Road Weather Management Benefit Cost Analysis Compendium

U.S. Department of Transportation
Federal Highway Administration

April 2017

FOREWORD

The Federal Highway Administration (FHWA) Office of Operations is pleased to present an update to the publication titled *Road Weather Management (RWM) Benefit Cost Analysis (BCA) Compendium*. The RWM BCA Compendium was initially published in 2014 (FHWA-HOP-14-033). This update includes ten additional BCA case studies on various road weather management strategies including connected vehicle applications.

The RWM 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 RWM strategies and technologies.

Mark Kehrli
Director, Office of Transportation Operations

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16. Abstract

The Road Weather Management (RWM) Benefit Cost Analysis (BCA) Compendium provides information about benefit cost analyses conducted around the country for specific RWM technologies or operational 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 a specific RWM technology or operational strategy. FHWA has developed a sketch planning BCA tool —the Tool for Operations Benefit/Cost (TOPS-BC)—for application to TSMO projects, including RWM 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 conducted, or could conduct, a BCA on one or more RWM technologies or strategies. There are 27 cases studies presented in the RWM Compendium, and each addresses one or more specific BCA concepts or procedures. Note that the hypothetical BCA case studies and scenarios included in this compendium for several road weather management strategies, including Connected Vehicle applications, utilize assumptions on costs and benefits that do not reflect actual costs and benefits associated with those strategies and are presented only for demonstration purposes.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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AADT	average annual daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ANN	artificial neural network
ADT	average daily traffic
ATDM	active transportation and demand management
ATM	active traffic management
ATMS	advanced traffic management system
ATR	automatic traffic recorder
AVL	automatic vehicle location
AWWS	automated wind warning system
BCA	benefit cost analysis
BCR	benefit cost ratio
CAL-BC	California Life-Cycle Benefit/Cost Analysis Model
CCTV	closed circuit television
CDPD	cellular digital packet data
CMA	calcium magnesium acetate
CMAQ	congestion mitigation and air quality
COATS	California / Oregon Advanced Transportation System
CPI	Consumer Price Index
CV	connected vehicle
DOT	department of transportation
DTS	dynamic traffic signal
EMDSS	enhanced maintenance decision support system
EMFITS	Evaluation Model for Freeway ITS Scoping
ESS	environmental sensor stations
FAST	fixed automatic spray technology
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FSUTMS	Florida Standard Urban Transportation Modeling System
GIS	geographic information system
GPS	Global Positioning System
HCM	Highway Capacity Manual
HERS	Highway Economic Requirements System
HOP	Office of Operations
HOV	high-occupancy vehicle
HWDS	high water detection system
IDAS	ITS Deployment Analysis System
ITD	Idaho Transportation Department
ITS	intelligent transportation system
IVU	in-vehicle unit
KDOT	Kansas Department of Transportation
MBCA	multimodal benefit cost analysis
MDOT	Michigan Department of Transportation
MDSS	maintenance decision support system

MDT	mobile data terminal
MNDOT	Minnesota Department of Transportation
MOE	measure of effectiveness
MP	milepost
MPH	miles per hour
MPO	metropolitan planning organization
MS	Microsoft
MTC	Metropolitan Transportation Commission
NA	not available
NB	northbound
NCHRP	National Cooperative Highway Research Program
NDDOT	North Dakota Department of Transportation
NDOR	Nebraska Department of Roads
NEPA	National Environmental Policy Act
NJDOT	New Jersey Department of Transportation
NPV	net present value
OATS	Office of Advanced Transportation Systems
OBE	on-board equipment
ODOT	Oregon Department of Transportation
OMB	The U.S. Office of Management and Budget
P4O	Planning for Operations
PDO	property damage only
PFDSS	Pooled Fund Decision Support System
PWOB	present worth of benefits
PWOC	present worth of costs
ROR	rate of return
RSE	roadside equipment
RWIS	road weather information system
RWM	road weather management
RWMIS	road weather management information system
SB	southbound
SCRITS	Screening Tool for ITS
SDDOT	South Dakota Department of Transportation
SHRP 2	Strategic Highway Research Program 2
SR	State Route
STA	state transportation agency
STEAM	Surface Transportation Efficiency Analysis Model
TDM	traffic demand management
TDM	travel demand model
TIGER	Transportation Investment Generating Economic Recovery
TMC	traffic management center
TOC	traffic operations center
TOPS-BC	Tool for Operations Benefit/Cost Analysis
TRIMMS	Trip Reduction Impacts of Mobility Management Strategies
TSMO	transportation systems management and operations
TxDOT	Texas Department of Transportation

UDOT	Utah Department of Transportation
USDOT	United States Department of Transportation
V/C ratio	vehicle to capacity ratio
VMT	vehicle miles traveled
VOC	vehicle operating costs
VSL	variable speed limit
WRATM	weather responsive active traffic management
WSDOT	Washington State Department of Transportation
WYDOT	Wyoming Department of Transportation

CHAPTER 1. INTRODUCTION

The *Road Weather Management Benefit Cost Analysis Compendium* (RWM Compendium) is a companion to the broader *Transportation Systems Management and Operations Benefit Cost Analysis Compendium* (TSMO Compendium). Both documents are additions to the series of reference documents and tools developed by the Federal Highway Administration Office of Operations (HOP) to assist planners and operations professionals in evaluating the benefits and costs of TSMO strategies and technologies.

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

The RWM Compendium expands the road weather management technologies and strategies covered in the TSMO Compendium to provide a more thorough and complete coverage of benefit cost analysis of road weather management projects. This body of work is part of a larger initiative in the Office of Operations referred to as *Planning for Operations* and is designed to better integrate planning and operations activities.

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. Road weather projects as a subgroup of TSMO programs have not escaped this scrutiny, and road weather 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 RWM 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 BCAs 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 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 FEDERAL HIGHWAY ADMINISTRATION TRANSPORTATION SYSTEMS MANAGEMENT AND OPERATIONS AND ROAD WEATHER MANAGEMENT COMPENDIA

The *Transportation Systems Management and Operations Benefit Cost Analysis (BCA) Compendium* (TSMO Compendium) is a collection of cases from across the country where benefit cost analysis have been applied to one or more TSMO technologies/strategies. The *Road Weather Management (RWM) Benefit-Cost Analysis Compendium* (RWM Compendium) follows this approach by providing information about BCAs conducted around the country for specific RWM technologies or operational 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 a specific RWM technology or operational strategy. The Federal Highway Administration (FHWA) has developed a sketch planning BCA tool —the Tool for Operations Benefit/Cost (TOPS-BC)—for application to TSMO projects, including RWM 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 conducted, or could conduct, a BCA on one or more RWM technologies or strategies. There are 27 case studies presented in the RWM Compendium, and each addresses one or more specific BCA concepts 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 the Desk Reference, and more detailed discussions can be found in FHWA's Road Weather Management Programs web page: http://ops.fhwa.dot.gov/weather/mitigating_impacts/technology.htm.

THE FEDERAL HIGHWAY ADMINISTRATION OPERATIONS BENEFIT/COST ANALYSIS DESK REFERENCE

The Federal Highway Administration (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 BCA 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, including RWM 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.

ROAD WEATHER MANAGEMENT STRATEGIES

Together, the Desk Reference and the RWM Compendium are intended to support the analysis of a wide range of RWM strategies. These "strategies" include the direct application of technologies and infrastructure to RWM (e.g., regional pre-deployment of assets), as well as many more difficult-to-define, nonphysical strategies (e.g., interagency coordination). While it is not possible to comprehensively provide guidance on applying every type and variation of diverse RWM strategies (especially in light of the fact that new strategies and technologies are constantly emerging), the strategies covered in the RWM Compendium, which are aligned with those strategies identified in the BCA Desk Reference, include strategies from the following categories:

1. Surveillance, Monitoring, and Prediction.
2. Information Dissemination.
3. Decision Support, Control, and Treatment.
4. Weather Response or Treatment.

