in crash rate for pre-set timing signal coordination 12.5% reduction in crash rate for traffic actuated signal timing 15% reduction in crash rate for centrally controlled signal timing
Ramp Metering	27% reduction in crash rate for pre-set timing metering 27% reduction in crash rate for traffic actuated metering 27% reduction in crash rate for centrally controlled metering

Table 6. Default Impact Assumptions Currently in the Tool for Operations Benefit-Cost Analysis (cont'd).

Strategy	Default Impact Assumptions
Traffic Incident Management	10% reduction in fatality crashes for incident detection/verification strategies due to faster response times Notes: –Reduced number of fatality crashes added to injury crashes totals. No net change in the number of total crashes. –User is provided opportunity to enter a percentage reduction (for all crash severity categories) to represent a reduction in secondary crashes resulting from the introduction of the traffic incident management strategies. Default in the tool is 0% (no change).
Pre-Trip Traveler Information	No change to default crash rates
En-route Traveler Information	No change to default crash rates
Variable Speed Limits/Speed Harmonization	7% reduction in crash rates
Work Zone Management	10% increase in base crash rate to reflect added risk of work zone 7% reduction in modified crash rates to reflect crash reduction benefit of work zone management strategies
Travel Demand Management	No change to default crash rates

Source: FHWA TOPS-BC

How to Use the Compendium

The Compendium is designed to work with the Desk Reference and the TOPS-BC User's Manual. Together the Desk Reference and the TOPS-BC User's Manual provide the basic instructions for conducting a BCA of a TSMO project. The Compendium compliments these tools by providing case references where BCA of TSMO projects have been completed. In addition, the hypothetical examples demonstrate particular uses and modifications of TOPS-BC. The intent is to demonstrate a broad range of Operations BCA cases so that users have a better idea of the structure and aspects of similar analysis they may interested in performing.

Users who have a particular strategy or technology they are interested in evaluating can find that strategy or technology in Table 7. This table lists types of strategies and technologies along with an indication of the project title if it is a previous BCA. If it is a hypothetical case, the description is more generic. The table also indicates some of the type of information addressed by each case study to assist the user in locating the case which will be most suited to their current needs.

TOPS-BC was released by FHWA in late 2013. As such, there are not many published analyses applying the software. Few of the real world cases presented in the Compendium use TOPS-BC. As with any job, finding the right tool is critical. In many cases this is a custom application developed for the particular project under review. Some BCA models are generic by design. They allow the user to construct the analysis of a particular project and the model assists with the calculation. An example of this type of model is BCA.net, available at http://www.fhwa.dot.gov/infrastructure/asstmgmt/bcanet.cfm.

A model like TOPS-BC is designed to cover a range of TSMO projects and include cost and benefit computations for each technology. Notably, some models are developed for a specific technology or strategy. For example, the Freeway Service Patrol Evaluation (FSPE) model was developed by the University of California Berkeley for the analysis of a specific technology. A technology/strategy specific model usually contains more detail about the deployment of the technology and may require more specific information from the user. Such a model is usually applied closer to deployment than a sketch planning tool.

Table 7 presents the listing of TSMO technologies covered in the Compendium. For each case the table works as a guide to help users find what they are looking for. Each case presented is an example of a benefit-cost analysis previously conducted for a TSMO strategy or technology or it is an example of how such an analysis could be undertaken in TOPS-BC. The column heading indicates some of the areas addressed in each case. These include:

- **Case Number and Name**
  - This Compendium of TSMO Benefit-Cost Analysis includes three general types of case studies:
    1) TSMO BCAs conducted by government or private agencies.
    2) Demonstration of TSMO BCAs using the TOPS-BC tool.
    3) Demonstration of a user modification to the TOPS-BC software.
- **TSMO Area**
  - The case studies are organized into seven general technology/strategy areas including: traveler information, arterials, freeway systems, demand management, transit, other strategies and combined strategies.
- **TSMO Strategy Type**
  - Within each strategy type, several examples of different types of strategies or analysis tools are provided.
- **Real or Hypothetical**
  - Case studies that report on the findings of previous BCA studies are referred to as real case studies. Hypothetical case studies are examples of how to run TOPS-BC or to carry out specific calculations using hypothetical data which may come from actual projects or averages of previous project data. Hypothetical case studies are for demonstration purposes only.
- **BCA Tool Demonstrated – TOPS-BC, Custom, Other**
  - The sketch planning TOPS-BC tool is highlighted in the TSMO BCA Desk Reference, but it is not the only such BCA tool and many cases report the use of custom software or other packaged tools for their BCA analysis of TSMO strategies.

Table 7. Case Study List

#	Case Name	Transportation Systems Management and Operations Area	Strategy Type	Benefit-Cost-Analysis Model	Actual or Hypothetical Case
5.1	Hypothetical Preset Arterial Signal Coordination	Arterial Operations	Signal Coordination	TOPS-BC	Hypothetical
5.2	Adaptive Traffic Signal Control in Greeley and Woodland Park, Colorado	Arterial Operations	Adaptive Signal Control	Custom In-house Analysis	Actual
5.3	Adaptive Traffic Signal Control	Arterial Operations	Adaptive Signal Control	Custom In-house Analysis	Hypothetical
5.4	Hypothetical Roundabouts	Arterial Operations	Roundabouts	TOPS-BC	Hypothetical
5.5	Effectiveness of Roundabouts in Maryland	Arterial Operations	Roundabouts	Custom Stand Alone BCA Model Focused on Safety Benefits	Actual
5.6	Effectiveness of Arterial Management in Florida	Arterial Operations	Arterial Management	TOPS-BC	Actual
6.1	Hypothetical Centrally Controlled Ramp Metering Deployment	Freeway Systems Management	Ramp Metering	TOPS-BC	Hypothetical

Table 7. Case Study List (cont'd)

#	Case Name	Transportation Systems Management and Operations Area	Strategy Type	Benefit-Cost-Analysis Model	Actual or Hypothetical Case
6.1	Florida DOT Road Ranger Program	Freeway Systems Management	Freeway Service Patrol	Custom Stand Alone BCA Model Focused on Safety Benefits	Actual
6.3	Metropolitan Area Transportation Operations Coordination Program	Freeway Systems Management	Freeway Management	Custom Stand Alone BCA Model	Actual
6.4	Regional Traffic Management Center, Ft. Lauderdale, FL	Freeway Systems Management	Traffic Management Center	Custom Stand Alone BCA Model	Actual
6.5	Coordinated Highways Action Response Team, Maryland	Freeway Systems Management	Traffic Management Center	Custom Stand Alone Benefit Analysis	Actual
6.6	Georgia NaviGator Traffic Incident Management System	Freeway Systems Management	Incident Management	Custom Stand Alone Benefit Analysis	Actual
7.1	Minnesota I-35W Urban Partnership	Demand Management	Demand Management, Congestion Pricing	Project Developed BCA Tool	Actual

Table 7. Case Study List (cont'd)

#	Case Name	TSMO Area	Strategy Type	BCA Model	Actual or Hypothetical Case
7.2	Interstate I-95 Express Managed Lanes	Demand Management	Managed Lanes	TOPS-BC	Actual
8.1	Transit Signal Priority, Portland Tri-Met	Transit Operations	Transit Signal Priority	Internal BCA Data Review	Actual
8.2	Transit Signal Priority, Los Angeles DOT/MTA	Transit Operations	Transit Signal Priority	Internal BCA Data Review	Actual
9.1	Oregon's Automated Wind Warning System	Traveler Information	Automated Wind Warning Systems	Custom In-House Analysis	Actual
9.2	Hypothetical Truck Tip-Over Warning System	Traveler Information	Curve Speed Warning Systems	TOPS-BC	Hypothetical

Table 7. Case Study List (cont'd)

#	Case Name	TSMO Area	Strategy Type	BCA Model	Actual or Hypothetical Case
9.3	Freight: Truck Over-Height Warning System	Traveler Information	Over-Height Warning System	TOPS-BC	Hypothetical
10.1	Road Weather Pooled Fund Maintenance Decision Support System (MDSS) Implementation	Other Strategies	Maintenance Decision Support System	Custom In-House Analysis	Actual
10.2	Hypothetical Maintenance Decision Support System (MDSS) Implementation	Other Strategies	Maintenance Decision Support System	TOPS-BC	Hypothetical
11.1	Automated License Plate Recognition	Multiple Strategies	Automated License Plate Recognition System, Weigh-in-Motion, Automatic Vehicle Identification	Custom In-House Tool	Actual

Table 7. Case Study List (cont'd)

#	Case Name	TSMO Area	Strategy Type	BCA Model	Actual or Hypothetical Case
11.2	Cincinnati Region Advanced Regional Traffic Interactive Management & Information System (ARTIMIS) Study	Multiple Strategies	Regional traffic operations center, traffic surveillance, incident management, freeway service patrols, traveler information, dynamic message signs, highway advisory radio	IDAS	Actual
11.3	Washington's Automated Anti-Icing System Study			Custom In-House Analysis	Actual

Source: JFA

Overall Lessons Learned from Case Studies

Each case study provides detailed key observation about the application of BCA to the specific TSMO projects. The following list of lessons learned apply to BCA in general and should be kept in mind when conducting BCA.

- ***Use Good Data – It Is Essential –*** TOPS-BC, BCA.net and other BCA Tools support the analytic process when good data on MOE change is available. When limited data is available, some BCA systems can still use default data to support preliminary system analysis.
- ***Clearly Identify the Baseline –*** A benefit-cost analysis compares and alternative to a baseline condition. The practitioner should calculate all benefits and cost in relation to that baseline to produce a meaningful analysis.
- ***Use Data from Real Projects –*** TOPS-BC and other BCA Tools often include default values for required inputs. These are national estimates taken from the published literature. Users should review these values to see if they seem appropriate for your region or project.
- ***Use Net Present Values –*** A benefit-cost analysis should calculate the NPVs of the streams of incremental benefits and costs over the lifetime of the project. TOPS-BC divides the resulting NPV of benefits by the NPV of costs to produce a meaningful benefit-cost ratio.
- ***Provide Additional Benefit Estimates –*** As TOPS-BC provides a specific set of benefits, you may have other benefit estimates such as reductions in vehicle emissions. TOPS-BC allows you to enter these values directly and have them included in the benefit-cost analysis.
- ***Evaluate Strategies –*** A benefit-cost analysis needs estimates of the change in MOEs to compare and contrast with and without technology conditions. These changes in MOEs can be quantified to compare with costs.
- ***Test the Deployment before Expanding the System Sensitivity Analysis –*** A benefit-cost analysis allows the user to examine the efficiency of the installation and compare it to alternative assumptions.
- ***Consider Combining Strategies –*** As many TSMO projects and strategies are synergistic, consider combining multiple strategies to maximize benefits.
- ***Conduct a Before and After BCA –*** BCA can and should be conducted before deployment, but it is also a good tool for post deployment analysis when project performance impacts are often observable.
- ***Add Qualitative Benefits –*** While not all benefits are easily quantifiable, qualitative descriptions of items like "improved quality of life" provide the decision maker and the public with a better understanding of what is accomplished by project deployment.

CHAPTER 5. ARTERIAL OPERATIONS

#	Case Name	Benefit-Cost Analysis (BCA) Model	Actual or Hypothetical Case
5.1	Hypothetical Preset Arterial Signal Coordination	TOPS-BC	Hypothetical
5.2	Adaptive Traffic Signal Control in Greeley and Woodland Park, Colorado	Custom In-house Analysis	Actual
5.3	Adaptive Traffic Signal Control	Custom In-house Analysis	Hypothetical
5.4	Hypothetical Roundabouts	TOPS-BC	Hypothetical
5.5	Effectiveness of Roundabouts in Maryland	Custom Stand Alone BCA Model Focused on Safety Benefits	Actual
5.6	Effectiveness of Arterial Management in Florida	TOPS-BC	Actual

Case Study 5.1 – Hypothetical Preset Arterial Signal Coordination

Strategy Type:	Arterials
Project Name	Hypothetical Preset Arterial Signal Coordination
Project Agency	Based on Data from Denver COG
Location:	Principal Arterial
Geographic Extent:	2.8 Mile Corridor
Tool Used:	TOPS-BC Tool

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Arterial signal coordination involves the coordination of traffic signal timing patterns and algorithms to smooth traffic flows—reducing stops and delays and improving travel times. Agencies can implement this strategy on a small corridor, a limited grid, or region-wide. 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.

Program and Project Goals and Objectives

Since 1989, Denver Regional Council of Governments' (DRCOG) Traffic Operations Program has been working with the Colorado Department of Transportation and local governments to coordinate traffic signals on major roadways in the region. DRCOG designed the program to reduce traffic congestion and improve air quality. DRCOG was one of the first metropolitan planning organizations (MPO) to conduct such a program, and remains the leader among the very few MPOs throughout the United States involved in traffic signalization efforts. Table 8 provides a snapshot of DRCOG's 2012 annual benefits summary of projects. Links for each project provide signal timing briefs (individual benefits summary reports for each project). To view the data shown in Table 8,
visit http://drcog.org/sites/drcog/files/2013%20Traffic%20Operations%20Program%20projects.pdf.

Table 8. Denver Regional Council of Governments 2012 Annual Benefits Summary of Projects.

Project	Limits	Number of Signals	Jurisdiction (Operators)	Project Type	Benefits				
					Travel Time Reduction (Hours/day)	Fuel Consumption Reduction (Gal/day)	Pollutant Emissions Reduction (lbs/day)	Greenhouse Gas Emissions Reduction (lbs/day)	User Savings ($/day)[1]
T13-1 Alameda Ave.	Sheridan Blvd. to Marion Pkwy.	29	Denver	Capital Improvement Signal Timing Project	671	406	99	8,451	$15,850
T13-2 University Blvd.	Alameda Ave. to Hampden Ave.	19	Denver, Englewood, CDOT	Capital Improvement Signal Timing Project	643	401	88	8,287	$15,150
T13-3 Arapahoe Blvd.	University Blvd. to Waco St.	29	CDOT, Centennial, Greenwood Village, Aurora, Arapahoe County	Capital Improvement Signal Timing Project	1,056	547	132	11,352	$24,550
T13-4 US-85	Bromley Lane to 104th Ave.	10	CDOT, Brighton	Capital Improvement Signal Timing Project	290	130	30	2,710	$6,550
T13-5a 120th Ave.	Nickel St. to Holly St.	30	CDOT, Thornton, Northglenn	Capital Improvement Signal Timing Project	1,097	590	151	12,201	$25,600
T13-5b Huron St.	128th Ave. to 104th Ave.	12	Westminster, Northglenn, CDOT	Signal Timing Project	502	266	67	5,541	$1,750
T13-5c Sheridan Blvd.	Aspen Creek Dr. to 118th Ave.	9	Broomfield, CDOT, Westminster	Signal Timing Project	309	157	35	3,267	$7,200
T13-6 84th Ave./Huron St.	84th Ave: Huron St. to Washington St.; Huron St: 84th Ave. to Connifer Rd.	12	Thornton	Capital Improvement Signal Timing Project	240	75	18	1,542	$5,400
T13-7 Wadsworth Blvd.	64th Ave. to 108th Ave.	33	CDOT, Westminster, Arvada	Capital Improvement Signal Timing Project	532	250	63	5,214	$12,300
T13-8 Parker Rd.	Chambers Rd. to Cottonwood Dr.	12	CDOT, Aurora, Arapahoe County, Centennial, Parker	Capital Improvement Signal Timing Project	886	447	99	9,278	$20,550

Table 8. Denver Regional Council of Governments 2012 Annual Benefits Summary of Projects (cont'd).

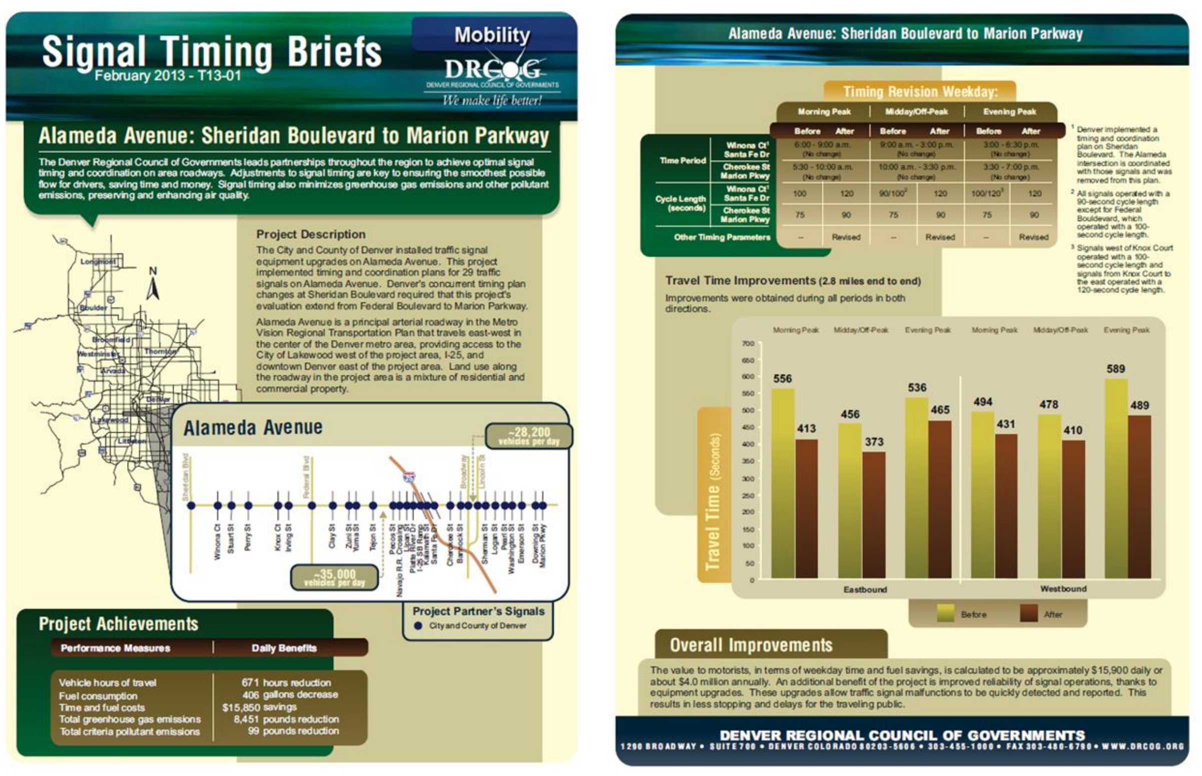
Project	Limits	Number of Signals	Jurisdiction (Operators)	Project Type	Benefits				
					Travel Time Reduction (Hours/day)	Fuel Consumption Reduction (Gal/day)	Pollutant Emissions Reduction (lbs/day)	Greenhouse Gas Emissions Reduction (lbs/day)	User Savings ($/day)[1]
T13-9 Church Ranch Blvd./104th Ave.	Wadsworth Pkwy to Sheridan Blvd.	12	Westminster, CDOT	Capital Improvement Signal Timing Project	361	190	45	3,924	$8,450
T13-10 State Hwy 52	I-25 Frontage Rd. to Frederick Way	8	CDOT	Signal Timing Project	327	166	38	3,464	$7,550
T13-11 State Hwy. 7	I-25 to Colorado Blvd.	6	Thornton, CDOT	Signal Timing Project	111	61	13	1,254	$2,600
T13-12 Martin Luther King Blvd./31st Ave.	Downing St. to Colorado Blvd.	16	Denver	Capital Improvement Signal Timing Project	107	79	22	1,641	$2,550
T13-13 North Quebec St.	Alameda Ave. to 56th Ave.	30	Denver	Capital Improvement Signal Timing Project	433	222	62	4,604	$10,050
T13-14 Leetsdale Dr.	Alameda Ave. to Mississippi Ave.	19	Denver	Capital Improvement Signal Timing Project	759	385	92	7,983	$17,650
T13-15 Speer Blvd.	Gilpin St. to Federal Blvd.	32	Denver	Capital Improvement Signal Timing Project	467	230	55	4,760	$10,800
Total	-	318	-	-	8,791	4,602	1,109	95,473	$204,550

[1] Fuel @ $3.51/gal., time value @ $21.43/hr.

Source: DRCOG

Data

DRCOG collects data prior to and after deployment of signal timing to evaluate benefits. Figure 12 provides data for Alameda Avenue, the first 2013 project listed in Table 8.
Visit http://www.drcog.org/documents/T13-01_Signal_Timing_Briefs_AlamedaAve.pdf for a full sized version of the flyer.



Source: DRCOG

Figure 12. Screenshot. Signal Timing Brief for Alameda Avenue.

Data collected include vehicles per day, length of the corridor, travel time in both directions for three time-periods (morning peak, midday/off-peak, evening peak) both before and after implementation, number of signals affected, and timing revisions. The signal timing briefs also provide estimates of daily benefits for five performance measures including vehicle hours of travel, fuel consumption, time and fuel costs, total greenhouse gas emissions, and total criteria pollutant emissions.

According to the Alameda Avenue Signal Timing Brief, "Adjustments to signal timing are key to ensuring the smoothest possible flow for drivers, saving time and money. Signal timing also minimizes greenhouse gas emissions and other pollutant emissions, preserving and enhancing air quality."

Benefit Cost Evaluation

State DOTs, MPOs and other local transportation agencies can use benefit cost evaluation to determine whether to implement traffic signal timing programs and projects. Benefit-cost analysis can inform decision-makers as to where the best locations to improve signal timing and the most cost-effective alternatives to employ. There is a variety of pre-developed tools available to conduct benefit cost evaluation. Users can also conduct benefit-cost analysis using their own custom spreadsheets or models. TOPS-BC, an FHWA developed spreadsheet-based tool, is one option. TOPS-BC also has a function designed to aid users in identifying additional tools.

The following presents the methodology and results of using TOPS-BC for a deployment of preset signal timing. While based on actual deployment information, this case study produces hypothetical results. The purpose of this example is to highlight how TOPS-BC can be deployed to evaluate similar strategies.

TOPS-BC Data Inputs

TOPS-BC provides input defaults for most variables that a planner would use in the evaluation of a signal-timing project. If a planner was looking at a system similar to this signal-timing project example, he could use the TOPS-BC defaults, or generate new data to make the example as realistic as possible by applying local data, which the TOPS-BC user can apply in place of the defaults. This also allows the TOPS-BC user to test the impact of changes in selected input data. For example, the TOPS-BC user can perform the analysis for examples that highlight local or recent information for their project using different technology costs, traffic levels, wait times, etc.

Table 9 provides a listing of the required input cost variables to run TOPS-BC for a preset traffic signal coordination project. TOPS-BC supplies many of the required inputs to run the model as shown in the final column of Table 9. The user must supply inputs that TOPS-BC does not provide. Each of the items shown in the final column of Table 9 are included in the default input data set, but may be replaced with user-supplied data as shown. If the TOPS-BC user enters user-supplied data, it will override the default value and TOPS-BC will use that data in all calculations that call for that input data.

Table 9. Input Variables & User-Supplied Cost Data for Preset Traffic Signal Coordination.

Required Input Variables	User Supplied Data Inputs	TOPS-BC Supplied Inputs
Basic Infrastructure Equipment		
Year of Deployment		2013
Number of Infrastructure Deployments	1	
Linked Signal System LAN - Useful Life		20
Linked Signal System LAN - Capital / Replacement Costs (Total)		$55,000
Linked Signal System LAN - O&M Costs (Annual)		$1,100
Incremental Deployment Equipment (per Intersection)		
Number of Incremental Deployments	29	
Signal Controller - Useful Life		15
Signal Controller - Capital / Replacement Costs (Total)		$6,250
Signal Controller - O&M Costs (Annual)		$350
Communication Line - Useful Life		20
Communication Line - Capital / Replacement Costs (Total)		$750
Communication Line - O&M Costs (Annual)		$6,600
Facility Characteristics		
Length of Analysis Period (Hours)	3	
Number of Analysis Periods per Year	500	
Link Length (Miles)	2.8	
Total Number of Lanes	4	
Link Capacity (All Lanes - for the time period of analysis)		27,000[1]
Free Flow Speed (MPH)	40	45
Facility Performance		
Link Volume (during the time period of analysis)	21,120	
Impacts Due To Strategy		
Change in Capacity (%)		12%
Change in Speed (%)		0%
Change in # of Lanes		0%
Reduction in Crash Rate (%)		2%
Reduction in Crash Duration (%)		0%
Reduction in Fuel Use (%)		5%

[1] Capacity is calculated as 4 lanes for 3 hours at 2250 v/l/h. Lane capacities per hour from the Highway Capacity Manual (HCM).

Note: For a detailed discussion of TOPS-BC data input procedures and options, see the TOPS-BC Manual at: http://plan4operations.dot.gov/topsbctool/index.htm

Model Run Results

Table 10 summarizes the benefits and costs that TOPS-BC calculated. The table shows total annual costs of $218,571. Additional detail in the TOPS-BC model provides information on costs by year as well as total net present value costs. According to TOPS-BC, the first year costs were $404,550 with continuing annual cost for the 20-year analysis period of $201,550. This results in a 20-year net present value of just over $1.76 million.

Table 10. Benefit Cost Summary.

Category	Value
Annual Benefits	
Travel Time	$1,174,801
Travel Time Reliability	$0
Energy	$317,436
Safety	$1,724
Other	$0
User Entered	$0
Total Annual Benefits	**$1,493,326**
Annual Costs	
Total Annual Costs	$218,571
Benefit-Cost Comparison	
Net Benefit	$1,274,755
Benefit-Cost Ratio	6.83

Since the deployment on Alameda Avenue is already complete, the local agency could enter the actual cost experience. TOPS-BC provides some cost defaults, but users are encouraged to review these values and make changes based on local data. Users may also wish to disaggregate costs by lower level traffic signal subsystem as was done in Case Study 5-2.

Benefits

TOPS-BC estimates benefits from the preset signal timing deployment from travel time savings, change in travel time reliability, reduced energy consumption and reduced crash events. Together they result in annual benefits of about $1.5 million. These benefits are in the range of benefits shown in Table 10 which range from $600 thousand to $6.2 million per project.

In this case, TOPS-BC estimates that the project benefits far exceed the costs by a ratio of 7 to 1. This positive result accrues from a gain in operating efficiency for the arterial system reducing travel time and fuel consumption. Prior to introducing the arterial signal coordination, insufficient capacity during the morning and evening peak traffic periods led to congestion and lost time for road users. With the introduction of improved traffic signal timing, traffic flows were smoother reducing stops and delays, and improving travel times. TOPS-BC also estimated a substantial reduction in energy (fuel consumption) costs due to congestion relief. The number of crashes was also estimated to decline slightly, providing an added cost reduction benefit.

Key Observations

This case examines how users can employ TOPS-BC to evaluate the benefits and costs of a traffic signal coordination project. Colorado's Alameda Avenue project provides some of the data to illustrate how a user can run TOPS-BC. By conducting post deployment BCA, DRCOG and CDOT built up a data base of signal control costs and benefits that could inform the decision process for future deployment consideration.

Case Study 5.2 – Adaptive Traffic Signal Control in Greeley and Woodland Park, Colorado

Strategy Type:	Arterial Operations
Project Name:	Adaptive Traffic Signal Control in Greeley and Woodland Park, Colorado
Project Agency:	Colorado DOT
Location:	Greeley and Woodland Park, Colorado
Geographic Extent:	One 4.00 mile and one 3.65 Mile Corridor
Tool Used:	Custom In-house Analysis

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Adaptive signal control systems coordinate control of traffic signals across a signal network, adjusting the lengths of signal phases and other parameters based on prevailing traffic conditions. This innovative technology uses real-time data collected by system detectors to optimize signal timing for each intersection in the corridor. The use of real-time data means that signal timing along the corridor changes to accommodate the traffic patterns at any given time of the day. There are many different adaptive traffic signal control systems.

Project Goals and Objectives

The City of Greeley implemented adaptive traffic signal control systems on 10th Street (US 34 Business) in Greeley and US 24 in Woodland Park. The Colorado DOT (CDOT) selected two alternative systems, System A and System B, for implementation. CDOT commissioned a study to summarize the evaluation results of the two systems. The purpose of the study was to summarize the results of the evaluation conducted regarding the implementation of two different adaptive traffic signal control systems in Colorado: the System A system on 10th Street (US 34 Business) in Greeley and the System B on US 24 in Woodland Park. The intent of the evaluation was not to make a recommendation for a specific system, but to report a comparison of the two systems, the requirements for installation and operations, and the benefits obtained from each system. This would allow decision makers and others interested in this innovative technology to make informed decisions regarding the installation of such a system on other highways and roadways within their jurisdictions

The primary goal of this effort was to reduce congestion, smooth traffic flows, improve travel times, maximize the benefits of signal timing, and potentially reduce crashes. Thus adaptive traffic signal control can be viewed as a way to delay the need for more costly improvements such as adding capacity to the corridor.

Data

The study collected data on before and after conditions and costs in order to conduct a benefit-cost analysis.

Before and After Conditions

The study evaluated corridor operations for both before and after conditions. Table 11 shows the results of the before and after travel time runs for the two corridors for both weekday and weekend traffic conditions. The percentages represent the combined improvement for travel times for a total of six runs through the corridor in each direction of travel during six time-periods for a weekday and one time-period for the weekends.

Table 11. Travel Time Study Results: Measure of Effectiveness Benefit (Percentage Change)

Study Period	Corridor	Travel Time	Stopped Delay	Average Speed
Overall Weekday	10th Street	-9%	-13%	11%
Overall Weekday	US 24	-6%	-15%	7%
Overall Weekend	10th Street	-11%	-37%	13%
Overall Weekend	US 24	-19%	-54%	22%

Source: Colorado DOT

Installation Costs

The study also calculated the actual costs that the agencies had to spend to install the new systems. Table 12 shows the costs associated with the installation of the systems, based on information provided by each agency. Implementing the System A adaptive control system on 10th Street cost approximately $905,500, while the System B system cost about $176,300.

Both of the systems installed required the agencies to spend additional funds to upgrade the existing signal system equipment in order to accommodate new system or operational needs. On 10th Street, several of the existing controller cabinets were not large enough to accommodate the new equipment and some of the intersections were in need of a new conduit to accommodate the wiring of new video detection cameras and their associated repeater devices. In addition, the installation required a communication system in order to ensure the controllers at each intersection could communicate with each other. It is possible that a corridor could have System A installed without the need to spend funds on any improvements, which would have saved almost $500,000 of the total $905,000 spent to install the system. On US 24, approximately $13,100 of the system installation costs was for new controllers to ensure the ability to run the firmware necessary to operate System B. Again, it is possible that this expense would not be necessary on another corridor, which would have reduced the overall cost of the project.

Table 12. Cost to Implement the Adaptive Signal Control Systems.

Item	Cost
System A Adaptive Control on 10th Street	
Misc. Construction (sidewalk, potholing, erosion, etc.)	$34,750
Bored Conduit	$6,600
Pull Boxes	$7,100
Wiring	$35,510
System A System and Components	$416,319
Install Controller Cabinets	$10,125
Telemetry (communication system)	$38,178
Construction equipment and control	$101,418
Engineering	$250,000
Annual Maintenance Costs (estimate)	$5,500
TOTAL	**$905,500**
System B Adaptive Control on US 24	
Central Control System	$30,750
10 -Local Controller Firmware	$36,000
Training	$3,000
Central/Local Software Install and Configuration	$3,300
Misc. Install Costs	$1,800
Support from Contractor	$8,500
Controller, HC11	$13,120
16 -Microwave Presence Detectors	$66,550
Misc. Cables/Tape/DSL Line/Computer	$1,580
CDOT Labor to Install (160 hours at $37.50 per hour)	$6,000
Annual Maintenance Costs	$4,500
TOTAL	**$176,300**

Source: Colorado DOT

The study included additional analysis to compare how much would have been spent maintaining and retiming the existing signal systems compared to how much the agencies expected to spend maintaining the new systems. One main assumption for maintaining the existing systems is the need to retime the signals every five years or approximately four times in the next 20 years.

Benefit Cost Evaluation

The benefit-cost analysis determined the payback period for each system, as well as the benefits that CDOT, the City of Greeley, but more importantly the general public and roadway users would realize in the future. Table 13 provides the factors the study used to calculate benefits and costs.

Table 13. Benefit and Cost Categories.

Benefits	Costs
• Travel time • Fuel consumption • Side-street delay	• Design and engineering cost • Adaptive system cost • Detection/communication upgrade cost • Construction/installation cost • Staff time spent for design, installation, and training • Expected annual maintenance

The local agencies directly provided the cost data. The following sections describe the calculation of each of the benefit categories.

Calculation of Benefits

Travel Time: The analysis multiplied total travel time (vehicle-hours) by the value of time and vehicle occupancy values for the area to calculate the cost savings in terms of reduced travel time.

Fuel Consumption: The analysis multiplied total travel time (vehicle-hours) by fuel consumption rates and the average per gallon fuel cost for the area.

Side-Street Delay: The analysis used the Highway Capacity Manual method for field measurement of intersection control delay to calculate intersection control delay and LOS.

Travel Time. The value of travel time is calculated as:

$$VTT = \Delta TT * VT * VO$$

Figure 13. Equation. The Value of Travel Time.

Where:

ΔTT is the change in Travel Time
VT is the Value of Time
VO is Vehicle Occupancy
VTT is Value of Travel Time Saved

The value of time for both corridors was obtained from research performed by FHWA and input from the CDOT Division of Transportation Development (DTD) staff and was found to be $15.00 per person per hour. CDOT staff indicated a recent study for the area identified the average vehicle occupancy for both of the highways is 1.3 people per vehicle. Annual costs and benefits were computed based upon a 350 day year (250 weekdays and 100 weekend days) to best capture the majority of typical traffic volume days. The remaining days of the year were considered non-typical travel days (holidays, events, weather, etc.) and were omitted from the computation.

Fuel Consumption. Fuel consumption is calculated as:

Total Travel Time (vehicle-hours) Fuel Consumption Rate * Average Price*

Figure 14. Equation. Fuel Consumption.

Internet research identified average fuel costs of $3.65 per gallon in the Greeley area and $3.50 in the Woodland Park area. Current fleet average fuel consumption rates at various speeds are available from EPA.

Side-Street Delay. For a signal control project with fixed cycle lengths during specific periods of the day, traffic simulation software can estimate side-street delay at study intersections. Because the adaptive traffic signal systems are continuously changing signal timing parameters to react to real-time travel demand, the analysis used the Highway Capacity Manual method for field measurement of intersection control delay to calculate intersection control delay and level of service (LOS). Video recordings were conducted at four intersections on each corridor, as identified by agency staff, to capture the before and after conditions during the morning, midday, and evening weekday peaks.

Summary of Benefits

Table 14 provides the benefits of implementing the adaptive signal control systems. The systems result in significant savings to both corridors, with 10th Street experiencing a predicted annual user savings of more than $1.326 million dollars per year and US 24 users experiencing an annual savings of almost $900,000 per year.

Table 14. Benefits of Implementing the Adaptive Signal Control Systems.

Measure of Effectiveness	Daily Benefit	Value of Daily Benefit (veh*hrs or gal)	Annual benefit[1] (millions)
System A Adaptive Control on 10th Street			
Travel Time (veh*hrs)	207	$4,034	$1.412
Fuel Consumption (gal)	122	$445	$0.156
Side-street delay	-41	-$805	-$0.282
Annual Maintenance (estimated by staff to be a 130 hours saving per year at $35 per hour)		$115	$0.041
TOTAL		**$3,789**	**$1.326**
System B Adaptive Control on US 24			
Travel Time (veh*hrs)	191	$3,730	$1.305
Fuel Consumption (gal)	149	$522	$0.183
Side-street delay	-87	($1,698)	-$0.594
Annual Maintenance (estimated by staff to be a 130 hours saving per year at $35 per hour)		$12.86	$0.005
TOTAL		**$2,567**	**$0.898**

[1] Assumes benefits realized for 350 days.
Source: Colorado DOT

Model Run Results

A consultant, using a standalone custom in-house analysis, conducted the benefit-cost analysis. Table 15 provides various metrics of benefits, costs, and savings that the consultant team calculated. Overall, benefit-cost ratios vary from 1.58 to 6.10 for the first year that the systems are in operation. Based on the analysis, Region 4 and the City of Greeley will accrue benefits of approximately $8.9 million over the first 20 years with System A managing the traffic operations on the 10th Street corridor. At the same time, Region 2 will accrue benefits of about $5.8 million over the first 20 years with System B managing the traffic operations on the US 24 corridor.

Table 15. Summary of the Results of the Benefit-Cost Analysis.

	System A		System B	
Category	**Actual Project**	**Minimal Project**	**Actual Project**	**Minimal Project**
Number of Intersections	11		8	
Daily cost saving (corridor)	$3,789		$2,567	
Annual cost saving (corridor)	$1.326 million		$898,500	
Install costs (corridor)	$905,500	$375,000	$176,300	$162,400
Daily cost saving (per intersection)	$344		$321	
Annual cost saving (per intersection)	$120,500		$112,300	
Install costs (per intersection)	$82,300	$34,000	$22,000	$20,300
Benefit to cost ratio	1.58	3.79	5.64	6.10
10-year projected savings	$4.2 million	$4.7 million	$2.8 million	$2.8 million
20-year projected savings	$9.2 million	$9.7 million	$5.7 million	$5.7 million

Note: Actual projects had unusual costs; minimal project represents the expected costs for other projects.
Source: Colorado DOT

Key Observations

This case evaluates the introduction of adaptive traffic signal control systems on two arterials. Adaptive signal control systems coordinate traffic signals across a network, adjusting the signal timing parameters based on prevailing traffic conditions. Prior to and after the deployment, the study collected data on performance to be able to compare the changes brought about by the deployment. The data collection revealed improvements in terms of travel time, fuel consumption and side street delay. The study also collected data on implementation costs and estimated implementation cost savings for specific costs that would not be necessary on another corridor. The analysis illustrates how benefit-cost analysis can be used to compare alternative adaptive traffic signal systems. It also informs decision makers and others interested in this innovative technology to make informed choices regarding the installation of such a system on other highways and roadways within their jurisdictions.

Case Study 5.3 – Adaptive Traffic Signal Control

Strategy Type:	Arterial Operations
Project Name:	Adaptive Traffic Signal Control
Project Agency:	State DOT Based on Colorado DOT Experience
Location:	Urban Area
Geographic Extent:	Corridor
Tool Used:	Custom In-house Analysis

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Adaptive signal control systems coordinate control of traffic signals across a signal network, adjusting the lengths of signal phases based on prevailing traffic conditions. This innovative technology uses real-time data collected by system detectors to optimize signal timing for each intersection in the corridor. The use of real-time data means that signal timing along the corridor changes to accommodate the traffic patterns at any given time of the day.

Project Goals and Objectives

A State DOT commissioned the evaluation of an adaptive traffic signal control system on a principal arterial. The goal of the traffic signal control project was to reduce congestion, smooth traffic flows, improve travel times, maximize the benefits of signal timing, and potentially reduce crashes, which delay the need for more costly improvements such as adding capacity to the corridor.

The corridor primarily serves local traffic, including commuters, during the week and visitors and recreational travelers on the weekends. The traffic patterns can vary rapidly and unpredictably on the weekend due to the nature of recreational travelers and weather conditions that may cause travelers to change when they begin and terminate their recreational activities. Thus, the current application of time-of-day based signal coordination plan were identified as inadequately adjusting to the travel patterns of the visitors that come to and pass through the area.

Data

The commissioned report described the changes that were required to install and operate the adaptive signal control system, including costs for installation and maintenance, and provide a comparison of before and after implementation measures of effectiveness (MOE) to quantify the benefits to traffic operations within the study area. The study collected data on before and after conditions and costs in order to conduct a benefit-cost analysis.

Before and After Conditions. The study evaluated corridor operations for both before and after conditions. The study evaluated the following MOEs for the corridor:

- Travel time.
- Fuel consumption and emissions.
- Intersection delay and level of service (LOS).
- Average number of stops.

Installation Costs. The study calculated the actual costs that the agencies had to spend to install the new systems. The study also conducted additional analysis to compare how much would have to be spent maintaining and retiming the existing signal systems compared to how much the agencies expected to spend maintaining the new systems. One main assumption for maintaining the existing systems was the need to retime the signals every five years or approximately four times in the next 20 years.

Calculation of Benefits

Travel Time: The analysis multiplied total travel time (vehicle-hours) by the value of time and vehicle occupancy values for the area to calculate the cost savings in terms of reduced travel time.

Fuel Consumption: The analysis multiplied total travel time (vehicle-hours) by fuel consumption rates and the average per gallon fuel cost for the area.

Side-Street Delay: The analysis used the Highway Capacity Manual method for field measurement of intersection control delay to calculate intersection control delay and LOS.

Benefit Cost Evaluation

The purpose of the benefit cost evaluation was to summarize the results of the evaluation conducted regarding the implementation of the adaptive traffic signal control system.

Approach. The benefit-cost analysis determined the payback period for each system, as well as the benefits that the State DOT and local agencies, and more importantly the general public and roadway users, would realize in the future. Table 16 provides the factors the study used to calculate benefits and costs.

Table 16. Benefit and Cost Categories for Adaptive Traffic Signal Control.

Benefits	Costs
• Travel time • Fuel consumption • Side-street delay reduction	• Design and engineering cost • Adaptive system cost • Detection/communication upgrade cost • Construction/installation cost • Staff time spent for design, installation, and training • Expected annual maintenance

The local agencies directly provided the cost data. The following sections describe the calculation of each of the benefit categories.

Travel Time. The analysis multiplied total travel time (vehicle-hours) by the value of time and vehicle occupancy values for the area to calculate the cost savings in terms of reduced travel time. The study obtained the value of time from research performed by FHWA and input from the State DOT staff and was found to be $15.00 per person per hour. A recent study for the area identified the average vehicle occupancy for the highway was 1.3 people per vehicle. Annual costs and benefits were computed based upon a 350 day year (250 weekdays and 100 weekend days) to best capture the majority of typical traffic volume days.

Fuel Consumption. The analysis multiplied total travel time (vehicle-hours) by fuel consumption rates and the average per gallon fuel cost for the area. Internet research identified average fuel costs.

Side-Street Delay. For a signal-timing project with fixed cycle lengths during specific periods of the day, traffic simulation software can estimate side-street delay at study intersections. Because the adaptive traffic signal systems are constantly changing cycle lengths to react to real-time travel demand, the analysis used the Highway Capacity Manual method for field measurement of intersection control delay to calculate intersection control delay and LOS. Video recordings were conducted at four intersections, to capture the before and after conditions during the morning, midday, and evening weekday peaks.

Model Run Results

A consultant, using a standalone custom in-house analysis, conducted the benefit-cost analysis. The consultant reported that, based on the benefits and cost to install the new system, the system implementation will:

- Result in a benefit to cost ratio for the first year of operation of 5.64, which means for every $1 spent installing the system the Region will experience a cost saving of $5.64 per dollar invested on the corridor.
- Provide a daily saving of $2,567 in terms of reduced delay and fuel consumption.
- Pay for itself in approximately 67 days, or 2.2 months, after the system is initially installed and made operational, which means the system had already paid for itself during the time this evaluation was being completed.
- Save the region and the road users more than $5.7 million over the first 20 years that the system is in operation.

Table 17 provides a summary of the results of the benefit-cost analysis.

Table 17. Summary of the Results of the Benefit-Cost Analysis for Adaptive Traffic Signal Control.

Category	Finding/Result
Number of Intersections	8
Daily cost saving (corridor)	$2,567
Annual cost saving (corridor)	$898,500
Install costs (corridor)	$176,300
Daily cost saving (per intersection)	$321
Annual cost saving (per intersection)	$112,300
Install costs (per intersection)	$22,000
Benefit to cost ratio	5.64
10-year projected savings	$2.8 million
20-year projected savings	$5.7 million

Key Observations

This case identifies the evaluation of an adaptive traffic signal control systems on an arterial. Adaptive signal control systems coordinate control of traffic signals across a signal network, adjusting the lengths of signal phases based on prevailing traffic conditions. Prior to and after the deployment, the study collected data on performance to be able to compare the changes brought about by the deployment. The data collection revealed improvements in terms of travel time, fuel consumption and side street delay. The study also collected data on implementation costs and conducted a benefit-cost analysis. The benefit-cost analysis did not properly frame the costs and benefits in relation to the alternatives and did not incorporate net present values of the streams of benefits and costs over the project life. The analysis illustrates how the use of a model such as TOPS-BC can structure the analysis to insure the analysis avoids common mistakes and produces meaningful results.

Case Study 5.4 – Hypothetical Roundabouts

Strategy Type	Arterial Operations
Project Name:	Hypothetical Roundabouts
Project Agency:	Washington State DOT
Location:	Urban Setting
Geographic Extent:	Urban/Suburban Arterials
Tool Used:	TOPS-BC

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Modern roundabouts are a type of intersection characterized by a generally circular shape, yield control on entry, and geometric features that create a low-speed environment. Modern roundabouts provide a number of safety, operational, and other benefits when compared to other types of intersections. On projects that construct new or improved intersections, planners should examine the modern roundabout as an alternative.

In the planning process for a new or improved intersection where a traffic signal is under consideration, a modern roundabout should likewise receive serious consideration as an alternative. This begins with understanding the site characteristics and determining a preliminary configuration. There are a number of locations where roundabouts are advantageous and a number of situations that may adversely affect their feasibility. As with any decision regarding intersection treatments, planners should take care to understand the particular benefits and trade-offs for each project site.

Project Goals and Objectives

The Washington State DOT's (WSDOT) website includes a page devoted to Roundabout Benefits (http://www.wsdot.wa.gov/Safety/roundabouts/benefits.htm). On that page, WSDOT states, "Studies have shown that roundabouts are safer than traditional stop sign or signal-controlled intersections." The WSDOT webpage also notes that roundabouts reduce delay and improve traffic flow. The webpage states, "Contrary to many peoples' perceptions, roundabouts actually move traffic through an intersection more quickly, and with less congestion on approaching roads. Roundabouts promote a continuous flow of traffic. Unlike intersections with traffic signals, drivers don't have to wait for a green light at a roundabout to get through the intersection. Traffic is not required to stop – only yield – so the intersection can handle more traffic in the same amount of time." Finally, the WSDOT webpage also notes that roundabouts are less expensive than traffic signals. The webpage states, "The cost difference between building a roundabout and a traffic signal is comparable. Where long-term costs are considered, roundabouts eliminate hardware, maintenance and electrical costs associated with traffic signals, which can cost between $5,000 and $10,000 per year."

Given these advantages, planners and traffic engineers may want to estimate the benefits of conversion of a signalized intersection to a roundabout. These practitioners can readily use TOPS-BC to perform such calculations at the sketch planning level.

Data

Note: The data used in this Case Study is used for illustrative purposes and not intended to suggest expected performance benefits from roundabouts. The next Case, Case 5-5, shows different operational and safety performance data assumed in Maryland.

The WSDOT webpage cites a study by the Insurance Institute for Highway Safety (IIHS) that estimates that roundabouts reduced injury crashes by 75 percent at intersections that achieved traffic control through stop signs or signals. Figure 15, reprinted from the WSDOT webpage and based on studies by the IIHS and Federal Highway Administration, shows that roundabouts may achieve:

- Thirty-seven percent reduction in overall collisions.
- Seventy-five percent reduction in injury collisions.
- Ninety percent reduction in fatality collisions.
- Forty percent reduction in pedestrian collisions.

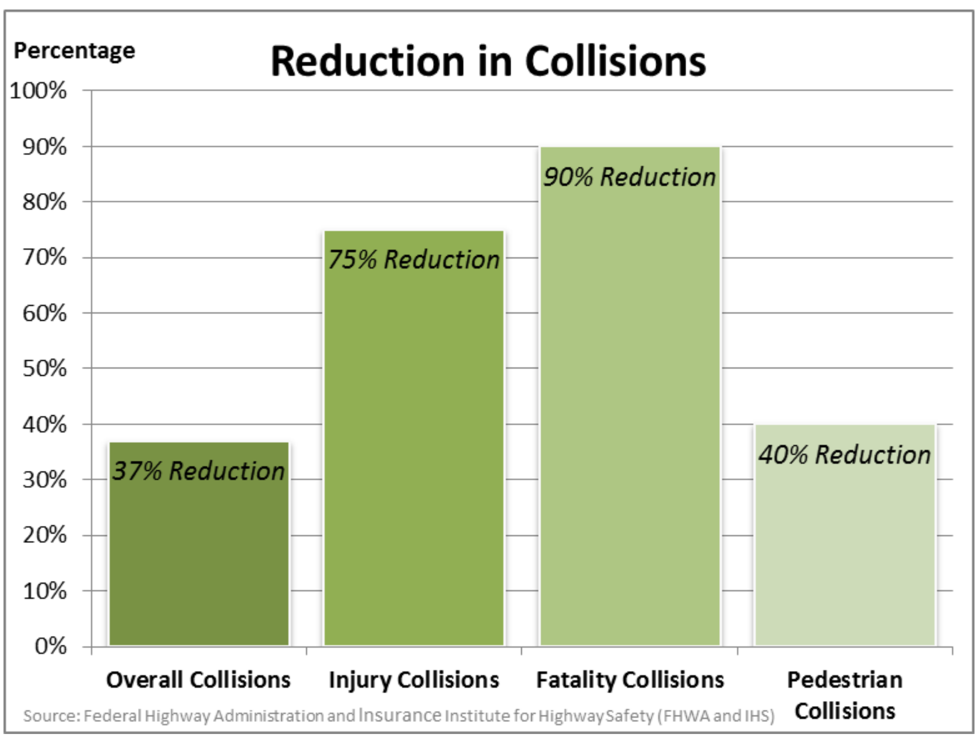


Figure 15. Graph. Reduction in Collisions for Roundabouts.

The WSDOT webpage cites studies by Kansas State University (http://www.ksu.edu/roundabouts/) that measured traffic flow at intersections before and after conversion to roundabouts. In each case, installing a roundabout led to a 20 percent reduction in delays.

Benefit Cost Evaluation

State DOTs, MPOs and other local transportation agencies can use benefit cost evaluation to aid in determining whether to implement an intersection project such as a roundabout. There is a variety of pre-developed tools available to conduct benefit cost evaluation. Users can also conduct benefit-cost analysis using their own custom spreadsheets or models. TOPS-BC, an FHWA developed spreadsheet-based tool, is one option. TOPS-BC also has a function designed to aid users in identifying additional tools.

TOPS-BC

TOPS-BC provides input defaults for most variables that a planner would use in the evaluation of a project. While TOPS-BC does not provide defaults for roundabouts, the user could still use TOPS-BC by adding a new strategy to the benefit estimation capability.

TOPS-BC Data Inputs. This hypothetical TOPS-BC case assumes that the initial costs of adding a signalized intersection and a roundabout are comparable and is just interested in the magnitude of benefits.

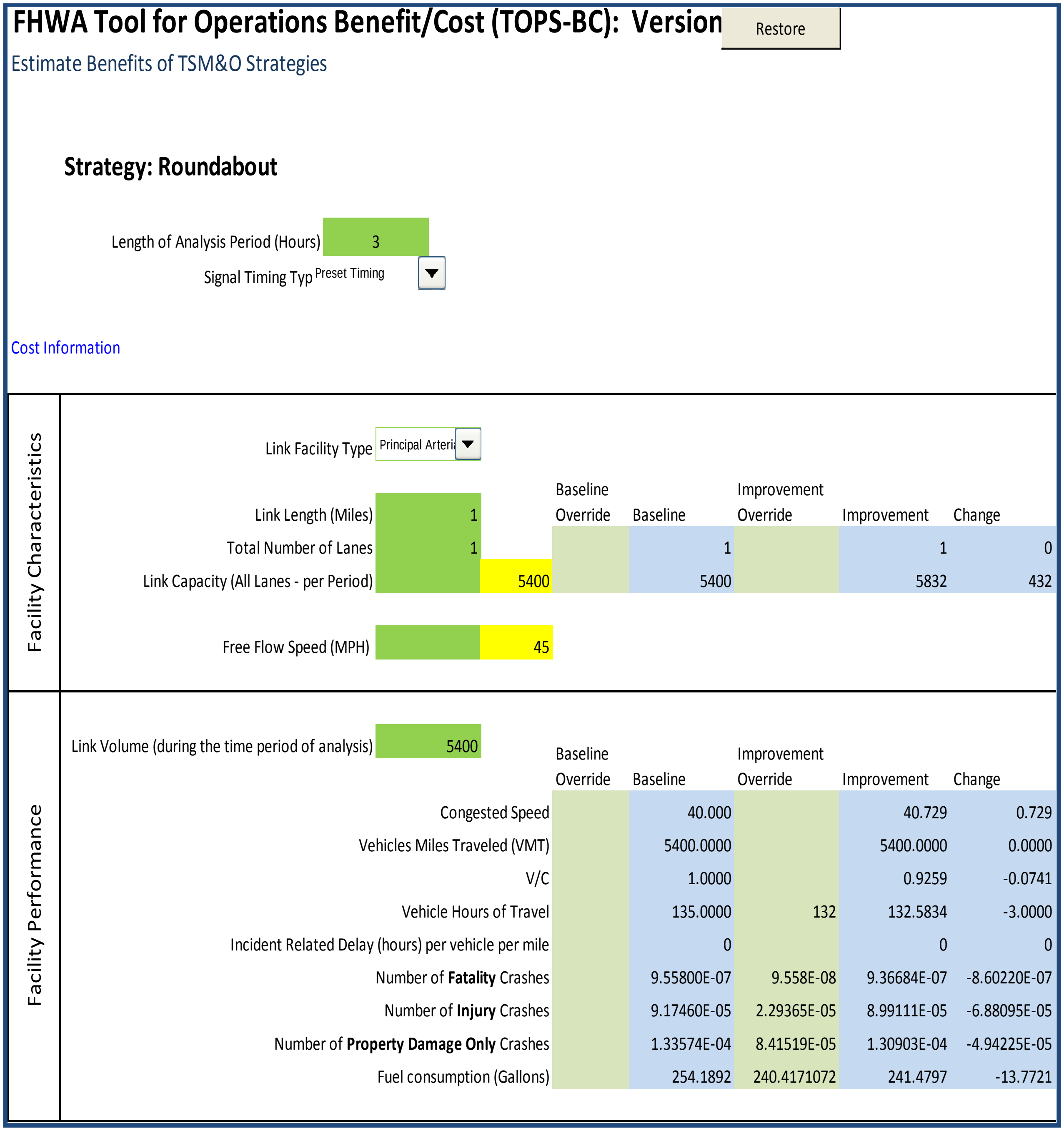
The user has several options for creating a new strategy in TOPS-BC. These include:

- The user may carefully review and consider the various strategies that are available, and select one to copy (or rename) that most closely resembles the analysis capabilities desired for the new strategy.
- The user may create a new strategy from the Generic Link Model worksheet that contains many common analysis methodologies for link based analyses.

This case assumes that the user has chosen the first option and will simply rename the strategy. Since the user is evaluating a roundabout, which is an arterial intersection project, the case assumes the user selected the "Arterial Strategy" "Signal Coordination." Figure 16 shows a partial view of the Signal Coordination Model sheet with the strategy renamed to "Roundabout."

User-supplied Performance Data

- **Vehicle Hours of Travel:** 132 hours of vehicle travel.
- **Number of Fatality Crashes:** Multiply the baseline value by 10 percent.
- **Number of Injury Crashes:** Multiply the baseline value by 25 percent.
- Number of Property Damage Only Crashes: Multiply the baseline value by 63 percent.
- **Fuel Consumption (Gallons):** Multiply Vehicle Hours of Travel by the ratio of Fuel Consumption to Vehicle Hours of Travel (132*241.4797/132.5834=240.4171).



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

Estimate Benefits of TSM&O Strategies

Strategy: Roundabout

Length of Analysis Period (Hours) 3

Signal Timing Typ Preset Timing

Cost Information

Facility Characteristics

Link Facility Type: Principal Arteri

	Input		Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Length (Miles)	1						
Total Number of Lanes	1			1		1	0
Link Capacity (All Lanes - per Period)		5400		5400		5832	432
Free Flow Speed (MPH)		45					

Facility Performance

Link Volume (during the time period of analysis) 5400

	Baseline Override	Baseline	Improvement Override	Improvement	Change
Congested Speed		40.000		40.729	0.729
Vehicles Miles Traveled (VMT)		5400.0000		5400.0000	0.0000
V/C		1.0000		0.9259	-0.0741
Vehicle Hours of Travel		135.0000	132	132.5834	-3.0000
Incident Related Delay (hours) per vehicle per mile		0		0	0
Number of **Fatality** Crashes		9.55800E-07	9.558E-08	9.36684E-07	-8.60220E-07
Number of **Injury** Crashes		9.17460E-05	2.29365E-05	8.99111E-05	-6.88095E-05
Number of **Property Damage Only** Crashes		1.33574E-04	8.41519E-05	1.30903E-04	-4.94225E-05
Fuel consumption (Gallons)		254.1892	240.4171072	241.4797	-13.7721

Source: Federal Highway Administration TOPS-BC

Figure 16. Screenshot. A Run for Roundabout Benefits Using the Tool for Operations Benefit-Cost Analysis.

User and TOPS-BC Supplied Site Data. Entering user-supplied data allows the TOPS-BC user to make the analysis as specific as possible for their project. This case assumes the TOPS-BC user has some specific site characteristics including Length of Analysis Period (3-hour peak-period), Link Length (one-mile), and Total Number of Lanes (one lane) and Link Volume (5,400 vehicles per period). As congestion exists in both directions during the peak, this case assumes the user sets the Number of Analysis Periods per Year to 500. None of these values override the values for which TOPS-BC provides a default value, such as Link Capacity (5,400 vehicles per period) or Free Flow Speed, for which TOPS-BC provides a value of 45 miles per hour.

User Supplied Performance Data. This case assumes that the TOPS-BC user enters specific data on the performance of roundabouts. TOPS-BC uses five performance characteristics in calculating the benefits. These performance characteristics, along with the user-entered values include:

1. ***Vehicle Hours of Travel.*** The WSDOT webpage provides an estimate of a 20 percent reduction in delay. If 5,400 vehicles traveled one mile at 45 miles per hour this would result in 120 hours of vehicle travel (5,400*60/45/60=120). However, TOPS-BC assumes this volume would cause average speed to drop to 40 mph resulting in 135 hours of vehicle travel (5,400*60/40/60=135), resulting in 15 hours of vehicle delay (135-120=15). If the user applies the 20 percent reduction in delay to the 15 hours of vehicle delay, this results in a reduction of delay of 3 hours (15*20%=3) and a new estimate of 132 hours of vehicle travel (135-3=132) with a roundabout in place. The case assumes the user enters the new estimate of 132 hours of vehicle travel in the Improvement Override field for Vehicle Hours of Travel.
2. ***Number of Fatality Crashes.*** The WSDOT webpage provides an estimate of a 90 percent reduction in fatality collisions. This case assumes the user enters a formula in the Improvement Override field for Number of Fatality Crashes that multiplies the Baseline Value by 10 percent (0.1), as only 10 percent of fatality collisions occur with a roundabout in place.
3. ***Number of Injury Crashes.*** The WSDOT webpage provides an estimate of a 75 percent reduction in injury collisions. This case assumes the user enters a formula in the Improvement Override field for Number of Injury Crashes that multiplies the Baseline Value by 25 percent (0.25), as only 25 percent of injury collisions crashes occur with a roundabout in place.
4. ***Number of Property Damage Only Crashes.*** The WSDOT webpage does not provide an estimate reduction in Property Damage Only Crashes. However, the webpage does provide an estimate of a 37 percent reduction in overall collisions. This case assumes the user enters a formula in the Improvement Override field for Number of Property Damage Only Crashes that multiplies the Baseline Value by 63 percent (0.63), as only 63 percent of all collisions occur with a roundabout in place.
5. ***Fuel Consumption (Gallons).*** The WSDOT webpage does not provide an estimate reduction in fuel consumption. This case assumes the user enters a formula in the Improvement Override field for Fuel Consumption that multiplies Improvement Override field for Vehicle Hours of Travel by the ratio of Fuel Consumption to Vehicle Hours of

Travel field for the Improvement Column (132*241.4797/132.5834=240.4171). This assumes that the reduction in fuel consumption follows a ratio of fuel consumption to vehicle hours of travel that is similar to the ratio obtained through signal coordination.

Default Economic Parameters. In addition to the characteristics that describe the project such as technology specific costs, roadway descriptions, number of installations, etc., the TOPS-BC user may also want to input values different from the TOPS-BC defaults for economic parameters related to the measures of benefits for the project. Examples include the value of time or reliability, the price of fuel, the cost of crashes or dollar value of other benefits the TOPS-BC user may have calculated such as vehicle emissions. This case assumes that the user has left all of these parameters unchanged.

Model Run Results

TOPS-BC estimates the annual benefits of the roundabout resulting from travel time savings, change in travel time reliability, reduced energy consumption and reduced crash events. Table 18 provides each of these benefits as TOPS-BC calculates and shows them on the "My Deployments" page. Together they result in annual benefits of $76,020.

Table 18. Benefit Summary.

Category	Annual Benefits
Travel Time	$45,591
Travel Time Reliability	$0
Energy	$25,272
Safety	$5,158
Other	$0
User Entered	$0
Total Annual Benefits	**$76,020**

With the introduction of a roundabout, rather than a traditional signalized intersection, traffic flows are smoother, reducing stops and delays, and improving travel times. TOPS-BC estimates a substantial reduction in travel times resulting in substantial travel time benefits. This reduction in stops and delays also reduces energy (fuel consumption) costs. Due to low travel speeds (drivers slow down and yield to traffic before entering a roundabout), no light to beat (roundabouts promote a continuous circular flow of traffic), and one-way travel (roundabouts direct drivers counterclockwise and eliminate the possibility for T-bone and head-on collisions) the number of crashes also declined, providing a safety benefit due to crash cost reduction.

Key Observations

This case examines how users can employ TOPS-BC to evaluate the benefits of a roundabout project. Washington State DOT's roundabouts webpage provides some of the data as an example of what a user might consider to run TOPS-BC. The TOPS-BC run estimates that the project would generate annual benefits of $65,204. This example illustrates how the user can add new strategies to TOPS-BC and use data from real world projects. In this case we also used information and methods contained in TOPS-BC on fuel savings from adaptive signal control projects to estimate fuel savings from roundabout installation. This is an approximation of the fuel savings from roundabouts. If consideration of roundabouts continued beyond this preliminary review, the analyst might consider developing better estimates of roundabout fuel savings.

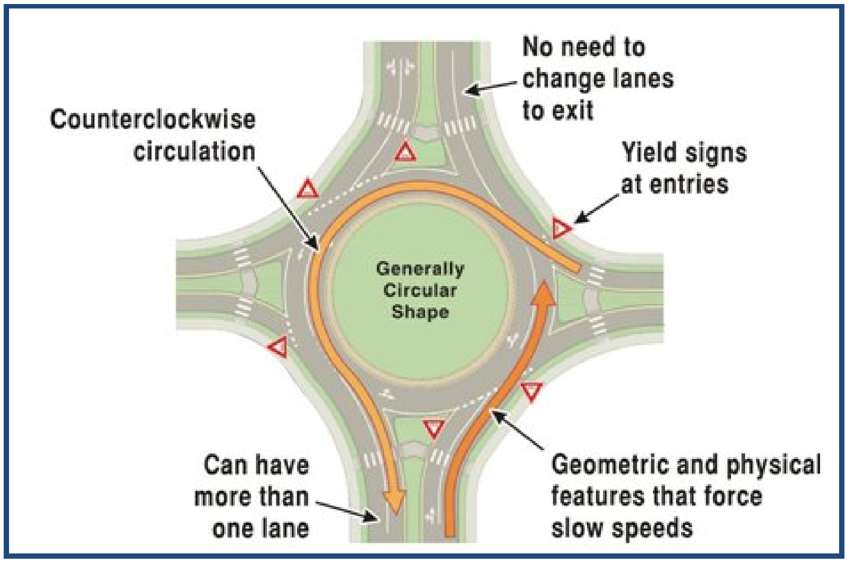
Case Study 5.5 – Effectiveness of Roundabouts in Maryland

Strategy Type:	Arterial Operations
Project Name:	Effectiveness of Roundabouts in Maryland
Project Agency:	Maryland Department of Transportation
Location:	Urban and Rural
Geographic Extent:	Statewide
Tool Used:	Custom Stand Alone BCA Model Focused on Safety Benefits

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Modern roundabouts are a type of intersection characterized by a generally circular shape, yield control on entry, and geometric features that create a low-speed environment. Modern roundabouts provide a number of safety, operational, and other benefits when compared to other types of intersections. On projects that construct new or improved intersections, planners should examine the modern roundabout as an alternative. Figure 17 provides a diagram illustrating the key characteristics of a modern roundabout.



Source: Maryland DOT

Figure 17. Diagram. Key Roundabout Characteristics.

In the planning process for a new or improved intersection where a traffic signal or stop control is under consideration, a modern roundabout should likewise receive serious consideration as an alternative. This begins with understanding the site characteristics and determining a preliminary configuration. There are a number of locations where roundabouts are advantageous and a number of situations that may adversely affect their feasibility. As with any decision regarding intersection treatments, planners should take care to understand the particular benefits and trade-offs for each project site.

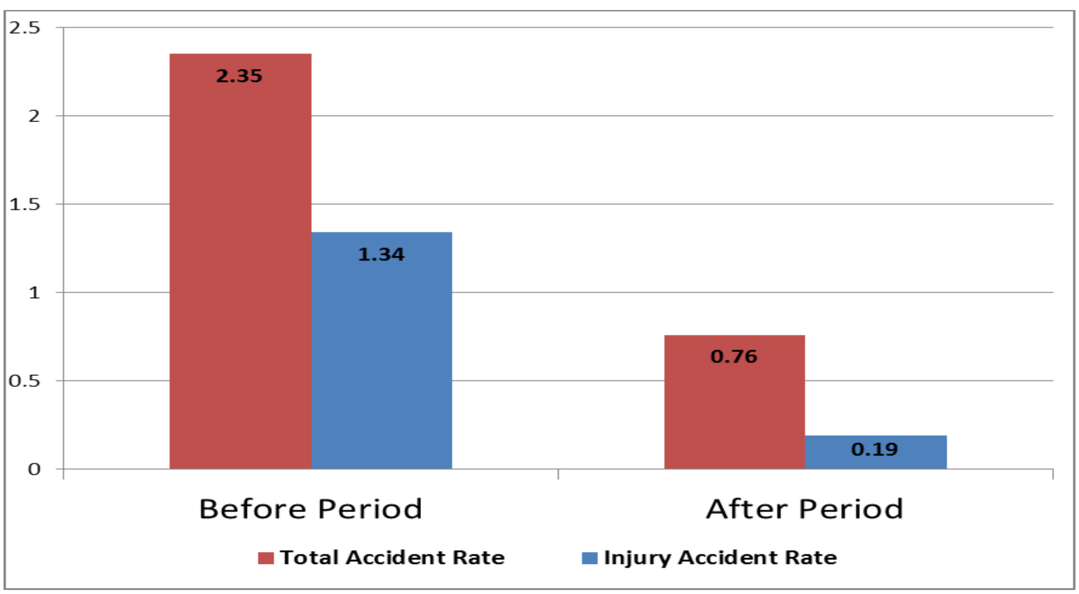
Calculations are based on the anticipated accident experience expected to occur had no roundabouts been installed compared to the actual after period accident experience.

Project Goals and Objectives

The State of Maryland published a report that evaluates the effectiveness of roundabouts in Maryland. Studies have found that one of the benefits of roundabout installations is the improvement of overall safety performance. The calculations in the report are based on the anticipated accident experience expected to occur had no roundabouts been installed compared to the actual accident experience at the roundabout locations. The state has found that single-lane roundabouts perform better than two-way, all-way stop and signalized intersections. Although the frequency of crashes is not always lower at roundabouts, particularly multi-lane roundabouts, injury rates are lower.

Data

The Maryland analysis indicates that at the 15 locations where Maryland has installed single lane roundabouts there has been a 68 percent decrease in the total accident rate per million vehicles entering the intersection (mve). In addition, there was a 100 percent decrease in the fatal accident rate/mve, an 86 percent reduction in the injury accident rate/mve, and a 41 percent reduction in the property damage only accident rate/mve. Figure 18 provides before and after graphical comparisons of the total and injury-only accident rates.



Source: Maryland DOT

Figure 18. Graph. Before and After Total and Injury Accident Rates.

The accident data is from the Maryland State Highway Administration (MDSHA) accident database. This database consists of all accidents for which the state received an official accident report form from the Maryland Automatic Accident Reporting System (MAARS). The study collected accident data for 15 single-lane mini roundabouts. The before and after period vary depending on completion dates of the roundabouts.

Maryland reports that the initial total cost of the roundabouts was $6,219,505. The state assumes the projects have a 15-year service life. The state assumes there is no before and after annual operating and maintenance cost or salvage value for these projects.

Benefit Cost Evaluation

The Maryland study utilized both the cost-effectiveness and the benefit cost techniques. The cost-effectiveness method determines the cost of preventing a single accident to decide whether the project cost was justified. This technique does not price benefits. Instead, the method determines the cost of reducing accidents by severity.

An alternate method is the benefit cost technique. The benefit-cost analysis compares the Annual Benefit (AB) to the Equivalent Uniform Annual Cost (EUAC) over the entire service life of the roundabouts. Maryland considers any project that has a benefit-cost ratio greater than 1.0 to be economically successful. Use of this method requires that the dollar value is placed on all cost and benefit elements related to the project. Maryland has developed its own average accident cost figures, stratified by severity.

Model Run Results

The Maryland State Highway Administration's Traffic Safety Analysis Division, using a stand-alone custom in house analysis, conducted the cost-effectiveness analysis and benefit-cost analysis. This analysis used Maryland's own accident cost figures by severity, which reports the average cost of a fatal accident at $4,167,062, the average injury accident cost at $110,584, and average property damage only accident cost at $26,156.

Maryland's objective in conducting the cost-effectiveness evaluation was to determine the amount of dollars spent to reduce one accident.

$$AC = TC * CRF$$

$$\frac{AC}{Acc} = \frac{TAC}{Acc}$$

Figure 19. Equation. Dollars Spent to Reduce One Accident.

Where:

AC = Levelized Annual Cost for Roundabout Program in Maryland

TC = Total Cost for Roundabout Program in Maryland

CRF = Capital Recovery Factor, assumes 6 percent interest rate and a 15 year project life

Acc = Number of accidents avoided

Table 19. Calculation of Cost per Accident Avoided by Roundabout Program in Maryland.

Data Definition	Estimated Value
Total Cost of Roundabout Program in Maryland	$6,219,505
Capital Recover Factor, 6% Interest & 15 Year Life	0.1030
Average Annual Cost (Levelized)	$640,609
Number of Accidents Avoided by 15 Roundabouts	49
Total Cost per Accident Avoided	$13,146
Estimated Average Cost of Non-fatal Accident	$200,000

Source: Maryland DOT

MDSHA estimated the annual benefit of crash avoidance by using the crash frequency and costs by crash type prior to the roundabout installation to estimate the expected crash frequency and costs after installation. The expected crashes without the roundabouts were compared to the actual crash results for a 4.5 year period after deployment. This resulted in an annual savings of $9.8m. For more detail on the MDOT benefit calculations, see the report referenced at the end of this case.

Equivalent Uniform Annual Cost (EUAU)

Equivalent Uniform Annual Cost is the "payment" required to fund the Life Cycle Cost over the service life. It is calculated as:

$$EUAC = (A/P, i, n)$$

Figure 20. Equation. Equivalent Uniform Annual Cost.

Where:

A/P = Annualized program cost ($/sq. ft.)
i = annual interest rate (%)
n = service life (years)

Unlike the cost effectiveness evaluation, which determines how many dollars the state must spend to reduce one accident, the benefit-cost analysis considers the initial cost of the projects for the entire service life (15-years) of the roundabouts. The Maryland BCA converts initial cost into an EUAC, also referred to as levelized cost. The analysis then divides the EUAC into the AB to reveal the BCR. The Maryland analysis does this to calculate the amount of money spent over the 15-year service life for roundabout installations as opposed to just calculating the dollar value realized through the annual safety benefits in accident prevention. The analysis indicates that for every dollar spent on the roundabout installation over the entire 15-year service life, the state anticipates that the roundabout users will realize approximately $15 in benefits through accident reduction. This calculation is:

$$\frac{Annual\ Benefits}{Annual\ Cost} = Benefit\ Cost\ Ratio$$

Figure 21. Equation. Benefit-Cost Ratio.

Table 20. Benefit-Cost Ratio for Roundabout Program in Maryland.

Data Definition	Estimated Value
Annual Crash Avoidance Benefit (AB)	$9,810,219
Equivalent Uniform Annual Cost (AC)	$640,609
Benefit-Cost Ratio (BCR)	15.3

Source: Maryland DOT

Key Observations

This case presents the results of an economic evaluation of roundabouts conducted by Maryland State Highway Administration's Traffic Safety Analysis Division, Office of Traffic & Safety. The calculations are based on the anticipated accident experience had no roundabouts been installed, compared to the actual after period accident experience. The state found that single-lane roundabouts perform better than two-way, all-way stop and signalized intersections. The state utilized both the cost-effectiveness and the benefit cost techniques.

The analysis illustrates how both cost-effectiveness and benefit-cost analysis can be useful to compare alternatives to operational strategies. It informs decision makers and allows others interested in this technology to make informed choices regarding the installation of such a system on roadways within their jurisdictions.

Cost-effectiveness (CE) and BCA are related and may both be appropriate ways for a decision maker to evaluate a potential deployment. For example, CE is better suited to situations when alternatives are expected to provide equal outcomes (benefits), so that the differentiator between alternatives is cost. BCA is more comprehensive, considering costs and benefits of alternative projects and project designs that may provide different levels and timing of both costs and benefits.

Case Study 5.6 – Effectiveness of Arterial Management in Florida

Strategy Type:	Arterial Operations
Project Name:	Effectiveness of Arterial Management in Florida
Project Agency:	Florida Department of Transportation
Location:	Urban
Geographic Extent:	Arterial Corridor
Tool Used:	TOPS-BC

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

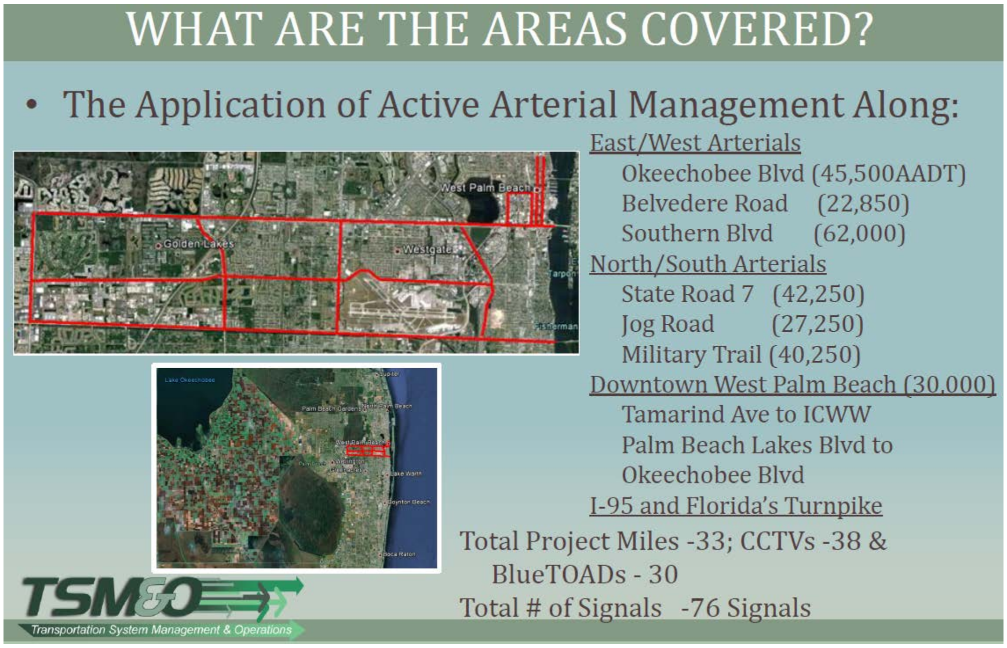
The following case study was prepared by Cambridge Systematics, Inc. for the Florida Department of Transportation (FDOT) as part of the "TOPS-BC Florida Guidebook" and is reproduced here with permission.

FDOT District 4 in collaboration with Palm Beach County Traffic Engineering Department (PBC TED) initiated the "Living Lab" pilot project in 2012 to actively monitor, manage, and improve arterial operations along three major east-west corridors – Okeechobee Boulevard, Belvedere Road, and Southern Boulevard between SR 7 and I-95.

Project Goals and Objectives

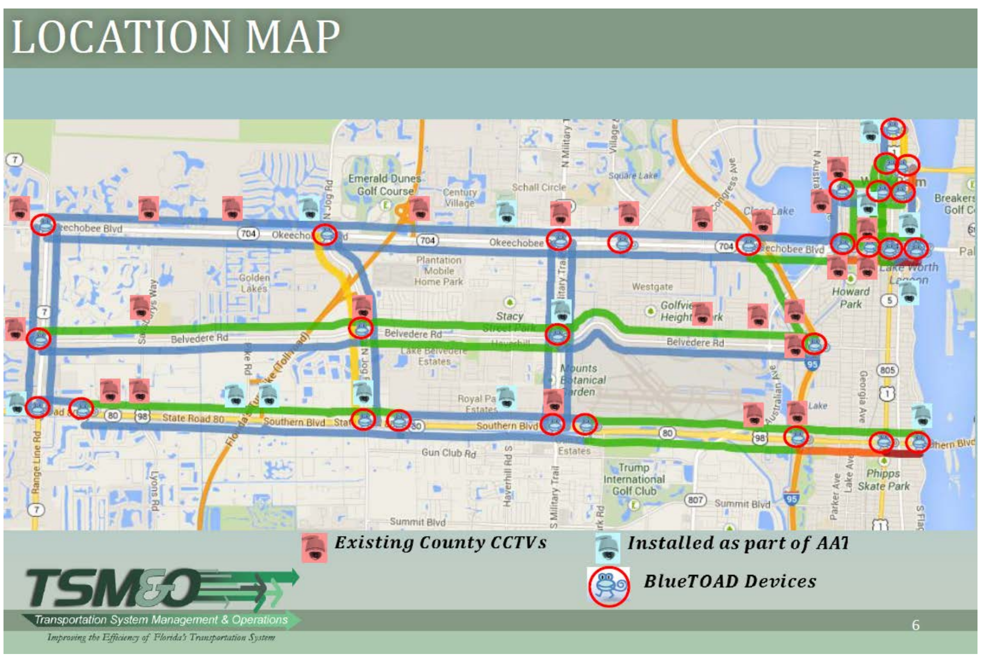
As part of this initiative, FDOT District 4 installed several CCTV cameras and BlueTOAD vehicle detection devices along these corridors to monitor traffic conditions and collect travel times in real-time. In addition, FDOT District 4 provided staffing resources at the Palm Beach County Traffic Management Center to monitor real-time traffic conditions, detect incidents, and support Palm Beach County Signal Timing staff in implementing real-time signal timing changes to improve traffic flow and reduce motorist delay.

FDOT District 4 Freeway Intelligent Transportation Systems (ITS) staff and Palm Beach County Signal Timing Engineers work together to improve freeway-arterial coordination during incidents on I-95 in Palm Beach County. The hours of operation are Monday through Friday from 7a.m. to 7p.m. Figures 22 and 23 show the location of the Living Lab and device locations along the instrumented roadways.



Source: Florida DOT

Figure 22. Screenshot. Palm Beach Living Lab Coverage.



Source: Florida DOT

Figure 23. Screenshot. Palm Beach Living Lab Device Locations.

Assumptions

There were many assumptions that went into the TOPS-BC analysis for the Palm Beach Living Lab case study. Also, several limitations should be noted. These are listed in the following sections.

Costs

Costs for implementing and operating the Living Lab project were provided by the PBC TED. The cost of equipment and devices installed in the study area (along with operations and maintenance costs) were assigned to the Incremental Deployment cost. Several costs were also provided by PBC TED that are used to manage the entire countywide traffic control system, i.e. TMC operators, incident management software, ATMS.now license, and INRIX data subscription. These costs were assigned to the basic infrastructure costs because they are needed to operate the countywide traffic signal system with or without the Living Lab project.

Benefits

It is not possible to analyze more than one corridor at a time using TOPS-BC. For this case study, a separate TOPS-BC spreadsheet was set up for each of the six primary corridors in the study area. A process to determine an overall BC ratio for the Living Lab program is described later in this section.

Link volume data was obtained from intersection counts conducted periodically by the PBC TED. The volumes are part of a countywide traffic count program and were counted on a rotating basis between 2010 and 2013. The link volume used in the calculation was determined by averaging the approach volumes of each intersection available in the intersection count program for the corridor (considering the east/west approaches on Okeechobee, Belvedere and Southern and the north/south approaches on Military, Jog and SR 7) and using the highest average volume as the volume in the spreadsheet. An example of the volumes for Okeechobee Blvd. is shown in Table 21. The volumes in the count program are defined by approach, EA is the east approach or westbound. The peak volume is the p.m. peak hour in the east approach (westbound).