The RWM Compendium provides brief summaries of the BCAs undertaken by transportation agencies, educational institutions, and firms to assess the value of these strategies. These examples evaluate the benefits and costs of some RWM deployments and identify the lessons that can be learned from the BCA. Hypothetical BCA examples were drawn from actual deployments, in part or whole, in order to demonstrate how the TOPS-BC model can be used and modified to support RWM BCA.

Following this introduction, Section 2 provides a brief summary of the fundamentals of the BCA as applied to transportation projects in general and to TSMO and RWM projects in particular. Section 3 introduces several BCA tools developed by FHWA and others for transportation applications and TSMO and RWM projects. The final four sections of this RWM Compendium contain several case studies including hypothetical examples and actual applications of BCA to RWM 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) and road weather management (RWM) projects. This is not intended to replace more extensive documents on economic analysis and benefit cost analysis (BCA) available from the Federal Highway Administration (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 RWM projects. Note that this chapter provides a summary of portions of the *FHWA Economics 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-2014***

Economic analysis is a critical component of a comprehensive project or program evaluation methodology that considers all key quantitative and qualitative impacts of TSMO and RWM 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 an RWM 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 Officials 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 and RWM decision making.

The 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 Desk Reference cited above. In addition, consistent with Executive Order 12893, the U.S. Department of Transportation (USDOT) requires a BCA to accompany all applications for Transportation Investment Generating Economic Recovery (TIGER) funding.

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 RWM 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 RWM and other comprehensive infrastructure management strategies.

Benefits of Using of Economic Analysis for RWM Projects

Among the beneficial applications of economic analysis to RWM 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.

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 and RWM investments. Project life cycle evaluation is important for TSMO projects—including RWM 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.

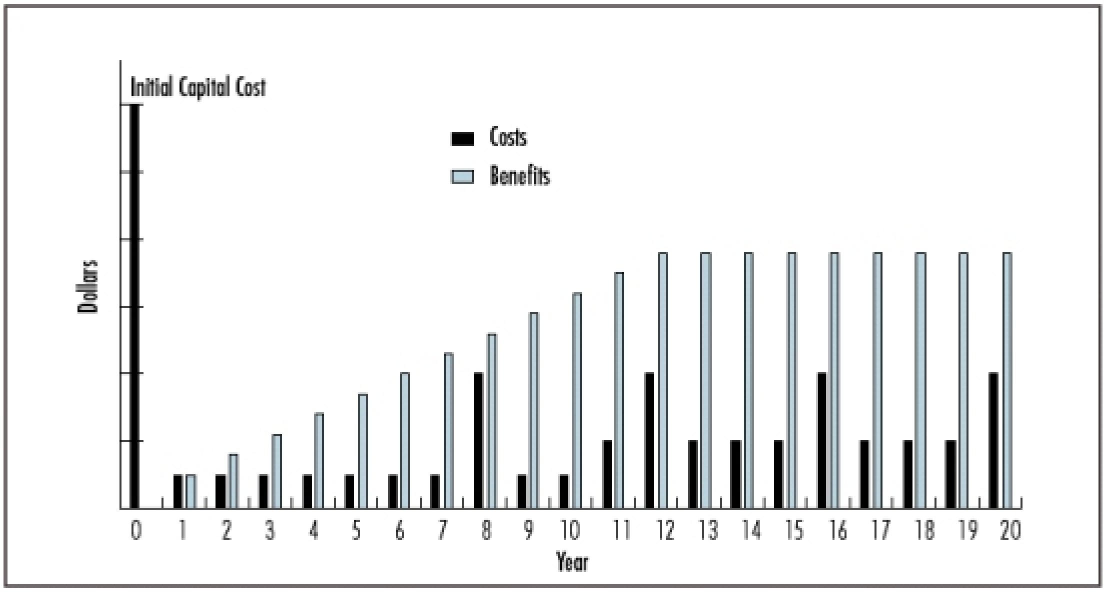


Figure 1. Chart. Time series of costs and benefits.

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 the box on the next page). 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.

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.

Formula for Discounting

The standard formula for discounting is as follows:

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

Figure 2. Equation. Standard 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. Discount factor.

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 RWM 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. Summation of discounted values.

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.

BENEFIT COST ANALYSIS

A 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.

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.

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.

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 RWM 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 RWM 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 Transportation System Management and Operations and Road Weather Management 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.

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 and RWM 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. The U.S. Department of Transportation (USDOT) 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,"[1] and "The Economic Impact of Motor Vehicle Crashes."[2])

[1] 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.

[2] 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: https://www.nhtsa.gov/press-releases/new-nhtsa-study-shows-motor-vehicle-crashes-have-871-billion-economic-and-societal.

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 (VOC) require good information on the relationship of vehicle performance to highway conditions and clear assumptions about future vehicle fleet fuel efficiency and performance. The USDOT does not provide official guidance on estimating VOC, but useful information on the valuation of VOC (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 will be addressed in any environmental review documents required under the the National Environmental Policy Act (NEPA), 23 USC § 109. 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 delays 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 Highway Economic Requirements System-State Version: Technical Report* by FHWA, which is available at: https://www.fhwa.dot.gov/asset/hersst/pubs/tech/tech07.cfm.

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

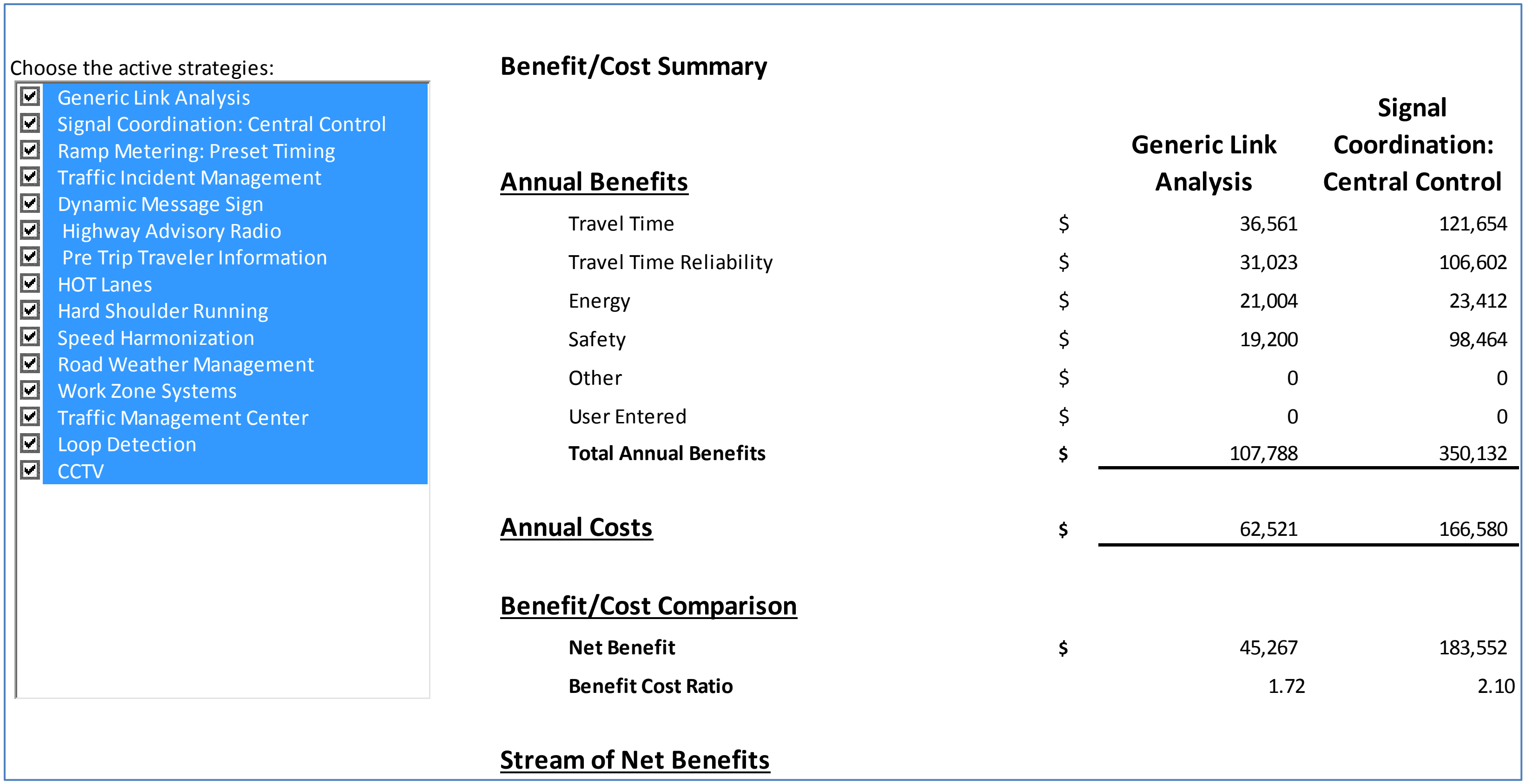
As with any analytic method, the BCA can give erroneous results if it is misused. Perhaps the foremost cause of error in a BCA is the selection of an unrealistic base case. The base case must be founded on intelligent use and management of each TSMO alternative under consideration during the analysis 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 and RWM 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 Benefit Cost Analysis