Table 21. Okeechobee Boulevard Volume Counts.

Road	Intersection	AM NA	AM SA	AM EA	AM WA	PM NA	PM SA	PM EA	PM WA
Okeechobee Blvd	at I-95	0	1497	2667	2141	0	1730	3082	2474
Okeechobee Blvd	at Australian Avenue	grade separated							
Okeechobee Blvd	at Congress Avenue	581	556	1825	1775	695	665	2182	2123
Okeechobee Blvd	at Military Trail	1257	1251	2172	2110	1468	1461	2536	2464
Okeechobee Blvd	at Haverhill Road	851	754	2104	2138	960	850	2373	2412
Okeechobee Blvd	at Jog Road	1169	1196	2249	2261	1216	1245	2341	2354
Okeechobee Blvd	at Sansbury's Way	139	311	2148	1974	147	329	2277	2092
Okeechobee Blvd	at SR 7	805	1513	1909	1668	1296	2437	3074	2687
Sum Total	**-**	**-**	**-**	**15074**	**14068**	**-**	**-**	**17866**	**16606**
Average	**-**	**-**	**-**	**2153**	**2009**	**-**	**-**	**2552**	**2372**

Source: Florida DOT

EA= east approach ▪ NA = north approach ▪ SA = south approach ▪ WA = west approach

The highest total volume is the sum of the east approaches. The average peak approach one hour volume is 2552. Each of the other corridor volume inputs was determined in this manner.

Speeds were also obtained from the PBC TED. The FDOT Systems Planning Office standard for free flow speed is the speed limit plus 5 miles per hour (mph). The speed limit varies in sections of the corridors between 35 and 50 mph. The free flow speed should then be between 40 and 55 mph. In this case study PBC TED provided data that allowed the free flow speed to be determined by averaging off-peak travel times along each corridor using the Bluetooth detectors and calculating the average speed over several months. The baseline speed is based on historic travel time data collected prior to the implementation of the Living Lab project. The Baseline Override speed shown is the speed for the peak hour and direction of the highest volume, in the Okeechobee case above the speed used in the spreadsheet is for the PM EA approach. The Improvement Override speed was collected after implementation of the Living Lab

> The case study east/west corridors are approximately 8 miles in length. The north /south corridors are approximately 2 miles long.

project by PBC TED using the Bluetooth detectors and reported in the PBC TMC Active Arterial Management Program Performance Measures Monthly Report. The speeds used were from the November 2013 report.

The number of analysis periods is different from for the I-95 Express Lanes case study. The benefits are accrued for the peak hour in the peak direction, which is represented by 250 analysis periods, which are the average number of work days in a year (total days minus weekends and holidays). However, while the p.m. peak hour was found to have the highest volumes, significant benefits are also accrued for the a.m. peak hour. In a case where the a.m. peak hour has the highest volumes, the p.m. peak hour should be included in the same manner. In order to account for those benefits the peak volume in the a.m. peak period was identified and a ratio of that volume to the highest peak hour volume was determined. That portion of the 250 analysis periods was added to the 250 original analysis periods. (Another option is to conduct two separate BCA analyses, one for each direction.) Using the Okeechobee example in Table 21, the corresponding peak period is the a.m. peak hour. The east approach was the highest volume approach in the a.m. period so that volume (2153) was used. The a.m. peak to p.m. peak hour volume ratio is 2153/2552 or 0.844. The a.m. peak should account for 84.4 percent of the amount of analysis periods that the p.m. peak hour provides, so 250 X .844 is 211; 211 + 250 is 461. The amount of benefits accrued in both the a.m. and p.m. peak hours is accounted for by using 461 analysis periods. The other corridors' benefits were calculated in the same manner. This methodology provides a conservative estimate of benefits since only two peak hours of benefits are accounted. Volumes for periods other than the peak hour were not available.

National average (default) input data was used for crashes, fuel consumption, and the value of time. This was due to the difficulty in collecting and summarizing data or the fact that data were not available at all.

Limitations. While TOPS-BC does include the benefits due to time savings in recurring and non-recurring travel during each analysis period, the impacts of improvements due to improved travel time reliability are included only in freeway analysis. Reliability has been recognized as an important consideration to travelers. Improving reliability is a benefit to travelers. The SHRP 2 research project dedicated a significant portion of its resources to defining, understanding and measuring reliability. SHRP 2 has released several reports relating to the topic. Not all of this research has been added to the TOPS-BC model Version 1. TOPS-BC V1 now estimates only the benefits from reducing incident related delay. In the future, TOPS-BC will add new code to address the current reliability benefits and add these benefits to the full BCA. The latest model will be available on the FHWA Planning for Operations web site (http://www.ops.fhwa.dot.gov/plan4ops/index.htm).

TOPS-BC does not have a trip assignment or mode choice module, therefore the operations strategy analysis only accounts for the number of trips given for each corridor, there are no trip diversions or mode changes due to congestion.

TOPS-BC will provide conservative estimates of benefits because only the benefits accrued during the selected time period are calculated. In many cases, additional benefits may be produced in off-peak times that are not included.

Changes in air quality due the operations strategies are not accounted for in TOPS-BC.

Methodology

The following are the steps to enter input data for the Palm Beach Living Lab case study. Note that separate TOPS-BC calculations are required for each of the six corridors in the study area. The steps are the same for each corridor but the input volumes and speeds are different.

Costs

1. Click on Traffic Signal Coordination Systems – Central Control under Section 3– Estimate Costs.
2. The incremental deployment costs are entered in each item row, both for capital/replacement cost and for operations and maintenance costs. Each item cost is the cost per intersection multiplied by the number of intersections. The signal controller cost includes the cost of any in-pavement presence loops.
3. The basic infrastructure costs are not included in the benefit-cost calculation, as this case is considering only the benefits of the incremental improvement by the Living Lab project.
4. Each item is assigned a useful life. The project life cycle is 20 years, so there are no replacement costs for the traffic signal and communications lines. There is one replacement assumed for the cameras and detectors. The useful life is entered for each cost item.
5. The annualized total project cost is then calculated by the spreadsheet as an output.
6. The total cost for the incremental deployment was determined and each corridor was assigned a percentage of the total project cost based on the ratio of the traffic signals along that corridor to the total number of traffic signals in the study area. Using Okeechobee as an example, there are 23 traffic signals in the Okeechobee corridor, which is 29.1 percent of the total 79 traffic signals in the study area. Therefore, Okeechobee was assigned 29.1 percent of the project cost. Using the total cost will account for the deployment in both directions even though the benefits are accrued for one direction in the peak hour. This will provide a conservative estimate of the B/C ratio.
7. The calculated costs of each corridor are then added back together to obtain a total project B/C ratio.

See Figure 24 for a screenshot of the Costs page for the Okeechobee Blvd. corridor in this case study.

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0

PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies

WORK AREA 1 - ESTIMATE AVERAGE ANNUAL COST

Traffic Signal Coordination Systems: Central Control

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrastructure Equipment				
Linked Signal System LAN	20	$ 55,000	$ 1,100	$ 3,850
TMC Hardware for Signal Control	5	$ 35,000	$ 2,000	$ 9,000
ATMS.now license (1)	1	$ 200,000	$ 15,000	$ 215,000
TMC Operators	1	$ -	$ 408,000	$ 408,000
Incident Managaemen Database (1)	1	$ 29,000		$ -
INRIX data subscription (1)	1		$ 7,000	$ 7,000
TOTAL Infrastructure Cost		$ 319,000	$ 433,100	$ 642,850
Incremental Deployment Equipment (per Intersection)				
Signal Controller (130)	15	$ 821,500	$ 377,000	$ 431,767
Communication Line (184,800 LF)	20	$ 809,424	$ 80,900	$ 121,371
Loop Detectors (with signal controllers)	5		$ -	$ -
CCTV cameras (35)	10	$ 140,000	$ 14,000	$ 28,000
Bluetooth detectors (30)	10	$ 165,000	$ 16,500	$ 33,000
Speedinfo detectors (6)	10	$ 30,000	$ 3,000	$ 6,000
				$ -
				$ -
				$ -
				$ -
TOTAL Incremental Cost		$ 2,105,924	$ 491,400	$ 620,138
INPUT Enter Number of Infrastructure Deployments	0			$ -
INPUT Enter Number of Incremental Deployments	1			$ 620,138
INPUT Enter Year of Deployment	2013			
Average Annual Cost				**$ 620,138**

Source: FHWA TOPS-BC

Figure 24. Screenshot. Tool for Operations Benefit-Cost Analysis Traffic Signal Coordination Systems Costs Page.

Benefits

The Okeechobee Blvd corridor will be used as an example for providing input data to the spreadsheet.

1. Click on Signal Coordination under Section 4 - Estimate Benefits. Input data into the Facility Characteristics section.
2. Enter one into the Length of Analysis Period green box because the traffic volume data is for a one hour period
3. Select Central Control for the Signal Timing Type, the Living Lab project provided central control in the study area.
4. Select Principal Arterial for the Link Facility Type since the corridors are principal arterials.
5. Enter 8 in the Link Length, which is the length of the east/west corridors.
6. Enter 4 in the Total Number of Lanes, which is the number of basic lanes in each direction in most segments along the corridor.
7. TOPS-BC will calculate the roadway capacity as an output.
8. Enter 41.5 into the Free Flow Speed green box, that speed was provided by PBC TED based on analysis of off-peak travel times using Bluetooth readers. The speed limit should not be used as the free flow speed arterials, it will not account for traffic stopping at signals. The correct method to obtain free flow speed is to measure travel time over the length of the corridor in uncongested times of day and divide by the corridor length.
9. In the Facility Performance section, enter 2552 into the Link Volume green box, which was provided PBC TED as described above.
10. Enter 26.0 into the Congested Speed, Baseline Override box, which the p.m. peak hour speed collected by PBC TED prior to implementation of the Living Lab project.
11. Enter 29.6 into the Congested Speed, Improvement Override box, which is the most current corridor p.m. peak hour speed reported by PBC TED in their monthly performance measures report.
12. Enter 461 into the Number of Analysis Periods per Year box, which accounts both the p.m. and the a.m. peak hours per year as described in the Assumptions section above.
13. As an output TOPS-BC will calculate the annual benefits to the corridor. For Okeechobee Blvd. the annual benefits were found to be $1,419,813.

See Figures 25 and 26 for screenshots of the Benefits page for the Okeechobee Blvd. corridor in this case study.

Length of Analysis Period (Hours)	1
Signal Timing Type	Central Control

Cost Information

Facility Characteristics

			Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Facility Type	Principal Arter						
Link Length (Miles)	8						
Total Number of Lanes	4			4		4	0
Link Capacity (All Lanes - per Period)		7200		7200		8064	864
Free Flow Speed (MPH)	41.5						

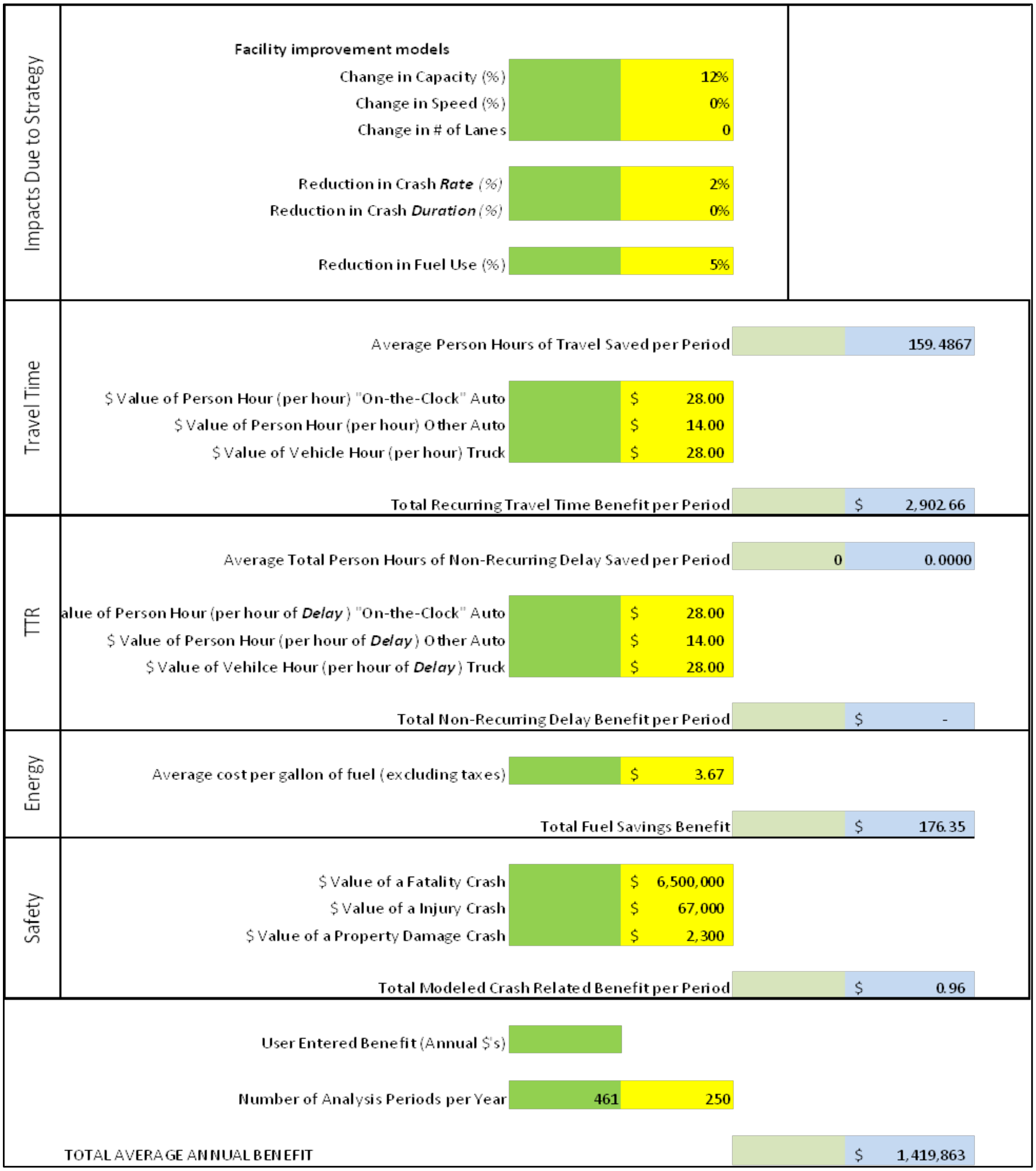
Facility Performance

Link Volume (during the time period of analysis)	2552

	Baseline Override	Baseline	Improvement Override	Improvement	Change
Congested Speed	26	40.658	29.6	40.788	3.600
Vehicles Miles Traveled (VMT)		20416.0000		20416.0000	0.0000
V/C		0.3544		0.3165	-0.0380
Vehicle Hours of Travel		785.2308		689.7297	-95.5010
Incident Related Delay (hours) per vehicle per mile		4.54056E-06		4.36076E-06	-1.79806E-07
Number of **Fatality** Crashes		3.61363E-06		3.54136E-06	-7.22726E-08
Number of **Injury** Crashes		3.46868E-04		3.39930E-04	-6.93736E-06
Number of **Property Damage Only** Crashes		5.05010E-04		4.94910E-04	-1.01002E-05
Fuel consumption (Gallons)		961.0234		912.9723	-48.0512

Source: FHWA TOPS-BC

Figure 25. Screenshot. Tool for Operations Benefit-Cost Analysis Traffic Signal Coordination Systems Benefits Page (part 1).



Source: FHWA TOPS-BC

Figure 26. Screenshot. Tool for Operations Benefit-Cost Analysis Traffic Signal Coordination Systems Benefits Page (part 2).

Preliminary Benefit Cost Evaluation

Based on the six corridors benefits and costs calculations using the TOPS-BC spreadsheet, the results are shown in Table 22.

Table 22. Benefits and Costs for the Palm Beach Living Laboratory Case Study.

Corridor	Peak Time/Direction	Benefits	Cost	B/C Ratio
Southern Blvd	AM EB	$2,179,220	$149,454	14.58
Belvedere Road	PM WB	$1,270,182	$133,330	9.53
Okeechobee Blvd	PM WB	$1,419,812	$180,460	7.87
Military Trail	PM NB	$972,212	$47,130	20.63
Jog Road	PM NB	$235,011	$55,192	4.26
SR 7	PM NB	$159,651	$55,192	2.89
Total System		$6,236,088	$620,758	10.05

Source: Florida DOT
B/C = benefit/cost

Key Observations

After conducting these and other TOPS-BC case studies and applications, several "lessons learned" have been identified. There are also a few hints to setting up the spreadsheet that will help TOPS-BC users achieve better results.

- Speed is the most important factor affecting the benefits of an operations strategy. A difference in "before" and "after" speed is the primary way to account for congestion and delay and improvement benefits in TOPS-BC. In the Palm Beach Living Lab case study, before and after speed was the only way to account for the operations of the traffic signal system along the corridor, it is the overall travel time (converted to speed) that accounts for the stop delay in a corridor. The number of traffic signals is not part of the calculation. It is relatively easy to collect current travel times using GPS travel time runs or Bluetooth detectors. However, it is more difficult to obtain historic corridor speeds for project already implemented or to estimate speeds for a project being planned. When actual historic data is not available, it is best to consult with the local MPO and obtain model speeds for the corridor.
- The free flow speed is important because it is the goal from which travel time savings potential is measured. The FDOT Planning Office free flow speed is the posted speed limit plus 5 mph. When conducting operations analysis and when historic data is available the free flow may be determined from collected data. For freeways, the average off-peak (uncongested) speed collected over time from detectors is the calculated free flow speed. For arterials the stop time

at traffic signals must be accounted for, so the operations method of determining free flow speed is to average off-peak corridor travel times over time, as was done in the Palm Beach case study. When conducting planning studies the speed limit plus 5 mph should be used as the free flow speed.

- Volume and volume/capacity ratio are also important factors in TOPS-BC calculations. The current volume is the only volume input, however, when needed (such as an intersection improvement) the capacity can be overridden for both the baseline and the improvement scenarios. Volume and V/C are used to calculate vehicle miles traveled and crash rates and affect the benefits calculation.
- The period of analysis must be correct in order to obtain accurate results. The number of hours of the analysis must match the length of the period of the volume data, that is, if the volumes are for a peak one hour, the period of analysis must be one.
- The number of analysis periods per year can be used to account for additional benefits not measured directly by data input. In the Palm Beach case study, the number of analysis periods was increased to account for the other peak hour of the day. The ratio of the a.m. peak hour to the p.m. peak hour was multiplied by the number of workday peak hours per year (250) to account for the benefits of both peak hours. Additional hours of benefits could have been added in the same manner if the volumes were known. Another option would be to conduct two BCA, one for each direction.
- For the cost calculations, there are several important considerations. The costs of providing basic services – services that would be provided whether or not the project being studied was implemented – and the cost of the incremental services enabled by the project must be sorted out and correctly assigned. Each cost item should have a corresponding operations and maintenance cost entered in the spreadsheet.
- It is also important to match the cost of a project to the benefits being calculated. For example, in the Palm Beach case study the cost of the project in a corridor was halved in the B/C calculation because the benefits were only calculated for one direction along that corridor.
- The user must be careful to pay close attention to the units that are assumed in the spreadsheet cells; i.e., be sure to determine if the model is assuming a daily rate vs. an annual rate for a factor.

CHAPTER 6. FREEWAY SYSTEMS MANAGEMENT

#	Case Name	Benefit-Cost Analysis (BCA) Model	Actual or Hypothetical Case
6.1	Hypothetical Centrally Controlled Ramp Metering Deployment	TOPS-BC	Hypothetical
6.1	Florida DOT Road Ranger Program	Custom Stand Alone BCA Model Focused on Safety Benefits	Actual
6.3	Metropolitan Area Transportation Operations Coordination Program	Custom Stand Alone BCA Model	Actual
6.4	Regional Traffic Management Center, Ft. Lauderdale, FL	Custom Stand Alone BCA Model	Actual
6.5	Coordinated Highways Action Response Team, Maryland	Custom Stand Alone Benefit Analysis	Actual
6.6	Georgia NaviGator Traffic Incident Management System	Custom Stand Alone Benefit Analysis	Actual

Case Study 6.1 – Hypothetical Centrally Controlled Ramp Metering Deployment

Strategy Type:	Freeway Management
Project Name:	Hypothetical Centrally Controlled Ramp Metering Deployment
Project Agency:	State Department of Transportation or Transportation Planning Agency
Location:	Urban and Rural
Geographic Extent:	Statewide, Corridor or Segment
Tool Used:	TOPS-BC

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Ramp metering 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 region-wide 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.

Project Goals and Objectives

A Midwestern traffic management agency deployed ramp metering on seven interchanges along a 5-mile corridor of a major Interstate. Ramp metering was selected as the most cost effective option, as increasing capacity or adding lanes would be expensive and difficult given limited right of way. The meters were installed at a cost of approximately $30,000 per on-ramp. The overall goal of the ramp metering program was to help decrease congestion by maximizing the flow of traffic and increasing merge safety on the freeway.

Data Requirements

Data was collected and analyzed prior to and after deployment of the ramp metering system to evaluate effectiveness.

The data used for the analysis consisted of loop detector speed and volume data and accident and incident management data. The study focused on morning peak period (6am to 8am) and afternoon peak period (4pm to 6pm). For the 2010-2011 initial evaluation, data was compiled for a 24-month period (March 2008 to March 2010) prior to the implementation of the metering system and for a 12-month period (April 2010 to March 2011) following the activation. For the 2011-2012 Long Term Impacts Evaluation, the data used was archived data from morning and afternoon peak hours for the all no-holiday weekdays following the activation of the system in April, 2010 through September, 2012.

The results of the evaluation indicated that the ramp meters were benefitting traffic flow on the Interstate and were meeting or exceeding the objectives for the system that were initially identified.

Benefit Cost Evaluation

A benefit cost evaluation could be used to determine whether to implement ramp metering technology. TOPS-BC provides input defaults for most variables that would be used in the evaluation of a new ramp meter system. If a planner was looking at a system similar to this ramp meter example, he or she could use the TOPS-BC defaults, or generate new data to make the example as realistic as possible by applying local data in place of the defaults. This also allows the user to test the impact of changes in selected input data. For example, the analysis can be carried out for cases that highlight local or recent information for the project using different technology costs, traffic levels, wait times, etc. Each of the items shown in Table 23 are included in the default input data set, but may be replaced with user supplied data as shown. If user supplied data is entered, it will override the default value and be used by TOPS-BC in all calculations that call for that input data.

In addition to the characteristics that describe your project such as technology specific costs, roadway descriptions, number of installations, etc., you may also want to input values different from the TOPS-BC defaults for economic parameters related to the measures of benefits for the project. Examples may be the value of time or reliability. Others include the price of fuel, the cost of crashes or dollar value of other benefits you may have calculated such as vehicle emissions.

Entering your own data allows you to make the analysis as specific as you can for your project. In addition, it provides a simple process for testing the sensitivity of the results to a particular variable or set of variables. Table 23 illustrates both user supplied data inputs and TOPS-BC supplied inputs.

TOPS-BC calculates a default *Freeway Link Capacity* based on the *HCM* and the default or user inputs peak hours and lanes for this case. Here the default capacity is 26400 vehicles per hour. TOPS-BC uses 2200 vehicles per hour per lane times 4 hours times three lanes. If the user felt that the free flow capacity were different for this facility, say 2000 vphpl, the calculation can be redone as 2000 times 4 hours times 3 lanes or 24000. Entering 24000 in the *User Supplied Data Input for Freeway Link* capacity cell would override the default in all future TOPS-BC calculations.

In this case we have some specific site characteristics including length, number of lanes, number of metered ramps, average speed and other characteristics. We also enter specific data about the performance of the facility we are analyzing. TOPS-BC has already done a literature review for the range of impacts of traffic centrally controlled ramp meters and provides a reasonable default value. However, in this case we have specific facility impacts and can input them into the system. We have chosen not to change the value of time, the value of reliability, energy prices or the value of crash avoidance for this example. In this run we are accepting the TOPS-BC default values found in the right column or on the Parameters page in the TOPS-BC model.

Table 23. Input Variables and User-Supplied Data for Ramp Metering Example.

Required Input Variables	User-Supplied Data Inputs	TOPS-BC-Supplied Inputs
Facility Characteristics		
Link Length (Miles)	5	
Total Number of Lanes	6	2
Freeway Link Capacity (All Lanes - for the time period of analysis)		26400
Free Flow Speed (MPH)	65	55
Number of Metered Ramps	15	1
Average Link Length (Miles)	0.25	0.25
Average Ramp Number of Lanes	1.5	1
Average Ramp Link Capacity (All Lanes - for the time period of analysis)		4800
Average Ramp Free Flow Speed (MPH)		35
Facility Performance		
Freeway Link Volume (during time period of analysis, 3-hour peak))	21,120	14,000
Average Ramp Link Volume (during time period of analysis, 3-hour peak)	3,840	5,200
Impacts Due To Strategy		
Change in Freeway Link Capacity (%)	20	12%
Change in Ramp Link Capacity (%)		-35%
Reduction in Freeway Crash Rate (%)	20	12%
Reduction in Freeway Crash Duration (%)		0%
Reduction in Fuel Use (%)		10%

Source: FHWA TOPS-BC

In this example, we are running TOPS-BC and we would like to modify the inputs to reflect new data. We might do this because of the similarity of this particular deployment to the one we are considering. We know in previous deployments that the freeway travel speeds increased by 20 percent and the crash rate also decreased by 20 percent. However the TOPS-BC default for both these values was 12 percent. By using the navigation column we can go to the benefit inputs page and input the new percent for volume increases and crash reductions. These values will be used in all calculations calling for these inputs in TOPS-BC.

The user can also test the inputs to see where additional benefits may be realized. This can be accomplished by modifying assumptions about the project costs, size or other dimension. One can also test the value assumptions. For example, an alternative set of crash costs by type (fatality, injury or property damage only (PDO)) that reflects local crash cost experience would improve the applicability of this tool for your project.

The three primary benefits of ramp metering deployments are improvements in travel time, travel time reliability, and crashes. In addition, the smoother traffic flow results in improved vehicle fuel efficiency and reduced emissions for most pollutants. Each project plan is different and the realized benefits can be impacted by the plan. By varying the assumptions in the plan, BCA models allow you to see how plan assumptions will impact the expected benefits.

Travel Time. Mainline and ramp delays increase travel time. Reducing delay and travel time is a benefit that accrues to the freeway user. Travel Time is usually calculated based on estimated link speeds in the corridor, both for the freeway and ramp links. Speeds may be estimated using the speed-flow relationship from the Highway Capacity Manual where a speed factor (to be applied to free flow speed) for varying degrees of congestion (as measured by volume/capacity ratio) can be found.

Speed is estimated for the baseline (without improvement) scenario by determining the correct speed-flow factor to apply based on your inputs for capacity and volume and applying the factor to the free flow speed you provided. These analyses must be performed separately for the freeway and ramp links. For the improvement scenario, average capacities are adjusted based on default impact percentages. BCA models usually provide these defaults or the user can supply impact values if available. These default impact values are sensitive to the Level of Timing Sophistication. The adjusted capacity value is used to determine an adjusted volume/capacity ratio which can be used to look up the speed-flow factor from the HCM or as a default in the model. The estimated speeds for the baseline and with improvement scenarios are used to estimate link travel time based on your inputs for link length and average volumes. The difference between the two scenarios in hours of travel time is monetized as the travel time benefit.

Travel Time Reliability. Travel time reliability can be based on the non-recurring delay estimation methodology developed for the Strategic Highway Research Program (SHRP 2 projects L03 and L05). The approach uses factors (applied to VMT) representing the expected amount of incident related delay based on the number of lanes on the facility, the length of the analysis period, the facility volume and the facility capacity. This analysis is only performed on the freeway links. The impact of the ramp metering strategy on incident related delay is two-fold – it is impacted by the change in facility capacity (discussed under the Travel Time impact above) and by a reduction in the number of crashes (discussed in the Crashes section below). The change in capacity results in a different volume/capacity ratio (between the without improvement and with improvement scenarios) being used with the incident related delay factors. Incident delay factor is multiplied with the VMT estimated for the facility. Further, the resulting estimated number of hours of incident related delay for the with improvement scenario are further reduced by the percentage decrease in the default crash rate. The incremental change in hours of non-recurring travel time delay between the baseline and with improvement scenario is assigned a dollar value. Tools like TOPS-BC or similar models will do all these calculations for you with data you provide about your project and its expected effects on performance.

Reliability has been recognized as an important consideration to travelers. Improving reliability is a benefit to travelers. The SHRP 2 research project dedicated a significant portion of its resources to defining, understanding and measuring reliability. SHRP 2 has released several reports relating to the topic. Not all of this research has been added to the TOPS-BC model Version 1. TOPS-BC V1 now estimates only the benefits from reducing incident related delay. In the future, TOPS-BC will add new code to address the current reliability benefits and add these benefits to the full BCA. The latest model will be available on the FHWA, Planning for Operations web site (http://www.plan4operations.dot.gov/).

Safety. Crashes represent the benefit in the reduction in crashes resulting from the smoothing of traffic conflicts in the merge area. A default crash rate factor is usually supplied by the BCA tool; however, if you have local data to support a different impact, you can usually input this project specific information in your model. For example, with TOPS-BC you can enter a factor in the "Reduction in Freeway Crash Rate (%)" cell. This impact factor will reduce the crash rates applied to all crash severities. Dollar values will be applied to the change in the number of crashes to estimate this benefit. The reduction in the number of crashes is also fed back into the calculation of incident related delay, producing a greater benefit level for travel time reliability.

Other benefits are often associated with ramp metering strategies including the reduction in vehicle emissions and fuel use. These two benefits are inherently difficult to estimate within a spreadsheet based model (e.g., spreadsheet based models are generally incapable of estimating the vehicle acceleration and deceleration profiles to accurately assess these impacts). Other models such as IDAS offer a link between the BCA and the regional TDM. In TOPS-BC, you are free to modify the analysis framework to include these benefits, or simply to add the estimated value of these benefits to the "User Entered Benefit" cell if there is data to support their inclusion.

Model Run Results

As shown in Table 24, TOPS-BC cost effectiveness analysis indicates that the first year cost for this ramp meter introduction will be $1.687 million with:

- A continuing annual cost for a 20 year analysis period of $93,250; and
- An additional cost every five years for software and system upgrades of $97,500.

This results in a 20 year net present value of just over $2 million or levelized annual cost of $172,600.

Costs

If the deployment was already complete, we could then use the actual cost experience in this case if it was felt that it was more accurate than the average cost shown by TOPS-BC. Costs shown in a single report may not be comparable to the default values as they may not include all deployment costs. TOPS-BC allows the user to add new cost components or to modify the cost categories. You are strongly encouraged to carefully review the default cost data and make modifications as necessary. You may change the predicted useful life, base unit cost of equipment, or continuing O&M cost for any piece of equipment. You may also delete or add pieces of equipment to better match your anticipated equipment mix for the strategy.

Benefits

TOPS-BC estimates benefits from the ramp meter deployment from travel time savings, change in travel time reliability, reduced energy consumption and reduced crash events. Together they result in levelized annual benefits of about $8 million.

In this case, TOPS-BC estimates that the project benefits far exceed the costs. This results from the gain in operating efficiency for the system under study. Prior to introducing the ramp meters, insufficient freeway capacity during the morning and evening peak traffic periods led to congestion and lost time for road users. With the introduction of the ramp meters, the roadway operated at its design capacity and offered a higher level of certainty for the peak period trips. TOPS-BC also estimated a substantial reduction in energy costs due to congestion relief. The number of crashes was also reduced, which provided the added benefit of crash cost reduction.

Table 24. Benefit-Cost Analysis Summary for a Hypothetical Centrally Controlled Ramp Metering Deployment.

ANNUAL BENEFITS	
Discount Rate	7%
Travel Time	$7,497,256
Travel Time Reliability	$36,835
Energy	$456,072
Safety	$4,218
Other	$0
User Entered	$0
Total Annual Benefits	**$7,994,382**
ANNUAL COSTS	
Total Annual Costs	**$172,600**
BENEFIT-COST COMPARISON	
Net Benefit	$7,821,782
Benefit-Cost Ratio	46.32

Source: FHWA TOPS-BC

Key Observations

This case identifies the introduction of a series of ramp meters at 15 on-ramps on an Interstate that is highly congested during the morning and evening peak periods. The peak congested periods last about two hours each on weekday. Prior to and after the deployment, the State DOT collected data on system performance to be able to compare the changes brought about by the deployment. Those performance changes revealed impacts on both freeway and ramp performance. These realized changes are what a pre-project deployment analysis needs in order to estimate the expected project benefits and costs. Once the project is deployed, performance indicators and their changes are known and can be used as an estimate of what might be expected if a similar project is deployed.

Case Study 6.2 – Florida DOT Road Ranger Program

Strategy Type:	Freeway Management
Project Name:	Road Ranger Program
Project Agency:	Florida Department of Transportation
Location:	Urban and Rural
Geographic Extent:	Statewide
Tool Used:	Custom Stand Alone BCA Model Focused on Safety Benefits

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

A Freeway Service Patrol (FSP) program comprises the necessary funding, personnel, training, equipment, operations, maintenance, and business practices that enable agencies to reduce traffic incident duration and thereby reduce traffic congestion on freeways and arterials in their jurisdiction. An effective FSP program requires highly trained personnel who use specially equipped vehicles and tools to systematically patrol congested highways searching for and responding to traffic incidents. A FSP provides incident response services, clearance resources, and free motorist assistance services. FSP functions include performing minor repairs, assisting motorists, removing debris, providing fuel, providing first aid, pushing vehicles out of travel lanes, and assisting emergency services at vehicle crash scenes.

Project Goals and Objectives

In 1999, the Florida Department of Transportation (FDOT) funded a traffic incident management program called Road Ranger. This freeway service patrol program consists of roving vehicles that provide primary incident response and assistance to disabled vehicles on Interstate corridors and construction zones. The objectives of the program include:

- Reducing incident duration;
- Reducing cost of towing/assistants for motorists;
- Increasing safety at incident locations;
- Reducing traffic delay;
- Reducing emissions; and
- Reducing fuel consumption.

To meet these objectives, Road Rangers provide direct assistance to motorists by quickly responding, assisting, and clearing primary incidents from the travel lanes in close coordination with the state highway patrol and other law enforcement and emergency response agencies. Road Rangers also assist disabled motorists with basic services including furnishing fuel, assisting with tire changes, and helping with other types of minor vehicle repairs. From 2000 to 2010, the number of Road Ranger assists climbed from 112,000 to 351,941 per year.[4]

In order to have a successful transportation systems management and operations (TSMO) deployment, you must first demonstrate that the benefits of the project exceed the costs. Your assumptions will be evaluated by decision makers so you should plan on providing sensitivity testing of your key input assumptions. BCA models like TOPS-BC allow you to quickly and easily vary input assumptions and compare results. This process lets you demonstrate a range of potential outcomes that can help you gain support from the public and the planning community.

In 2012, FDOT commissioned the Center for Urban Transportation Research (CUTR) at the University of South Florida to conduct an independent evaluation of the Road Ranger program and develop a benefit-cost analysis. The study, "Review and Update of Road Ranger Cost Benefit Analysis," presents a district- and state-level evaluation of the program's costs and benefits and provides recommendations for improvements.

The FSPE model:

- Distributes the incident types over a specified road segment during the service period proportional to the Vehicle Miles Traveled (VMT) in that segment during different periods of the day.
- Uses study area traffic profiles and AADT volumes on the study segments to calculate VMT during different times of the day and assigns incidents accordingly.
- Calculates the benefits for one average day and then multiplies it by the number of days of service to yield the total benefit.

This case study presents the methodology, tools and data used to analyze the benefits and costs of the Road Ranger program and discusses how they relate to TOPS-BC.

Data

The study utilized a customized version of the Freeway Service Patrol Evaluation (FSPE) model. The FSPE model was developed by the Institute of Transportation Studies at the University of California, Berkeley for the California Department of Transportation (Caltrans). The model uses Microsoft Excel and it is available at no cost to the public subject to the approval of Caltrans.[5]

To apply the FSPE model to evaluate the Florida Road Ranger program, the model was calibrated to suit Florida traffic, roadway conditions, and information availability. Required data inputs included:

- Highway district name, hours of operation and traffic volumes.
- Design characteristics of the highway including number of lanes, presence of shoulders/medians.
- Traffic characteristics including AADT, percentage of trucks.
- Incident characteristics including mean time, percentage of incidents by location.
- Traffic parameters including percentage of hourly volume in a 24 hour period by direction.

In Florida's case, the State DOT uses an advanced traffic management system software system to collect and access these and other traffic related data elements.

Benefit Cost Evaluation

To calculate the benefits and costs of the Road Ranger program, the CUTR researchers:

- Selected a recognized methodology and tool, the Freeway Service Patrol Evaluation model, for evaluating Freeway Service Patrols.
- Obtained and analyzed traffic volume and incident data.
- Conducted a benefit-cost analysis using the FSPE model developed by the University of California, Berkeley.

Researchers developed the two types of benefit categories – individual benefits and general public benefits. Individual benefits included: increased safety at the incident scene, reduced incident duration and reduced cost of towing or assistance for the motorist being helped. General public benefits included increased safety at the scene, reduced traffic delays, reduced emissions and reduced fuel consumption.

The FSPE methodology uses nine types of incidents to estimate benefits. These include: accident (right shoulder, in lane, left shoulder), breakdown (right shoulder, in lane, left shoulder), and debris (right shoulder, in lane, left shoulder). The model distributes the incident types over a specified road segment during the service period proportional to the vehicle miles traveled (VMT) in that segment during different periods of the day. The model uses study area traffic profiles and average annual daily traffic (AADT) volumes on the study segments to calculate VMT during different times of the day and assigns incidents accordingly. It calculates the statewide benefits for one average day and then multiplies it by the number of days of service to yield the total benefit.

After collecting traffic volume and incident response data, the team selected Version 12.1 of the FSPE model. The model uses Microsoft Excel workbooks for all the inputs and outputs. The inputs are used by FSPE to estimate hourly traffic flow due to FSP service. The model uses a queuing model for calculating the delay. The FSPE delay model uses VBA code implemented as an add-in module to accommodate the more detailed queuing model. (Visual Basic for Applications or VBA is a sophisticated MS Excel tool for Excel power users. See for example: Getting Started with VBA in Excel 2010 at http://msdn.microsoft.com/en-us/library/office/ee814737(v=office.14).aspx.) The model estimates delay saving benefits based on geometric and traffic characteristics, and the frequency and type of FSP-assisted incidents.

To apply the FSPE model to evaluate the Florida Road Ranger program, the model was calibrated to suit Florida traffic, roadway conditions, and information availability.

Model Run Results

Benefits

The main benefit categories estimated by the FSPE model are delay, fuel, and emissions savings for carbon monoxide (CO), volatile organic compounds (VOC), and nitrogen oxide (NOx). Note that emissions savings were not monetized in the BCA. The total annual emissions savings were estimated at 7,818 Kg for CO and 90,371 Kg for VOC. For NOx, the emissions increased to 59,829 Kg., and CO and VOC are reduced in most cases with increased speeds. NOx emissions increase at high speeds, therefore the emissions for nitrogen oxide increased as overall highway speed increased.

Costs

The total cost used in the FSPE model was the contract value to operate and maintain the Road Ranger program. This amount was over $20 million.

Table 25. Benefit-Cost Summary (Statewide) for the Florida DOT Road Ranger Program.

ANNUAL BENEFITS	
Delay Savings	$128,600,175
Fuel Savings	$5,060,615
Total Annual Benefits	**$133,660,790**
ANNUAL COSTS	
Total Annual Costs	**$20,019,939**
BENEFIT-COST COMPARISON	
Net Benefit	$113,640,851
Benefit-Cost Ratio	6.68

Source: FHWA TOPS-BC

Key Observations

Conducting BCA of TSMO projects can seem very challenging at first. However, many previous studies and tools are available to assist you in the process. Some items of particular interest in this case include:

- ***Availability of Alternative Models*** – The U.C. Berkeley Freeway Service Patrol Evaluation (FSPE) model is an alternative model for evaluating the benefits and costs of freeway service patrol programs. The analysis produced by the FSPE Model demonstrates that for Florida DOT a freeway service patrol program's benefits, which include reduced delays, fuel consumption and emissions, outweigh the cost of program management and operation.
- ***Use of Real Project Data*** – TOPS-BC and other BCA Tools—such as the FSPE used in this case study—often include default values for required inputs. These are national estimates taken from the published literature. You should review these values to see if they seem appropriate for your region or project.
- ***Use of User-Furnished Data –*** FSPE offers a simple process for using your own data to run the model. Simply add the values to want to add, descriptions, features, values to the designated green cells in the worksheet.
- ***Inclusion of Additional Benefit Estimates –*** As TOPS-BC provides a specific set of benefits, you may have other benefit estimates such as reductions in vehicle emissions. TOPS-BC allows you to enter these values directly and have them included in the benefit-cost analysis.

Alternatively, the FSPE model features a built in and customizable module for emissions benefit estimates.

Case Study 6.3 – Metropolitan Area Transportation Operations Coordination Program

Strategy Type:	Freeway Management
Project Name:	Metropolitan Area Transportation Operations Coordination (MATOC) Program
Project Agency:	Metropolitan Washington Council of Governments (MWCOG)
Location:	Urban and Rural
Geographic Extent:	Regional/Urban
Tool Used:	Custom Stand Alone BCA Model

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Problem Technology or Strategy

The National Capital Region (NCR) features a multi-jurisdictional and multi-modal transportation system. The system includes highways, multiple transit services, rail, carpool lanes, bicycle trails, and walking trails, with over 300 centerline miles of Interstate, tollways and HOV/HOT lanes. To aid in the quick and reliable exchange of transportation system information among operating agencies in the region, partnering jurisdictions organized the Metropolitan Area Transportation Operations Coordination (MATOC) program in 2008.

Project Goals and Objectives

The goal of MATOC is to facilitate real-time situational awareness of transportation operations during significant incidents in the National Capital Region. MATOC monitors, collects, analyzes, and coordinates the sharing of information among the stakeholders regarding incidents of regional significance and actions taken by the agencies involved.

In 2010 the Metropolitan Washington Council of Governments (MWCOG) published an evaluation of the MATOC program, which included a benefit-cost analysis. The BCA uses a customized traffic model, incident data, and engineering judgment to estimate loss of roadway capacity, vehicular queuing, travel delay, and costs (i.e., emissions, fuel consumption, value of time) associated with a select number of regionally significant traffic incidents for the purpose of quantifying benefits attributable to MATOC.

This case study will summarize the approached used to identify, quantify and analyze the benefits and costs of this traffic incident management program. This procedure may be reproduced and customized to fit your organization's needs. This study also serves as an example of how the value of time is addressed in a transportation systems management and operations (TSMO) benefits analysis.

Data

The MWCOG analysis compares the actual mobility costs for an incident in which MATOC is involved in the response to the costs of the same incident assuming only a local agency response (i.e. "Without MATOC" scenario). The analysis relied on empirical data collected by the MATOC from participating agencies. Data elements included traffic volume, incident detection time, response time, time on scene, and time to return to normal traffic operations.

Benefit Cost Evaluation

The objectives of the BCA study were to assess the benefits that are unique to the coordinated management of incidents affecting regional travel in the NCR; determine how regional coordination of major traffic incidents that span jurisdictional boundaries enhances existing local incident management and mobility savings (e.g., time, fuel, emissions); and determine the benefit-to-cost ratio of the MATOC Program.

To complete this task, the study used the following approach:

1. **Develop case studies.** Three regionally significant incidents that involved MATOC management were selected and data was collected.
2. **Model traffic incidents.** Researchers developed and calibrated a traffic model for each incident to reflect the actual timeline of events and document the queue lengths and duration. Scenarios were run for the with-MATOC and without-MATOC involvement.
3. **Estimate costs.** Costs were estimated for each incident with and without MATOC involvement in terms of emissions, fuel, value of time due to resulting queue and traffic delay.
4. **Annualize benefits.** Using historical data on how often similar incidents occur per year, benefits estimates were extrapolated.

The study used a series of custom Microsoft Excel spreadsheets and Synchro/SimTraffic, a microscopic simulation model, to model the traffic incidents under each scenario.

Model Run Results

Costs

The study utilized the MATOC annual operating budget as the source for program cost data. Cost categories included:

- Service contracts.
- Operations staff.
- Regional Integrated Transportation Information System (RITIS) support.
- Other direct costs (office space, etc.).
- Contingency funds.

The total annual cost of the program is $1.2 million.

Benefits

Dollar estimates for the following benefits were developed based on a University of Maryland and Maryland State Highway Administration benefit cost study:

- Emissions.
- Fuel consumption.
- Value of time.

In transportation economics, the value of time is considered the opportunity cost of the time that a commuter spends on his/her journey. It is typically expressed as the dollar amount a commuter would be willing to pay in order to save time or the amount they would accept as compensation for lost time.

The MWCOG study used the following cost conversion factors, developed by the University of Maryland and Maryland State Highway Administration, to quantify the value of time in the "with" and "without MATOC" scenarios used in the BCA study:

- Cost to car occupant per vehicle-hour of delay in queue: $26.58.
- Cost to truck driver per vehicle-hour of delay in queue: $20.68.
- Cost to truck cargo per vehicle hour of delay in queue: $45.40.

According to the MWCOG study, an average of 224 police-reported crashes occur each day in the National Capital Region. A portion of these nonrecurring incidents are regionally significant and require MATOC involvement. The study assumed that MATOC is involved in about 20 minor incidents (such as vehicle fires) and one major incident (such as a bus crash) per month on freeways, arterials or transit.

When modeling the minor incident both with and without MATOC involvement, it was found that MATOC contributed to a total savings of $30,260 in terms of emissions, fuel consumption, and the value of time, as shown in Table 26. When modeling the major incident, it was found that MATOC contributed to a total savings of $382,830 in terms of emissions, fuel consumption, and the value of time, as shown in Table 27. For both of these estimates, the assessment is conservative, as it does not include potential savings for reduced or eliminated secondary queues, secondary incidents, or the potential delay reduction due to rubbernecking in the opposite direction.

Table 26. Minor Incident Costs With and Without Metropolitan Area Transportation Operations Coordination Program Involvement

Measure of Effectiveness/Cost	Coordinated Regional Incident Management	Local Incident Management
Max Queue Length (miles)	9.1	10.5
Queue Duration (hours)	2.3	2.5
Queue Delay (vehicle hours)	4,260	5,080
Queue Travel (vehicle miles)	60,960	80,000
Cost ($) – Total Emissions	5,370	6,400
Cost ($) – Greenhouse Emissions	4,960	5,910
Cost ($) – Excess Fuel	2,280	2,720
Cost ($) – Lost Time	157,260	1,875,203
Cost ($) – TOTAL	164,910	196,640
Total Benefit ($) = $196,640 - $164,910 = $30,260		

Source: Metropolitan Washington Council of Governments

Table 27. Major Incident Costs With and Without Metropolitan Area Transportation Operations Coordination Program Involvement.

Measure of Effectiveness/Cost	Coordinated Regional Incident Management	Local Incident Management
Max Queue Length (miles)	12.7	21.6
Queue Duration (hours)	3.8	5.0
Queue Delay (vehicle hours)	9,490	20,170
Queue Travel (vehicle miles)	173,730	625,850
Cost ($) – Total Emissions	11,910	25,310
Cost ($) – Greenhouse Emissions	10,990	23,360
Cost ($) – Excess Fuel	4,570	9,700
Cost ($) – Lost Time	323,700	688,000
Cost ($) – TOTAL	340,180	723,010
Total Benefit ($) = $723,010 - $340,180 = $382,830		

Source: Metropolitan Washington Council of Governments

The evaluation estimated that the benefits of one year of MATOC operation amounted to the following:

Benefit of Minor Incident: $30,260 x 20 x 12 = $7.3 million/year

Benefit of Major Incident: $382,830 x 1 x 12 = $4.6 million/year

As shown in Table 28, the BCA results show that MATOC yielded positive benefits associated with reduced traffic delay, reduced emissions and reduced fuel consumption. The total annual benefit was an estimated $11.9 million per year (7.3 million + $4.6 million). The total annual cost of the program was $1.2 million. The resulting benefit-to-cost ratio is 10:1 ($11.9 million in benefits / $1.2 million in costs).

Table 28. Benefit-Cost Summary for the Metropolitan Area Transportation Operations Coordination Program.

ANNUAL BENEFITS	
Minor Accident Savings	$7.3 million
Major Accident Savings	$4.6 million
Total Annual Benefits	**$11.9 million**
ANNUAL COSTS	
Total Annual Costs	**$1.2 million**
BENEFIT-COST COMPARISON	
Net Benefit	$11.9 million
Benefit-Cost Ratio	10:1

Key Observations

Conducting benefit cost analyses of TSMO projects can seem very challenging at first. However, many previous analysis and tools are available to assist you in the process. Some items of particular interest in this case include: Many MPO and SDOT planning and operations offices utilize a variety of traffic models to describe how the transportation system operation changes with the introduction of new technologies or strategies. These data are often used in BCA and when they are not available, assumed values can provide the information needed to conduct the preliminary BCA. In this case, MWCOG made assumptions about the crash frequency and severity based on available information. They further assume that the MATOC would not be involved in all crashes, so they created a reasonable baseline, local management, and compared the cost of the crash management impacts to what could be expected in the subset of crashes where central management would be appropriate.

Some additional observations from the MWCOG BCA include:

- ***Real Projects Data May be Used –*** TOPS-BC and other BCA Tools often include default values for required inputs. These are national estimates taken from the published literature. You should review these values to see if they seem appropriate for your region or project.
- ***Alternative Models May be Used –*** The sketch-planning methodology developed and implemented in this case can be reproduced in Excel and be used in combination with your existing traffic simulation models.
- ***Value of Time May be Incorporated –*** This case study describes how you can use conversion factors to quantify the value of time benefits. MWCOG used a ratio established by the State DOT. You may need to select a ratio that fits your jurisdiction's characteristics.
- ***Additional Benefit Estimates May be Included –*** As TOPS-BC provides a specific set of benefits, you may have other benefit estimates such as reductions in vehicle emissions and the value of time. TOPS-BC allows you to enter these values directly and have them included in the benefit-cost analysis.

Case Study 6.4 – Regional Traffic Management Center, Ft. Lauderdale, FL

Strategy Type:	Freeway Systems
Project Name:	Regional Traffic Management Center
Project Agency:	Florida Department of Transportation (FDOT)
Location:	Urban and Rural
Geographic Extent:	Regional/Urban
Tool Used:	Custom Stand Alone BCA Model

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Problem Technology or Strategy

Florida Department of Transportation (FDOT) District 4 operates The Fort Lauderdale System Management for Advanced Roadway Technologies (SMART) SunGuide Regional Traffic Management Center (RTMC). The center manages intelligent transportation systems (ITS) for the Florida Interstate Highway System (FIHS) in Broward County. The program area includes the I-95, I-75, and I-595 corridors in Broward County. The RTMC operates 7 days per week, 24 hours per day. The program is the product of a FDOT effort that began in the mid-1990s, designed to deploy ITS technologies to manage the region's surface transportation system from a common facility. The system became fully operational in 2004.

Project Goals and Objectives

The goals of SMART SunGuide RTMC are to:

- Provide outstanding ITS products and services to transportation planning stakeholders and the traveling public continuously; and
- Be the best ITS program, by maximizing roadway efficiency, using technology, innovation, and continuous improvement.

To meet these objectives, the program applies ITS technologies to make the transportation system more efficient and facilitates interagency communication and coordination to respond to traffic incidents. The RTMC's ITS technologies include:

- Closed circuit television (CCTV) cameras used for real-time monitoring and incident detection directly from the SMART SunGuide RTMCs.
- Dynamic message signs (DMS) located on the highway and many arterial roads leading to the highway.
- SunGuide software in all of the TMCs in Florida.
- Vehicle detection system that is made up of roadside detectors placed approximately every half mile, which capture traffic data, such as speed, volume and occupancy.

In 2006, FDOT commissioned a study by the Lehman Center for Transportation at Florida International University to evaluate the RTMC programs from a benefit cost perspective.

This case study will summarize the approached used to identify, quantify and analyze the benefits and costs of this traffic management center. This procedure may be reproduced and customized to fit your organization's needs. This study also serves as an example of how one BCA methodology can be used to evaluate multiple strategies.

Data

The FDOT SMART database was used to gather inputs for the BCA study. This database provides detailed incident statistics by location, frequency, duration and type of blockage and the number of DMS message activations. Other FDOT databases provide AADT and hourly volume statistics and roadway geometry information (number of lanes, section length, etc.).

Benefit Cost Evaluation

The objectives of FDOT BCA were to evaluate the cost and benefits attributed to the RTMC operations. The study used a series of custom Excel spreadsheets that calculated delays; queue lengths and total number of vehicles queued using a combination of information from the SMART database and the highway capacity manual, which provides data for capacity under incident and no-incident conditions. A Florida-specific IDAS model was used to calculate emissions, fuel consumption, and safety impacts.

Model Run Results

Costs

Cost data for the RMTC program were derived from the FDOT annual operating budget. In 2006, the total annual cost of the program was $8,239,397. The considered costs include capital, operation, and maintenance costs. This figure also included was the value of service contracts for freeway service patrol operators and related incident response management activities.

Benefits

Dollar estimates for the following benefits were developed:

- Reduction in travel time.
- Reduction in secondary incidents.
- Reduction in fatalities due to faster response.
- Reduction in fuel consumption.

Calculating Benefits

- The difference between incidents duration was considered the total travel time reduction benefit. The time savings, expressed in hours, was then multiplied by value of time conversion factors ($13.35 per hour for automobiles and $71.05 per hour for trucks) to convert the time savings to dollar values.
- 10% fatality reduction factor.
- 2.8% crash reduction factor.
- Dollar values for avoided crash incidents: $3,200,000 per fatal crash, $74,730 per injury crash, and $2,000 per property-damage-only crash.

- Reduction in emissions.
- Monetary benefits to drivers due to free services provided by the freeway service patrol.

Of particular note is the evaluation's method to quantify the reduction in travel time. The study used an Excel spreadsheet model that compiles the number and type of freeway incidents for the region in a given year and calculates the durations of each incident where the RTMC was involved. These values were compared to estimates of detection, verification and response times from the available literature. The difference between incident duration was considered the total travel time reduction benefit. The time savings, expressed in hours, was then multiplied by value of time conversion factors ($13.35 per hour per passenger for automobiles and $71.05 per hour for trucks) to convert the time savings to dollar values.

The analysis estimated the impact of two safety-related benefits: 1) reduction in secondary incidents and 2) reduction in fatalities due to faster response. These safety benefits were calculated by estimating the annual frequencies of fatal, injury and property damage only (PDO) crashes with no automated traffic management system (ATMS) in place. These were calculated using Florida urban freeway incident rates in the IDAS program, which were modified to reflect Florida specific traffic conditions. The benefits were estimated by multiplying this annual frequency of crashes by reduction factors estimated on previous ATMS studies.

The study used a fatality reduction factor of 10 percent to account for faster response to injuries. This figure was based on IDAS default rates which contains estimates for reduction in incident notification and response times that results in faster provided care to injured travelers; result in a 10-15 percent decrease in urban Interstate fatalities. (Additional information on IDAS rates can be found in the Section 2.6 - Benefits – of the IDAS User Guide).

The study used a 2.8 percent crash reduction factor to estimate of the impact of traffic management strategies on the number of fatal, injury, and PDO crashes. This factor was selected after a review of previous studies indicating that incident management resulted in 2.8 percent reduction in crashes in San Antonio, Texas. However, other studies have indicated higher reductions in crash rates (15-40 percent reductions) due to the implementation of incident management strategies. The lowest reduction factor was selected to ensure a conservative benefits estimate.

The evaluation also provides a methodology for additional safety benefits, which are expressed as reduced crash related injuries and fatalities. Using a method similar to the time savings benefit estimation above, the study used the following conversion factors to convert avoided crash incidents into dollar values: $3,200,000 per fatal crash, $74,730 per injury crash, and $2,000 per PDO crash.

As shown in Table 29, the BCA results show that in 2006 RTMC program yielded significant benefits. The resulting benefit-to-cost ratio is $10.44:1.

Table 29. Benefit-Cost Summary for the Regional Traffic Management Center in Ft. Lauderdale.

2006 Benefits	
Total Benefits	**$86,002,364**
2006 Costs	
Total Costs	**$8,239,397**
Benefit-Cost Comparison	
Net Benefit	$77,762,967
Benefit-Cost Ratio	10.44:1

Source: Florida DOT

Key Observations

Conducting benefit cost analyses of TSMO projects can seem very challenging at first. However, many previous analysis and tools are available to assist you in the process. For example the sketch-planning methodology developed and implemented in this case can be reproduced in Excel and be used in combination with your existing traffic simulation models. This will allow you to use your own traffic and incident data. If you plan to use TOPS-BC as alternative, there are default values that should be review to see if they seem appropriate for your region or project.

TOPS-BC covers all of the key benefit categories including: reduction in travel time, reduction in secondary incidents, reduction in fatalities due to faster response, reduction in fuel consumption, and reduction in emissions. The user can rely on TOPS-BC defaults or employ local information.

Monetary benefits to drivers due to free services provided by the freeway service patrol is another important benefit of this program.

This case study also showed that you can use different conversion factors to quantify the value of time and safety benefits. Florida DOT's study used ratios developed by a local university. You may need to select a ratio that fits your jurisdiction's characteristics.

Case Study 6.5 – Coordinated Highways Action Response Team, Maryland

Strategy Type:	Freeway Management
Project Name:	Coordinated Highways Action Response Team
Project Agency:	Maryland Department of Transportation (MDOT)
Location:	Urban and Rural
Geographic Extent:	Regional/Urban
Tool Used:	Custom Stand Alone Benefit Analysis

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Problem Technology or Strategy

Coordinated Highways Action Response Team (CHART) is a joint initiative of the Maryland Department of Transportation, Maryland Transportation Authority and the Maryland State Police, in cooperation with other federal, state and local agencies. The program began in the mid-1980's in an effort to improve travel to and from Maryland's eastern shore. It has evolved into a multi-jurisdictional and multi-disciplinary program.

Today, this advanced traffic management system is enhanced by a command and control center called the Statewide Operations Center (SOC). The SOC is the "hub" of the CHART system, functioning 24 hours-a-day, seven days a week with four satellite Traffic Operations Centers (TOCs) located across the state to handle peak-period traffic.

Project Goals and Objectives

CHART's mission is to improve "real-time" operations of Maryland's highway system through teamwork and technology. To meet this objective, CHART oversees the following activities:

- Traffic monitoring.
- Incident response.
- Dissemination of local traveler information via website.
- Traffic management.
- Severe weather and emergency operations.

The Maryland State Highway Administration tasked the University of Maryland to conduct an annual performance evaluation and benefits analysis of the program.

This case study will summarize the approached used to identify, quantify and analyze the benefits of this traffic incident management program. Specifically, this case study will highlight the study's approach to quantifying the benefits of reduced delay to highway users. This procedure may be reproduced and customized to fit your organization's needs.

Data

Since 1997, University of Maryland researchers have used actual performance data collected from the CHART program. This data included incident management records from the statewide operation centers as well as accident report data from the Maryland State Police. In 2012, CHART recorded over 63,500 emergency response cases. Data elements for each case include:

- Location and road name of each incident.
- Incident by type and by number of lanes closed.
- Incidents and disabled vehicles by time of day.
- Source and time of incident detection.
- Time and duration of incident response.

This study conducted a statistical analysis of incident durations to provide insight into the characteristics of incident durations under various conditions. The distributions of average incident duration were identified by a range of categories including: nature, county, weekdays and weekends, peak and off-peak hours, CHART involvement, and roads.

Researchers also collected and compared average duration of incidents and response times from incidents managed by other agencies.

Benefit Cost Evaluation

The objectives of the benefits analysis were is to evaluate the effectiveness of CHART's incident detection, response, and traffic management operations on Interstate freeways and major arterials. An estimate of CHART benefits is also provided quantify the benefits the state obtains from its ongoing programs. The most recent study was published in July 2013.

To complete this task, researchers used the following methodology:

1. Collect and assess the quality of data.
2. Conduct a statistical analysis of incident data characteristics and compare average incident duration caused by different types of accidents.
3. Analyze data to determine the efficiency and effectiveness of incident detection.
4. Conduct a statistical analysis of incident response times.
5. Conduct a statistical analysis of incident duration times.
6. Estimate the direct benefits of CHART.
7. Compare the costs and benefits.

Model Run Results

Costs

The focus of the evaluation was to analyze and quantify the benefits of the program. No specific comparison of the cost was completed.

Benefits

Direct benefits associated with CHART include:

- Assistance to drivers.
- Reduction in secondary incidents.
- Reduction in driver delay time.
- Reduction in vehicle operating hours.
- Reduction in fuel consumption.
- Reduction in emissions.

Of note is the researchers' approach to estimating the value of time benefits resulting from reduced delays. By calculating the difference between actual incident durations resulting from CHART involvement to average incident duration times collected from similar state agencies where CHART was not involved, the study estimates the total time saved by type of vehicle attributable to the CHART program. Incident duration is defined as the time from the lane-blocking incident to the time the lanes are re-opened. Using the unit rates obtained from the U.S Census Bureau (2012) and the Energy Information Administration (2012), researchers then convert delays to monetary value. Each delay is multiplied by the value of time factors - $20.21 per hour for driver and $45.40 per hr. for truck.

The study also used a similar approach to quantify the reduction in fuel consumption and emissions attributed to CHART involvement. The reductions in delay were multiplied by the following conversion factors:

- Fuel consumption was computed based on the rate of 0.156 gallons of gas per hour for passenger cars from the Ohio Air Quality Development Authority and the rate of 0.85 gallon per hour for trucks from the literature and the Environmental Protection Agency (EPA).
- Emissions reductions were computed based on the unit rates of 19.56 pounds CO_2/gallon of gasoline and 22.38 pounds CO_2/gallon of diesel from the Energy Information Administration and $23/metric ton of CO_2 from the Congressional Budget Office's cost estimate outlined in the America's Climate Security Act of 2007.

Table 30. Benefit-Cost Summary for the Coordinated Highways Action Response Team.

Annual Benefits	
Reduced Delay, Trucks	$108.59 million
Reduced Delay, Cars	$799.54 million
Total Fuel Consumption Savings	$21.01 million
Emissions	$32.56 million
Total Annual Benefits	**$961.69 million**

Key Observations

Conducting benefit cost analyses of transportation systems management and operations (TSMO) projects can seem very challenging at first. However, many previous analyses and tools are available to assist you in the process. Some items of particular interest in this case include:

- *Use of Real Project Data* – TOPS-BC and other BCA tools often include default values for required inputs. These are national estimates taken from the published literature. You should review these values to see if they seem appropriate for your region or project.
- *Availability of Alternative Models* – The sketch-planning methodology developed and implemented in this case can be reproduced in Excel and be used in combination with your existing traffic simulation models.
- *Incorporation of the Value of Time –* This case study describes how you can use conversion factors to quantify the value of time benefits. Researchers in this study developed their time conversion factors using the U.S. Census Bureau. You may need to select a ratio that fits your jurisdiction's characteristics.
- *Inclusion of Additional Benefit Estimates –* As TOPS-BC provides a specific set of benefits, you may have other benefit estimates such as reductions in vehicle emissions and the value of time. TOPS-BC allows you to enter these values directly and have them included in the benefit-cost analysis.

Case Study 6.6 – Georgia NaviGator Traffic Incident Management System

Strategy Type:	Freeway Management
Project Name:	NaviGator Traffic Incident Management System
Project Agency:	Georgia Department of Transportation (GDOT)
Location:	Urban and Rural
Geographic Extent:	Regional/Urban
Tool Used:	Custom Stand Alone Benefit Analysis

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Traffic incident management is the process of coordinating the resources of a number of different partner agencies and private sector companies to detect, respond to, and clear traffic incidents as quickly as possible to reduce the impacts of incidents on safety and congestion, while protecting the safety of on-scene responders and the traveling public.

Project Goals and Objectives

The Georgia NaviGAtor system is a highly integrated traffic incident management system that uses a variety of technologies and processes to monitor the operation of the freeway and arterial system, respond to a variety of incidents, and disseminate traveler information. The goal of NaviGAtor is to reduce traffic congestion caused by traffic incidents as well as secondary crashes that result from incident-related congestion, and to improve overall mobility for the public.

In 2006, Georgia DOT published a study that established a methodology to assess a wide range benefits associated with the Georgia NaviGAtor system and described the resulting benefits and cost analysis.

This case study highlights key methods utilized in the BCA analysis to calculate three of these benefits. These include: 1) reduction in travel delay, 2) savings due to delay reduction, and 3) savings due to secondary crash reduction.

Data

Costs. Cost data used in the BCA were obtained from the NaviGator program's annual operating budget for 2003 through 2004. This amounted to $42.5 million.

Benefits. As shown in Table 31, the BCA analysis selected six areas of program benefits, with associated measures of benefits.

Table 31. Benefit Categories for Traffic Incident Management.

Program Area Goal	Benefit Measure
Mobility	• Reduction in travel time and delay • Reduction in travel time variation
Safety	• Reduction of crash rate
Capacity	• Increase in throughput
Customer Satisfaction	• Level of Service • Survey responses
Energy and Environment	• Reduction in emissions • Reduction in fuel consumption
Productivity/Cost Savings	• Money saved due to delay reduction • Money Saved due to secondary crash reduction • Money Saved due to emission reduction • Money Saved due to fuel consumption reduction • Money Saved due to motorist assistance

Benefit Cost Evaluation

This case study highlights key methods utilized in the BCA analysis to calculate three benefits types: 1) reduction in travel delay, 2) savings due to delay reduction, and 3) savings due to secondary crash reduction.

Reduction in Travel Delay. The traffic incident management system reduces travel delay by reducing: incident detection times, emergency response times and durations. The delay savings were calculated as the result of the reduction time it takes to respond to and clear an incident using the NaviGator system when compared with a response time of a similar incident responded to without the Navigator System (also called the "baseline" scenario). Using the NaviGator system logs and surveys of emergency response organizations, the "Navigator Managed" and" Baseline" data sets were developed. Average incident detection times, emergency response times and incident durations where NaviGator managed the response were subtracted from the baseline. For example, the average reduction in incident-duration because of NaviGAtor is calculated as:

> Average reduction in incident-duration = Baseline incident duration – NaviGAtor managed incident duration = 66.6 minutes - 20.7 minutes = 45.9 minutes

Savings Due to Travel Delay Reduction. After calculating the total delay savings (vehicle-hours), the cost savings associated with delay reduction was calculated. These savings result from the decrease in time that motorists spend in traffic attributed to NaviGAtor, as converted to a dollar figure estimate for the motorists' value of time. The dollar amount used to estimate the value of motorists' time was based on data from the Bureau of Labor Statistics. The study assumed that the average vehicle occupancy on Atlanta freeways for persons driving from home to work is 1.16 persons per vehicle. The savings due to delay reduction calculation uses this occupancy value to capture the driver and passenger's time. The percent cars and trucks are also determined, based on the segment where the incident occurs, to give a more accurate estimate of the value of time. The average truck's value of time is different from the average value of time for an individual in a car, and different corridors in the Atlanta region have wide variations in percent trucks. The percentage of trucks on highway segments that NaviGAtor manages was determined by using data from GDOT count stations.

The equation used to determine the individual incident savings attributed to NaviGator is as follows:

$$IDS(Cost) = IDS(Veh\text{-}Hr) * [(Cars(\%) * Occ * Car(Cost)) + (Trucks(\%) * Truck(Cost))]$$

Figure 27. Equation. Individual Incident Savings.

From this calculation, the cost savings for all incidents worked by NaviGAtor are summed to give the total cost savings:

$$Total\ IDS(Cost) = \Sigma x/1\ IDS(Cost)$$

Figure 28. Equation. Cost Savings for All Incidents

Where:

IDS(Cost) = Incident Delay Savings in Terms of Dollars Saved
Cars(%) = Percent Cars by Segment (Varies)
Cars(Cost) = Cost Per Passenger Per Hour ($19.14/hour)
Trucks(%) = Percent Trucks by Segment (Varies)
Truck(Cost) = Cost Per Vehicle Per Hour ($32.15/hour)
x = Number of Incidents Worked by NaviGAtor
Occ = Vehicle Occupancy (1.165 persons/vehicle)

Savings Due to Secondary Crash Reduction. Secondary crashes are the result of the change in traffic patterns because of the effects of an upstream incident and can be defined by the occurrence of a crash within a predefined distance and time threshold from a primary crash. The reduction in secondary crashes due to NaviGAtor is a result of the reduced incident duration time from the incident management program. The BCA analysis used the equation below to calculate the number of secondary crashes that would occur on average, based on the assumption that 15 percent of all crashes are secondary crashes.

The calculation is as follows:

Number of secondary crashes in the baseline condition = X * 15.00%

Figure 29. Equation. Number of Secondary Crashes in the Baseline Condition.

Where:

X = Total number of crashes in the baseline condition = 4512

The above number is the number of crashes with in the presence of the NaviGAtor system and is an estimate to the number of crashes in the baseline condition. The baseline condition is expected to have a higher number of incidents; therefore, this number is a conservative estimate.

Number of secondary crashes in the baseline condition = 4512 * 15.00% = 676 crashes

The estimated decrease in secondary crashes is computed as:

Decrease in secondary crashes because of NaviGAtor = Number of secondary crashes in baseline condition * [(T1 - T2)/T1]

Figure 30. Equation. Estimated Decrease In Secondary Crashes.

Where:

T1 = Average incident duration (baseline condition) = 66.6 minutes
T2 = Average incident duration (NaviGAtor condition) = 20.7 minutes

Therefore:

Decrease in secondary crashes because of NaviGAtor = 676 crashes* [(66.6 minutes - 20.7 minutes)/ 66.6 minutes] = 466 crashes

The cost savings from the reduction in secondary crashes is:

Cost Savings = Decrease in secondary crashes because of NaviGAtor * Acc$

Figure 31. Equation. Cost Savings from the Reduction in Secondary Crashes.

Where:

Acc$ = Average cost of a two-vehicle property damage only crash = $3,458 per crash

Therefore:

Cost Savings = 466 crashes ** $3,458 /crash* = $1,611,054

The average cost associated with each crash is based on data provided by the National Highway Traffic Safety Administration. The rate used is for a low-impact crash (property damage only) involving two vehicles. While crashes that result from a vehicle queue can be severe and result in injuries, a low-impact crash assumption was chosen to give a more conservative estimate for the cost savings benefit.

Model Run Results

The study determined that annual benefit-cost ratio of the NaviGAtor system in 2003/2004 was 4.4:1 ($186.8M/$42.5M). Table 32 summarizes the BCA results.

Table 32. Benefit-Cost Summary for the Georgia NaviGator Traffic Incident Management System.

ANNUAL BENEFITS (2003-2004)	
Mobility – incident delay savings	$152,053,180
Environmental – reduced emissions	$20,243,009
Environmental – reduced emissions	$10,365,969
Safety – reduced secondary crashes	$1,611,054
Customer Satisfaction – motorist assistance	$2,955,323
Total Annual Benefits	**$187,228,535**
ANNUAL COSTS	
Total Annual Costs	**$42.5 million**
BENEFIT-COST COMPARISON	
Benefit-Cost Ratio	**4.4:1**

Source: Georgia DOT

Key Observations

This case identifies three potential methodologies that can be replicated to estimate benefits associated with traffic incident management system deployment. Specifically, this case outlined specific mathematical equations that can be used to quantify the reductions in travel incident delay, savings due to delay reduction, and savings due to secondary crash reduction. In this case, the agency used data from responders and the incident management system's database to compare and contrast program results with a baseline condition where no program existed.

CHAPTER 7. DEMAND MANAGEMENT

#	Case Name	Benefit-Cost Analysis (BCA) Model	Actual or Hypothetical Case
7.1	Minnesota I-35W Urban Partnership	Project Developed BCA Tool	Actual
7.2	Interstate I-95 Express Managed Lanes	TOPS-BC	Actual

Case Study 7.1 – Minnesota I-35W Urban Partnership

Strategy Type:	Demand Management and Congestion Pricing
Project Name:	Minnesota Urban Partnership Agreement (UPA)
Project Agency:	U.S. Department of Transportation
Location:	Urban Region
Geographic Extent:	Regional/Urban
Tool Used:	Project Developed BCA Tool

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

In 2006, the U.S. Department of Transportation, in partnership with metropolitan areas, initiated a program to explore reducing congestion through the implementation of congestion pricing activities combined with necessary supporting elements. This program was instituted through the Urban Partnership Agreements (UPA) and the Congestion Reduction Demonstrations (CRDs). Minneapolis, Minnesota was selected for a UPA award. The projects under the Minnesota UPA focused on reducing traffic congestion in the I-35W corridor and in downtown Minneapolis. I-35W South is the section south of downtown Minneapolis and I-35W North is the section north of downtown Minneapolis.

This case study and all tables and data are taken directly from Appendix J of *Urban Partnership Agreement: Minnesota Evaluation Report*, http://www.dot.state.mn.us/rtmc/reports/hov/20130419MnUPA_Evaluation_Final_Rpt.pdf

The Minnesota UPA included 24 projects. A major focus of the Minnesota UPA was on reducing congestion on I-35W South. As a result, the Minnesota UPA Benefit-Cost Analysis (BCA) focused on projects associated with I-35W South. Table 33 describes the projects associated with I-35W South that were included in the BCA and how the portion of the costs included in the BCA were determined.

Table 33. Minnesota Urban Partnership Agreement Projects Included in the Benefit-Cost Analysis.

Urban Partnership Agreement Project	Notes on Costs Included
Expanding existing high-occupancy vehicle (HOV) to high-occupancy toll (HOT) lanes, new HOT lanes, priced dynamic shoulder lane (PDSL), and auxiliary lanes	The costs of these projects are included in the benefit-cost analysis
Kenrick Park-and-Ride Lot Cedar Grove Park-and-Ride Lot Apple Valley Transit Station and Park-and-Ride Lot Lakeville Park-and-Ride Lot	The cost of the projects included in the benefit cost analysis was based on the percentage of routes using I-35W South. For Kenrick this is 100%, for Cedar Grove it is 42% (5 of 12 routes), for Lakeville it is 100%, and for Apple Valley it is 66.7% (2 of 3 routes)
27 new buses, 22 in service and 5 spares	The cost was based on the number of buses (7) assigned to the I-35W South routes. This includes 5 for Kenrick (5 of 22 = 22.7%) and 2 for Apple Valley (2 of 22 x 66.7% = 6.1%)
Driver Assist Systems (DAS) for shoulder-running buses	All costs for the project were included in the benefit-cost analysis
eWorkPlace Telecommuting Program	Partial costs determined by number of eWorkPlace telecommuters using I-35W South (14 percent)
ATM signing and real-time transit and traffic informational signs	All costs of Advanced Traffic Management(ATM) and costs for real-time traffic and transit signs on I-35W South
MARQ2 contraflow bus lanes in downtown Minneapolis	All costs for the project were included in the benefit-cost analysis
"Transit Advantage" bus bypass lane/ramp at the Highway 77/Highway 62 intersection	All costs for the project were included in the benefit-cost analysis
Real-time transit and next bus arrival information in downtown Minneapolis and selected park-and-ride lots	All costs for the project were included in the benefit-cost analysis
Reconstruction of the Crosstown Commons section	All costs for this project were included since the benefits of the project were inseparable from the benefits of the Urban Partnership Agreement projects

Source: Federal Highway Administration

Three Minnesota UPA projects were not included in the BCA because they are on I-35W North, outside the main UPA focus corridor of I-35W South. The projects not included in the BCA are the I-35W North and 95th Avenue park-and-ride lot expansion, the new park-and-ride lot at I-35W North and County Road C, and the real-time traffic and transit information signs along I-35W North.

Project Goals and Objectives

The addition of the MnPASS HOT lanes, the PDSL, the new and expanded park-and-ride lots, the new bus routes, the new auxiliary lanes on I-35W South, and the MARQ2 lanes in downtown Minneapolis provided additional capacity on I-35W South and travel options for users. The new general-purpose freeway lanes in the Crosstown Commons section, which were not part of the UPA, also added capacity and, along with other improvements in this section, eliminated a major bottleneck on the freeway. All of these improvements were expected to result in increased travel speeds, reduced travel times, and increased throughput.

Data

The BCA for the Minnesota UPA projects used several data sources:

- Data on the capital costs of projects were obtained from the Minnesota Department of Transportation (MnDOT), Metro Transit, and the City of Minneapolis.
- Data on the operation and maintenance costs associated with the projects was obtained from these same agencies. MnDOT had overall responsibility for the freeway projects and the eWorkPlace telecommuting program. Metro Transit had overall responsibility for the transit projects, although Minnesota Valley Transit Authority (MVTA) was the designated lead agency on the driver assist system (DAS) for shoulder running buses and one of the park-and-ride lots. The City of Minneapolis was the designated lead agency on the Marquette and Second Avenue (MARQ2) dual bus lanes in downtown Minneapolis.
- Information on benefits, including travel-time savings, fuel savings, emissions reductions, and changes in crash rates was obtained from the analyses presented in the Minnesota UPA Evaluation Report (http://www.dot.state.mn.us/rtmc/reports/hov/20130419MnUPA_Evaluation_Final_Rpt.pdf).
    - The trip- time savings and traffic volumes on I-35W South were obtained from the MnDOT loop detector data examined in Appendix A – Congestion Analysis.
    - The reductions in emissions from the UPA projects were obtained from Appendix H – Environmental Analysis.
    - The safety benefits were estimated using the Minnesota Department of Public Safety (DPS) Crash Database presented in Appendix F – Safety Analysis.
    - The change in fuel use was based on the information in Appendix H – Environmental Analysis and gasoline prices from the U.S. Energy Information Administration monitored in Appendix K – Exogenous Factors.

Minnesota UPA Projects – Costs

Data on the capital costs, the implementation costs, the operating and maintenance costs, and the replacement and re-investment costs for the projects were obtained from MnDOT and Metro Transit. To convert any future year costs to year 2009 dollars, a real discount rate of 7 percent per year was used (based on guidance from http://www.whitehouse.gov/omb/assets/a94/a094.pdf (page 9) and current FHWA guidance (Federal Register, Vol. 75, No. 104, p. 30476)).

A 10-year post-deployment timeframe was used for the BCA since many aspects of the projects were technology- or pricing-related. Both technology and pricing systems have relatively short life spans. Thus, only expenditures prior to December of 2019 incurred as a result of implementing the UPA projects were considered. In addition, only the marginal costs associated with the UPA projects and the reconstruction of the Crosstown Commons section were included in the cost data. The BCA timeframe began with the first expenses incurred and ends in 2019, after 10 years of operations. **The Minnesota UPA projects with useful lives longer than 10 years, such as new park-and-ride lots or new HOT lanes, were accounted for by including their salvage value in year 10.**

The U.S. DOT allocated $133.3 million for the Minnesota UPA projects. The state of Minnesota funded the eWorkPlace telecommuting program. The funding was used to plan, design, and construct the various projects. Operating and maintaining the projects over the BCA timeframe of 10 years will require additional funding. To address costs incurred in years other than 2009, those costs were adjusted to a common year using a discount rate of 7 percent. Therefore, determining the costs of the UPA projects was more difficult than simply assuming that the costs total $133 million. Table 34 describes the costs associated with the Minnesota UPA BCA.

Table 34. Minnesota Urban Partnership Agreement Project Costs included in the Benefit-Cost Analysis.

Urban Partnership Agreement Project Component	Planning, Design, and Construction/Purchase Costs (2009 dollars)	Operation and Maintenance Costs (years 2010 to 2019 in 2009 dollars)
High-occupancy toll lanes, priced dynamic shoulder lanes, and auxiliary lanes	$39,616,038	$836,600 per year for years 2010-2019 = $5,875,928
Four new or expanded park-and-ride facilities	Krenick ($12,515,367) + Lakeville ($2,263,590) + Cedar Grove (0.42x$2,521,227) + Apple Valley (0.667x$22,791,796) + MnDOT Project 2716-67 ($533,528) = $31,707,815	$40,000 per year for 10 years = $300,609
27 new buses	5 of the 22 (68%) were for Kenrick and 2 were for Apple Valley (x 0.667) plus 5 were spares. Cost = 28.8% x $12,743,259 = $3,668,514	Annual figures provided by METRO, converted to 2009 dollars = $5,548,871
Lane guidance system for shoulder-running buses[1]	$5,315,573	Annual figures provided by METRO, converted to 2009 dollars = $106,215
eWorkPlace Telecommuting Program	$3,304,355 x 14% = $462,610 Estimated 14% of travelers were on I-35W south of town.	
Active traffic management signing and real-time traffic and transit informational signs	$22,558,642	$300,000 per year for 5 years starting in 2015 = $877,015

Table 34. Minnesota Urban Partnership Agreement Project Costs included in the Benefit-Cost Analysis (cont'd).