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 benefit cost ratio (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. Figure 5 and Table 2 provide example tabular displays of the BCA results from the Tool for Operations Benefit/Cost (TOPS-BC) and the Clear Roads BCA Toolkit.



		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			

Figure 5. Screenshot. Tool for Operations Benefit/Cost tabular display of benefit cost analysis results.

Table 2. Clear Roads tabular display of benefit cost analysis results.

Costs and Benefits	Iowa
Agency Costs – Initial	
Material spreader ($800)	$720,000
Flow controller	($2,389)
Agency Costs – Annual	
Material costs ($30/ton)	$4,536,000
Production costs ($14.42)	$0
Equipment maintenance ($14.42)	$192,780
Corrosion/environmental costs/ton	$0
Total Costs – Summary	
Annualized cost	$7,137,418
Present value	$57,153,817
Present value	$9,042
User Benefits	
General savings	$0
Cash 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

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 3 was developed by the NJDOT to evaluate the benefits and costs of their Incident Manage 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 3. 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**
Benefit Cost Ratio	**23.87**	**43.87**

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 6 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-to-cost ratio.

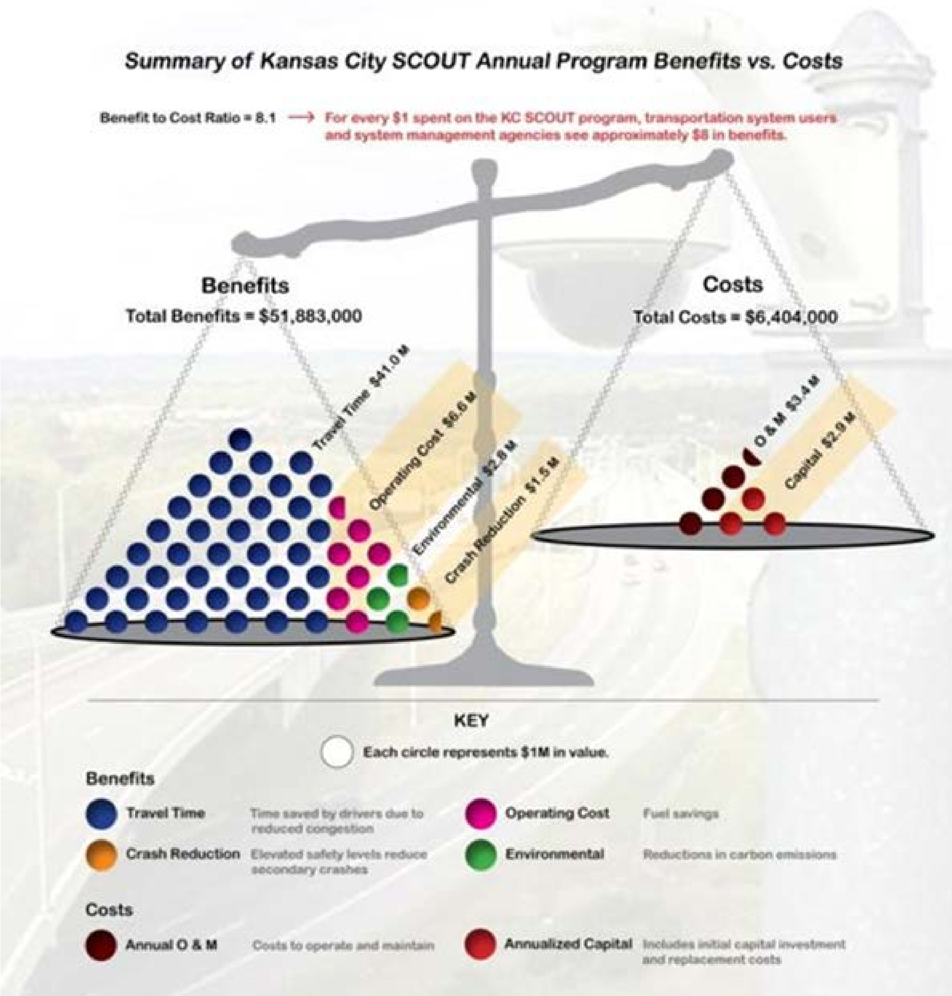


Figure 6. Screenshot. Kansas City graphic display of benefit cost analysis results.

In another BCA, the Southwest Pennsylvania Regional Traffic Signal Program used a "newsletter" approach to highlight the results of their study. Figure 7 is an example of this BCA display technique.

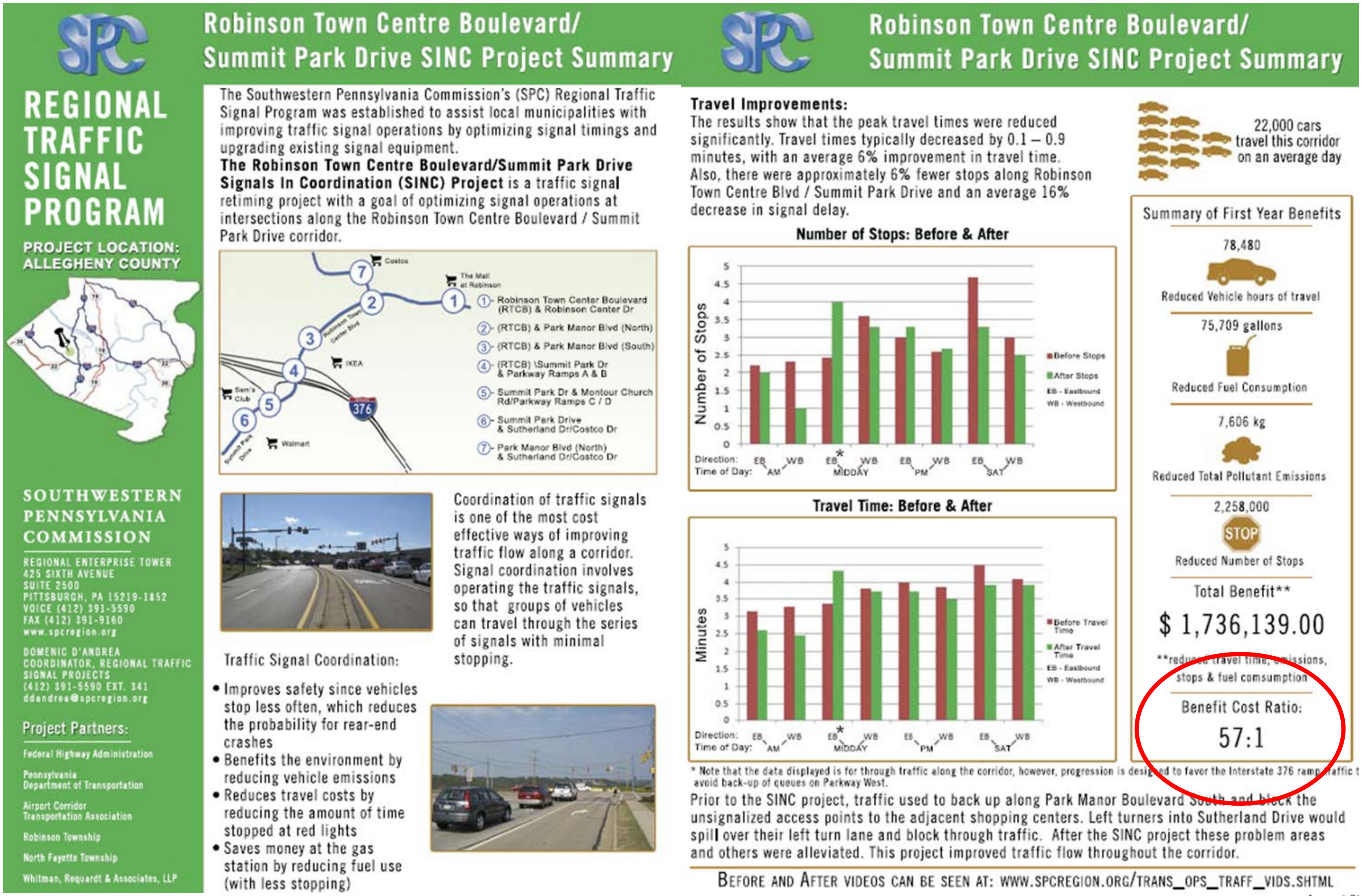


Figure 7. Screenshot. Southwest Pennsylvania regional traffic signal program graphic display of benefit cost results.

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 8). 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.

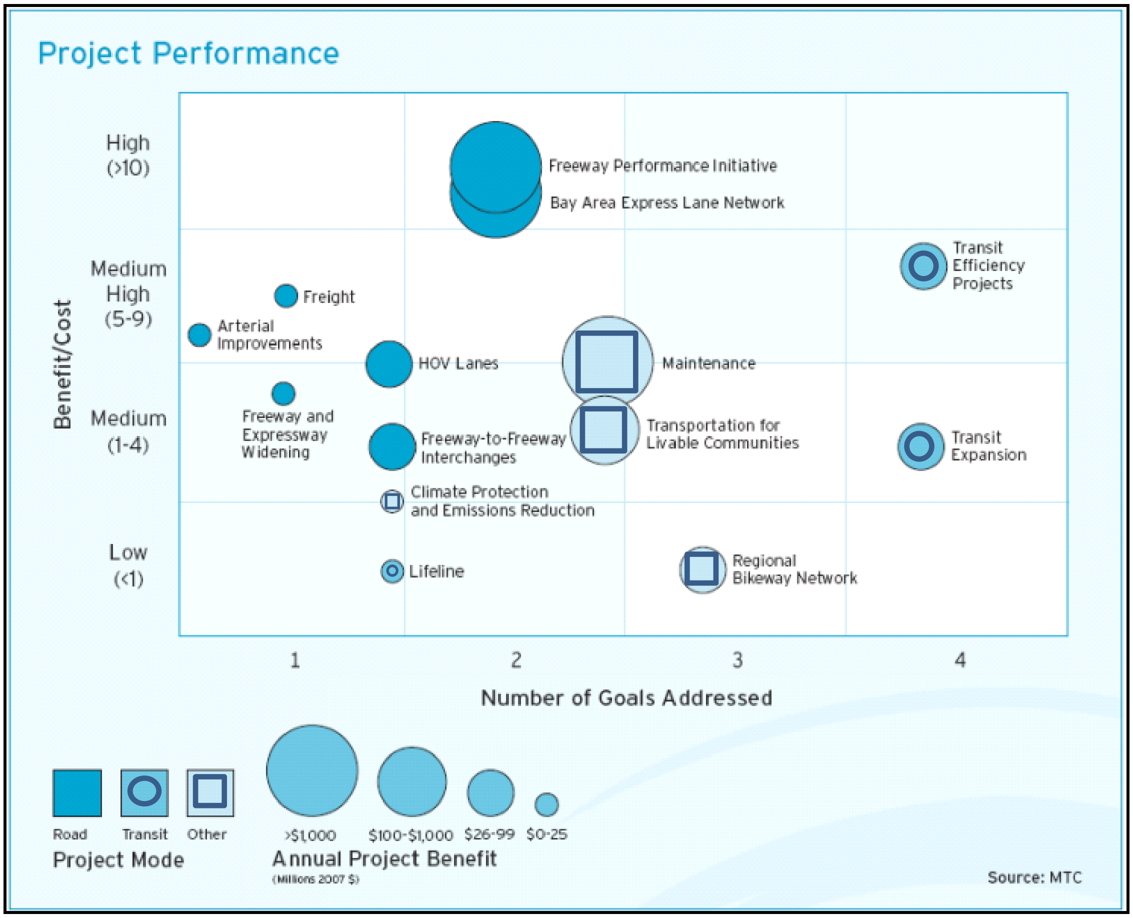


Figure 8. Chart. Multidimensional display from the Metropolitan Transportation Commission.

CHAPTER 3. INTRODUCTION TO BENEFIT COST ANALYSIS TOOLS

Conducting a benefit cost analysis (BCA) for one or more RWM strategies can be accomplished 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 road weather management (RWM) 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 and 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. For example, the Clear Roads Pooled Fund Study has developed a detailed internet-based Winter Weather Road Management BCA Tool.

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

Table 4. Summary of existing benefit cost analysis tools and methods for road weather management projects.

Tool/Method	Developed by	Web Site
BCA.net	Federal Highway Administration (FHWA)	http://www.fhwa.dot.gov/infrastructure/asstmgmt/bcanet.cfm
CAL-BC	Caltrans	http://www.dot.ca.gov/hq/tpp/offices/eab/LCBC_Analysis_Model.html
Clear Roads Benefit Cost Toolkit	Montana State University under contract to Clear Roads Consortium	http://clearroads.org/cba-toolkit/
COMMUTER Model	U.S. Environmental Protection Agency	Not Available
Evaluation Model For Freeway Intelligent Transportation Systems (ITS) Scoping (EMFITS)	New York State Department of Transportation (DOT)	Not Available
The Florida ITS Evaluation (FITSEval) Tool	Florida DOT	Not Available

Table 4. Summary of existing benefit cost analysis tools and methods for road weather management projects (continuation).

Tool/Method	Developed by	Web Site
ITS Deployment Analysis System (IDAS)	FHWA	Not available
Multimodal Benefit Cost Analysis (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 (TOPS-BC)	FHWA	http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm
Trip Reduction Impacts of Mobility Management Strategies (TRIMMS)	Center for Urban Transportation Research at the University of South Florida	http://www.nctr.usf.edu/abstracts/abs77805.htm

The following sections provide a brief introductory description of the tools and methods presented in Table 4. More detailed information can be accessed by following the links provided.

- BCA.Net – BCA.Net is the FHWA's web-based BCA tool designed 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 – Is an Excel spreadsheet-based tool developed by Caltrans. Originally designed to conduct BCAs of traditional highway improvements, Cal-BC 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 and is expandable so future winter maintenance elements may be added as needed. This toolkit was initially developed by the Western Transportation Institute at Montana State University and Current Transportation Solutions, Inc. under contract to the Clear Roads Consortium and Wisconsin Department of Transportation.

- COMMUTER Model – Is a spreadsheet-based analysis tool developed by the U.S. Environmental Protection Agency to estimate emissions benefits related to a number of employer-based travel demand management strategies.

- Evaluation Model For Freeway ITS Scoping (EMFITS) – Is a BCA methodology developed for New York State Department of Transportation (DOT) and is incorporated in the New York State DOT ITS Scoping Guidance (Project Development Manual).

- Florida ITS Evaluation (FITSEval) – Is a tool currently under development by the Florida DOT. The tool is a travel demand model post-processor designed to estimate the benefits and costs of using ITS from the State's standardized Florida Standard Urban Transportation Modeling System (FSUTMS) model structure.

- ITS Deployment Analysis System (IDAS) – Was initially developed by the FHWA in 2001, and has undergone multiple updates since. It is a sketch-planning tool operating as a travel demand model post-processor that 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 organization (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.