Urban Partnership Agreement Project Component	Planning, Design, and Construction/Purchase Costs (2009 dollars)	Operation and Maintenance Costs (years 2010 to 2019 in 2009 dollars)
Double contraflow bus lanes on Marquette and 2nd Avenues (MARQ2) in downtown Minneapolis	$33,405,610	Annual figures provided by METRO, converted to 2009 dollars = $724,602
"Transit Advantage" bus bypass lane/ramp at the Highway 77/Highway 62 intersection	$714,779	$0
Real-time transit and next bus arrival information	$14,114,219	Annual figures provided by METRO, converted to 2009 dollars = $1,526,918
Crosstown Commons	$228,000,000	$632,122
TOTALS	**$379,563,800**	**$15,592,281**

[1]There will be a small reinvestment cost ($2,400) for lane guidance equipment in the year 2015. For simplicity this has been added to the operations and maintenance costs.

In December 2019 some of the above items will still have value, which is known as salvage value. The salvage value will be subtracted from the total cost above (approximately $395,156,082) to determine the cost over the 10 year BCA timeframe. The electronic components of the DAS for shoulder-running buses, real-time transit and next bus arrival information, transit signal priority along Central Avenue, the telework program, and the real time traffic informational signs were assumed to have negligible salvage value at the end of 10 years. For the physical infrastructure (HOT lane, PDSL, P&R lots, MARQ2, and Transit Advantage Lane) Minnesota's BCA guidance was used (http://www.dot.state.mn.us/planning/program/benefitcost.html) to obtain the salvage value using the following formula:

$$\text{Salvage Value} = \frac{(1+r)^n \times \left[\left(\frac{(1+r)^L - 1}{r(1+r)^L}\right) - \left(\frac{(1+r)^n - 1}{r(1+r)^n}\right)\right]}{\left(\frac{(1+r)^L - 1}{r(1+r)^L}\right)}$$

Figure 32. Equation. Salvage Value.

Where

r = the discount rate (0.07)

n = number of years in the analysis period (10)

L = useful life of the asset

This same guidance suggests the useful life of surface (pavement) is 25 years, sub-base and base are 40 years, and major structures have longer timeframes. Since many of these items are additional lanes or parking lots, a life span of 40 years was chosen. The salvage value is therefore:

$$\text{Salvage Value} = \frac{(1+0.07)^{10} \times \left[\left(\frac{(1+0.07)^{40}-1}{0.07\times(1+0.07)^{40}}\right) - \left(\frac{(1+0.07)^{10}-1}{0.07\times(1+0.07)^{10}}\right)\right]}{\left(\frac{(1+0.07)^{40}-1}{0.07\times(1+0.07)^{40}}\right)} = \frac{1.97\times(13.33-7.02)}{13.33} = 0.931 = 93.1\%$$

Figure 33. Equation. Salvage Value Calculated Using Minnesota Urban Partnership Agreement Data.

$\text{Salvage Value} = 93.1\% \times (\$39,616,038 + \$31,707,815 + \$33,405,610 + \$714,779 + \$228,000,000) = 93.1\% \times \$333,444,242 = \$310,367,064$

The one remaining item is the salvage value of the 27 new buses after 10 years of service. Assuming that the buses have a useful life of 12 years then the salvage value equals: $3,668,514 x 22.8% = $835,075.

Therefore, the resulting 10-year costs from the Minnesota UPA projects were $395,156,082 - $310,367,064 - $835,075= $83,953,942.

Benefits

The benefits of the Minnesota UPA projects are similar to benefits from many transportation infrastructure projects and the calculation methodology will follow standard practice (http://bca.transportationeconomics.org/). This section highlights how the benefits were calculated for the UPA projects.

The preferred option to estimate the impacts, and therefore benefits, of the UPA projects was to use the Metropolitan Council's urban planning model. Unfortunately, the output from the model for the year 2010 for I-35W South was considerably different than results recorded in the field based on data from Minnesota's extensive loop detector system. For example, the model output showed considerable congestion during the morning and evening peak period where actual data showed only minor congestion. Travel speeds in the model were between 10 mph to 30 mph slower than actual speeds (depending on direction, segment of I-35W and time of day). Thus, the model could not be expected to accurately capture the change in travel conditions caused by the UPA projects. Additionally, the amount of modifications and calibrations that would have been required to adjust model outputs to real world results would have yielded a model that was so altered that it could no longer be expected to properly estimate the impacts of the UPA projects.

Using actual data to estimate the impact of the UPA projects has one main advantage – it is the true data but has several disadvantages. The main disadvantages are (1) the impact of exogenous factors, for example the price of gas impacting travel or the new cross town connector, cannot be properly excluded and (2) actual data is good only for the year it was collected and impacts in future years must be estimated. An assumption was made that the impacts observed in the first year post-deployment will remain constant over the 10-year timeframe. In theory, using year one changes would represent a conservative estimate of benefits since many key benefits of the UPA projects would increase over time given the expected continued increase in regional traffic volumes and health care costs (which will equate to greater benefits associated with emissions reductions).

Finally, since the reconstruction of the Crosstown Commons section occurred at the same time as the UPA projects, it was impossible to separate the impacts (benefits) of the UPA projects from the Crosstown Commons section reconstruction. Therefore, the benefits outlined below are likely due to the UPA projects and the Crosstown Commons section reconstruction. As a result, the costs of both the UPA projects and the Crosstown Commons section were included in the BCA.

Travel Time Savings

The amount of time saved by travelers was converted to monetary benefits based on FHWA guidance (Table 4 in http://www.transportation.gov/sites/dot.gov/files/docs/USDOT%20VOT%20Guidance%202014.pdf). The value of time for the year 2009 was $12.50 based on local travel, weighted by the average of both business and other travel. This value was adjusted for future values of time by increasing it by 1.6 percent per year (prior to applying the discount rate) as outlined in the FHWA document http://www.transportation.gov/sites/dot.gov/files/docs/USDOT%20VOT%20Guidance%202014.pdf.

Travel time data for travelers on I-35W South was obtained from MnDOT's extensive system of loop detectors and analyzed as part of the traffic data analysis conducted as part of the UPA evaluation. These detectors provided a reliable source of data to determine travel speeds pre- and post-deployment of the UPA projects. The pre- deployment data used in the congestion analysis covered the period from October 2008 to April of 2009 and the post-deployment data covered the period from December 2010 to October 2011. The loop detector data was obtained from the following three sections of I-35W South for the congestion analysis.

- From Burnsville Parkway to north of I-494 where the existing HOV lanes were expanded to HOT lanes. This section is referred to as the "HOT" section in Table 35.
- From 76th Street to 42nd Street through the Crosstown Commons section, where a new HOT lane and a new general-purpose freeway lane was added in each directions of travel. This section is referred to as the "XTOWN" in Table 35.
- From 42nd Street to 26th Street, where the new PDSL is located. This section is referred to as the "PDSL" section in Table 35.

Only peak periods travel times were included in the analysis. The UPA projects were expected to have minimal to no impact on travel times in off peak periods as those travel times were already free- flow. The travel time savings are shown in Table 35.

Table 35. Travel Time Savings on I-35W South (minutes).

Direction	Lane	Section	Time of Day (half hour ending time)									
			6:30	7:00	7:30	8:00	8:30	9:00	9:30	10:00		
Northbound	General purpose lane	High-occupancy toll lanes	0.7	0.87	2.515	4.465	3.2	1.995	1.12	1.06		
Northbound	General purpose lane	Out of town lanes	1.155	2.17	3.065	4.98	4.735	5.13	3.695	2.57		
Northbound	General purpose lane	Priced dynamic shoulder lanes	-0.135	-0.205	-0.435	-1.76	-1.36	-0.93	-0.395	-0.2		
Northbound	High-occupancy toll lanes	High-occupancy toll lanes	0.08	0.3	0.33	0.38	0.485	0.41	0.76	0.625		
Northbound	High-occupancy toll lanes	Out of town lanes	0.715	1.88	2.89	6.44	6.115	5.835	4.13	2.9		
Northbound	Single lane	Priced dynamic shoulder lanes	-0.44	-0.375	-0.56	-0.83	-0.69	-0.38	-0.16	-0.04		
			14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00
Southbound	General purpose lane	Priced dynamic shoulder lanes	1.34	1.6	2.61	2.355	2.71	2.715	2.43	2.175	1.605	1.07
Southbound	General purpose lane	Out of town lanes	1.55	1.81	2.015	2.405	2.73	2.495	2.52	2.85	2.715	1.835
Southbound	General purpose lane	High-occupancy toll lanes	0.08	0.08	0.155	0.69	2.535	4.58	5.035	3.195	0.09	0.92
Southbound	High-occupancy toll lanes	Out of town lanes	1.72	1.88	1.995	2.38	2.555	2.38	2.38	2.61	2.33	1.555
Southbound	High-occupancy toll lanes	High-occupancy toll lanes	0.21	0.12	0.2	0.35	0.2	1.685	1.095	3.87	2.145	1.455

Note: Negative values indicate an increase in travel time after the UPA projects.

Source: Federal Highway Administration

The next step in the BCA was to determine the number of vehicles that obtained these travel time savings. Existing (before UPA projects) travelers will receive the travel time savings shown in Table 36. New vehicles (induced demand due to improved traffic flow) would not necessarily gain the entire savings based on their previous travel. To induce these new travelers, this route may save them anywhere from almost no time up to almost the full time savings shown in Table 35**. It was generally assumed that a reasonable estimate is that half the time shown in Table 35 was saved by additional vehicles to the roadway.**

Finally, the total vehicle hours of travel time savings was obtained using the following calculation:

Travel Time Saved = (Before Volumes) x (Travel Time Savings) +
(Volume Change) x (0.5 x Travel Time Savings)

Figure 34. Equation. Total Vehicle Hours of Travel Time Savings.

Total time savings for all time periods amounted to 1,255 vehicle- hours in the morning and 2,987 vehicle hours in the afternoon. This figure was multiplied by the number of days per year with congestion (Monday through Friday minus holidays, approximately 254 per year) resulting in 1,077,324 vehicle-hours per year saved on I-35W South.

These 1,077,324 vehicle-hours were then split into trucks (heavy vehicles) and automobiles. According to MnDOT, during the peak periods trucks represent 8.1 percent of traffic on I-35W South. Therefore, there were 87,263 truck-hours of delay and 990,061 automobile-hours of delay. The automobile delay was then adjusted to person-hours based on average vehicle occupancy (AVO) on I-35W of 1.1 during the peak periods. This figure was provided by MnDOT. The resulting total savings of 1,089,067 person-hours of delay was for automobiles. These savings were assumed to continue from 2010 to 2019. The saved travel times were then multiplied by the value of time for trucks ($24.70/hour) and automobile travelers ($12.50/hour) (adjusted to 2009 values), resulting in a total benefit of $139,474,650 (in 2009 dollars).

The methodology to calculate the value of travel time savings obtained by transit riders was similar to that of automobile travelers. Additionally, the value of their time was identical to what was outlined for automobile travelers. In this case the number of transit riders before and after the UPA projects, along with their travel time savings, was obtained from the transit analysis in Appendix C of the Minnesota UPA Evaluation – Transit Analysis.

There was almost no change in the number of riders from 2009 to 2011 on I-35W South. The morning peak period increased from 4,814 riders per day to 4,859 riders per day. The afternoon peak increased from 4,592 riders per day to 4,602 riders per day. For existing (2009) riders, it was assumed they received the full travel time savings presented in Appendix C, which are 4 minutes and 26 seconds in the morning peak period and 1 minute and 15 seconds in the afternoon peak period. For new riders, it was assumed riders average half of those travel-time savings. This amounts to 21,441 rider minutes in the morning peak period and 5,746 rider minutes in the afternoon peak period. Multiplying by 254 days per year results in a total travel-time savings for transit riders of 115,095 rider hours per year on I-35W South.

Transit riders also saved considerable travel time in downtown Minneapolis from the MARQ2 lanes. Data from Metro Transit on travel-time savings are presented in Table 36. Combining all of the travel-time savings results in a total of 71,203 person minutes per day from the MARQ2 lanes. Assuming 254 work days per year where these travel-time savings occur results in a total of 301,426 person-hours per year of travel time savings. Combining both the I-35W South and the MARQ2 lanes travel-time savings for transit riders results in a savings of 416,521 passenger- hours per year. Assuming:

- The amount of travel time savings remains constant at 416,521 passenger-hours per year from 2010 to 2019;
- The inflation rate for the value of time is 1.6 percent;
- The discount rate for BCA is 7 percent; and
- The in-vehicle value of time for a transit rider is $12.50/hour (in 2009 dollars).

The resulting benefit from travel-time savings for transit riders was $45,332,821 in 2009 dollars.

Table 36. Travel Time Savings for Transit Riders from the MARQ2 Lanes.

Location	Time of Day	Travel Time		Ridership		Travel Time Savings	
		Before Urban Partnership Agreement (March 2008)	With Urban Partnership Agreement (Feb 2011)	Before Urban Partnership Agreement (March 2008)	With Urban Partnership Agreement (Feb 2011)	Existing Riders	New Riders
Marquette Avenue	AM Peak	8	6.1	6,380	8,294	12,182	1,827
	PM Peak	10.7	7.3	3,487	6,169	12,023	4,624
Second Avenue	AM Peak	7.7	4.4	5,195	6,132	16,928	1,527
	PM Peak	8.1	5.1	7,160	7,896	21,013	1,080

Source: Federal Highway Administration

Safety Benefits

Crash data for I-35W South was obtained from Appendix F of the Minnesota UPA Evaluation Report – Safety Analysis. Any changes in crashes on I-35W South were monetized based on the values shown in Table 36. Table 37 presents the pre- and post-deployment crash data for I-35W South. The analysis assumes that any changes in the number of crashes were attributed to the UPA projects. These values were adjusted for future years using an inflation rate of 0.877 percent, based on 1.6 percent inflation rate raised to the power of .55 income elasticity) and a discount rate of 7 percent. (This calculation is estimating the value of a statistical life in future years where the change in income, as well as the general change in the price level (inflation) is accounted for. As we become more affluent, we value lives more, but a future dollar has lower value than a current dollar. Thus two adjustments are required.) Due to the small sample size of crashes in some categories (such as 0 fatal crashes and 2 incapacitating injury crashes), the number of crashes were combined into two categories: (1) no injury crashes and (2) possible/definite injury/fatality. To determine the monetary cost of a possible/definite injury/fatality crash a weighted average cost was developed using the following formulas:

Weighted Cost of a possible/definite injury/fatality crash = (Fatal Crashes (0) x $6,339,701 + Incapacitating Crashes (2) x $4,778,463 + Non-Incapacitating Crashes (40) x $741,925 + Possible Injury Crashes (153) x $307,037) / (0+2+40+153) = $442,106.

Table 37. Unit Costs for Police-Reported Injury Scale (KABCO) (2008 $).

Police Reported Injury	Economic Cost		Comprehensive Cost[1]	
	Crashworthiness	Crash Avoidance	Crashworthiness	Crash Avoidance
O (No Injury)	$68,185	$74,129	$198,819	$204,764
C (Possible Injury)	$109,001	$115,088	$300,950	$307,037
B (Non Incapacitating)	$263,973	$273,270	$732,628	$741,925
A (Incapacitating)	$1,663,924	$1,701,826	$4,740,561	$4,778,463
K (Killed)	$1,248,086	$1,272,912	$6,314,875	$6,339,701
U (Injury Severity Unknown)	$100,776	$102,832	$291,925	$293,982

[1]Based on $6.0 million value of a statistical life http://www.dot.gov/sites/dot.dev/files/docs/VSL%20Guidance.doc)
Source: KABCO, 2008

Table 38. Department of Public Safety Crash Data for I-35W South.

Accident Severity	Pre-Deployment period (Nov 2008 – April 2009)	Post-Deployment Period (Nov 2010 – Apr 2011)	Percent change in crashes[1]
Fatal plus Injury[2]	90	105	-9.4 (12.1)
Property Damage Only	338	322	**-25.6** (5.5)
Monthly average VMT	418,768	534,722	
6-month average VMT (exposure in VMT for 6 months)	2,512,608	3,208,332	

[1] Measured from before to after time periods accounting for VMT change.
[2] Combines fatal, incapacitating injury, non-incapacitating injury, and possible injury.
Note: Statistically significant results at 95 percent are presented in bold. ♦ Standard errors are given in parentheses.
Source: Federal Highway Administration.

The 9.4 percent reduction in possible/definite injury/fatality crashes represents a decrease of 16.92 of these types of crashes per year. The 25.6 percent decrease in property damage only crashes represents a decrease of 173.06 of these types of crashes per year. Assuming that the number and severity of the crashes does not change from 2010 to 2019, the change in crash rates is due to the UPA projects, and the cost of crashes as outlined in Table 37, the total benefit of the reduced crashes was $317,582,808 in 2009 dollars.

Fuel Benefits

A reduction in congestion has the potential to change the vehicle operating cost of passenger vehicles and trucks. These operating costs are comprised of items such as maintenance, reduced wear and tear on a vehicle, reduced fuel use, and other factors due to reduced congestion and a smoother driving cycle. The reduction in fuel use is often the largest change from a monetary perspective. For this analysis, the change in fuel use was the only vehicle operating cost calculated, since the urban planning model could not be used to calculate any other changes. Although not ideal, the amount of costs or benefits not included will be very small in comparison to travel time and safety benefits and would have had little to no impact on the BCA.

The change in fuel use was calculated as part of the environmental analysis in Appendix H of the Minnesota UPA Evaluation. The change on I-35W South was estimated to be a reduction of 363.89 gallons per day. Assuming 254 days per year when this savings occurs, this yields a total reduction in fuel use of 92,428 gallons per year. This was the assumed to be the amount of fuel saved for all years from 2010 to 2019. Again, this is likely a conservative assumption since fuel savings due to the UPA projects should increase as traffic congestion increases on the highway.

The cost of fuel (minus taxes) for 2010 and 2011 was obtained from the U.S. Energy Information Administration and is for all grades of gasoline for an entire year for Minnesota (http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_smn_a.htm). Taxes of 18.4 cents (Federal) and 27.1 cents (State of Minnesota on gasoline) were then removed from the final amount shown in Table 39. The estimated cost of fuel (minus taxes) for future years was obtained from Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks (Office of Regulatory Analysis and Evaluation, National Center for Statistics and Analysis, National Highway Transportation Safety Administration, March 2009 http://www.nhtsa.gov/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/CAFE_Final_Rule_MY2011_FRIA.pdf).

Table 39 also presents actual and estimated future year gas prices based on the Corporate Average Fuel Economy (CAFE) legislation. Multiplying the amount of fuel saved per year (92,428 gallons) by the cost of the fuel (in 2009 dollars as shown in Table J-10) resulted in a total benefit of $2,866,642.

Table 39. Gasoline Prices.

Year	Actual Gasoline Price Excluding Taxes	Actual Gasoline Price Excluding Taxes Adjusted to 2009 $/gallon
2010	2.330 (2010 $/gallon)	2.493
2011	3.095 (2011 $/gallon)	3.543
Year	**Forecast Gasoline Price Excluding Taxes in 2007 $/gallon**	**Forecast Gasoline Price Excluding Taxes Adjusted to 2009 $/gallon**
2012	2.558	2.929
2013	2.611	2.989
2014	2.668	3.055
2015	2.688	3.077
2016	2.736	3.132
2017	2.801	3.207
2018	2.846	3.258

Source: NHTSA

Emissions Benefits

The volume of emissions reduced from the Minnesota UPA projects was calculated in Appendix H of the Minnesota UPA Evaluation Report and is summarized in Table 40. Note that these values were calculated only for I-35W south of town.

Table 40. Volume of Reduced Emissions.

Pollutant	Reduction in Emissions (pounds per day)	Reduction in Emissions (tons per year)
Volatile organic compounds (VOC)	7.98	1.0
Nitrous oxide (NOx)	22.29	2.8
Carbon monoxide (CO)	228.71	29.0
Carbon dioxide (CO_2)	7320.95	845.2

Source: NHTSA

The current year value of the societal benefit from reduced pollution was derived from the U.S. Environmental Protection Agency estimates of the value of health and welfare-related damages (incurred or avoided) and are recommended for use in current FHWA guidance (*Federal Register*, Vol. 75, No. 104, p. 30479). The values are found in the report Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks (Office of Regulatory Analysis and Evaluation, National Center for Statistics and Analysis, National Highway Transportation Safety Administration, March 2009 http://www.nhtsa.gov/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/CAFE_Final_Rule_MY2011_FRIA.pdf, Table VIII-5, page VIII-60) and are shown in Table 41.

Future year values are taken from the Highway Economic Requirements System documentation (Highway Economic Requirements System, Federal Highway

Administration http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersdoc.cfm) and are also shown in Table 41. Note that neither of these references provides a value per ton of CO and therefore CO has not been included in this calculation. These values were interpolated (assuming a linear change in values per year) to obtain the monetary benefit of the three pollutants in each year from 2010 to 2019. Multiplying these values by the amount of pollution reduced (Table 41), then adjusting the 2007 dollars to 2009 dollars using a discount rate of 7 percent, results in a total benefit of $154,110 from NOx, $228,864 from CO_2 and $15,606 from VOC. Combining these, results in a total environmental benefit of $398,580.

Table 41. Values of Reduced Emissions (in 2007 $).

Pollutant	Cost in 2009	Cost in 2015	Cost in 2020
Carbon monoxid (CO)	Not included	Not included	Not included
Volatile organic compounds (VOC)	$1,700 per ton	$1,200 per ton	$1,300 per ton
Carbon dioxid (CO_2)	$21 per metric ton	$24 per metric ton	$26 per metric ton
Nitrous oxide (NOx)	$4,000 per ton	$4,900 per ton	$5,300 per ton

Source: FHWA

Summary of BCA

The total planning, construction, operation, and maintenance cost (in 2009 dollars) for the I-35W and MARQ2 UPA projects, along with the Crosstown Commons section reconstruction, was $395,156,082. Components of the UPA projects will have salvage value at the end of the 10- year BCA timeframe and this salvage value was subtracted from the total cost. For the physical infrastructure the salvage value was found to be:

$$\text{Salvage Value} = 93.1\% \times (\$39{,}616{,}038 + \$31{,}707{,}815 + \$33{,}405{,}610 + \$714{,}779 + \$228{,}000{,}000) = 93.1\% \times \$333{,}444{,}242 = \$310{,}367{,}064$$

For the buses, the salvage value was found to be:

$$\text{Salvage Value} = 22.8\% \times \$3{,}668{,}514 = \$835{,}075$$

Therefore, the resulting 10-year costs from the Minnesota UPA projects, along with the Crosstown Commons section reconstruction, were $395,156,082- $310,367,064 - $835,075 = $83,953,942. The benefits that were identified in previous sections for I-35W South and the MARQ2 lanes are shown in Table 42.

Table 42. Benefit-Cost Summary for the Minnesota I-35W Urban Partnership Agreement.

Travel Time Savings	$139,474,650 + $45,332,821 = $184,807,471
Reduced Auto Fuel Use	$2,866,642
Reduced Emissions	$398,580
Reduced Crashes	$317,582,808
TOTAL	**$505,655,501**

Source: FHWA

As shown in Table 43, the benefit-to-cost ratio for the Minnesota UPA I-35W South and MARQ2 projects, along with the Crosstown Commons section reconstruction, was 6.0 ($505,655,501 / $83,953,942).

Table 43. Minnesota Urban Partnership Agreement Benefit-Cost Analysis Results.

Hypotheses/Questions	Result	Evidence
What are the overall benefits, costs, and net benefits from the Minnesota UPA projects?	Positive	Benefits: $505,601,501 Costs: $83,953,942 Net Benefits: $421,701,558 Benefit-to-cost ratio of 6.0 The costs and benefits of the Crosstown Commons section reconstruction are included in these figures.

Source: FHWA

Key Observations

The analysis had several limitations and required numerous assumptions. None of these would change the overall conclusion of a benefit to cost ratio above 1.0, although the exact value of that ratio could change.

For example, the reduction in crashes by VMT on I-35W South represent a major benefit in the BCA. The estimated BCA would be lower if the crash reduction by VMT had not occurred. Crash data over a longer period of time is needed to fully assess possible changes in crashes by VMT, which would influence the BCA. In addition, vehicle operating costs included only reduced fuel consumption for automobile travel. Data on possible reduction in fuel used by buses was not available. The future year costs and benefits represent the best estimates available, but they are only estimates, and the actual costs and benefits may vary. Possible costs and benefits associated with Highway 77 were also not included in the BCA due to lack of data.

Case Study 7.2 – Interstate I-95 Express Managed Lanes

Strategy Type:	Demand Management
Project Name:	I-95 HOT Lanes
Project Agency:	Florida Department of Transportation (FDOT)
Location:	Urban Freeway
Geographic Extent:	Regional/Urban
Tool Used:	TOPS-BC

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

The following case study was prepared by Cambridge Systematics, Inc. for the Florida Department of Transportation (FDOT) as part of the "TOPS-BC Florida Guidebook" and is reproduced here with permission.

The I-95 Express Managed Lanes began operating Phase 1A in December 2008, providing travelers with an alternative to the congested general purpose travel lanes between downtown Miami and the Golden Glades Interchange to the north. The project was funded by the United States Department of Transportation's (USDOT) Urban Partnership Agreement (UPA)/Congestion Reduction Demonstration (CRD) program. The UPA is an agreement between the USDOT and FDOT, the Miami-Dade and Broward metropolitan planning organizations (MPO), Miami-Dade Transit (MDT), Broward County Transit (BCT), the Miami-Dade Expressway Authority, and Florida's Turnpike Enterprise. The UPA was formed to address the problem of congestion, and it consists of two components: (1) converting HOV lanes into Managed Use Lanes (MUL) and (2) implementing Bus Rapid Transit services within the portions of the newly converted lanes. The UPA funded the construction of the MULs and the capital portion of the transit using Federal funds. Revenue generated from I-95 Express tolls support the operations and maintenance of the transit service.

Project Goals and Objectives

I-95 Express was scheduled to be constructed in the following phases:

- Phase 1A opened in December 2008 and runs northbound on I-95 from I-195/SR-112 to the Golden Glades area just north of 151st Street in Miami-Dade County. Phase 1B opened for tolling in January 2010 and runs southbound on I-95 from just south of Miami Gardens Drive/NW 186th Street to just north of I-395/SR-836. Phase 1B also extended the northbound express lanes further to the south from just north of I-195/SR 112 to I-395/SR-836. In this report, where it states Phase 1, it refers to both Phase 1A and Phase 1B.
- Phase 2 construction started on November 28, 2011, and will last approximately three years. Phase 2 will extend the express lanes to provide a continuous facility between I-395/SR-836 in Miami-Dade County and Broward Boulevard in Broward County. Phase 2 Express Lanes should be operational near the end of 2014.

The UPA calls for additional Bus Rapid Transit service as part of Phase 2 implementation, and FDOT will be working closely with BCT and MDT to plan the additional service.

The I-95 Express project involved replacing one high occupancy vehicle (HOV) lane in each direction with two variable-priced managed lanes in each direction that allow registered carpools of three or more occupants to travel free, together with enhanced express bus services. The number of general purpose lanes and shoulders were restriped in order to provide for the same number of lanes as before, four in each direction, with the lanes and shoulders being slightly narrower. The result was to improve the peak-period operations on this corridor through:

- Increased vehicle and person throughput;
- Increased travel speeds;
- Improved travel time reliability; and
- Enhanced transit service.

These improvements resulted largely from increased capacity due to the addition of one travel lane in each direction. This was accomplished within the existing right-of-way by relying on design variances for roadway lane and shoulder widths. However, the addition of 12 peak hour express buses and accommodating registered vanpools and carpools have been a valuable contributor to the successful management of this corridor for reliable peak period travel.

Data

Costs

- Total Phase 1 construction cost from FDOT District 6 = $132,000,000 (includes roadway construction, ITS and tolling equipment installation.
- Tolling software cost for adding module to FDOT SunGuide = $2,000,000
- Project life cycle is 25 years
- Expected life cycle is 10 years for ITS equipment, project start was 2008
- Replacement costs, assumes two replacements over the 25 year life cycle.
    - Closed Circuit TV = 40 x 2 x $24,000 = $1,920,000
    - Microwave Vehicle Detection System = 54 x 2 x $10,000 = $1,080,000
    - Dynamic Message Sign (brick) = 18 x 2 x $50,000 = $1,800,000
    - Dynamic Message Sign (full matrix) = 22 x 2 x $135,000 = $5,940,000
- Total Capital + replacement cost = $142,740,000
- Express lane = 9 miles, D6 total ITS Miles Managed = 48.1, Express lanes are 18.7% of total miles managed by ITS, use 25% of total ITS budget (Express Lanes are more tightly managed.

- 2012-2013 FDOT District 6 ITS Operating cost = $17,100,950
- Assumed I-95 Express Lanes annual operating cost = 25% x $17,100,950 = $4,275,237

Benefits

- Current volume and speed data was obtained from the I-95 Express Monthly Operations Report provided by FDOT District 6. The volumes and speeds used in the analysis were from the December 2013 report.
- The monthly operations report provides volumes in terms of 3-hour peak periods. The reported periods are 6:00-9:00 a.m. for southbound and 4:00-7:00 p.m. for northbound. The length of analysis period is then 3 hours.
- The number of general-purpose lanes throughout the corridor is four lanes in each direction. There are two express lanes in each direction.
- The FDOT Systems Planning Office standard for free flow speed is the speed limit plus 5 mph. The speed limit in all lanes in the I-95 corridor is 55 mph. The free flow speed should then be 60 mph. In this case study it is important to use the differential speeds in the express lanes and in the general purpose lanes. The speed used is the I-95 Express Monthly Operations Report is an average overall speed by direction (for GP lanes - 57 mph SB, 56 mph NB, for Express lanes – 66 mph SB, 64 mph NB). This study used the speeds reports in the I-95 Express December 2013 monthly report.
- The case study corridor length is 9 miles.
- FDOT District 4 and 6 has been monitoring the I-95 High Occupancy Vehicle lanes for many years. The 2008 HOV Monitoring Report provided an analysis of the HOV and GP lane operations (before tolling was initiated) just prior to opening the Express Lanes. The baseline congested speeds were obtained from this 2008 HOV Monitoring Report. The speeds reported were from two segments: Golden Glades Interchange to 125th Street and 125th Street to I-195 (SR 112), these two sets of reported speeds were averaged. The baseline speeds used for the a.m. SB period were 15.0 mph in the GP lanes and 20.5 mph in the HOV lane. The baseline speeds used for the p.m. NB period were 20.9 mph in the GP lanes and 27.2 mph in the HOV lane.
- The number of analysis periods was assumed 250, which is the average number work days in a year (total days minus weekends and holidays). This assumption is because most benefits are accrued during the peak periods in the peak direction.
- National average (default) input data was used for crashes, fuel price, and the value of time. This was due to that data being difficult to collect and summarize or not being available.

Limitations

- While TOPS-BC does include the benefits due to time savings in recurring and non-recurring travel during each analysis period, the impacts of improvements due to improved travel time reliability are not included.

- Reliability has been recognized as an important consideration to travelers. Improving reliability is a benefit to travelers. The SHRP 2 research project dedicated a significant portion of its resources to defining, understanding and measuring reliability. SHRP 2 has released several reports relating to the topic. Not all of this research has been added to the TOPS-BC model Version 1. TOPS-BC V1 now estimates only the benefits from reducing incident related delay. In the future, TOPS-BC will add new code to address the current reliability benefits and add these benefits to the full BCA. The latest model will be available on the FHWA, Planning for Operations web site.
- TOPS-BC does not have a trip assignment or mode choice module, therefore the operations strategy analysis only accounts for the number of trips given for each corridor, there are no assumed trip diversions or mode changes due to congestion.
- TOPS-BC will provide conservative estimates of benefits because only the benefits accrued during the selected time period are calculated. In many cases, additional benefits may be produced in off-peak times that are not included.
- Changes in air quality due the operations strategies are not accounted for in TOPS-BC.

Methodology

The following are the steps to enter input data for the I-95 Express Lanes case study. Note that separate TOPS-BC calculations are required for each of the northbound and southbound directions. The steps are the same for each direction but the volumes and speeds input are different. The same cost figures were calculated for each direction; however, the actual cost must be divided by two so that a separate B/C ratio can be calculated for each direction. The costs are then added back together to obtain a total project B/C ratio.

1. Open the TOPS-BC spreadsheet template
2. Click on the Active Transportation and Demand Management (ATDM) High Occupancy Toll Lanes page under section 3 – Estimate Costs
3. Since this analysis assumes that the Express Lanes were added to the existing I-95 roadway, we will assume that there is no cost for the existing road and ITS equipment and the Express Lanes project is an incremental addition
4. Change the title under the Incremental Deployment Equipment first row to Project Total Cost
5. Using the cost assumptions described in the preceding Assumptions sections, enter $144,740,000 in the Capital/Replacement Costs column
6. Using the cost assumptions described in the preceding Assumptions sections, enter $4,275,237 in the O & M Costs column
7. Enter 25 years into the Useful Life column. This assumes a relatively long life for the project. Actually, after 25 years some type of reconstruction or repair, which will cost less than the original investment, will be more likely than a complete reconstruction.
8. Enter 0 into the Number of Infrastructure Deployments green box

9. Enter 1 into the Number of Incremental Deployments green box
10. Enter 2008 into the Year of Deployment green box

The spreadsheet immediately calculates the Average Annual Cost as an output. This is the annualized initial capital cost plus the annualized replacement cost (for two equipment replacements over the 25 year life of the project) plus the annual operating and maintenance costs for the portion (assume to be 25 percent) of the total District 6 ITS O&M budget.

See Figures 35 and 36 for screenshots of the costs page for this case study.

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0

PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies

WORK AREA 1 - ESTIMATE AVERAGE ANNUAL COST

Other Strategies: ATDM High Occupancy Toll Lanes

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrascture Equipment				
TMC Lane Control Hardware	5			$ -
TMC System Integration	20		$ -	$ -
TMC Lane Control Software	2			$ -
TMC Labor		$ -		$ -
Toll Processing Center Hardware	10			$ -
Toll Processing Center Software	10			$ -
Toll Processing Center Labor		$ -		$ -
Communications	20			$ -
TOTAL Infrastructure Cost		$ -	$ -	$ -

Source: FHWA TOPS-BC

Figure 35. Screenshot. Tool for Operations Benefit-Cost Analysis Advanced Transportation Demand Management High Occupancy Toll Lanes Costs Page (part 1).

Incremental Deployment Equipment					
	Incremental costs for HOT lane deployments are extremely variable depending on the type of deployment.				
	User should enter and edit costs appropriate to their planned strategy. Example costs include:				
	Project total cost	25	$142,740,000	$ 4,275,237	$ 9,984,837
					$ -
					$ -
					$ -
					$ -
	TOTAL Incremental Cost		$142,740,000	$ 4,275,237	$ 9,984,837
INPUT	Enter Number of Infrastructure Deployments	0			$ -
INPUT	Enter Number of Incremental Deployments	1			**$ 9,984,837**
INPUT	Enter Year of Deployment	2008			
	Average Annual Cost				**$ 9,984,837**

Source: FHWA TOPS-BC

Figure 36. Screenshot. Tool for Operations Benefit-Cost Analysis Advanced Transportation Demand Management High Occupancy Toll Lanes Costs Page (part 2).

Benefits

The steps for the benefits calculations are described for the southbound direction. The step for the northbound direction must use a separate TOPS-BC spreadsheet template, but they are identical. Refer to the benefits assumptions described above.

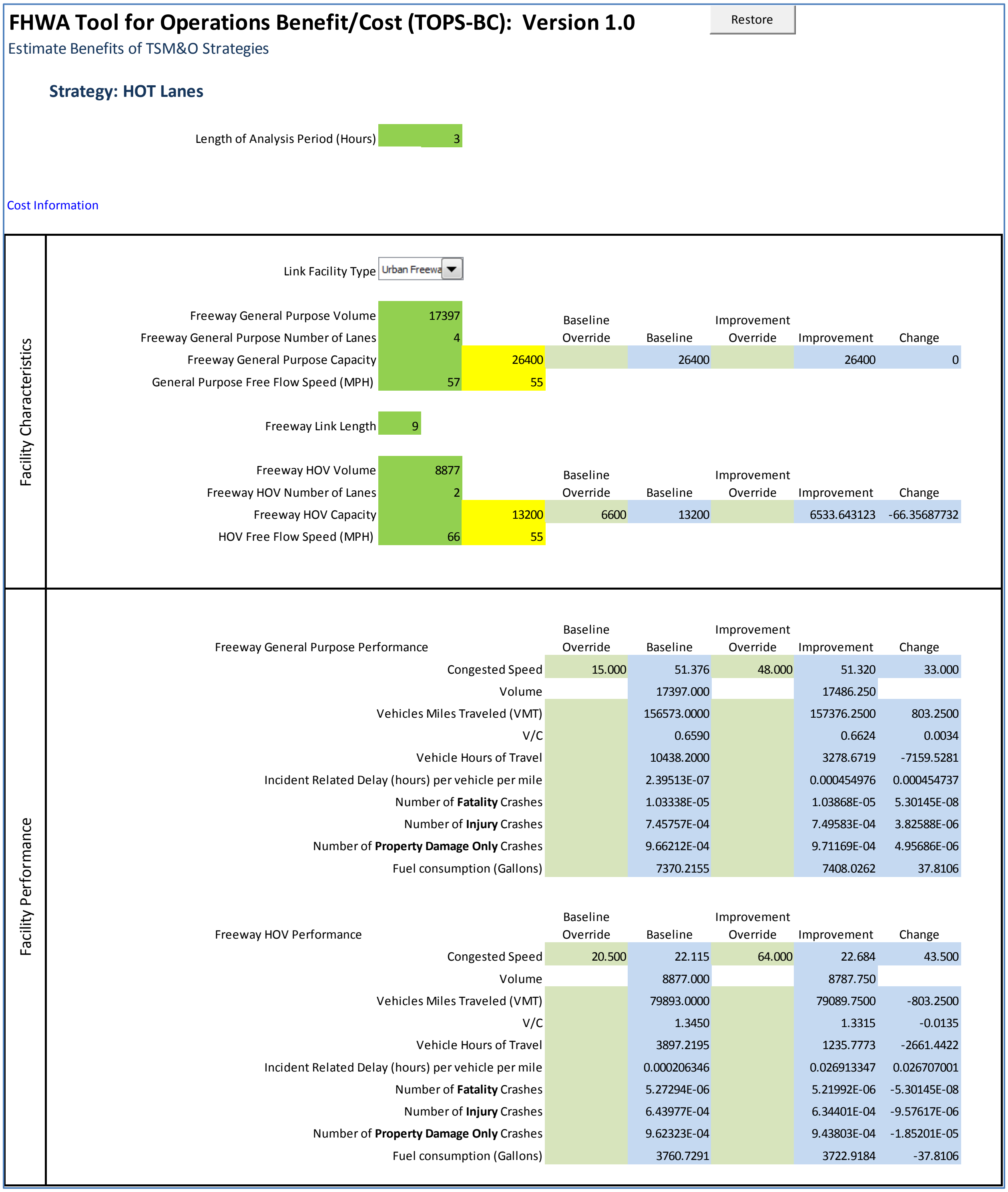
1. Click on ATDM HOT Lanes under Section 4 - Estimate Benefits. Input data into the Facility Characteristics section.
2. Enter 3 into the Length of Analysis Period (hours) green box. The volumes were provided by District 6 for a three hour (6:00-9:00 a.m.) peak period for the SB direction.
3. Enter the volume for the general purpose lanes, in this case it is 17397, as reported in the Express Lanes Operations December 2013 Monthly Report. Enter the volume into the Freeway General Purpose Volume green box
4. Enter 4 into the Freeway General Purpose Number of Lanes green box
5. Enter 57 into the General Purpose Free Flow Speed green box. This is the overall average speed report in the Express Lanes Monthly Operations Report for December 2013 for the GP lanes.
6. The capacity for the general purpose lanes is then calculated by the TOPS-BC spreadsheet as an output.

7. Enter 9 into the Freeway Link Length green box. This is the total project corridor length in miles. This covers phase 1 of the Express Lanes project, which what is operational at this time (March 2014).
8. Enter the volume into the Freeway HOV Volume green box. In this case, it is 8877, as reported in the Express Lanes Operations December 2013 Monthly Report.
9. Enter two into the Freeway HOV Number of Lanes green box.
10. Enter 66 into the Freeway HOV Free Flow Speed green box. This is the overall average speed report in the Express Lanes Monthly Operations Report for December 2013 for the Express Lanes.
11. Enter 6600 into the Baseline Override for Freeway HOV Capacity. This is the capacity of the "before" condition for one HOV lane.
12. The capacity for the freeway HOV lanes is then calculated by the TOPS-BC spreadsheet as an output.
13. Now input data into the Facility Performance section.
14. First for the Freeway General Purpose Performance area, enter the GP lanes speed for the corridor obtained before the project was implemented (in this case, prior to 2008) into Congested Speed row for the Baseline Override column. If that baseline speed is not known, it could be estimated by using the MPO's modeled speed for that corridor. In this case, the 2008 speed was found in the I-95 HOV Monitoring Report, which is 15 mph.
15. Then in the Congested Speed row, enter the current corridor speed (in this case the SB a.m. peak period speed) into the Improvement Override column, which is 46 mph.
16. Repeat these two steps for the Freeway HOV Performance area. Insert 2008 corridor speed (20.5 mph) into the Congested Speed row, Baseline Override column and the current corridor speed (64 mph) into Congested Speed row, Improvement Override column.
17. Enter 250 into the Number of Analysis Periods per Year green box.