- 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 – highway, 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 assessments, grant applications, and education programs. MBCA is set up with standard U.S. and Canadian values for user benefit, which are not tied to any specific study area.

- Screening Tool for ITS (SCRITS) – Is a spreadsheet application developed by the FHWA for estimating user benefits of ITS at the sketch-planning level. SCRITS provides a highly approximate subset of the capabilities found in TOPS-BC.

- Surface Transportation Efficiency Analysis Model (STEAM) - Uses information developed through the travel demand modeling process to compute the net value of mobility and safety benefits attributable to regionally important transportation projects. Developed by the FHWA, STEAM uses information developed through the travel demand modeling process to compute the net value of mobility and safety benefits attributable to regionally important transportation projects.

- Tool for Operations Benefit Cost (TOPS-BC) – Was developed in parallel with the Desk Reference and is intended to support the guidance contained in the Desk Reference by providing four key capabilities:

    1) Allows users to look up the expected range of transportation system management and operations (TSMO) strategy impacts based on a database of observed impacts in other areas.
    2) Provides guidance and a selection tool for users to identify appropriate BCA 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 TSMO strategies.
    4) Allows for benefits estimation using a spreadsheet-based sketch-planning approach and the comparison with estimated strategy costs. The capabilities of TOPS-BC are highlighted in several case studies in this Compendium.

- Trip Reduction Impacts of Mobility Management Strategies (TRIMMS©) – Is a model developed by the Center for Urban Transportation Research at the University of South Florida. TRIMMS allows quantifying the net social benefits of a wide range of transportation demand management initiatives in terms of emission reductions, accident reductions, congestion reductions, excess fuel consumption, and adverse global climate change impacts. The model also provides a program cost-effectiveness assessment to meet FHWA's CMAQ Improvement Program requirements for program effectiveness assessment and benchmarking.

- Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools – the Transportation Research Board's second Strategic Highway Research Program (SHRP 2) Reliability Project L04 has produced a pre-publication, non-edited version of a report titled *Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools* that explores the underlying conceptual foundations of travel modeling and traffic simulation and provides a practical means of generating realistic reliability performance measures using network simulation models.

The above tools and research efforts represent a sample of the available methods that may be used for supporting and conducting benefit cost 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* (this publication is available at: http://www.ops.fhwa.dot.gov/publications/fhwahop12028/index.htm).

In addition, these developed tools and associated published research often form the basis for the benefit and cost estimation capabilities incorporated in the TOPS-BC tool developed for the FHWA Office of Operations Planning for Operations initiative.

TOOL FOR OPERATIONS BENEFIT/COST – A TOOL FOR BENEFIT COST ANALYSIS OF ROAD WEATHER MANAGEMENT STRATEGIES

TOPS-BC provides an analysis framework and many default parameters that offer the capability to conduct simple sketch-planning-level BCAs for selected TSMO strategies, including a framework for addressing RWM strategies. This capability provides practitioners with the ability to conduct a BCA quickly, simply, and with generally available input data. A number of the sketch-planning tools and analysis frameworks described above give analysts the ability to assess the benefits of a particular 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 estimate benefits and costs directly within a single tool is uncommon in existing tools. Further, the TOPS-BC benefit estimation methodology was developed to incorporate the assessment of new performance measures (e.g., travel time reliability) that are more capable of capturing the unique impacts of many operations strategies. Finally, the benefits estimation capability of TOPS-BC incorporated much of the latest research on the benefits of TSMO and RWM, particularly for many new and emerging strategies.

> Compendium users should familiarize themselves with TOPS-BC. This can be accomplished by:
>
> - Downloading and reviewing the *Operations Benefit Cost Analysis Desk Reference* at http://ops.fhwa.dot.gov/publications/fhwahop12028/fhwahop12028.pdf
> - Downloading and reviewing the TOPS-BC User Manual at http://www.ops.fhwa.dot.gov/publications/fhwahop13041/
> - Downloading and reviewing TOPS-BC at http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm
>
> FHWA also maintains an information base on TSMO including RWM costs and benefits that provides links to a variety of previous studies and data on TSMO strategies and deployments.

TOPS-BC provides the ability to assess the sketch-planning level benefits of various TSMO and RWM strategies using minimal user 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 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 conducting BCAs for those deployments that require detailed output and high levels of confidence in the accuracy of the results as well as 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 them 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 benefit estimation capabilities provide a common instructional worksheet with links to individual strategies housed on separate worksheets. The outputs from the benefits estimation function 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.

TOOL FOR OPERATIONS BENEFIT/COST 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 ratio of the analyzed facility and increase at higher levels of congestion. Table 5 shows the safety rates use for the different categories. Table 6 shows the volume-to-capacity-ratio-sensitive rates used for estimating the freeway injury and PDO crashes.

Table 5. Crash rates per million vehicle miles traveled.

Severity	Freeway	Arterial
Fatality	0.007	0.018
Injury	Variable	1.699
Property Damage Only	Variable	2.474

Table 6. Volume/capacity-ratio-sensitive crash rates per million vehicle miles traveled.

Volume/Capacity Ratio	Freeway Injury Crashes	Freeway Property-Damage-Only Crashes
0.1 to 0.7	0.476	0.617
0.8	0.532	0.718
0.9	0.677	0.836
1+	0.706	0.919

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

In addition to this general estimation methodology, some RWM-related strategies available for analysis 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 7 presents these default impacts currently used in the tool. TOPS-BC provides the user the ability to accept all defaults and complete a run or to modify defaults with other available data and run the analysis with the new assumptions. This also allows the user to conduct a simple results sensitivity analysis based on specific assumptions.

Table 7. Default impact assumptions currently in the Tool for Operations Benefit/Cost.

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
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
Travel Demand Management	No change to default crash rates

BENEFIT COST ANALYSIS FOR ROAD WEATHER CONNECTED VEHICLE APPLICATIONS

In 2013, FHWA published the document *Road Weather Connected Vehicle Applications – Benefit-Cost Analysis*.[3] This report, herein referred to as the CV BCA Study, explains the purpose of connected vehicle (CV) applications that support RWM practices. The report describes seven road weather CV applications, including their concepts of operations. The applications are fully defined in the companion report, *Concept of Operations for Road Weather Connected Vehicle Applications*.[4] Table 8 lists all seven applications and provides a brief description of each.

Table 8. Road weather connected vehicle application descriptions.

Application	Description
Enhanced Maintenance Decision Support System	Data from snow plows and other agency fleet vehicles can result in improved maintenance operations and increased safety.
Information for Maintenance and Fleet Management Systems	Newly collected data are key inputs to Maintenance and Fleet Management Systems.
Variable Speed Limits for Weather Responsive Traffic Management	New data collection systems inform variable speed limit systems by providing real-time information on appropriate speeds.
Motorist Advisories and Warnings	Road weather data provides advance warning on deteriorating road and weather conditions.
Information for Freight Carriers	Road weather data provides information to both truck drivers and their dispatchers. This information can be used to improve scheduling decisions or delivery schedules.
Information and Routing Support for Emergency Responders	Road-weather connected vehicle data inform emergency responders, including ambulance operators, paramedics, and fire and rescue companies about road-weather alerts and warnings.
Weather Responsive Signal Timing	Road weather data is used by signals to optimize timing for safety and mobility during adverse weather conditions.

FHWA also conducted a number of informational BCA workshops in 2015 and 2016. The goal of the workshops was to familiarize agency staff with benefit cost analysis (BCA) as an economic evaluation tool for TSMO planning and decision-making. For these workshops, FHWA developed an expanded version of TOPS-BC for demonstration purposes. This version, called TOPS-BC 1.2 Beta – Connected Vehicles, includes the CV strategies listed in Table 8. In this compendium, BCA of five CV strategies are added as follows:

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[3] FHWA, *Road Weather Connected Vehicle Applications* (2013), FHWA-JPO-14-124. Available at http://ntl.bts.gov/lib/54000/54400/54480/Road_Weather_Connected_Vehicle_Applications_Benefit-508-v8.pdf.

[4] FHWA, *Concept of Operations for Road Weather Connected Vehicle Applications* (2013), FHWA-JPO-13-047. Available at http://ntl.bts.gov/lib/47000/47300/47330/74CD2020.pdf.

1. Motorist Advisories and Warnings (Case Study 5.3).
2. Information for Freight Carriers (Case Study 5.4).
3. Weather-Responsive Signal Timing (Case Study 6.4).
4. Variable Speed Limits for Weather-Responsive Traffic Management (Case Study 6.7).
5. Support System (Case Study 7.10).

By evaluating these different strategies in a hypothetical CV environment, the compendium aims to provide guidance on how to measure the costs and benefits of Road Weather CV applications, what information or data are needed to run a BCA, and how TOPS-BC can be used.

The case studies analyze each of the five strategies in the same hypothetical State. The next section describes the basic infrastructure investments needed to implement CV applications. This infrastructure serves as backbone for all strategies analyzed in this document. Each case study provides a description of the different costs and benefits associated with deployment.

Note that the CV BCA report considers deploying CV applications at the national level. In contrast, the individual case studies presented in this compendium look at a hypothetical State. This State is assumed to have 2 percent of the U.S. population.

Connected Vehicle System Basic Infrastructure Costs

There are three categories of costs considered in the analysis: basic infrastructure costs, road weather specific CV costs, and application specific costs. The first set of costs is incurred regardless of which applications are deployed and can be used by all CV applications including those designed for a purpose other than road weather management. The basic infrastructure CV environment will require the deployment of several types of equipment to wirelessly connect vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). Vehicles will have on-board equipment (OBE) units which broadcast and capture signals from other vehicles and from the infrastructure. To collect and collate information from multiple vehicles in an area, roadside equipment (RSE) is expected to be required to receive and broadcast signals between vehicles and traffic management centers (TMC). Currently OBEs and RSEs are not widely developed or deployed; therefore to assess the coverage of a CV system, the deployment scenario must assume a set of projections for the deployment of these technologies.

We used the 2013 CV BCA report to gather basic background information needed to perform BCA of CV applications. Based on this data, new cost line items were added to an existing cost sheet within TOPS-BC.[5] Figure 9 shows the different cost items that were added. The illustration is extracted from a spreadsheet within TOPS-BC that calculates the costs of specific CV strategies. Basic Infrastructure refers to the required infrastructure investments while the Incremental Deployment section includes cost items that are application-specific. The Basic Infrastructure and Incremental Deployment sections include estimated annualized costs, operations and maintenance (O&M) costs, item-specific counts and the user-selected quantities used in this analysis.

[5] FHWA, *Tool for Operations Benefit/Cost Analysis*, available at http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

Equipment		Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count	Unit Costs
Basic Infrastructure Equipment and Costs								
	Urban Freeway RSE w/ wireline	**25**	$ 230,095	$ 5,752	$ 14,956	**24**	**1 per Mile**	$ 9,600
	Urban Freeway RSE wireless	**25**	$ 1,946,222	$ 48,656	$ 126,504	**96**	**1 per Mile**	$ 20,300
	Urban Signal RSE w/ wireline	**25**	$ 2,335,467	$ 58,387	$ 151,805	**201**	**2/3 of signals**	$ 11,600
	Urban Signal RSE wireless	**25**	$ 17,958,935	$ 448,973	$ 1,167,331	**805**	**2/3 of signals**	$ 22,300
	Rural Interstate w/ powergrid connection	**25**	$ 7,640,697	$ 191,017	$ 496,645	**261**	**1 per 2 Miles**	$ 29,300
	Rural Interstate w/o powergrid connection	**25**	$ 2,418,685	$ 60,467	$ 157,215	**65**	**1 per 2 Miles**	$ 37,100
	TOTAL Infrastructure Cost		$ 32,530,101	$ 813,253	$ 2,114,457			
Incremental Deployment Equipment - Please See Chart on the Right for Application-Specific Information								
	Application Development Costs	1	$ 191,746	$ -	$ 191,746	**1**	**1 per Application**	$ 191,746
	System Integration & Backoffice	35	$ 25,886	$ 3,835	$ 4,575	**1**	**1 per Application per TMC**	$ 25,886
	Vehicle On-Board Equipment	12	$ 4,800,000	$ 288,000	$ 688,000	**48,000**	**1 per Vehicle**	$ 100
	Vehicle Data Translator (This Item is RWM-specific only)	25	$ -	$ -	$ -		**1 per TMC**	$ 1,000,000
	Maintenance Vehicle Costs	5	$ -	$ -	$ -		**1 per Maintenance Vehicle**	$ 30,000
	Dynamic Message Sign	10	$ -	$ -	$ -		***VSL ONLY***	$ 82,000
	Education & Outreach	1	$ -	$ -	$ -		**1 per capita**	$ 0.045
	TOTAL Incremental Cost		$ 5,017,632	$ 291,835	$ 884,321			
INPUT	Enter Number of Infrastructure Deployments	1	**$ 2,114,457**					
INPUT	Enter Number of Incremental Deployments	1	**$ 884,321**					
INPUT	Enter Year of Deployment	2020						
Average Annual Cost	**$ 2,998,777**							

Figure 9. Screenshot. Tool for Operations Benefit/Cost cost spreadsheet with connected vehicle cost items.

While the CV BCA report focused on the entire United States, the case studies assumed the hypothetical State contains 2 percent (1 of 50 States) of the entire population of the United States. The basic infrastructure quantities used in the analysis were derived from that assumption and are shown in Figure 9. When the new cost lines shown in Figure 9 are entered into the Excel-based tool, the CV BCA report contains a table, shown in Figure 10, that identifies the cost elements needed to perform a proper cost analysis. If users want to analyze a specific CV application deployment strategy, the table allows for a quick identification of those costs.

Strategy: Road Weather Management Connected Vehicle Applications

Length of Analysis Period (Hours)	3

Facility Characteristics

	Input	Input	Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Facility Type	Urban Freewa	2					
Link Length (Miles)		100					
Total Number of Lanes		2		2		2	0
Link Capacity (All Lanes - Per Period)		13200		13200		14520	1320
Free Flow Speed (MPH)	65	55					

Facility Performance

Link Volume (Per Period)	11,880

	Baseline Override	Baseline	Improvement Override	Improvement	Change
Congested Speed		50.864		54.146	3.282
Vehicles Miles Traveled (VMT)		1188000.0000		1188000.0000	0.0000
V/C		0.9000		0.8182	-0.0818
Vehicle Hours of Travel		23356.5295		21940.8197	-1415.7099
Incident Related Delay (hours) per vehicle per mile		4.24545E-05		3.67189E-05	-5.7356E-06
Number of **Fatality** Crashes		7.84080E-03		7.29194E-03	-5.48856E-04
Number of **Injury** Crashes		8.04276E-01		6.06842E-01	-1.97434E-01
Number of **Property Damage Only** Crashes		9.93762E-01		8.09308E-01	-1.84454E-01
Fuel consumption (Gallons)		55921.6216		55921.6216	0.0000

Figure 10. Screenshot. Assumptions for all connected vehicle application benefit estimations.

The quantities shown in Figure 9 are assumptions made for the hypothetical State being analyzed. Different regions or States in the United States will likely have a different set of characteristics. Care must be taken when applying this analytic approach to other locations. However, when these characteristics are known, the tool offers a high-level insight into the relationships and trade-offs between benefits and costs that are useful in decision-making. Finally, the number of infrastructure and incremental deployments was set to 1, because the extent of the roadway structure for the entire CV system is already represented in the quantities shown in every cost line.

Note that the three incremental cost elements (*Application Development*, *System Integration and Backoffice Costs*) as well as *Incremental On-Board Equipment* are shown in Figure 9, even though they do not constitute basic infrastructure costs. They are listed in the illustration nevertheless, since they are necessary for all applications mentioned in the case studies. *Application Development* is set to 1, since each application is analyzed individually. It is also assumed that every application needs 1 traffic management center (TMC), which is why the quantity for *System Integration and Backoffice* is set to 1 as well. Finally, the average amount of cars per 1000 people in the United States was used inthe case studies, which for the hypothetical State is assumed to have 2 percent of the U.S. population, or 6 million inhabitants. One percent of this number was assumed to be early adopters of vehicle on-board equipment, or about 48,000 vehicles.