The spreadsheet immediately calculates the Total Average Annual Benefit. All of these steps are repeated for the northbound TOPS-BC spreadsheet using the appropriate northbound volumes and speeds.

All of the green boxes may be used to enter additional local data if they are available. In this case study, there may have been crash data and value of time data available by conducting extensive analysis. However, previous studies have indicated that local data does not usually vary significantly from the national default data and it was decided that the effort to obtain local data for crashes and time value was not worthwhile. Additionally there is a need for data collected over a long period of time, especially for injuries and fatalities, since a small sample can skew the results.

See Figures 37 and 38 for screenshots of the benefits page for the southbound direction in this case study.



FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0 Restore

Estimate Benefits of TSM&O Strategies

Strategy: HOT Lanes

Length of Analysis Period (Hours): 3

Cost Information

Facility Characteristics

Link Facility Type: Urban Freewa

	Input	Default	Baseline Override	Baseline	Improvement Override	Improvement	Change
Freeway General Purpose Volume	17397						
Freeway General Purpose Number of Lanes	4						
Freeway General Purpose Capacity		26400		26400		26400	0
General Purpose Free Flow Speed (MPH)	57	55					

Freeway Link Length: 9

	Input	Default	Baseline Override	Baseline	Improvement Override	Improvement	Change
Freeway HOV Volume	8877						
Freeway HOV Number of Lanes	2						
Freeway HOV Capacity		13200	6600	13200		6533.643123	-66.35687732
HOV Free Flow Speed (MPH)	66	55					

Facility Performance

Freeway General Purpose Performance	Baseline Override	Baseline	Improvement Override	Improvement	Change
Congested Speed	15.000	51.376	48.000	51.320	33.000
Volume		17397.000		17486.250	
Vehicles Miles Traveled (VMT)		156573.0000		157376.2500	803.2500
V/C		0.6590		0.6624	0.0034
Vehicle Hours of Travel		10438.2000		3278.6719	-7159.5281
Incident Related Delay (hours) per vehicle per mile		2.39513E-07		0.000454976	0.000454737
Number of **Fatality** Crashes		1.03338E-05		1.03868E-05	5.30145E-08
Number of **Injury** Crashes		7.45757E-04		7.49583E-04	3.82588E-06
Number of **Property Damage Only** Crashes		9.66212E-04		9.71169E-04	4.95686E-06
Fuel consumption (Gallons)		7370.2155		7408.0262	37.8106

Freeway HOV Performance	Baseline Override	Baseline	Improvement Override	Improvement	Change
Congested Speed	20.500	22.115	64.000	22.684	43.500
Volume		8877.000		8787.750	
Vehicles Miles Traveled (VMT)		79893.0000		79089.7500	-803.2500
V/C		1.3450		1.3315	-0.0135
Vehicle Hours of Travel		3897.2195		1235.7773	-2661.4422
Incident Related Delay (hours) per vehicle per mile		0.000206346		0.026913347	0.026707001
Number of **Fatality** Crashes		5.27294E-06		5.21992E-06	-5.30145E-08
Number of **Injury** Crashes		6.43977E-04		6.34401E-04	-9.57617E-06
Number of **Property Damage Only** Crashes		9.62323E-04		9.43803E-04	-1.85201E-05
Fuel consumption (Gallons)		3760.7291		3722.9184	-37.8106

Source: FHWA TOPS-BC

Figure 37. Screenshot. Tool for Operations Benefit-Cost Analysis Advanced Transportation Demand Management High Occupancy Toll Lanes Benefits Page (part 1).

Impacts Due to Strategy	**Facility improvement models**				
	Change in HOV Capacity (%)		-1.00541%		
Travel Time	Average Person Hours of Travel Saved per Period				16401.0204
	$ Value of Person Hour (per hour) "On-the-Clock" Auto		$ 28.00		
	$ Value of Person Hour (per hour) Other Auto		$ 14.00		
	$ Value of Vehicle Hour (per hour) Truck		$ 28.00		
	Total Recurring (Non-delay) Travel Time Benefit per Period				$ 298,498.57
TTR	Average Total Person Hours of Incident Related Delay Saved per Period				-3682.1862
	$ Value of Person Hour (per hour of ***Delay***) "On-the-Clock" Auto		$ 28.00		
	$ Value of Person Hour (per hour of ***Delay***) Other Auto		$ 14.00		
	$ Value of Vehilce Hour (per hour of ***Delay***) Truck		$ 28.00		
	Total Incident Related Delay Benefit per Period				$ (67,015.79)
Energy	Average cost per gallon of fuel (excluding taxes)		$ 3.67		
	Total Fuel Savings Benefit				$ (0.00)
Safety	$ Value of a Fatality Crash		$ 6,500,000		
	$ Value of a Injury Crash		$ 67,000		
	$ Value of a Property Damage Crash		$ 2,300		
	Total Modeled Crash Related Benefit per Period				$ (0.61)
	User Entered Benefit (Annual $'s)				
	Number of Analysis Periods per Year	250	250		
	TOTAL AVERAGE ANNUAL BENEFIT				$ 57,870,542.57

Source: FHWA TOPS-BC

Figure 38. Screenshot. Tool for Operations Benefit-Cost Analysis Advanced Transportation Demand Management High Occupancy Toll Lanes Benefits Page (part 2).

Preliminary Benefit Cost Evaluation

Based on the northbound and southbound benefits and costs calculations using the TOPS-BC spreadsheet, the results are shown in Table 44.

Table 44. Benefits and Costs for the I-95 Express Lanes Case Study

Corridor	Peak Time / Direction	Benefits	Costs	Benefit-Cost Ratio
I-95	PM NB	$11,723,238	$4,992,418	2.35
I-95	AM SB	$57,870,543	$4,992,419	11.59
Total System		**$69,593,591**	**$9.984,837**	**6.97**

Source: FHWA TOPS-BC

The large difference between the AM and PM peak numbers is due to the AM SB direction experiencing greater congestion (slower congested speed) than the PM NB peak period.

Key Observations

After conducting this case study and other TOPS-BC case studies and applications, several "lessons learned" have been identified. There are also a few hints to setting up the spreadsheet that will help TOPS-BC users achieve better results.

- Speed is the most important factor affecting the benefits of an operations strategy. A difference in "before" and "after" speed is the primary way to account for congestion and delay and improvement benefits in TOPS-BC. In the I-95 Express Lanes case study, the speed differential between before and after deployment provided the data to calculate the vehicle hours of travel and delay in the corridor. It is relatively easy to collect current travel times using GPS travel time runs or Bluetooth detectors. However, it is more difficult to obtain historic corridor speeds for project already implemented or to estimate speeds for a project being planned. When actual historic data is not available, it is best to consult with the local MPO and obtain model speeds for the corridor.

- The free flow speed is important. The FDOT Planning Office free flow speed is the posted speed limit plus 5 mph. When conducting operations analysis and when historic data is available the free flow may be determined from collected data. For freeways, the average off-peak (uncongested) speed collected over time from detectors is the calculated free flow speed. For arterials the stop time at traffic signals must be accounted for, so the FDOT Operations method of determining free flow speed is to calculate average off-peak corridor travel times. When conducting planning studies the speed limit plus 5 mph should be used as the free flow speed.

- Volume and volume/capacity ratio are also important factors in TOPS-BC calculations. The current volume is the only volume input, however, when needed (such as an intersection improvement) the capacity can be overridden for both the baseline and the improvement scenarios. Volume and V/C are used to calculate vehicle miles traveled and crash rates and affect the benefits calculation.

- The period of analysis must be correct in order to obtain accurate results. The number of hours of the analysis must match the length of the period of the volume data, that is, if the volumes are for a peak one hour, the period of analysis must be ”1”. In the I-95 Express Lanes case, the volumes were for a three hour peak period, so the period of analysis was entered as ”3.”
- The number of analysis periods per year can be used to account for additional benefits not measured directly by data input.
- In conducting several case studies, it has been determined that the crash data and value of time factors do not often vary significantly from the national data used as the default in each data item. The data for these factors are difficult and expensive to collect and a large amount of data collected over a period of time is needed. It is suggested that the effort to collect these data are not usually worth the amount of impact to benefits that local data would make on these factors. Likewise, the cost of fuel will not create a measurable change to benefits unless the price is significantly different from the default price. It must be noted that the price of fuel is not the cost of regular grade gasoline, but a blended cost of all grades of gasoline, diesel, and liquefied natural gas fuel.
- For the cost calculations, there are several important considerations. The costs of providing basic services – services that would be provided whether or not the project being studied was implemented – and the cost of the incremental services enabled by the project must be sorted out and correctly assigned. Each cost item should have a corresponding operations and maintenance cost entered in the spreadsheet.
- The user must be careful to pay close attention to the units that are assumed in the spreadsheet cells, i.e. be sure determine if the model is assuming a daily rate vs. an annual rate for a factor.

CHAPTER 8. TRANSIT OPERATIONS

#	Case Name	BCA Model	Actual or Hypothetical Case
8.1	Transit Signal Priority, Portland Tri-Met	Internal BCA Data Review	Actual
8.2	Transit Signal Priority, Los Angeles DOT/MTA	Internal BCA Data Review	Actual

Case Study 8.1 – Transit Signal Priority, Portland Tri-Met

Strategy Type:	Transit Operations
Project Name:	Transit Signal Priority
Project Agency:	Portland Tri-Met
Location:	Urban Transit
Geographic Extent:	Regional/Urban
Tool Used:	Internal BCA Data Review

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

The Tri-County Metropolitan Transportation District of Oregon (Tri-Met) is one of many metropolitan transit agencies that have deployed both automatic vehicle location (AVL) and automatic passenger counter (APC) systems. These technologies are important components of the agency's automated bus dispatching system (BDS). The AVL and APC systems at Tri-Met recover comprehensive operations and passenger activity data at the bus stop level that is archived for later analysis. With its AVL and APC systems, Tri-Met is now automatically collecting and archiving over 500,000 stop and event data records per day. Offline analysis of this data supports a wide array of agency activities. The success of these technologies allowed the installation of Transit Signal Priority (TSP) on key bus routes.

Project Goals and Objectives

The intended goal was that TriMet would recoup its investment through running time saved by streamlining—in other words, if four or five peak buses could be saved, the bus operating cost savings would offset the investment in transit preferential treatments paid for through TriMet's contributions to the overall program.

The goals of the TSP implementation included:

- Increase attractiveness of transit
- Increase ridership
- Reduce transit travel time
- Improve transit schedule reliability (on time and predictable, reduce excess passenger wait time)
- Avoid providing additional transit capacity
- Reduce operating costs
- Minimize impacts to general traffic.

All of the streamlined routes are also Frequent Service routes, operating at 15-minute or better headways throughout the day, each day of the week. Time saved through more efficient routings and through transit signal priority reduces passengers' overall trip times. Transit signal priority also helps maintain schedule reliability.

The purpose of this case study is to demonstrate how TOPS-BC can be used to support the analysis of AVL technology using the existing TOPS-BC technology cost database and external calculations of TSP benefits that is incorporated into the TOPS-BC analysis.

Data Requirements

Archived AVL and APC data support a variety of regular reporting activities at Tri-Met. The data are also used to support analysis of specific needs and problems that relate to both short and long term planning, scheduling, and operations. Analysis of archived AVL data is also undertaken in response to specific issues that arise related to service design, delivery and use.

Capital, Operations and Maintenance Costs

The cost of implementation for the TriMet TSP system was $5.8M. (Year 2000 $). Cost of maintenance is estimated by TriMet to be 0.2 full time equivalent (FTE) staff (650 buses) for 5 years. There was no additional cost for signal maintenance. The following is a summary of the streamlining impacts that can be quantified to date:

- The time savings resulting from streamlining has not allowed TriMet to permanently reduce the number of peak buses on a route. As a result, there have been no short-term operations savings.
- The 12 streamlined routes, on average, operate a round trip 0.8 minutes faster now during the weekday a.m. peak than they did in September 2000. In comparison, 7 non-streamlined routes that mainly operate in the city of Portland operate a round trip 1.3 minutes slower on average, and 4 primarily suburban routes operate a round trip 2.3 minutes slower on average.
- The full impacts of streamlining on running time variability have not yet been quantified. A study conducted by Portland State University (Kimpel et al. 2005) compared travel time variability on six routes (109, 12, 112, 14, 72, and 94). This study found minimal reductions in recovery time on average (0.1 minutes per trip), although Routes 12 and 94 outbound during the weekday p.m. peak showed substantial reductions (10 to 14 minutes per trip, respectively).
- The running time savings that have been achieved through streamlining have postponed the need to add buses to streamlined routes by eight years, at the current rate that scheduled times are increasing due to congestion. Assuming an annual $140,000 operating cost saved per peak bus, multiplied by 12 routes over 8 years, equals about $13.4 million in long-term savings in present dollars. The value of postponing the purchase of 12 additional buses for 8 years would be an additional capital cost savings. Any recovery time savings that can be quantified would be an additional operating cost savings.
- The combination of focusing service increases on Frequent Service routes, accompanied by streamlining and marketing efforts, has resulted in 12,000 more weekday bus boardings than

would have occurred had the service increases been spread system-wide and no other efforts made. These additional riders translate into $1.7 million additional farebox revenue annually.

- On-time performance has declined system wide from 1999 to 2005. However, the on-time performance of streamlined routes has declined at half the rate of non-Frequent Service routes.

In summary, the Streamline Program is a long-term investment for TriMet. The payoff will primarily be in the future, as additional service will not need to be added as soon to streamlined routes. Because ridership has increased on the streamlined routes by a substantially larger percentage than can be attributed to just the increase in service, some portion of the $1.7 million additional annual farebox revenue can be attributed to streamlining, although the exact contribution cannot be quantified.

Benefit Analysis

Key investments on the City's part were the installation of transit signal priority at 275 intersections and installation of signal priority emitters on nearly the entire TriMet bus fleet. The evaluation of the Streamline program focused on four key MOEs: ridership changes, additional fare revenue, on-time performance, and round trip time savings.

Given the 3.6 percent increase in overall bus service hours from 1999 and 2005, and applying the observed non-Frequent Service elasticity of 0.30, weekday bus ridership would have been expected to increase from approximately 200,040 passengers in 1999 to 202,200 in 2005, all other things being equal. Instead, as a result of a combination of service increases, streamlining, and marketing efforts, weekday ridership increased to 214,230 passengers, a difference of approximately 12,000 passengers per weekday.

Improved Service Increases Ridership

12,000 additional weekday passengers x 250 weekdays per year = 3 million additional annual bus boardings per year

Increased Ridership Increases Revenue

Corresponding fare revenue increase = approximately $1.7 million.

On average, the 12 streamlined routes operated 0.8 minutes faster per round trip in 2005 than in 2000, while 7 comparative non-streamlined Portland routes operated 1.3 minutes slower. The difference is 2.1 minutes per trip. The City of Portland/TriMet's Streamline program reported positive results. According to the Journal of Public Transportation (2006), long term saving are estimated at approximately $13.4 million for TriMet.

The time saved by streamlining comes from two main sources: running time savings and recovery time savings. Transit signal priority, curb extensions, and queue jump lanes help a bus travel its route faster than it otherwise would have. Signal priority also helps reduce the variability in the time buses take to make a trip from one end of a route to the other, allowing schedulers to reduce the amount of recovery time provided between trips. Recovery time is an allowance for late trips, ensuring that a bus can depart on time for its next trip.

On the 12 routes where Streamline is in use, round trip operations averaged 0.8 minutes faster in 2005 than in 2000. Comparing that to seven other routes, where round trip operations averaged 1.3 minutes slower in 2005 than in 2000, there is an overall estimated improvement of 2.1 minutes per route. The variability of route times was also reduced over the course of the day, leading to more predictability for passengers.

Through the implementation of the Streamline program (along with other complimentary transit improvements such as exclusive bus lanes, queue jumps, and stop improvements), TriMet buses improved in efficiency and reduced their fuel usage. As noted previously, buses on Streamlined routes averaged 0.8 minutes faster on route overall (Kittleson & Associates, 2009). Even this small savings has significant implications for transit operations over the course of an operating day in terms of on-time performance, fuel usage, and emissions.

Streamline eliminated the need to add eight buses to TriMet's fleet, which deferred the release of an additional 3,600 lbs. of carbon emissions daily, as well as eliminated the need for 165 additional gallons of fuel daily.

According to Kittleson & Associates (2009), 92 percent of the 12,000 new transit trips (11,055 trips) generated through the implementation of the Streamline Program, would shift from driving a personal vehicle; a net reduction of 8,189 vehicles (based on a 1.35 persons per vehicle occupancy). From this reduction in daily vehicle trips in 2005, approximately 1,900 gallons of fuel were not consumed. Additionally 36,000 pounds of daily carbon emissions were avoided.

Benefit Cost Evaluation

TOPS-BC, BCA.net, IDAS and other benefit-cost analysis tools provide systematic organization of BCA input and output to support decision making. Most models also provide input defaults for most variables that would be used in the evaluation of a bus operations streamlining program. If a planner was looking at a bus operating improvement project similar to the Portland TriMet example, he could use the TOPS-BC defaults, or generate new data to make the example as realistic as possible by applying local data which can be applied in place of the defaults. The following steps can be taken in TOPS-BC to generate a BCA.

1. Open TOPS-BC, and click on *Estimate Life-Cycle Cost* which takes you to the cost section
2. In the left most navigation column under 3) *Cost Estimation* click on *Transit Signal Priority* which will open the cost page. Determine if the items and their costs agree with your previous information. If they do not, you can add items or edit the existing items.
3. Now in the Green cells you can input the number of expected infrastructure deployments, the number of incremental deployments (buses to be equipped) and the year of deployment.
4. TOPS-BC will now calculate the annual cost and the net present value for a 20 year program that you described. You can also change the length of the period or the discount rate selected.

Now we will move on to the Benefit Page. TOPS-BC does not at this time have a unique benefit calculation algorithm. New material is constantly being added to TOPS-BC, so be sure to check if there has been an update in this area. If not, you can still use TOPS-BC and the cost information you have already input to provide a computational tool for calculating the annual benefits and comparing them to the annual costs. You can modify an existing benefit page to meet your needs or you can estimate the benefits outside the model and input them into a *User Entered Benefit (Annual $'s)* cell on any benefit page. See for example Figure 39.

Recall that for the City of Portland/TriMet's streamlining program, on average, the 12 streamlined routes operated 0.8 minutes faster per round trip in 2005 than in 2000, while 7 comparative non-streamlined Portland routes operated 1.3 minutes slower. The difference is 2.1 minutes per trip. If this allowed for four fewer buses to be run per day, operating cost could be reduced be $140,000 per bus or $700,000. Of course there could be other benefits such a quicker and more reliable service saving commuters time and adding reliability. For this example, let us just start with the $700,000 in annual cost avoidance and enter that value into TOPS-BC. So, from the cost page we just completed:

1. In the left navigation column click on Signal Coordination which will take you to the Benefits Page.
2. If we were estimating the benefits of Signal coordination we would use the top of this page to estimate the travel time, reliability, safety, and energy benefits of the program.
3. Go to the last block and enter into the *User Entered Benefit (Annual $'s) cell, $700,000*.

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0

PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies

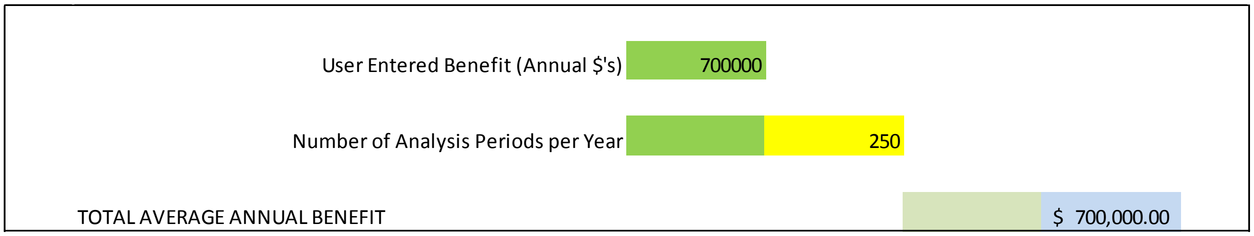
WORK AREA 1 - ESTIMATE AVERAGE ANNUAL COST

Traffic Signal Coordination Systems: Transit Signal Priority

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrastructure Equipment (per Intersection)				
Signal Preemption Receiver	5	$ 4,000	$ 125	$ 925
Signal Controller Upgrade	20	$ 3,500	$ -	$ 175
Telecommunications (low usage)		$ -	$ 190	$ 190
TOTAL Infrastructure Cost		$ 7,500	$ 315	$ 1,290
Incremental Deployment Equipment (per Transit Vehicle)				
Signal Preemption Processor	10	$ 450	$ 10	$ 55
Cell Based Communications Equipment	10	$ 200	$ 10	$ 30
TOTAL Incremental Cost		$ 650	$ 20	$ 85
INPUT Enter Number of Infrastructure Deployments	30			**$ 38,700**
INPUT Enter Number of Incremental Deployments	50			**$ 4,250**
INPUT Enter Year of Deployment	2014			
Average Annual Cost				**$ 42,950**

Source: FHWA TOPS-BC

Figure 39. Screenshot. Tool for Operations Benefit-Cost Analysis Lifecycle Signal Priority Cost Page.



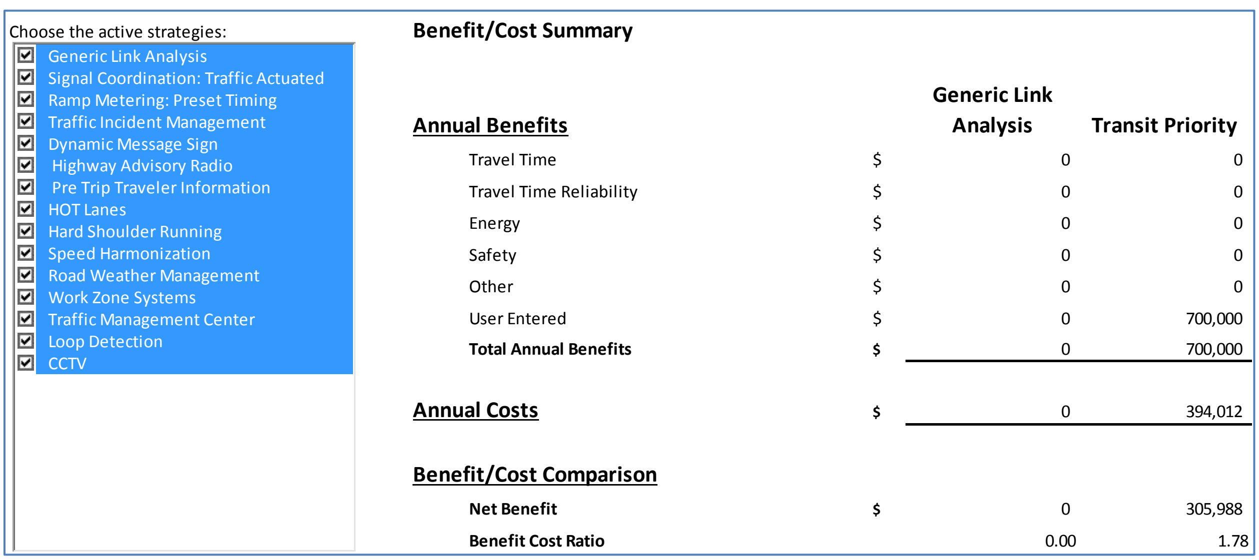
Source: FHWA TOPS-BC

Figure 40. Screenshot. Partial View of the Tool for Operations Benefit-Cost Analysis Benefit Estimation Page.

This also allows the user to test the impact of changes in selected input data. For example, the analysis can be carried out for examples that highlight local or recent information for your project using different technology costs, boardings, wait times, route times etc. Now we will see what TOPS-BC has done with the input cost and benefit data.

1. On the navigation column, or on the page tabs below the Excel sheet, click on *My Deployments*. If you were considering several project deployments, each can be displayed on this summary of the BCA.

Figure 41 displays a portion of the Summary page containing the user estimated benefits and TOPS-BC estimated annual cost. Other portions of this page contain annual costs and benefits.



		Generic Link Analysis	Transit Priority
Annual Benefits			
Travel Time	$	0	0
Travel Time Reliability	$	0	0
Energy	$	0	0
Safety	$	0	0
Other	$	0	0
User Entered	$	0	700,000
Total Annual Benefits	$	0	700,000
Annual Costs	$	0	394,012
Benefit/Cost Comparison			
Net Benefit	$	0	305,988
Benefit Cost Ratio		0.00	1.78

Source: FHWA TOPS-BC

Figure 41. Screenshot. Partial View of the Tool for Operations Benefit-Cost Analysis Transit Priority Benefit-Cost Summary Page.

Key Observations

Operation of a bus rapid transit system in a major city is complex. Developing ways to improve system operations can be even more challenging. What Portland TriMet learned was that system improvement required an advanced data collection system that would provide researchers the information necessary to identify if new technology investments and system operations translated into improvements in key MOEs. With the assistance of BCA tools, changes in MOEs can be used to estimate the dollar benefits of these changes. These dollar benefits can then be compared to the added cost to the transit property for capital equipment, labor, maintenance and other costs.

Case Study 8.2 – Transit Signal Priority, Los Angeles DOT/ MTA

Strategy Type:	Transit Operations
Project Name:	Transit Signal Priority
Project Agency:	Los Angeles DOT/ MTA
Location:	Urban Transit
Geographic Extent:	Regional/Urban
Tool Used:	Internal BCA Data Review

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

The City of Los Angeles Department of Transportation (LADOT), in collaboration with the Los Angeles County Metropolitan Transportation Authority (MTA), has successfully implemented an advanced Traffic Signal Priority (TSP) system along several major transit corridors in the Los Angeles Region. Using loop detector technology and state of the art transit management software, the LADOT Traffic Signal Priority has received several awards for creativity and innovation from prominent transportation industry organizations nationwide.

The LADOT TSP is currently active on four of the busiest transit corridors in Los Angeles: Ventura Boulevard, Wilshire/Whittier Boulevards, Vermont Avenue, and Broadway. The Ventura Boulevard Corridor, consisting of 89 signalized intersections and 16-miles of roadway, connects the Metro Red Line Station at Universal City to the Warner Center, a major commercial and business center in the West San Fernando Valley. The Wilshire/Whittier Boulevard Corridor, consisting of 123 signalized intersections and 14-miles of roadway, traverses through the central part of the Los Angeles Basin and connects East Los Angeles with the Central Business District, and the Cities of Beverly Hills and Santa Monica. Wilshire Boulevard is a prime business district with extensive commercial office buildings, museums and retail stores. Whittier Boulevard serves as a major East-West arterial in East Los Angeles and is fronted by a mixture of retail stores and residential area. These two streets are connected by the one-way street couplet of Fifth and Sixth Streets in the downtown Central Business District. The Vermont Avenue Corridor, consisting of 67 signalized intersections and 13 miles of roadway, connects the Metro Green Line Vermont Avenue Station to the Metro Red Line Sunset Boulevard Station. The Broadway Corridor, consisting of 79 signalized intersections and 11 miles of roadway, connects the Metro Green Line Harbor Freeway Station with the Downtown Central Business District and the Metro Gateway Plaza at Union Station.

Automated Traffic Surveillance and Control and Transit Priority Manager System Operation

Each signalized intersection in the project area is equipped with loop detectors that serve as Automatic Vehicle Identification (AVI) sensors. These sensors embedded in the pavement receive a radio-frequency code from a small transponder installed on the underside of a vehicle. Buses equipped with unique transponders are detected when traveling over the loop detectors. These loops are connected to a sensor unit within the traffic signal controller at each intersection, which transmits the bus identification number to the Transit Priority Manager (TPM) computer in the City's Automated Traffic Surveillance and Control (ATSAC) Center at City Hall East for tracking and schedule comparison.

Once the bus identification and location are received by the TPM, the computer makes a determination of the need for traffic signal priority. If the bus is early or ahead of the scheduled headway, no traffic signal priority treatment is provided. However, if the bus is late or beyond the scheduled headway, then the downstream traffic signal controller will provide signal priority to help the buses catch up with the scheduled headway. In addition, real-time data links from the MTA dispatch center to the ATSAC center is used to obtain the daily bus assignment for schedule comparison.

Types of Priority

- Early Green priority is granted when a bus is approaching a red signal. The red signal is shortened to provide a green signal sooner than normal.
- Green Extend priority is granted when a bus is approaching a green signal that is about to change. The green signal is extended until the bus passes through the intersection.
- Free Hold priority is used to hold a signal green until the bus passes through the intersection during non-coordinated (free) operation.
- Phase Call brings up a selected transit phase that may not normally be activated. This option is typically used for queue jumper operation, or a priority left turn phase.

Project Goals and Objectives:

The TSP is a critical element of the Metro Rapid Bus (MRB) Demonstration Program that was jointly developed by LADOT and MTA. The initial phase of the Metro Rapid Bus was deployed on June 24, 2000, when the Metro Red Line subway was extended to the North Hollywood Stations in the San Fernando Valley. The purpose of the Metro Rapid Bus Demonstration Program is to offer rail-type frequent and high quality transit services connecting the terminus of the Red Line to major destinations in the outlining areas. The TSP serves to improve the on-time performance of the Metro Rapid Bus by adjusting the signal timing at intersections for buses as their approach is detected. The TSP is also used to provide real-time next bus arrival information to passengers waiting at bus stations and assist bus fleet management by recording the travel time for each bus run.

Data Requirements

Before and After Study of Bus Travel Times and Travel Speeds

A detailed evaluation of the Traffic Signal Priority System was undertaken three months after the beginning of the Metro Rapid Bus service. This allowed time for bus operators, passengers and general automotive traffic to become aware of the system. The first part of the evaluation ensures the effectiveness of the system in terms of overall travel time savings along the route and the reduction of time transit vehicles spent waiting at red traffic signals. The second part of the evaluation measures the impacts to general automotive traffic from the implementation of the Traffic Signal Priority System. Data for each evaluation was collected independently, and the results of these are presented below.

Previous Bus Delay Study

In the spring of 1998, LADOT staff conducted a manual data collection program along Wilshire and Ventura Boulevards to analyze the major causes of bus delay and operating inefficiency. The findings of that study indicated that the overall bus delays can be attributed to two major factors: buses stopped for red traffic signals, and buses delayed at bus stops loading and unloading passengers. Approximately 20 percent of the total bus running time was spent waiting at traffic signals, and another 25 percent of the total bus running time was due to bus loading delays at bus stops. These combined delays represent 45 percent of the total bus running time.

Before and After Study Methodology

The Traffic Signal Priority System records the time and date each transponder-equipped bus passes over a loop detector in the system. This provides a complete record of each bus trip made along the Rapid Bus route. From this detailed recorded data, it is possible to determine exactly the running times of the buses. For the period September 5, 2000 through September 14, 2000, a total of 13 Rapid Buses (seven assigned to the Wilshire/Whittier Boulevard route and six assigned to the Ventura Boulevard route) were not given priority at any of the traffic signals. All of the remaining 99 Rapid Buses operated with priority.

Ventura Boulevard Travel Time Analysis

Data collected along Ventura Boulevard was used to determine the amount of time saved between local buses and Rapid Buses both with and without priority. This information shows how much of the travel time savings is due to the Traffic Signal Priority System as compared to the Rapid Buses alone.

The combined effects of the Rapid Bus service and the Traffic Signal Priority System have reduced the average running times along Ventura Boulevard by 23 percent, of which 33 percent is due to TSP, and 67 percent due to the Rapid Buses. The average travel speed for local buses was 15 miles-per-hour.

Wilshire/Whittier Boulevard Travel Time Analysis

Similar analysis based on the data collected along Wilshire/Whittier Boulevards determined the amount of time saved between local buses and Rapid buses both with and without priority, and how much of the travel time savings was due to the Traffic Signal Priority System, as compared to the Rapid Buses alone.

The combined effects of the Rapid Bus service and the Traffic Signal Priority System have reduced the average running times along Wilshire/Whittier Boulevards by 28 percent, of which 27 percent is due to the signal priority system, and 73 percent due to the Rapid Buses. The average speed for local buses was 11 miles-per-hour.

Summary of Findings about Travel Time Saving

The evaluation of the results show that the combined benefits of traffic signal priority and the limited stop Rapid Bus led to a net travel time saving of 28 percent on Wilshire/Whittier Boulevards and 23 percent on Ventura Boulevard. Based on further analysis, LADOT estimated the following results in the four TSP selected corridors:

- On Ventura Boulevard, 33 percent of the travel time savings is due to the Traffic Signal Priority System and 67 percent from other components of the Metro Rapid Bus Program.
- On Wilshire/Whittier Boulevards, 27 percent of the savings is due to the Traffic Signal Priority System and 73 percent from other components of the Metro Rapid Bus Program.
- On Ventura Boulevard, the Traffic Signal Priority System reduced the delays caused by traffic signals by 36 percent.
- On Wilshire/Whittier Boulevards, the Traffic Signal Priority System reduced the delays caused by traffic signals by 33 percent.

Benefit Cost Evaluation

The LADOT used this information to conduct a preliminary benefit-cost analysis. Attribution of cost and the resulting benefits to specific technologies or strategies is a challenging exercise. Engineers can test the system by using a sample of buses operating without the TSP operating and compare travel times for buses with and without technology buses as was done in the Los Angeles study.

Cost Estimation

The results of this evaluation analysis can be used to estimate the cost saving obtained from the Traffic Signal Priority System. The MTA indicates that the current system average cost of operating a bus is $98 per hour. With a traffic signal delay reduction of 4.5 minutes per hour, this translates into a cost saving of approximately $7.35 per hour per bus. For a bus operating along these routes for 15 hours per day, the cost saving would be approximately $110.25 per day. Some additional capital cost should be allocated to the TSP system. A centrally controlled or adaptive signal system was required along with the loop detectors and on board transponders. The latter may be directly attributable to the TSP and a portion of the traffic management system may also be attributed to the TSP to develop a full understanding of the system costs. The Traffic Signal Priority System cost almost $3 million to install along both Ventura Boulevard and Wilshire/Whittier Boulevards, including the cost of the software development. A total of 211 signalized intersections are outfitted with the Traffic Signal Priority System, at an average intersection cost of $15,000 per intersection.

Benefit Quantification

Assuming 100 buses per day for an average of 300 days per calendar year in the two corridors, this translates into approximately $3.3 million annual operating cost saving for the MTA. This saving does not include the added benefit of travel time saving to the Rapid Bus passengers. TOPS-BC can be used to provide a sketch planning analysis of the benefits and costs of TSP when MOEs are available. Within TOPS-BC, TSP can be found on the navigation column under Estimated Costs and the Traffic Signal Coordination Systems group. TOPS-BC provides defaults data on the value of travel time savings which can be combined with travel time MOEs calculate dollar benefits that can be added to the system savings produced by the operating efficiencies.

Using TOPS-BC the analyst can use available data from current operations to evaluate future signal priority systems. Currently TOPS-BC offers a cost estimation sheet for Transit Signal Priority, but no benefit page dedicated to TSP. The user can calculate benefits outside the model and enter the calculated benefit values, taking advantage of the TOPS-BC defaults and system architecture. Let us use TOPC-BC to evaluate the Ventura Boulevard and Wilshire/Whittier Boulevards TSP systems.

1. Open TOPS-BC, and click on *Estimate Life-Cycle Cost* which takes you to the cost section
2. In the left most navigation column under 3) *Cost Estimation* click on *Transit Signal Priority* which will open the cost page. Determine if the items and their costs agree with your previous information. If they do not, you can add items or edit the existing items.
3. Now in the Green cells you can input the number of expected infrastructure deployments, the number of incremental deployments (buses to be equipped) and the year of deployment.
4. TOPS-BC will now calculate the annual cost and the net present value for a 20 year program that you described. You can also change the length of the period or the discount rate selected.

LAMTA reported that the full cost of the TSP on these two routs was $15,000 for each of 211 intersections or $3,165,000. Assume 20 percent of this was software related and we have $633,000 for software and $2,532,000 for hardware and installation or $12,000 per intersection. For this case we will assume these costs are equally divided between the Signal Preemption Received and the Signal Controller Upgrade. So enter the unit costs at $6,000 for each under the Basic Infrastructure Equipment (per Intersection) cell. We will use the TOPS-BC estimate for the signal infrastructure O&M. We will also use the TOPS-BC estimate for the on-board technology installation. For number of buses to be equipped with on-board systems, we will assume 30 miles of served roadway with one quarter mile headway between buses or 120 buses to be equipped.

Figure 42 displays the cost page with our entries. TOPS-BC has calculated the average annual system cost based on an assumed discount rate of 7 percent and 20 year project life to get to the cost of $393,165 per year. This results in a net present value cost of $3,766,521 in 2014 in 2010 dollars, as shown in Figure 43. TOPS-BC uses 2010 as the default year for the definition of the dollars. However, the user can change this to any other year on the TOPS-BC *Parameters* Page. The user can also select alternatives to the Discount Rate, to the deployment year and to the base year dollars.

Now that we have estimates of cost, we can move on to the benefit calculation. TOPS-BC does not have at this time a benefit calculation sheet for TSP. We can calculate benefits of TSP outside the model and enter the results. TOPS-BC will then utilize the costs and benefits calculated and provided to generate the BCA and a Summary page. LA MTC reports that the bus operation costs are $98 per hour. There are 120 buses estimated to save 4.5 minutes per hour for a saving of $110.25 per day per bus. Total savings are:

Total Annual Savings = 120 buses at $110.25 per day for 300 days per year = $3,969,000 savings per year

We take the following steps:

1. In the left navigation column click on Signal Coordination which will take you to the Benefits Page.
2. If we were estimating the benefits of Signal Coordination we would use the top of this page to estimate the travel time, reliability, safety, and energy benefits of the program, but we are not so,
3. Go to the last block and enter into the *User Entered Benefit (Annual $'s)* cell $3,969,000.
4. Now navigate to the *My Deployments* page either in the navigation column or on the tab below the spreadsheet.

Figure 43 shows the BCA summary for this case study.

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0

PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies

WORK AREA 1 - ESTIMATE AVERAGE ANNUAL COST

Traffic Signal Coordination Systems: Transit Signal Priority

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrastructure Equipment (per Intersection)				
Signal Preemption Receiver	5	$ 6,000	$ 125	$ 1,325
Signal Controller Upgrade	20	$ 6,000	$ -	$ 300
Telecommunications (low usage)		$ -	$ 190	$ 190
TOTAL Infrastructure Cost		$ 12,000	$ 315	$ 1,815
Incremental Deployment Equipment (per Transit Vehicle)				
Signal Preemption Processor	10	$ 450	$ 10	$ 55
Cell Based Communications Equipment	10	$ 200	$ 10	$ 30
TOTAL Incremental Cost		$ 650	$ 20	$ 85
INPUT Enter Number of Infrastructure Deployments	211			**$ 382,965**
INPUT Enter Number of Incremental Deployments	120			**$ 10,200**
INPUT Enter Year of Deployment	2014			
Average Annual Cost				**$393,165**

Source: FHWA TOPS-BC

Figure 42. Screenshot. Tool for Operations Benefit-Cost Analysis of Transit Signal Priority Costs.

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

Traffic Signal Coordination Systems: Transit Signal Priority

Cost Item	2013	2014	2015	2016	2017	2018	2019	2020
Infrastructure Costs	$ -	$ 2,598,465	$ 66,465	$ 66,465	$ 66,465	$ 66,465	$ 1,332,465	$ 66,465
Incremental Costs	$ -	$ 80,400	$ 2,400	$ 2,400	$ 2,400	$ 2,400	$ 2,400	$ 2,400
Total Annual Cost	$ -	$ 2,678,865	$ 68,865	$ 68,865	$ 68,865	$ 68,865	$ 1,334,865	$ 68,865
Cumulative Cost	*$ -*	*$ 2,678,865*	*$ 2,747,730*	*$ 2,816,595*	*$ 2,885,460*	*$ 2,954,325*	*$ 4,289,190*	*$ 4,358,055*

INPUT	Enter Number of Years in the Analysis Time Horizon		20	Source: TIGER Grant Application Recommendations
INPUT	Enter the Beginning Year of the Analysis	2014	2013	
INPUT	Enter Discount Rate		7.0%	Source: Office of Management and Budget

NET PRESENT VALUE OF COSTS $3,766,521

2014 TO 2034

Source: FHWA TOPS-BC

Figure 43. Screenshot. Tool for Operations Benefit-Cost Analysis Annual and Net Present Value of Cost.