The combination of basic and incremental deployment equipment costs necessary for each CV application in this compendium leads to total average annual costs of about $3 million. Additional costs will be added for each application as shown in Table 9.

Table 9. Application cost element matrix.

Application	Maintenance Vehicles Will Have Environmental Sensor Stations	Application Development	System Integration and Back Office Costs	Education and Outreach	Incremental Onboard Equipment	Variable Speed Limit Sign
Enhanced maintenance decisions support system	✓	✓	✓	✓	✓	
Information for maintenance and fleet management systems		✓	✓		✓	
Variable speed limits for weather-responsive traffic management		✓	✓	✓	✓	✓
Motorist advisories and warnings		✓	✓	✓	✓	
Information for freight carriers		✓	✓		✓	
Information and routing support for freight carriers		✓	✓		✓	
Weather-responsive signal timing		✓	✓	✓	✓	

Source: Booz Allen Hamilton, January 2013.

Connected Vehicle Applications Benefits Estimation

The CV BCA report made several general assumptions that are valid for benefits estimation of weather-related CV applications. Figure 10 shows a portion of the CV Benefit worksheet in TOPS-BC that includes these preset assumptions. Since TOPS-BC focuses on peak periods as opposed to the entire day, the length of the analysis period is set to 3 hours, as this constitutes a standard peak period in a metropolitan area. Subsequently, the link facility type is set to Type 2 – Urban Freeway, as most of the benefits of CV applications will likely be generated in urban areas. The total link length of urban freeways in the hypothetical State is assumed to be 100 miles. The average number of lanes is set to two. This assumption offers a conservative estimation of benefits, since more lanes generally yield higher benefits when traffic conditions improve. The link capacity in the yellow cell is calculated by the tool depending on the number of lanes, length of the analysis period, and the link facility type. Free flow speed is set to 65 mph instead of the standard value of 55 mph, because the analysis assumes that the average roadway user exceeds the official speed limit on a regular basis, and some metropolitan areas allow for higher speed limits than 55 mph. Finally, the link volume is set to 11,880, which is derived by calculating 90 percent of the link capacity. This assumption ensures that the traffic flow is heavy and close to the maximum capacity of the roadway structure for the peak period.

Each case study describes the costs and benefits of the CV application. The cost section explains the incremental costs since the basic infrastructure costs are already discussed above. The analysis includes specific incremental cost elements for each application as presented in Table 9. The case studies also describe several assumptions made regarding costs and benefits.

HOW TO USE THE COMPENDIUM

The RWM 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 RWM BCA. The RWM Compendium complements these resources by providing case references where BCAs have been completed for RWM projects. In addition, the hypothetical examples demonstrate particular uses and modifications of TOPS-BC.

A model like TOPS-BC is designed to cover a range of projects and include cost and benefit computations for each technology. Notably, some models are developed for a specific technology or strategy. For example, the Clear Roads Pooled Fund Decision Support System (PFDSS) provides a specific analysis of maintenance decisions, including RWM technologies.[6] A technology- or 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.

Users who have a particular strategy or technology they are interested in evaluating can check Table 10 to see if their strategy is included in this compendium. This table lists types of strategies and technologies along with an indication of the project title if it is a previous BCA. If

[6] FHWA, Road Weather Management Program Projects and Activities Web page, "Maintenance Decision Support System (MDSS) Prototype." Available at: http://ops.fhwa.dot.gov/weather/mitigating_impacts/programs.htm#p3.

it is a hypothetical case, the description is more generic. The table also indicates the kind of information addressed by each case study to assist the user in locating the example that will be most suited to their current needs.

Each case presented is an example of a BCA previously conducted for an RWM strategy or technology or an example of how such an analysis could be undertaken in TOPS-BC. The column headings indicate some of the areas addressed in each case. These include:

- Case Number and Name
  - This Compendium includes three general types of case studies:
    1) RWM BCAs conducted by a government and private agencies.
    2) Demonstrations of BCAs using the TOPS-BC tool.
    3) Demonstration of a user modification to the TOPS-BC software.
- RWM Strategy Type
  - Within each strategy type, several examples of different types of strategies or analysis tools are provided.
- BCA Model 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 BCA tool. Many cases report the use of custom software or other packaged tools for BCA analysis of TSMO strategies. TOPS-BC is a user-friendly sketch-planning analysis spreadsheet tool that offers users a lot of flexibility to modify the tool to meet specific user or project needs. Selected cases demonstrate some of these user modifications.
- 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 be averages of previous project data. Hypothetical case studies are for demonstration purposes only.
- Key Benefits
  - Safety – Safety benefits are often considered in the selection of individual and combined RWM Strategies, and this column indicates where this analysis is included in the example.
  - Mobility (Travel Time & Reliability) – Reliability of travel time has emerged as a new and important measure of RWM strategy benefits and is included in several case studies.
  - Efficiency – RWM deployment seeks to meet operational goals in the most cost-effective manner. BCA tools assist in the organization and presentation of key strategy information.
  - Productivity – Some RWM strategies are deployed to provide redundant services and to address potential risks to efficient highway operation. This column identifies such cases.
  - Energy & Environment – Energy costs and environmental impacts are often critical decision factors in selecting the best strategy options.

  - Customer Satisfaction – RWM deployment decisions provide direct benefits such as safety and improved operations, which lead to the indirect benefit of customer satisfaction. Selected cases cover both situations.
- Special Strategy Example Problem Illustration
  - Custom Safety Data – Some cases focus on the analysis of safety benefits.
  - Sensitivity Analysis or Testing – Many BCA studies test their input assumptions with sensitivity testing. This column identifies cases where sensitivity testing is demonstrated.
  - Use of Multiple Strategies – RWM strategies are often deployed in combination, and some of the cases included such examples.

TOPS-BC was released by FHWA in late 2013. As such, not many completed and published analyses using the software exist. Few of the real-world cases presented in the RWM Compendium use TOPS-BC. As with any analysis, finding the right tool is critical. In many cases this is a custom application developed for the particular project under review. In the future, TOPS-BC will facilitate this process by providing a model with default data and algorithms that allow the user to get started quickly and to easily modify the tool as new data and methods evolve during the planning process. Some BCA models are generic by design. They allow the user to construct the analysis of a particular project, and the models assist with the calculation. An example of this type of model is BCA.Net, which is available at https://fhwaapps.fhwa.dot.gov/bcap/BaseLogin/LoginReg.aspx.

Table 10. Road weather management case study list.

#	Case Name	Strategy Type	Benefit Cost Analysis (BCA) Model	Actual or Hypothetical Case	Key Benefits: Safety	Key Benefits: Mobility (Time & Reliability)	Key Benefits: Efficiency	Key Benefits: Productivity	Key Benefits: Energy and Environment	Key Benefits: Customer Satisfaction	Special Strategy Example Problem Illustrates: Custom Safety Data	Special Strategy Example Problem Illustrates: Sensitivity Analysis or Testing	Special Strategy Example Problem Illustrates: Use of Multiple Strategies
4.1	Michigan Department of Transportation (DOT) Regional Pre-deployment Studies	Surveillance, Monitoring, and Prediction	ITS Deployment Analysis System (IDAS)	Actual	Substantial Positive Impacts	Yes	Yes	Substantial Positive Ompacts		Positive Impacts		Yes	Yes
4.2	Utah DOT Weather Operations/Road Weather Management Information System Program	Surveillance, Monitoring, and Prediction	An Artificial Neural Network Model	Actual	Substantial Positive Impacts	Yes	Yes	Substantial Positive Impacts		Positive Impacts			Yes
4.3	Implementation of Bridge Condition Monitoring System for Water Scour	Surveillance, Monitoring and Prediction	Tool for Operations Benefit/Cost (TOPS-BC)	Hypothetical	Substantial Positive Impacts	Yes	Yes				Yes	Yes	
4.4	Road Weather Information System Deployment in Idaho	Surveillance, Monitoring and Prediction	TOPS-BC	Actual	Yes						Yes Based on Local Experience	Yes	
4.5	High Water Detection System in Texas	Surveillance, Monitoring and Prediction	TOPS-BC	Actual	Substantial Positive Impacts	Yes	Yes				Yes		
5.1	Rural Intelligent Transportation System Deployment - Oregon's Automated Wind Warning System	Information Dissemination	Custom In-House Analysis	Actual	Substantial Positive Impacts	Yes	Yes	Yes		Positive Impacts		Yes	
5.2	Salt Lake City's Traffic Operations Center Study	Information Dissemination	An Artificial Neural Network Model	Actual	Substantial Positive Impacts	Yes	Yes			Positive Impacts		Yes	

Table10. Road weather management case study list (continuation).