Note: TOPS-BC carries out the annual cost series for the specified analysis period.

Choose the active strategies:

- ☑ Generic Link Analysis
- ☑ Signal Coordination: Central Control
- ☑ Ramp Metering: Preset Timing
- ☑ Traffic Incident Management
- ☑ Dynamic Message Sign
- ☑ Highway Advisory Radio
- ☑ Pre Trip Traveler Information
- ☑ HOT Lanes
- ☑ Hard Shoulder Running
- ☑ Speed Harmonization
- ☑ Road Weather Management
- ☑ Work Zone Systems
- ☑ Traffic Management Center
- ☑ Loop Detection
- ☑ CCTV

Benefit/Cost Summary

		Generic Link Analysis	Signal Coordination: Central Control
Annual Benefits			
Travel Time	$	0	0
Travel Time Reliability	$	0	0
Energy	$	0	0
Safety	$	0	0
Other	$	0	0
User Entered	$	0	3,969,000
Total Annual Benefits	$	0	3,969,000
Annual Costs	$	0	393,165
Benefit/Cost Comparison			
Net Benefit	$	0	3,575,835
Benefit Cost Ratio		0.00	10.09

Source: FHWA TOPS-BC

Figure 44. Screenshot. Tool for Operations Benefit-Cost Analysis Benefit-Cost Summary.

The analysis indicates that for each dollar in cost spent, the TSP investments will return over $10 in benefits. Recall also that we only estimated cost savings to the agency and adding consumer benefits would increase the Benefit-Cost Ratio (BCR).

Key Observations

Major urban centers like Los Angeles are seeking every efficiency advantage in the operations of their Major Arterial networks. Transportation planners in LA realized that heavy congestion and signaled intersections were adding to the travel time on several major corridors. They selected four such major arterials, each about 15 miles in length and with 70 to 120 signalized intersections.. By installing Transit Signal Priority Service for buses on these corridors, planners were able to improve operating efficiency thus reducing the number of buses required and reduced travel time providing additional benefits to the bus riders.

Planners tested the impact of the TSP system in two corridors by selecting a sample of about ten percent of the operating buses and running them without the TSP technology in place. By measuring transit times for busses with and without the technology they were able to estimate the effectiveness of the TSP technology in improving system operations. In this case we used the TOPS-BC cost sheets populated with information from the LA MTC case and estimated benefits on the realized agency cost savings. These data were use within TOPS-BC to estimate a BCR that was very similar to the value estimated by MTA staff.

CHAPTER 9. TRAVELER INFORMATION

#	Case Name	BCA Model	Actual or Hypothetical Case
9.1	Oregon's Automated Wind Warning System	Custom In-House Analysis	Actual
9.2	Hypothetical Truck Tip-Over Warning System	TOPS-BC	Hypothetical
9.3	Freight: Truck Over-Height Warning System	TOPS-BC	Hypothetical

Case Study 9.1 – Oregon's Automated Wind Warning System

Strategy Type:	Traveler Information System
Project Name:	The Rural California / Oregon Advanced Transportation Systems (COATS) Automated Wind Warning System (AWWS)
Project Agency:	The Oregon and California Departments of Transportation (ODOT and Caltrans, respectively)
Location:	The Rural California / Oregon Advanced Transportation Systems Study Area (US Route 101)
Geographic Extent:	Two Selected Regions
Tool Used:	Custom In-House Analysis

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

To address localized high cross-wind challenges, the Oregon and California Departments of Transportation (ODOT and Caltrans, respectively) have used intelligent transportation system (ITS) installations to alert motorists of dangerously windy conditions automatically. Such a system is known as an Automated Wind Warning Systems (AWWS). ODOT designed its AWWS to send warning messages to drivers at locations where they can either stop and wait until conditions have improved or opt to take an alternate route.

ODOT has deployed two such systems in the rural California/Oregon Advanced Transportation Systems (COATS) study area, at the following locations:

- Between Port Orford and Gold Beach, Oregon on US Route 101 between mileposts (MP) 300.10 and 327.51 ("South Coast System")
- Between mileposts 141.27 (SB) and 142.08 (NB) on the Yaquina Bay Bridge (US Route 101) in Oregon.

The two systems had similar components and are being observed by both departments of transportation to evaluate future AWWS deployments in their respective States. Wind gauges (anemometers) were connected to roadside static message signs and flashers were activated when average wind speeds reached predetermined threshold levels. The system automatically recorded the severity of the cross winds and notified traffic operators of the system's status. Once wind conditions were verified by the Traffic Operations Center, additional warnings were posted on the Oregon DOT TripChek Web site. The warning messages were deactivated when wind speeds dropped below threshold levels.

Project Goals and Objectives

US Route 101 is a very important corridor for the movement of freight and tourists, so it is critical to keep this highway open. Therefore, ODOT ITS Unit designed and deployed automated wind warning systems (AWWS) to reduce the number of road closures on US Route 101 and improve efficiency. As part of this process, ODOT performed BCA of these systems to evaluate their effectiveness in meeting their objectives. In order to provide comparable benefits and costs within the analysis, ODOT carefully selected key measures of effectiveness (MOEs) as the focus of this analysis. These measures included:

1. Safety (Reduction in wind induced accident frequency and severity);
2. Efficiency (Traveler awareness of these systems);
3. Customer Satisfaction (Traveler perception of the usefulness of these systems);
4. Reliability (Traveler perception of the reliability of the system);
5. Productivity; and
6. Operational cost savings.

Methodology

This analysis measured MOE 1 (Safety) through an analysis of crash data for the years 1997-2003, reviewed MOEs 2 through 5 (Efficiency, Customer Satisfaction, Reliability and Productivity) in the motorist survey results, and quantified MOE 6 (Operational Cost Savings) through the operational assessment. Table 45 summarizes the objectives and MOEs proposed for this evaluation.

Table 45. Goals, Objectives, and Measures of Effectiveness

Goal	Objectives	Potential Measures of Effectiveness	Data Source
Improve the safety and security of the region's rural transportation system	Improve the safety of high profile vehicles	• Crash frequency for high profile vehicles • Crash severity for high profile vehicles	Crash Data
	Improve safety of lower profile vehicles	• Crash frequency for all vehicles • Crash severity for all vehicles	Crash Data
Provide sustainable traveler information systems that collect and disseminate credible, accurate, "real-time" information	Improve the motorist information on severe weather conditions	• System usage by motorists • Awareness of system among motorists	Motorist Survey
	Improve motorist acceptance and perception	• Sign clarity • Message credibility and reliability	Motorist Survey
Increase operational efficiency and productivity focusing on system providers	Improve staff operations efficiency	• Savings in personnel time • Reduction in the time to post a message	Maintenance Logs
	System reliability	• Number of full system outages • Number of partial system outages	Maintenance Logs
	Improving emergency response	• Information Sharing	Kick-Off

Source: Oregon DOT

Benefits

The direct benefits of the AWWS result from labor and equipment cost savings realized through avoiding road closures and the need to manually monitor conditions (on-site) during high-wind events at regular intervals. In both locations, annual savings are a function of the number of high-wind events observed at each site.

As shown in Table 46, labor and equipment cost savings were calculated using average durations of road closures for two systems - South Coast and the Yaquina Bay Bridge systems. The study compiled data on the number of annual closure incidents, the average distances between the maintenance yards and the system locations, the average labor and vehicle costs per closure and for an average year. The labor rates were calculated from prevailing wage rates published by the Oregon Bureau of Labor and Industries.

Table 46. Labor and Equipment Cost Savings for Automated Wind Warning Systems.

Cost Category	South Coast		Yaquina Bay Bridge	
	Per Closure	Per Year	Per Closure	Per Year
ODOT Maintenance Crew				
Personnel				
Number of Crew Members	3	30	3	90
Work Hours	6	60	3.5	105
Labor Cost (@$33.47 average wage)	$603	$6,030	$351	$10,530
Vehicle Operations				
Number of Vehicles	2	20	2	60
Miles Driven	4	40	3	90
Vehicle Cost (@$0.50/mile)	$32	$320	$18	$540
Oregon State Police				
Personnel				
Number of Crew Members	2	20	2	60
Work Hours	6	60	3.5	105
Labor Cost (@$33.47 average wage)	$384	$3,840	$224	$6,270
Vehicle Operations				
Number of Vehicles	2	20	2	60
Miles Driven	4	40	2	60
Vehicle Cost (@$0.50/mile)	$8	$80	$4	$120
Total Labor and Equipment Cost Savings	**$1,027**	**$10,270**	**$597**	**$17,910**

Source: Oregon DOT

The study also calculated the benefits of two types of delay savings realized from the AWWS. First, road closures are not automatically enacted when high winds occur, which means that delay will be reduced for motorists when the road can be kept open. Second, for those occasions when a road closure is required, the automated system allows for quicker removal of the closure when winds subside. In both cases, the estimated delay associated with road closures is based on traffic characteristics associated with each location.

Traffic volumes were used to estimate delay savings. Traffic volumes were estimated based on average duration wind events (6 hours for South Coast, 3 ½ hours for Yaquina Bay). Two volume scenarios are presented: an average volume scenario which assumes the closure may happen at any time of the day, and a high volume scenario, which includes the 30th highest hour volume as the volume during one hour of the closure. It is possible that a certain percentage of motorists choose to take an alternate route during high-wind events. An estimation of the percentage of drivers that may choose to take an alternate route was performed based on the responses to the motorist survey conducted for the two systems. As shown in Table 47, these traffic volume scenarios were then combined with value of time factors from the FHWA HERS model to calculate the average delay costs per road closure for passenger vehicles and heavy trucks.

Table 47. Average Delay Costs per Road Closure (South Coast System).

Measure	Average Volume Scenario	High Volume Scenario
Passenger Vehicles		
Vehicles Delayed per Closure	394	697
Average Value of Time per Hour	$18.65	$18.56
Average Cost	$7,313	$12,936
Heavy Trucks		
Trucks Delayed per Closure	37	65
Average Value of Time per Hour	$27.83	$27.83
Average Cost	$1,030	$1,809
Average Cost of Delay per Closure	**$8,343**	**$14,745**

Source: Oregon DOT

Costs

The implementation costs were estimated to be approximately $90,000 for the combined systems. The annual maintenance costs of the South Coast and Yaquina Bay Bridge systems are expected to be $3,000 and $3,500 per year, respectively. These costs were estimated as the systems were designed, built and installed by ODOT, and numerous State resources were used in the process that was not readily traceable. Maintenance cost estimates are based on another COATS Showcase study on maintenance costs of field elements in rural areas.

Benefit-Cost Ratio

The benefit-cost ratios were estimated based on the following assumptions:

- A 10-year analysis period for the calculation of benefit-to-cost ratio;
- A traffic growth rate of 2 percent per year and a rate of return (ROR) of 7 percent; and
- Three percent inflation for the calculation of the benefits in 2004 U.S. dollars.

Model Run Results

Accounting for motorist delay reduction as well as other benefits such as improved safety for motorists (and maintenance personnel) during high wind events, the benefit-to-cost ratios for the South Coast system and Yaquina Bay Bridge system were 4.13:1 and 22.80:1, respectively. The Yaquina Bay Bridge system had a higher benefit-to-cost ratio reflecting the higher frequency of cross winds in the area and heavier traffic volumes compared to the South Coast system. The analyses assumed the system would reduce delay by approximately 20 percent as a result of prompt deactivation of wind warnings. The benefit-cost ratio calculations, and the number of years until the benefits exceed the costs (break even analysis), are shown in Table 48.

Table 48. Benefit Cost Calculations for Automated Wind Warning Systems.

Category	South Coast		Yaquina Bay Bridge	
	Average[1] (5 closures per year)	High[2] (10 closures per year)	Average[1] (30 closures per year)	High[2] (30 closures per year)
Benefits				
Direct Savings from Non-Closure	$5,135	$10,270	$11,940	$17,910
Delay Reductions from Non-Closure	$41,715	$73,725	$242,570	$465,200
Delay Reductions from Quicker Deactivation	$2,980	$5,275	$18,960	$35,350
Costs				
Initial Installation Costs (non-recurring)	$90,000		$90,000	
Power, Communication, and Maintenance (recurring)	$3,000		$3,500	
Benefit-Cost Ratio[3]				
Direct Benefits Alone	0.87		1.46	
Direct and Indirect Benefits	4.13		22.80	
Number of Years Before Benefits Exceed Costs				
Direct Benefits Alone	12 years		7 years	
Direct and Indirect Benefits	3 years		1 year	

[1] "Average" scenario includes average number of wind events and average traffic volumes.
[2] "High" Scenario includes high number of wind events and high traffic volumes.
[3] Benefit-cost ratio is calculated based on "average" benefits.
Source: Oregon DOT

The estimated benefit-cost ratios indicate that the direct benefits from the two AWWS systems in Oregon would exceed their installation, operational and maintenance costs between seven years for the Yaquina Bay Bridge system and twelve years for the South Coast system after installation, depending on the frequency of road closures related to high wind events and the traffic volume through these locations. If delay reductions to the motorists are considered, the benefits of the system pay for the system installation and maintenance costs within three years for the South Coast system and one year for the Yaquina Bay Bridge system. These benefit-cost ratio estimates did not include any indirect benefits such as improved safety for maintenance personnel and improved safety for the motorists during high wind events. A positive benefit-cost ratio was achieved counting only the motorist delay reduction benefits. The continued deployment of these systems will provide more information about the safety benefits to workers and drivers in the future. As this study was completed with only 1-2 deployment history, statistically reliable crash reduction estimates could not be developed at this time.

The results of the BCA showed rural AWWS deployments to be an extremely efficient investment. The potential benefits included reduced travel time delay, crash reduction during adverse weather, and operating cost savings through more efficient use of winter maintenance resources. 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 improved AWWS in the regions.

Key Observations

This case evaluated AWWS in Oregon rural highway corridors. From the BCA results, AWWS deployments offered significant cost savings to drivers as well as ODOT. These systems also allow more prompt high wind notifications to the drivers thus reducing exposure of the driving public to high cross winds along US Route 101.

Overall, this case showed that weather management costs decreased with increased use of weather information and with improved accuracy. Therefore, agencies should consider expanding the use of current resources and investing in improving the accuracy of their weather information to realize cost savings. The use of low and high traffic volumes can be used for a break-even analysis. It is also important to consider both direct and indirect benefits of your deployments. Care must be taken not to double count benefits as many indirect benefits may already be embodied in the direct benefits. This is the difference between BCA and Impact analysis. In impact analysis, all economic changes, positive or negative, direct or indirect, are accounted for.

Case Study 9.2 – Hypothetical Truck Tip-Over Warning System

Strategy Type:	Traveler Information System
Project Name:	Hypothetical Truck Tip-Over Warning System
Project Agency:	Colorado DOT
Location:	Freeways and Other Systems
Geographic Extent:	Nationwide
Tool Used:	TOPS-BC

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Curve speed warning systems use roadside detectors and electronic warning signs to warn drivers, typically those in commercial trucks and other heavy vehicles, of potentially dangerous speeds in approach to curves on highways.

Project Goals and Objectives

In Colorado, the State DOT deployed a Truck Tip-Over Warning System I-70 eastbound just outside Idaho Springs to help prevent rollover crashes on sharp curves. The system consisted of two piezo weigh-in-motion (WIM) devices, traffic detectors, four fiber optic message signs, computer processing equipment and associated software, and a controller cabinet. When the system detects vehicles exceeding the maximum safe speed for their weight category, the warning system activates and the roadside message signs display messages on otherwise blanked-out screens.

Data Requirements

The system helps prevent rollover accidents on sharp curves. The system consists of two weigh in motion sensors and loop detectors to detect vehicle speed, vehicle axles, and vehicle weight. System electronics process information from the sensors in real time, just milliseconds after the vehicle has passed over the sensor configuration. A maximum safe speed is determined specifically for the curve and vehicle weight category. System electronics then match this information with the vehicle speed record. If the actual speed of the vehicle exceeds the calculated maximum safe speed, a roadside blank out sign illuminates a warning message.

The low bid for the project was $446,687 in 2002. Table 49 presents the equipment list of the major components identified in the bid tabulation. The project description did not provide maintenance costs or service lives for the system components.

Table 49. Equipment List of Major Components.

Equipment List - Major Components from Bid Tab	Cost
Truck Tip Over Warning System (Ea.) (WIM)	$ 278,611.00
Blank Out Sign (Fiber Optic) (4 Ea. x 8,788 $/Ea.)	$ 35,112.00
Steel Sign Post (W 6x12) (39.5 lf x 23 $/lf)	$ 908.50
Steel Sign Post (W 8x18) (33 lf x 32 $/lf)	$ 891.00
Concrete Footing (Type 3) (3 ea. x 976 $/ea.)	$ 2,928.00
Concrete Footing (Type 1) (2 ea. x 941 $/ea.)	$ 1,882.00
Other	$ 126,354.00
Total Low Bid Amount	**$ 446,686.50**

Source: "In Oregon and Colorado, Downhill Speed Warning Systems Decreased Truck Crashes up to 13 Percent at Problem Sites," Intelligent Transportation Systems Joint Programs Office, U.S. DOT. Available at: http://www.itsbenefits.its.gov/ITS/benecost.nsf/ID/3E417EC229AF6288852573DA00578A60?OpenDocument&Query=Home

A conference presentation at the 12th Annual ITS Forum, Wisconsin Chapter of ITS America in October 2006 provided an overview of several ITS technologies that improve safety for commercial vehicles operating in rural areas. This overview noted, "Several years of safety data collected at multiple sites show that road geometry warning systems can eliminate rollover crashes and the impacts are sustainable. Downhill speed warning systems have proven effective at mitigating risk to large trucks in areas with steep terrain. At problem sites in Oregon and Colorado, these systems have decreased truck crashes by up to 13 percent."

Benefit Cost Evaluation

Planners and traffic engineers can use data on the costs and benefits of projects such as speed warning systems to evaluate whether such systems provide a positive return on public investment. In this case, the data presented in the previous section provide many of the data required to perform such a benefit-cost analysis. This case study illustrates how a TOPS-BC user can add a cost worksheet for a Truck Tip-over project and add the cost data that Table 49 provides.

Model Run Results

TOPS-BC maintains a blank cost estimation worksheet that can be used to create cost estimation capabilities for new strategies that may not currently be included. A hidden sheet titled COST TEMPLATE, shown as Figure 44, provides a blank cost estimation worksheet. This worksheet has all the analysis capabilities present in all other strategy worksheets, but lacks any default equipment or cost data.

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0

PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies

WORK AREA 1 - ESTIMATE AVERAGE ANNUAL COST

Strategy: Generic Costs

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrastructure Equipment and Costs				
Infrastructure Item 2		$ -	$ -	$ -
Infrastructure Item 3		$ -	$ -	$ -
Infrastructure Item 4		$ -	$ -	$ -
Infrastructure Item 5		$ -	$ -	$ -
Infrastructure Item 6		$ -	$ -	$ -
Infrastructure Item 7		$ -	$ -	$ -
Infrastructure Item 8		$ -	$ -	$ -
Infrastructure Item 9		$ -	$ -	$ -
Infrastructure Item 10		$ -	$ -	$ -
Infrastructure Item 11		$ -	$ -	$ -
Infrastructure Item 12		$ -	$ -	$ -
Infrastructure Item 13		$ -	$ -	$ -
Infrastructure Item 14		$ -	$ -	$ -
Infrastructure Item 15		$ -	$ -	$ -
Infrastructure Item 16		$ -	$ -	$ -
Infrastructure Item 17		$ -	$ -	$ -
Infrastructure Item 18		$ -	$ -	$ -
Infrastructure Item 19		$ -	$ -	$ -
Infrastructure Item 20		$ -	$ -	$ -
Infrastructure Item 21		$ -	$ -	$ -
Infrastructure Item 22		$ -	$ -	$ -
Infrastructure Item 23		$ -	$ -	$ -
Infrastructure Item 24		$ -	$ -	$ -
Infrastructure Item 25		$ -	$ -	$ -
Infrastructure Item 26		$ -	$ -	$ -
Infrastructure Item 27		$ -	$ -	$ -
Infrastructure Item 28		$ -	$ -	$ -
Infrastructure Item 29		$ -	$ -	$ -
Infrastructure Item 30		$ -	$ -	$ -
Infrastructure Item 31		$ -	$ -	$ -
Infrastructure Item 32		$ -	$ -	$ -
Infrastructure Item 33		$ -	$ -	$ -
TOTAL Infrastructure Cost		$ -	$ -	$ -
Incremental Deployment Equipment				
Equipment Item 2		$ -	$ -	$ -
Equipment Item 3		$ -	$ -	$ -
Equipment Item 4		$ -	$ -	$ -
Equipment Item 5		$ -	$ -	$ -
Equipment Item 6		$ -	$ -	$ -
Equipment Item 7		$ -	$ -	$ -

Source: FHWA TOPS-BC

Figure 45. Screenshot. Partial View of the Tool for Operations Benefit-Cost Analysis Blank Cost Template Worksheet.

Unhiding the Cost Template in TOPS-BC

To unhide the COST TEMPLATE sheet, put your mouse over the worksheet tabs, left click, select "unhide" in the popup menu, select the worksheet COST TEMPLATE, and click "OK"

Rename and populate the new worksheet with customized defined equipment and cost data to create new strategies. To rename the COST TEMPLATE sheet, put your mouse over the COST TEMPLATE worksheet tab, right click, select "rename" and then type in the new name. In addition, type in the new Strategy name in cell K6.

TOPS-BC assumes that user enters the new data in the same format (e.g., equipment name, capital cost, useful life, annual O&M costs).

Figure 45 shows a Partial Screen View of a new TRUCK TIP-OVER cost worksheet. The user has added costs from Table 49.

- Since there is no central infrastructure for this system (such as a DOT would deploy at a traffic management center), the user enters all of the cost items under the Incremental Deployment Equipment section, as all of the costs represent costs necessary to add one additional roadside element to the deployment.
- The user assumes that annual O&M will only be necessary for the first two items (the warning system and the blank-out sign).
- The user estimates that the annual O&M will equal five percent of the capital cost and enters the corresponding values in the O&M Costs column.
- The user also sets the Number of incremental deployments to one (1) and the year of Deployment to 2014.
- The TOPS-BC user deletes unneeded rows in the working calculations sheet.

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0

PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies

WORK AREA 1 - ESTIMATE AVERAGE ANNUAL COST

Strategy: Truck Tip-Over Warning System

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrastructure Equipment and Costs				
TOTAL Infrastructure Cost		$ -	$ -	$ -
Incremental Deployment Equipment				
Truck Tip Over Warning System (Ea.) (WIM)	20	$ 278,611	$ 13,931	$ 27,861
Blank Out Sign (Fiber Optic) (4 Ea.x 8,788 $/ea.)	20	$ 35,112	$ 1,756	$ 3,511
Steel Sign Post (W 6x12) (39.5 lf x 23 $/lf)	20	$ 909	$ -	$ 45
Steel Sign Post (W 8x18) (33 lf x 32 $/lf)	20	$ 891	$ -	$ 45
Concrete Footing (Type 3) (3 ea x 976 $/ea)	20	$ 2,928	$ -	$ 146
Concrete Footing (Type 1) (2 ea x 941 $/ea)	20	$ 1,882	$ -	$ 94
Other	20	$ 126,354	$ -	$ 6,318
TOTAL Incremental Cost		$ 446,687	$ 15,686	$ 38,020

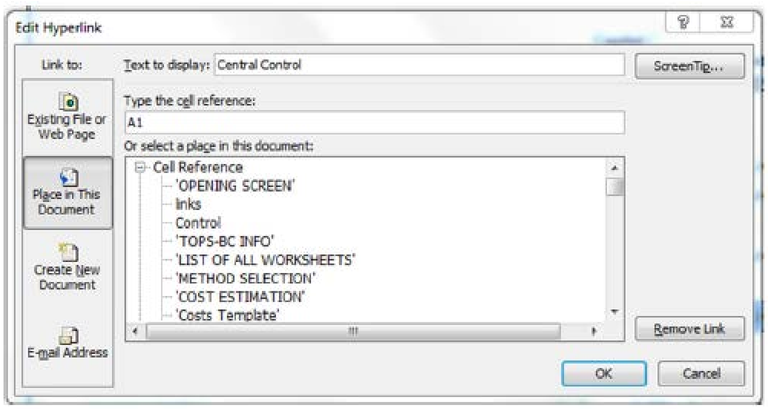
INPUT	Enter Number of Infrastructure Deployments	0	$ -
INPUT	Enter Number of Incremental Deployments	1	**$ 38,020**
INPUT	Enter Year of Deployment	2014	

Average Annual Cost $ 38,020

Source: FHWA TOPS-BC

Figure 46. Screenshot. Partial View of a Tool for Operations Benefit-Cost Analysis New Truck Tip-Over Cost Worksheet.

The TOPS-BC user will also need to modify the navigation capabilities manually and link the new worksheet to the SUMMARY sheet or other worksheets where they intend to use the output cost data. TOPS-BC maintains a common Navigation Menu that it uses on nearly all sheets in the workbook. This Navigation Menu automatically regenerates on each page when the user opens the sheet. Therefore, the user cannot directly edit it on the individual sheets, as TOPS-BC would overwrite any changes the next time the user opens the sheet.



Source: FHWA TOPS-BC

Figure 47. Screenshot. Creating a New Hyperlink in the Master Navigation Menu.

The TOPS-BC user will also need to link the new worksheet to the COSTS SUMMARY and MY DEPLOYMENTS sheets if they intend to use the output cost data together with other benefits or costs. This case study does not cover these techniques, as they require advanced Excel skills.

Modifying the Navigation Menu in TOPS-BC

TOPS-BC maintains The Master Navigation Menu on a hidden worksheet named "links." To modify the navigation menu:

- Put your mouse over the worksheet tabs, left click, select "unhide" in the popup menu, select the worksheet LINKS, and select "OK."
- Insert an entire row in the desired location and enter the desired name of the worksheet. You will then need to create a hyperlink for the new entry by right clicking in the cell for the new entry and selecting "Hyperlinks" from the pop-up menu.
- Select the "Place in this document" option in the "Link to" setting box as shown in Figure 31. You then select the name of the worksheet from the list of worksheets shown near the top of the "Or select a place in this document" box, and then click "OK."

Key Observations

This case study identifies the evaluation of a truck tip-over warning system on a freeway. Curve speed warning or truck tip-over warning systems use roadside detectors and electronic warning signs to warn drivers, typically those in commercial trucks and other heavy vehicles, of potentially dangerous speeds in approach to curves on highways. This case highlights data collected on the cost of such a system and presents some general data on the subsequent reduction in crashes that similar systems have experienced. A TOPS-BC user can employ these types of data points to conduct a benefit-cost analysis.

This case study also illustrates how a TOPS-BC user can add a cost worksheet for a truck tip-over project, add cost data specific to the project, and add the new cost worksheet to the Master Navigation Menu. This allows the user to employ their Microsoft Excel skills to create a structured custom benefit-cost analysis.

Case Study 9.3 – Freight: Truck Over-Height Warning System

Strategy Type:	Traveler Information System
Project Name:	Freight: Truck Over-Height Warning System
Project Agency:	National Pooled Fund Committee with About 25 State DOTs
Location:	Nationwide
Geographic Extent:	All Network Components
Tool Used:	TOPS-BC

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Over-height/0ver-width warning systems use roadside detectors and electronic warning signs to warn drivers of vehicles that are too tall or wide to pass under bridges or through tunnels.

Project Goals and Objectives

When a new Costco distribution center opened in January 2010 near the MD 75/Baldwin Road intersection, it led to increased truck traffic on nearby roadways. When drivers of high profile vehicles continue along southbound MD 75 south of Baldwin Road, they encounter a low clearance bridge at the CSX railroad crossing. This has resulted in truck bridge collisions. In order to avoid a collision, drivers must place their vehicles in reverse and proceed backwards on MD 75, as there are no areas to turn around large vehicles. This has in disabled trucks in the roadway and significant backups and delays for other traffic. Figure 48 provides a picture of a truck that collided with the MD 75 Bridge.

In October 2010, the Maryland State Highway Administration (MDSHA) installed the first phase of a $146,000 over-height warning system on both sides of the bridge. Reflective tubes strung between two 30-foot steel poles strike any vehicle too high to pass under the bridge, acting as an audible alert. In February, the SHA installed Phase 2, the addition of steel poles with infrared height detectors on the eastbound and westbound approaches to the MD 75 and Baldwin Road intersection.

Source: *The Frederick News-Post*

Figure 48. Photo. A Truck that Collided with the MD 75 Bridge.[(7)]

Source: *The Frederick News-Post*

Figure 49. Photo. Truck Over-Height Warning System.[(8)]

Data Requirements

The MDSHA reports that the number of tractor-trailer incidents has decreased by 75 percent (from an average of nine per month to three each month) since the project was completed. A tractor-trailer has not struck the bridge since MDSHA completed the permanent system. The number of tractor-trailers that have become stuck due to the lack of a turnaround at the MD 75 Bridge in Monrovia has also declined since the installation of the truck warning system.

Benefit Cost Evaluation

Planners and traffic engineers can use data on the costs and benefits of projects such as over-height warning systems to evaluate whether such systems provide a positive return on public investment. In this case, the data presented in the previous section provide many of the data required to perform such a benefit-cost analysis. This case study discusses how a planner or traffic engineers can conduct a benefit-cost analysis for an over-height warning system

The first step would be for the BC analyst to collect data on the costs of the project. This should include construction costs as well as operating and maintenance charges that will occur in each year for the lifetime of the project.

BCA Steps

1. Collect data on the costs of the project – include construction, operations and maintenance costs.
2. Calculate the benefits of the system – reduced accidents and reduction in lost time and travel.
3. Compare the ratio of net present value of benefits to net present value of costs for the lifetime of the project.

The second step would be to calculate the benefits of the system. In this case, the benefits are of two types. The first type is reduced accidents, as trucks do not collide with the bridge. The analysis should calculate the number and costs of accidents before and after the installation of the warning system. The second is reductions in lost time and travel. If trucks collide with the bridge or cannot turnaround, this causes delays for both the trucks and for other vehicles. The analysis should calculate the lost time and extra travel time before and after the installation of the warning system. The delays can result in extra travel time for highway users. This additional cost can be estimated using estimates of vehicle operating costs and the value of time estimates for autos and trucks. The benefits are the reduction in accident and time/travel costs with the warning system in place. This analysis should forecast the values of these reductions over the lifetime of the system.

The third step in the analysis would be to compare the ratio of net present value of benefits to net present value of costs. The analysis will require the selection of a discount rate. While TOPS-BC does not address this technology, users can develop their own spreadsheets and may be able to borrow some components of TOPS-BC to assist in the development.

Key Observations

This case identifies the evaluation of an over-height warning system for trucks on an arterial. Over-height warning systems use roadside detectors and electronic warning signs to warn drivers of vehicles that are too tall to pass under bridges or through tunnels. This case highlights data collected on the cost of such a system and presents some general data on the subsequent reduction in crashes and delays that occurred in this deployment. A TOPS-BC user can employ these types of data points to conduct a benefit-cost analysis.

CHAPTER 10. OTHER STRATEGIES

#	Case Name	Benefit-Cost Analysis (BCA) Model	Actual or Hypothetical Case
10.1	Road Weather Pooled Fund Maintenance Decision Support System (MDSS) Implementation	Custom In-House Analysis	Actual
10.2	Hypothetical Maintenance Decision Support System (MDSS) Implementation	TOPS-BC	Hypothetical

Case Study 10.1 – Road Weather Pooled Fund Maintenance Decision Support System (MDSS) Implementation

Strategy Type:	Other Strategies
Project Name:	Maintenance Decision Support System (MDSS) Pooled Fund Study
Project Agency:	South Dakota Department of Transportation
Location:	Highways
Geographic Extent:	New Hampshire, Minnesota, Colorado
Tool Used:	Custom In-House Analysis

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Sixteen States have joined the Maintenance Decision Support System (MDSS) Pooled Fund Study led by the South Dakota DOT to develop an enhanced MDSS based on the Federal MDSS prototype. The MDSS integrates relevant road weather forecasts, coded maintenance rules of practice, and maintenance resource data to provide winter maintenance managers with recommended road treatment strategies. Coupled with other advanced technologies, MDSS has revolutionized DOT winter operations.

MDSS is an integrated software application that provides users with real-time road treatment guidance for each maintenance route (e.g., treatment locations, types, times, and rates) to address the fundamental questions of *what*, *how much*, and *when* according to forecast road weather conditions, available resources, and local rules of practice. In addition, MDSS can be used as a training tool, as it features a "what if" scenario treatment selector that can be used to examine how the road condition might change over a 48-hour period with the user-defined treatment times, chemical types, or application rates.

The essential functions of an MDSS may be visualized in three tiers: global, primary, and secondary. The global essential function of the MDSS is fulfilled as two interrelated applications: a "real-time assessment of current and future conditions" and "real-time maintenance recommendations." Primary functions are those that have been created as part of the MDSS development process such as the road treatment module. A secondary function is one that is or can be accomplished by existing systems such as road weather management information systems (RWMIS) or road weather forecasts.

Project Goals and Objectives

The purpose of this research project was to assess the benefits and costs associated with implementation of MDSS by State transportation agencies. In order to provide comparable benefits and costs within the analysis, South Dakota DOT carefully selected key MOEs to focus primarily on benefits to the implementing agency and ultimate users, including:

- Reduced material use (agency benefit),
- Improved traffic safety (user benefit), and
- Reduced traffic delay (user benefit).

Detailed descriptions of the data collection and evaluation process are available in the full report referenced at the conclusion of this case. The costs and benefits associated with this technology are included in Table 50.

Table 50. Benefit and Cost Categories Expected from Maintenance Decision Support System Deployment.

	Agency	Motorist	Society
Benefit	**Reduced materials costs** Reduced labor costs Reduced equipment costs Reduced fleet replacement costs Reduced infrastructure damage due to road salts	**Reduced motorist delay (through improved LOS)** **Improved safety (through improved LOS)** Reduced response time Reduced clearance time Reduced vehicular corrosion due to road salts	Reduced environmental degradation
Cost	**Software and support costs** **Communications costs** **In-vehicle computer hardware investment** **Training** **Administrative costs** **Weather forecast provider costs**		

LOS = Level of service.
Note: Bold indicates included in methodology.
Source: South Dakota DOT

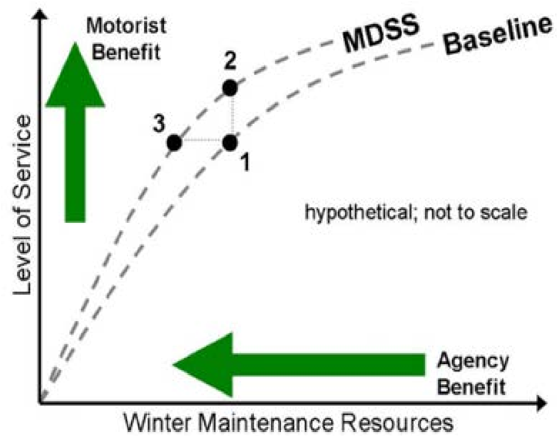
Methodology

A methodology consisting of a baseline data module and a simulation module was developed to analyze tangible benefits, which include the three selected benefits listed above. The methodology was applied to three Pooled Fund States: New Hampshire, Minnesota, and Colorado. The three States were chosen to provide case studies on the benefit-cost ratio of using MDSS. They were selected because they:

- Represented different climates,
- Provided good historical data on maintenance problems, and
- Captured a variety of traffic and terrain conditions.

These criteria were selected so the results would be transferable to other Pooled Fund States.

To evaluate the three cases, several years of historical weather, maintenance, and traffic use data were incorporated to establish baseline information for each route segment. Then, a simulation generated output from the MDSS for each of three scenarios: base case (point 1); same resources (Point 2), which means better level of service; and same conditions (Point 3), fewer resources, as shown in Figure 49. The simulation outputs from selected route segments were extrapolated to other route segments in each state to achieve a statewide BCA.



Source: North Dakota DOT

Figure 50. Graph. Benefit-Cost Methodology and Relationship between Level of Service and Costs.

The data from the three case studies was utilized to estimate a range of benefit and cost results for various conditions and situations. Compendium users can conduct similar analyses for their regions by using the process followed in this study and using their own State data. A complete citation for the study is available at the end of this case study.

Model Run Results

BCA results indicated that the use of MDSS could bring more benefits than costs. The case studies showed that the annual net benefit of using MDSS outweighed the cost to a significant degree, ranging from $488,000 to $2.68 million. The benefit cost findings are shown in Table 51. The benefit-cost ratios do not indicate conclusively which scenario produces better results. The case studies showed that there is a trade-off between agency benefits and user benefits. Increased use of material will achieve greater motorist benefits while increasing agency costs, and vice versa.

Table 51. Benefit-Cost Summary for the South Dakota Study.

Case State	Scenario	Benefits	User Savings (%)	Agency Savings (%)	Costs	B/C Ratio
New Hampshire	Same Condition	$2,367,409	50	50	$332,879	7.11
	Same Resources	$2,884,904	99	1		8.67
Minnesota	Same Condition	$3,179,828	51	49	$496,952	6.40
	Same Resources	$1,369,035	187	-87		2.75
Colorado	Same Condition	$3,367,810	49	51	$1,497,985	2.25
	Same Resources	$1,985,069	90	10		1.33

Source: South Dakota DOT

For the Same Condition scenario, the report notes that the contributions of user benefits to total benefits are almost the same as agency benefits for all cases. The split of benefits for the Same Resources scenario, however, have large variations. In the Minnesota case, the Same Resources scenario used much more salt (12.7 percent of total use) than the Base Case for winter maintenance and seemed to deviate more from the assumed "Same Resources" point 2 (in Figure 49) than the other two cases. Thus, Table 51 shows the negative impact on Agency Savings. The additional use of salt did improve motorist safety and mobility, but the total benefits were reduced. By comparing benefit-cost ratios, the Same Condition scenario tends to produce similar or better results than the Same Resources scenario.

Overall, the study found MDSS offers State DOTs valuable guidance in their efforts to fine tune their maintenance decisions on winter operations, justifying their intent to continue future investments in MDSS.

Key Observations

This case study presented a BCA of deploying MDSS for winter maintenance. A methodology that consisted of a baseline data module and a simulation module was developed and applied to three pooled fund States to analyze tangible benefits. Tangible costs were calculated based on winter maintenance information requested from the case study states.

The three case studies collectively showed that the benefits of using MDSS outweighed associated costs. The benefit-cost ratios did not indicate which MDSS scenario was (always) better. However, it is most likely that an agency implementing MDSS would fall somewhere between the Same Resources scenario and the Same Condition scenario, seeking to achieve both a level of service improvement and a reduction in winter maintenance costs. The case studies also showed that there is a trade-off between agency benefits and user benefits. Increased use of material will achieve more motorist benefits while increasing agency costs, and vice versa.

Case Study 10.2 – Hypothetical Maintenance Decision Support System (MDSS) Implementation

Strategy Type:	Other Strategies
Project Name:	Maintenance Decision Support System (MDSS) Implementation
Project Agency:	National Pooled Fund Committee with About 25 State DOTs
Location:	Nationwide
Geographic Extent:	All Network Components
Tool Used:	TOPS-BC

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

Several State DOTs and municipal public works departments have deployed Maintenance Decision Support Systems (MDSS) in urban settings. MDSS offers road maintenance managers guidance on efficient tactical deployment of road crews, equipment, and materials with the expectation that the MDSS can save State and local transportation agencies money and time while also enhancing the safety and mobility of the traveling public.

Project Goals and Objectives

The purpose of this hypothetical BCA is to demonstrate how the TOPS-BC tool could support an RWM BCA evaluation where the user is supplying the required cost and benefit inputs. The example suggests that the user had estimated a clear set of benefits, along with real cost savings, that strongly justify the value—not only to State DOTs but also to local DOTs—of having an MDSS among the suite of tools and services they rely upon to support their road maintenance decisions.

Data

This hypothetical evaluation was designed to be a "with-without MDSS" analysis intending to quantify the two benefit areas: those due to atmospheric and pavement forecasts and those resulting from treatment recommendations.

Evaluation Hypothesis #1 – By using the MDSS forecasts as a tactical decision support tool, the State DOT will achieve reductions in shift hours or eliminate shift call-ins, thereby reducing labor hours and associated costs for winter maintenance. Over two winters combined, MDSS forecasts are assumed to be used for 56 events.

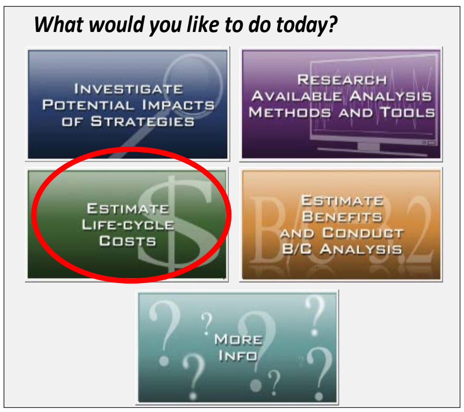
Evaluation Hypothesis #2 – By using the MDSS updates and treatment recommendations, State DOTs will experience a reduction in the amount and cost of material used and a decrease in the number of truck miles, and hence cost of fuel and maintenance, over the course of an entire winter.

The treatment assessment test was assumed to be conducted three times during one winter. It is assumed that only seven events occurred and most of them required primarily spot treatments and not extended material use.

Benefits are realized primarily by reductions in labor hours due to the tactical decision support of deployment of road crews, equipment and materials offered by the MDSS. Costs will include one-time set-up costs and annual contract costs for the MDSS. Benefits and costs in this hypothetical scenario will be adjusted to constant 2009 dollars using inflation rates from the Bureau of Labor Statistics.

Benefit-Cost Analysis

A BCA to determine whether to implement the MDSS for weather forecasting can be conducted using TOPS-BC. In this case, the user can utilize the TOPS-BC architecture to set up the BCA, to estimate annualized cost and benefits, to apply alternate discount rates, to estimate some benefits, and to display the results. Since TOPS-BC does not now provide cost and benefit data unique to a RWM MDSS application, the user must supply much of this data. The information can be collected from other DOTs that have implemented MDSS programs for weather forecasting, or the data can be produced from vendor estimates. A search of the FHWA ITS database may provide much of this information.



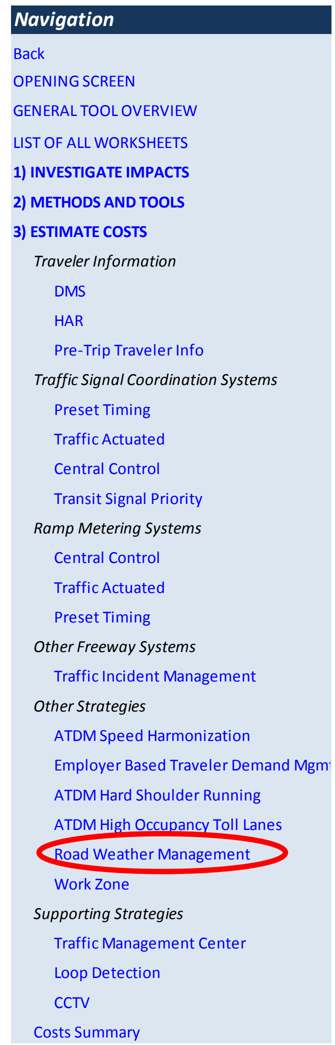
Source: FHWA TOPS-BC

Figure 52. Screenshot. Tool for Operations Benefit-Cost Analysis Start Page – Estimate Life-Cycle Costs Function

To set up TOPS-BC to conduct this analysis, the user will open the spreadsheet modeling tool to the start page (Figure 51) and click on "Estimate Life-Cycle Costs."

In the left-hand column of the Cost Page (Figure 52), click on "Road Weather Management." Depending on the current version of TOPS-BC, you may or may not see any information on the costs of MDSS systems.

If no MDSS costs are displayed, the user can input cost data from



Source: FHWA TOPS-BC

Figure 51. Screenshot. Tool for Operations Benefit-Cost Analysis Navigation Column for Estimating Costs – Road Weather Management Strategies

available information on the specific project or locate cost information on the FHWA ITS Cost database. (http://www.itscosts.its.dot.gov/its/benecost.nsf/ByLink/CostDocs).

If the user needs to input new cost information, TOPS-BC maintains a blank cost estimation worksheet that can be used to create cost estimation capabilities for new strategies that may not currently be included. A blank cost estimation worksheet is provided as a hidden sheet titled COST TEMPLATE, or the user can edit the cost line items on the Road Weather Cost sheet.

In this case, we have edited the existing RWM cost sheet to reflect the cost assumptions. These are hypothetical costs only to demonstrate how TOPS-BC works. It is suggested that you download the latest version of the TOPS-BC model and follow along with this discussion. These procedures are explained in the TOPS-BC User's Manual, which is available at: http://www.ops.fhwa.dot.gov/publications/fhwahop13041/fhwahop13041.pdf.

If we take the cost estimates for a statewide deployment of AVL to support the maintenance vehicle fleet as shown in Figure 52, the user can create a cost sheet in TOPS-BC. TOPS-BC will take the basic cost information provided and generate the annual costs as well as the net present value of cost for use in a BCA. The user also provides a start date, an analysis period, and a discount rate.

In this example, we are running TOPS-BC and we would like to modify the inputs to reflect new data. We might do this because of the similarity of this particular deployment to another deployment where data has been collected on the actual costs or benefits experienced.

With the MDSS option, we know that certain benefits will be realized as we tested (assumed) the historic application in our community and measured the changes in agency staff costs for overtime. We also investigated the change in materials application, but at this time we could not definitively identify materials savings. By using the navigation column on the far left, (Figure 54) we can go to the Road Weather Management benefit inputs page and input new information specific to MDSS. These values will be used in all calculations calling for these values in TOPS-BC.

The user can also test the inputs to see where additional benefits may be realized. This can be accomplished by modifying assumptions about the project costs, size or other dimension. The user can get a range of estimated benefits and costs. One can also test the value assumptions. For example, an alternative set of data on materials savings from application of MDSS forecasts could reflect a cost savings that would improve the applicability of this tool for any project.

Go to the "Benefits" section of Road Weather Management spreadsheet and move to the very bottom of the page to the cell labeled "User Entered Benefit (Annual $s)" and enter the calculated benefit amount, in this case, $100,000. (Remember that FHWA is always adding material to TOPS-BC, so check to see if the model contains benefit data assumptions that might be helpful.) TOPS-BC will now use the $100,000 entry in all of its BCA calculations.

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0

PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies

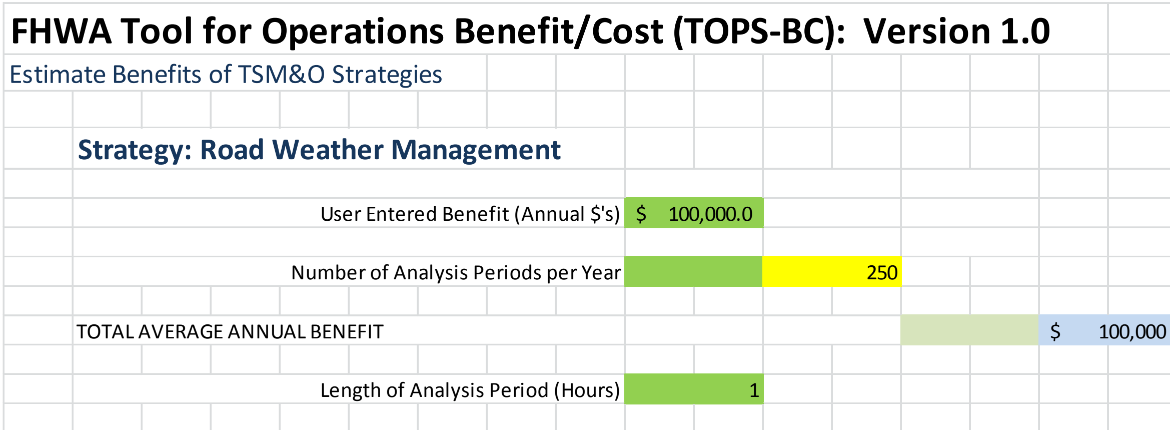
WORK AREA 1 - ESTIMATE AVERAGE ANNUAL COST

Road Weather Management - MDSS Utilization

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrastructure Equipment				
MDSS Information Dissemination Hardware	10	$ -	$ 375	$ 375
MDSS Information Dissemination Software (Registration)	10	$ -	$ 20,000	$ 20,000
TMC System Integration	5	$ -	$ 5,000	$ 5,000
Labor for Weather Information Review & Action Plan		$ -	$ 20,000	$ 20,000
Communications	0	$ 4,000	$ 2,200	$ 2,200
TOTAL Infrastructure Cost		$ 4,000	$ 47,575	$ 47,575
Incremental Deployment Equipment				
Incremental costs for road weather management deployments are extremely variable depending on the type of deployment. User should enter and edit costs appropriate to their planned strategy. Example costs include:				
				$ -
				$ -
				$ -
Remote Weather Station	25	$ 11,530	$ 2,500	$ 2,961
TOTAL Incremental Cost		$ 11,530	$ 2,500	$ 2,961
INPUT Enter Number of Infrastructure Deployments	1			**$ 47,575**
INPUT Enter Number of Incremental Deployments	1			**$ 2,961**
INPUT Enter Year of Deployment	2014			
Average Annual Cost				**$ 50,536**

Source: FHWA TOPS-BC

Figure 53. Screenshot. Tool for Operations Benefit-Cost Analysis Cost Table Edited for Maintenance Decision Support System Cost Inputs.



Source: FHWA TOPS-BC

Figure 54. Screenshot. Bottom of Road Weather Management Benefit Spreadsheet

Source: FHWA TOPS-BC

Figure 55. Screenshot. TOPS-BC Navigation Column for Estimating Benefits – My Deployments

Model Run Results

Now go back to the far left Navigation Column (Figure 54) and select, "My Deployments." In the middle of the sheet you will see the results as shown in Table 52.

Table 52. Benefit-Cost Summary from the Tool for Operations Benefit-Cost Analysis "My Deployments" Sheet.

	Road Weather Management	Total Benefits
Annual Benefits		
Travel Time Reliability	0	0
Energy	0	0
Safety	0	0
Other	0	0
User Entered	$100,000	$100,000
Total Annual Benefits	**$100,000**	**$100,000**
Annual Costs	**$50,536**	**$50,536**
Benefit-Cost Comparison		
Net Benefit	$49,464	$49,464
Benefit-Cost Ratio	1.98	1.98
Stream of Net Benefits - Active Strategies	**2013**	**2014**
Road Weather Management	$100,000	$38,395

Source: FHWA TOPS-BC

In this case, TOPS-BC estimates that the project benefits exceed the costs. This results from the gain in operating efficiency (labor savings) for the system under study. This is a hypothetical case, but it is loosely based on an actual MDSS deployment and evaluation so that we could provide a demonstration of how TOPS-BC can be used as the BCA tool to support RWM decisions.

Key Observations

Although not directly assessed in this BCA, the benefits at the agency level that have been observed in this hypothetical example flow down to the traveling public in terms of the agency's ability to maintain the level of service on the roadways and thereby make them safer for travelers. Finally, although this model is just a prototype, it provides a framework for the development of a model which could be used to measure the effectiveness in costs savings and expected safety (as measured by crash reductions) of a roadway, thereby providing an agency with objective and predictable measures for determining whether an MDSS deployment is necessary. Prior to and after the deployment, the State DOT should collect data on system performance to be able to compare the changes brought about by the deployment. Those performance changes reveal impacts on both freeway and MDSS performance. These realized changes are what a pre-project deployment analysis needs in order to estimate the expected project benefits and costs. Once the project is deployed, performance indicators and their changes are known and can be used as an estimate of what might be expected if a similar project is deployments.

CHAPTER 11. BENEFIT-COST ANALYSIS STUDIES USING MULTIPLE STRATEGIES

#	Case Name	Benefit-Cost Analysis (BCA) Model	Actual or Hypothetical Case
11.1	Automated License Plate Recognition	Custom In-House Tool	Actual
11.2	Cincinnati Region Advanced Regional Traffic Interactive Management & Information System (ARTIMIS) Study	IDAS	Actual
11.3	Washington's Automated Anti-Icing System Study	Custom In-House Analysis	Actual

Case Study 11.1 – Automated License Plate Recognition

Strategy Type:	Combined Strategies
Project Name:	Automated License Plate Recognition
Project Agency:	National Pooled Fund Committee with about 25 State DOTs
Location:	State or Province-wide
Geographic Extent:	All Network Components
Tool Used:	Custom In-House Tool

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

An agency considered adding an automated license plate recognition system (APLRS) for commercial motor vehicles (CMVs) to a voluntary system that uses in-vehicle transponders. The result would be an increase in mobility and efficiency by collecting data for CMVs at highway speeds using weigh-in-motion (WIM) and automatic vehicle identification (AVI) technologies.

Project Goals and Objectives

The analysis evaluated the marginal benefits of adding an automated license plate recognition system (ALPRS) for commercial motor vehicles (CMV) to the British Columbia Ministry of Transportation's (BCMOT) Green Light Transportation System (GLTS), which BCMOT launched in the spring of 2009. GLTS was a voluntary program for CMVs to increase mobility by collecting data for CMVs at highway speeds using weigh-in-motion (WIM) and automatic vehicle identification (AVI) technologies. GLTS utilizes an in-vehicle transponder that electronically relays vehicle registration and other pertinent information to the inspection station as the vehicle approaches WIM scales. The GLTS allows vehicles that have been pre-screened to bypass physical inspection unless the system randomly selects them for inspection. The ALPRS functions similarly to the GLTS because it interfaces with the multiple databases for credentialing and enforcement purposes, but relies on photographing the front and rear license plates instead of using a transponder to relay information to the system.

Because of the voluntary nature of the GLTS program, the BCMOT estimate for penetration is approximately 15 percent in 5 years. Because the ALPRS system would not require registration of CMVs, penetration is at the level of accurate plate reading, which according to tests is nearly 90 percent. BCMOT can also achieve this higher penetration in a shorter time-period. However, the GLTS system transponders provide a stop/do not stop for inspection indication up to 15 minutes before the CMV arrives at an inspection station, while the ALPRS system would require high accuracy of information passed to CMV drivers through variable message signs and drivers following those directions. The resulting conservatively estimated APLR penetration rate is 60 percent.

Benefit Cost Evaluation

Table 53 provides the findings of the benefit-cost analysis of the ALPRS investment. According to the analysis the magnitude of the figures indicates that a substantial return on an investment would result from adding ALPR to the GLTS. The addition of ALRP increases the penetration of the credentialing system in the fleet, reduces delays, crashes and fuel consumption by allowing compliant vehicles to bypass the inspection/weigh station and by allowing enforcement officialy to better target vehicles for pull overs.

The benefit-cost analysis indicates that adding the automated license plate reader system to supplement an electronic credentialing system produces an estimated benefit-cost ratio of 26.2:1.

Table 53. Benefit-Cost Analysis of Automated License Plate Recognition System Investment.

Benefit Category	Annual Benefit	Investment	Benefit-Cost Ratio
Time Savings[1]	$2,074,409	-	-
Fine revenue[2]	$1,132,583	-	-
Fuel Savings[1]	$431,089	-	-
Emission Reduction[1]	$111,324	-	-
Accident Reduction[2]	$24,052,000	-	-
Total	**$27,801,405**	**$1,060,200**	**26.2**

[1] At three selected inspection stations.
[2] Province wide.
Note: All cost figures are reported in 2009 Canadian dollars
Source: USDOT

Even if the investment in ALPR were doubled or the benefits reduced by 25 percent, this observation remains valid. However the bulk of the monetary benefits of using ALPR technology in addition to the GLTS are from collision avoidance. The evaluation of benefits and the weight placed on this benefit should be evaluated carefully. For example, there is continuous debate over the underlying values of the cost of injury and fatalities. In addition, collision avoidance was estimated from province wide figures. On the other hand, the application of the ALPR and GLTS would be at the eight inspection stations that account for the majority of the intercity movement of trucks. Even if the collision benefits were reduced by 50 percent, the benefit-cost ratio would still be substantial. The collection of revenue from fines exceeds the investment costs of the ALPR assuring that the costs of the program will be quickly recovered.

Key Observations

This case identifies the evaluation of adding an additional operations strategy to an existing system. In this case, the agency evaluates adding an automated license plate recognition system to a voluntary system that uses in-vehicle transponders. The agency designed the existing system to increase mobility and efficiency by collecting data for CMVs at highway speeds using WIM and AVI technologies. The marginal license plate recognition system would further those goals. The benefit-cost analysis indicates that adding the automated license plate reader system to supplement an electronic credentialing system produces an estimated benefit-cost ratio of 26.2:1. The results suggest that the two technologies be integrated in the current inspection process to maximize the benefits and minimize the limitations of each.

Case Study 11.2 – Cincinnati Region Advanced Regional Traffic Interactive Management & Information System (ARTIMIS) Study

Strategy Type:	Combined Strategies
Project Name:	Cincinnati Region ARTIMIS Study
Project Agency:	Ohio-Kentucky-Indiana (OKI) Regional Council of Governments
Location:	Region
Geographic Extent:	All Network Components
Tool Used:	IDAS

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

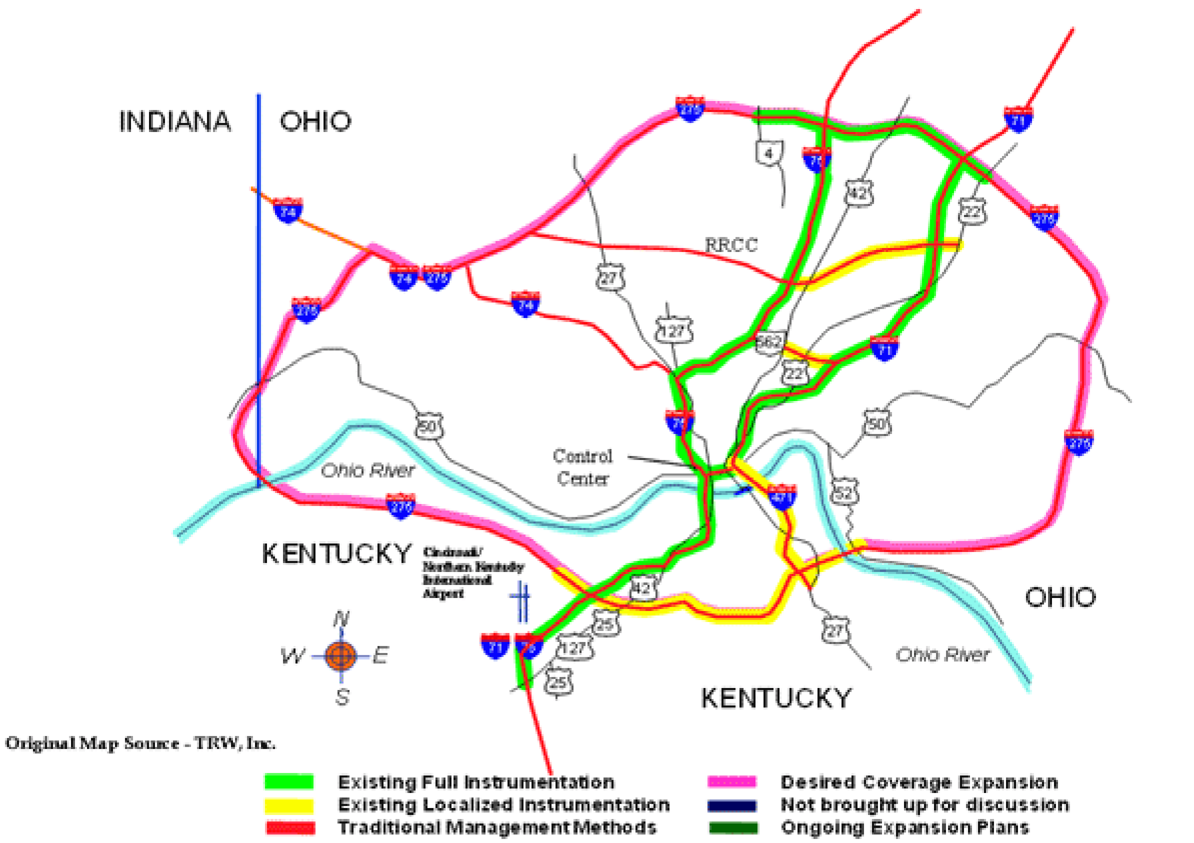
Project Technology or Strategy

The Ohio-Kentucky-Indiana (OKI) Regional Council of Governments, the Metropolitan Planning Organization (MPO) for the Cincinnati, Ohio region, assessed the benefits of their Advanced Regional Traffic Interactive Management and Information System, known as ARTIMIS. The ARTIMIS program is responsible for deploying and operating a number of transportation systems management and operations (TSMO) 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
- Dynamic message signs (DMS) and highway advisory radio (HAR), among other applications.

Project Goals and Objectives

Many of ARTIMIS applications had been successfully applied to many of the key freeway corridors located within the region's suburban beltway network by the early 2000s. However, there was an increasing need to expand these capabilities to key sections of the beltway and the remaining radial freeways. Figure 56 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 and transportation improvement program.



Source: Ohio-Kentucky-Indiana (OKI) Regional Council of Governments

Figure 56. Diagram. Advanced Regional Traffic Interactive Management and Information System 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 the project with 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.

Data Requirements

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.

Model Run Results

The results of the BC analysis showed the existing ARTIMIS program to be an extremely cost effective investment returning a BC 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 54 shows selected measures, benefits, and costs of expanding the ARTIMIS program compared with a single corridor roadway widening project.

Table 54. Comparison of Advanced Regional Traffic Interactive Management and Information System 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 *Annual* Benefit	$53 Million	$35 Million
Total Project Cost	$40 Million	$800 Million
Benefit-Cost Ratio	**12:1**	**1.1:1**

Source: FHWA TOPS BC

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.

Key Observations

TSMO projects are often deployed as groups of technologies. Planners can evaluate individual technologies or strategies, but when they do, they are forced to allocate portions of costs such as the Traffic Control Center construction and operating costs to individual projects which can be arbitrary. Evaluating the deployment of multiple technologies simultaneously, including enabling technologies eliminates the challenge of cost allocation.

This case evaluates a series of TSMO technologies in the Cincinnati, Ohio region. The planners choose to utilize the IDAS BCA tool to assist with their analysis. This decision was made in part due to the availability and experience with the regional travel demand model and their ability to rerun the TDM to test alternatives

Conducting benefit cost analyses of TSMO projects can seem very challenging at first. However, many previous analysis and Tools are available to assist you in the process.

Case Study 11.3 – Washington's Automated Anti-Icing System Study

Strategy Type:	Weather Response or Treatment
Project Name:	Washington's Automated Anti-icing System Study
Project Agency:	The Washington State Department of Transportation (WSDOT)
Location:	Urban Highway Operations
Geographic Extent:	The High Crash Corridor from Milepost 137.67 (the Columbia River Bridge) to Milepost 138.49 (near the State Route 26 Interchange)
Tool Used:	Custom In-House Analysis (WSDOT Benefit-Cost Worksheet for Collision Reduction)

Note: Chapters 2, 3, and 4 of this Compendium contain a discussion of the fundamentals of benefit-cost analyses (BCA) and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Technology or Strategy

To address weather-related crashes on a section of Interstate 90 near Vantage, Washington, the Washington State Department of Transportation (WSDOT) assessed the benefits and costs of deploying an automated anti-icing system to prevent the formation of pavement frost and black ice and to reduce the impact of freezing rain. The system design included the following TSMO strategies:

- Anti-icing system (control system, chemical storage tank, distribution lines, pump, and nozzles)
- Road weather management information system (RWMIS)
- Communications
- Traffic surveillance (a closed circuit television (CCTV) camera for remote viewing)
- Traffic management centers (an environmental sensor station (ESS) and a computerized control system, among other applications)

Project Goals and Objectives

The primary purpose of winter highway maintenance is to provide vehicular traffic with a roadway surface that can be safely traveled. Roadway geometrics and an icy surface may create specific locations that are particularly susceptible to snow- and ice-related accidents. WSDOT developed a BCA to explore the feasibility of incorporating an intelligent transportation system (ITS) method to assist maintenance operations at a high accident location on Interstate 90 in Washington State.

It is proposed to address ice- and snow-related accidents by preventing the formation of ice on the roadway surface. The process explored by this case is with anti-icing chemicals applied to the roadway surface by an automatic anti-icing system. This BCA identifies the system costs and cost savings due to accident prevention and calculates a benefit-cost ratio. WSDOT selected the key MOE in the BCA to be Safety.

Methodology

The value of the anti-icing system approach to reducing snow- and ice-related accidents is assessed using a benefit-cost ratio, where the present worth of benefits (PWOB) divided by the present worth of costs (PWOC) equals the benefit-cost ratio. The PWOB, PWOC, and benefit-cost ratio are calculated using the WSDOT Benefit-Cost Worksheet for Collision Reduction. Cost elements include design, construction, power and communication, operations and maintenance costs. Benefits are the estimated reduction in snow, ice, and wet pavement crashes. Using historical crash data, the annual rate of collisions over a 3-year period was determined and compared to the expected rate of collisions after system implementation. Initially, it was estimated that 60 percent of snow and ice crashes would be eliminated by the proposed system, with no reduction in wet-pavement crashes. Based upon discussions with Pennsylvania DOT maintenance managers, this estimate was revised. After the revision, **it was estimated that 80 percent of the snow, ice, and wet pavement crashes would be eliminated.** The cost per collision was used to determine the annual safety benefit.

Benefit-Cost Analysis

Project Cost. Project cost is the estimated total cost to develop and construct the system. It includes the anti-icing system (control system, chemical storage tank, distribution lines, pump, and nozzles), RWMIS, camera, connection to power and communications, and design and construction engineering.

Operations and Maintenance Costs. Annual Operations & Maintenance Costs are the sum of materials, power, communications, weather forecasting, training, and system maintenance. The material is the liquid chemical. The amount needed per year was estimated by calculating the amount of chemical required to melt the expected freezing precipitation. The expected freezing precipitation was estimated to be half the weekly average winter precipitation, assuming that over a 4-month period half the precipitation would occur during periods when air and surface temperatures were above 32 degrees F. It was determined, by using this method, that approximately 12,000 gallons of liquid chemical was needed to treat the 2.4 lane miles of roadway for a 16-week winter period.

Safety Benefits. Annual safety benefits are the estimated benefits of accident reduction. Only the snow- or ice-related accidents occurring during the winter time period over the 3 year study period were considered. The annual rate of collisions over a 3-year period, categorized by collision type (fatality, disabling injury, property damage only, etc.), was determined, and the expected rate of collisions after implementing the safety improvement was estimated. Estimates were based on the analyst's assumptions and data obtained from Pennsylvania DOT, which had used similar systems with positive results.

The annual crash estimate was determined by multiplying the annual collision rate by the resultant factor, which is the estimated percentage of collisions expected after the improvement is implemented. According to the report, there is no history in Washington of the resultant rate of collision reduction accountable to an automatic anti-icing system. Therefore, the analysis selected a mid-range resultant factor of 0.40 based on the assumption that 60 percent of snow or ice accidents (but not wet roadway accidents) would be eliminated. The assumption was based on information from maintenance managers at Pennsylvania DOT, who had observed systems in place in Pennsylvania and indicated that accident reduction due to automatic anti-icing systems was closer to 100 percent.

Given that information, further consideration was warranted. Allowing for wet pavement accidents and the possibility of ice-related accidents during a refreeze or heavy snow conditions, a higher resultant factor of 0.20 was used. Thus the study analysts presumed that 80 percent of snow- and ice-related accidents would be eliminated.

Collision Costs. The cost per collision by type was determined by WSDOT. The methodology used was not described in the report. The sum of these costs represents the total cost of collisions.

Service Life and Salvage Value. Service life and salvage value are derived from discussions with representatives of the private sector marketing automatic anti-icing systems.

Model Run Results

WSDOT calculated the PWOC and PWOB by a spreadsheet using the present worth factor of a uniform series, as shown below. The calculated benefit-cost ratio and net benefit are the result of the worksheet. Using this worksheet, a benefit-cost ratio of 2.36 and a net benefit of $1,179,274 was calculated. This ratio validated the viability of the proposed solution.

In addition to cost savings from crash reductions, WSDOT management expects that the use of abrasives will be significantly reduced, resulting in lower cleanup costs and less damage to drainage structures. Improved levels of service should also result from the deployment, enhancing mobility.

Safety Improvement Location: SR: 90 MP 137.69 MP 138.29

Safety Improvement Description: Automatic Anti-Icing System

Evaluator: Date: 11/8/1999

1. **Initial Project Cost, I:** $599,500.00

2. **Net Annual Operations & Maintenace Costs, K:** 32,800

3. Annual Safety Benefits in Number of Collisions:

Collision Type	Before (historic) No.	Yrs.		Rate	-	After (Estimated) Resultant Factor	Rate	=	Annual Benefit
a) Fatality	0.00	3	=	0.00		0.20	0.00	=	0.00
b) Disabling Injury	1.00	3	=	0.33		0.20	0.07	=	0.27
c) Evident Injury	1.00	3	=	0.33		0.20	0.07	=	0.27
d) Possible Injury	2.00	3	=	0.67		0.20	0.13	=	0.53
e) Property Damage Only	3.00	3	=	1.00		0.20	0.20	=	0.80

4. Costs Per Collision:

Collision Type	Cost
a) Fatality	$ 800,000
b) Disabling Injury	$ 800,000
c) Evident Injury	$ 62,000
d) Possible Injury	$ 33,000
e) Property Damage Onl	$ 5,800

5. Annual Safety Benefits by Costs of Collision:

a) (3a)(4a)	=	0
b) (3b)(4b)	=	213,333
c) (3c)(4c)	=	16,533
d) (3d)(4d)	=	17,600
e) (3e)(4e)	=	4,640
f) Total, B	=	252,107

6. Service Life, n = 10 7. Salvage Value, T = 20000 8 Interest Rate, i = 0.04

9. Present Worth of Costs, PWOC:

b) Present Worth Factorof a uniform series, SPWin 8.11

c) PWOC= I + K(SPWin)-T(PWni) 865,538

10. Present Worth of Benefits, PWOB=B(SPWin) 2,044,812

11. **Benefit Cost Ratio, B/C=PWOB/PWOC** **2.36**

12. **Net Benefit = PWOB-PWOC** 1,179,274

Source: WSDOT

Figure 57. Screenshot. Washington State DOT Benefit-Cost Worksheet for Collision Reduction.

Key Observations

The analysis indicates that the proposed automatic anti-icing system is a viable and cost-effective method of reducing the snow- and ice-related accidents in the Interstate 90 high crash corridor, with a resulting benefit-cost ratio being greater than two, and the net benefit being more than $1 million.

ITS solutions to winter maintenance and operations problems are considered experimental in Washington State. This project could be considered a model to evaluate other areas on the State highway system that are prone to snow- and ice-related accidents. Overall, this ITS solution has the potential to significantly reduce accidents within this high-accident corridor and should be considered as more practical than high-cost alignment revisions.

CHAPTER 12. REFERENCES

1. Transportation Systems Management and Operations (TSMO) is also often referred to as Operations and Maintenance (O&M) or as SSOM for the AASHTO Subcommittee on Transportation Systems & Operations.

2. Federal Aviation Administration, "Revised Departmental Guidance: Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses," February 2008. Available at: https://www.faa.gov/regulations_policies/policy_guidance/benefit_cost/media/Revised%20Value%20Of%20Life%20Guidance%20Feburary%202008.pdf

3. National Highway Transportation Safety Administration, "New NHTSA Study Shows Motor Vehicle Crashes Have $871 Billion Economic and Societal Impact on U.S. Citizens," (press release), May 28, 2014. Available at: http://www.nhtsa.gov/About+NHTSA/Press+Releases/2014/NHTSA-study-shows-vehicle-crashes-have-$871-billion-impact-on-U.S.-economy,-society

4. Florida Department of Transportation, Traffic Engineering and Operations Division, "Road Ranger Assistance Annual Statistics" web page. Available at: http://www.dot.state.fl.us/trafficoperations/traf_incident/rrangers/rranger.shtm

5. For more information on the FSPE Model and how to obtain it, please contact: Mr. Alexander Skabardonis, Professor & Research Engineer, Department of Civil & Environmental Engineering, Institute of Transportation Studies, University of California, Berkeley, 109 McLaughlin Hall, Berkeley CA 94720-1720, Phone: 510-642-9166.

6. Kelsi Loos, "Some drivers opt to avoid CSX bridge at Md. 75," Frederick News-Post, August 22, 2013. Available at: http://www.fredericknewspost.com/news/politics_and_government/governmental_and_political_topics/transportation/some-drivers-opt-to-avoid-csx-bridge-at-md/article_0d45c833-ec2c-5a66-9781-9f37b6685c5a.html?mode=story

7. Sam Yu, "System intended to solve stuck truck problem," Frederick News-Post, October 15, 2010. Available at: http://www.fredericknewspost.com/archive/system-intended-to-solve-stuck-truck-problem/image_b57194d9-0b11-505c-9ac3-a2e8a08bd64a.html

CHAPTER 13. BIBLIOGRAPHY

Akcelik & Associates Website. Available at: http://www.sidrasolutions.com/Company/About

Cambridge Systematics, Inc. and Florida Department of Transportation, *Tool for Operations Benefit/Cost (TOPS-BC) for Florida DOT Applications - TOPS-BC Florida Guidebook* (June 11, 2014).

Center for Urban Transportation Research, *Review and Update of Road Ranger Cost Benefit Analysis* (January 2012). Available at: http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_TE/FDOT_BDK84_977-15_rpt.pdf

Chang, G.L., *Performance Evaluation and Benefits Analysis for CHART in Year 2012* (Department of Civil Environmental Engineering, University of Maryland, College Park, July 2013). Available at: http://chartinput.umd.edu/reports/CHART_2012_final.pdf

City of Los Angeles, Department of Transportation, *Traffic Signal Priority's Role in Bus Rapid Transit* (August 2003). Available at: http://www.ite.org/Membersonly/annualmeeting/2003/AB03H5203.pdf

Denver Regional Council of Governments "Traffic Operations Program" web page. Available at: http://drcog.org/programs/transportation-planning/traffic-operations-program

Denver Regional Council of Governments, *Signal Timing Briefs*, "Alameda Avenue: Sheridan Boulevard to Marion Parkway," T13-01 (February 2013). Available at: http://www.drcog.org/documents/T13-01_Signal_Timing_Briefs_AlamedaAve.pdf

Denver Regional Council of Governments, "Traffic Operations Program Projects Completed in Calendar Year 2013." Available at: http://www.drcog.org/documents/2013%20projects.pdf

Federal Highway Administration, "Roundabouts Technical Summary" (2010). Available at: http://safety.fhwa.dot.gov/intersection/roundabouts/fhwasa10006/ppt/fhwasa10006ppt.pdf

Federal Highway Administration, *Operations Benefit/Cost Analysis TOPS-BC User's Manual – Providing Guidance to Practitioners in the Analysis of Benefits and Costs of Management and Operations Projects*, "Chapter 6. Conduct Simple Spreadsheet-Based B/C Analysis for Selected TSM&O Strategies" FHWA-HOP-13-041 (June 2013). Available at: http://www.ops.fhwa.dot.gov/publications/fhwahop13041/sec6.htm

Federal Highway Administration, *Traffic Control Systems Handbook*, FHWA-HOP-6-006 (October 2005). Available at: http://ops.fhwa.dot.gov/publications/fhwahop06006/

Florida Department of Transportation, "Benefit Cost Analysis of the SMART SunGuide Operations in Fort Lauderdale, Florida" (2006). Available at: http://www.smartsunguide.com/pdf/Benefits-CostAn_SMART.ppt

Florida Department of Transportation, *District IV Intelligent Transportation Systems Benefit Cost Analysis Report* (January 2006) Available at: http://www.smartsunguide.com/pdf/Smart_SunGuide_BC_v7%2006_JAN_31%20FINAL.pdf

Garland, C. and J. Lee, *Evaluation of Automated License Plate Recognition for Improving British Columbia's Green Light Program*, (ITS America, September 2009).

Georgia Department of Transportation, *Benefits Analysis for the Georgia Department of Transportation NaviGAtor Program* (2006). Available at: www.ops.fhwa.dot.gov/travelinfo/gdotbenefit/gdotfinalreport_0806.pdf

Kumar, M., and Christopher Strong, *Comparative Evaluation of Automated Wind Warning Systems,* U.S. DOT Research and Innovative Technology Administration (February 2006).

Loos, K., "Some Drivers Opt To Avoid CSX Bridge At Md. 75," *The Frederick News-Post*, August 22, 2013.

Maryland Department of Transportation, State Highway Administration, SHA Installs New Over Height Warning Detection System on MD 75 in Frederick County, (August 25, 2010).

Maryland State Highway Administration's Traffic Safety Analysis Division, Office of Traffic & Safety, Maryland's Roundabouts: Accident Experience and Economic Evaluation (April 5, 2004). Available at: http://safety.fhwa.dot.gov/intersection/resources/fhwasa09027/resources/Marylands%20Roundabouts%20Accident%20Experience%20and%20Economic%20Evaluation.pdf

Metropolitan Washington Council of Governments, MATOC Benefit Cost analysis White Paper (June 2010). Available at: http://www.mwcog.org/uploads/committee-documents/Yl5ZVlZc20100607114406.pdf

Mlot, S. CSX Bridge Clearance Warning Is Doing Its Job, (The Frederick News-Post, Frederick, MD, April 2, 2011).

National Traffic Incident Management Coalition, Benefits of Traffic Incident Management (2006).

Niederhauser, M.E., B.A. Collins, P.E. and E.J. Myers, P.E., The Use of Roundabouts: Comparison with Alternate Design Solution. Available at: http://trid.trb.org/view.aspx?id=485198

Petrov, A., et. al., Evaluation of the Benefits of a Real-Time Incident Response System (University of Maryland, 2004).

Research and Innovative Technology Administration, Intelligent Transportation Systems Joint Program Office, "In Oregon and Colorado, Downhill Speed Warning Systems Decreased Truck Crashes up to 13 Percent at Problem Sites." Available at: http://www.itsbenefits.its.dot.gov/ITS/benecost.nsf/ID/3E417EC229AF6288852573DA00578A60?OpenDocument&Query=Home

Research and Innovative Technology Administration, Intelligent Transportation Systems Joint Program Office, "Adding an Automated License Plate Reader System To Supplement an Electronic Credentialing System Produces an Estimated Benefit-Cost Ratio of 26.2:1." Available at: http://www.itsbenefits.its.dot.gov/ITS/benecost.nsf/ID/9128DED94CF68EC685257B39006C3C33?OpenDocument&Query=Home

Research and Innovative Technology Administration, Intelligent Transportation Systems Joint Program Office, "An Over-height Warning System at a CSX Bridge in Maryland Decreased the Number of Tractor-Trailer Incidents By 75 Percent." Available at: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/SummID/B2011-00750?OpenDocument=&Query=Home

Research and Innovative Technology Administration, Intelligent Transportation Systems Joint Program Office, *Urban Partnership Agreement: Minnesota Evaluation Report, Appendix J - Cost Benefit Analysis*, FHWA-JPO-13-048 (January 2013). Available at: http://www.dot.state.mn.us/rtmc/reports/hov/20130419MnUPA_Evaluation_Final_Rpt.pdf

Research and Innovative Technology Administration, Intelligent Transportation Systems Joint Program Office, *Benefit–Cost Assessment of a Maintenance Decision Support System (MDSS) Implementation: The City and County of Denver*, FHWA-JPO-10-018 (December 2009). Available at: http://ntl.bts.gov/lib/33000/33100/33156/denver_mdss_bca_report_final.pdf

South Dakota Department of Transportation, *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs* (May 2009). Available at: http://www.westerntransportationinstitute.org/documents/reports/4W1408_Final_Report.pdf

Strathman, J.G., *Tri-Met's Experience With Automatic Passenger Counter and Automatic Vehicle Location Systems*, Center for Urban Studies, School of Urban Studies and Planning, Portland State University (September 2002).

Stowe, R., *A Benefit/Cost Analysis of Intelligent Transportation System Applications for Winter Maintenance*, Paper No. 01-0158, presented to the Transportation Research Board 80th Annual Meeting, Washington, DC, January 7-11, 2001. Available at: http://www.smartbridge.okstate.edu/new_information/OtherInfo/BCanalysisWSDOT.pdf

University of Maryland and Maryland State Highway Administration, *Performance Evaluation and Benefit Analysis for CHART – Coordinated Highways Action Response Team – Annual Reports.*

Washington State Department of Transportation, "Roundabout Benefits" web page. Available at: http://www.wsdot.wa.gov/Safety/roundabouts/benefits.htm

U.S. Department of Transportation
Federal Highway Administration

U.S. Department of Transportation
Federal Highway Administration
Office of Operations (HOP)
1200 New Jersey Avenue, SE
Washington, D.C. 20590

http://ops.fhwa.dot.gov/

FHWA-HOP-14-032

July 2015