#	Case Name	Strategy Type	Benefit Cost Analysis Model	Actual or Hypothetical Case	Key Benefits						Special Strategy Example Problem Illustrates		
					Safety	Mobility (Time & Reliability)	Efficiency	Productivity	Energy and Environment	Customer Satisfaction	Custom Safety Data	Sensitivity Analysis or Testing	Use of Multiple Strategies
5.3	Motorist Advisory and Warning (Connected Vehicle (CV) Application)	Information Dissemination	TOPS-BC Beta CV	Hypothetical	Substantial Positive Impacts	Yes	Yes						Yes
5.4	Information for Freight Carriers (CV Application)	Information Dissemination	TOPS-BC Beta CV	Hypothetical	Substantial Positive Impacts	Substantial Positive Impacts	Yes	Yes			Yes		Yes
6.1	Minnesota DOT Gate Operations	Decision Support, Control and Treatment	Custom In-House Analysis	Actual	Positive Impacts	Yes	Yes					Yes	
6.2	Hypothetical Road Closure Feasibility	Decision Support, Control and Treatment	TOPS-BC	Hypothetical	Positive Impacts	Yes	Yes				Yes	Yes	
6.3	Hypothetical Freeway Systems: Dynamic Traffic Signal Control Systems Deploy-ment and Feasibility	Decision Support, Control and Treatment	TOPS-BC	Actual	Positive Impacts	Yes	Yes		Yes		Yes	Yes	
6.4	Weather Responsive Signal Timing (CV Application)	Decision Support, Control and Treatment	TOPS-BC Beta CV	Hypothetical	Positive Impacts	Yes	Yes	Yes					Yes
6.5	Road Condition Reporting Application in Wyoming	Decision Support, Control and Treatment	TOPS-BC	Actual			Yes	Yes					
6.6	Weather Responsive Active Traffic Management System in Oregon	Decision Support, Control and Treatment	TOPS-BC	Actual	Positive Impacts	Yes	Yes						Yes
6.7	Variable Speed Limit (CV Application)	Decision Support, Control and Treatment	TOPS-BC Beta CV	Hypothetical	Positive Impacts	Substantial Positive Impacts	Yes					Yes	

Table 10. Road weather management case study list (continuation).

#	Case Name	Strategy Type	Benefit Cost Analysis Model	Actual or Hypothetical Case	Key Benefits						Special Strategy Example Problem Illustrates		
					Safety	Mobility (Time & Reliability)	Efficiency	Productivity	Energy and Environment	Customer Satisfaction	Custom Safety Data	Sensitivity Analysis or Testing	Use of Multiple Strategies
7.1	Maintenance Decision Support System Implementation: The City and County of Denver	Weather Response or Treatment	Custom BCA Model – "with-without" Analysis	Actual	Substantial Positive Impacts	Yes	Yes	Substantial Positive Impacts	Positive Impacts			Yes	
7.2	Pooled Fund Maintenance Decision Support System Implementation	Weather Response or Treatment	Custom In-House Analysis	Actual	Substantial Positive Impacts	Yes	Yes			Positive Impacts		Yes	
7.3	Hypothetical Maintenance Decision Support System Implementation	Weather Response and Treatment	TOPS-BC	Hypothetical	Substantial Positive Impacts	Yes	Yes	Substantial Positive Impacts	Positive Impacts		Yes	Yes	
7.4	Washington's Automated Anti-icing System Study	Weather Response or Treatment	Washington DOT Benefit/ Cost Worksheet for Collision Reduction	Actual	Substantial Positive Impacts	Yes	Yes	Substantial Positive Impacts	Positive Impacts				Yes
7.5	Bridge Prioritization for Installation of Anti-icing Systems in Nebraska	Weather Response or Treatment	Custom BCA Model	Actual	Substantial Positive Impacts	Yes	Yes	Substantial Positive Impacts	Positive Impacts				
7.6	De-icing in Iowa	Weather Response or Treatment	TOPS-BC	Hypothetical	Yes	Yes	Yes	Yes	Yes		Yes	Yes	
7.7	Evaluation of North Dakota's Fixed Automated Spray Technology Systems	Weather Response or Treatment	Custom In-House Analysis	Actual	Substantial Positive Impacts	Yes	Yes	Substantial Positive Impacts	Positive Impacts			Yes	
7.8	Automatic Vehicle Location System Deployment in Kansas	Weather Response or Treatment	Custom In-House Analysis	Actual	Substantial Positive Impacts	Yes	Yes	Substantial Positive Impacts		Positive Impacts		Yes	
7.9	Hypothetical Study of the Use of Automatic Vehicle Location for Highway Maintenance Activities	Weather Response or Treatment	TOPS-BC	Hypothetical	Substantial Positive Impacts	Yes	Yes	Substantial Positive Impacts		Positive Impacts	Yes	Yes	

Table 10. Road weather management case study list (continuation).

#	Case Name	Strategy Type	BCA Model	Actual or Hypothetical Case	Key Benefits						Special Strategy Example Problem Illustrates		
					Safety	Mobility (Time & Reliability)	Efficiency	Productivity	Energy and Environment	Customer Satisfaction	Custom Safety Data	Sensitivity Analysis or Testing	Use of Multiple Strategies
7.10	Enhanced Maintenance Decision Support System (CV Application)	Weather Response or Treatment	TOPS-BC Beta CV	Hypothetical	Substantial positive impacts	Yes	Yes				Yes		Yes

CHAPTER 4. CASE STUDIES FOR SURVEILLANCE, MONITORING, AND PREDICTION

Table 11. Case studies for surveillance, monitoring, and prediction.

#	Case Name	Benefit/Cost Analysis Model	Actual or Hypothetical Case
4.1	Regional Pre-deployment Studies of Road Weather Management Information Systems	Intelligent Transportation System Deployment Analysis System	Actual
4.2	The Utah Department Of Transportation Weather Operations/Road Weather Management Information System Program	An Artificial Neural Network Model	Actual
4.3	Implementing a Bridge Condition Monitoring System for Water Scour	Tool for Operations Benefit/Cost	Hypothetical
4.4	Road Weather Information System Deployment In Idaho	Tool for Operations Benefit/Cost	Actual
4.5	High Water Detection System in Texas	Tool for Operations Benefit/Cost	Actual

Note: Use the hyperlinks in this table to jump directly to the case study.

CASE STUDY 4.1 – MICHIGAN DEPARTMENT OF TRANSPORTATION REGIONAL ROAD WEATHER MANAGEMENT INFORMATION SYSTEMS PRE-DEPLOYMENT STUDIES[7]

Strategy Type:	Surveillance, Monitoring and Prediction
Project Name:	Regional Pre-deployment Studies of Road Weather Management Information Systems (RWMIS)
Project Agency:	The Michigan Department of Transportation (MDOT)
Location:	Rural RWMIS Deployments
Geographic Extent:	Four Selected Regions
Tool Used:	IDAS

Project Technology or Strategy

The Michigan Department of Transportation (MDOT) developed its road weather management information systems (RWMIS) to help local agencies and travelers better react to weather conditions affecting the roads. The Michigan's DOT Regional Pre-deployment Program is responsible for deploying and operating a number of surveillance, monitoring, and prediction tools to mitigate the impacts of adverse weather or optimize activities such as maintenance in favorable weather, including the following:

- Environmental Sensor Stations (ESS) - near or actually embedded in the road surface, they report common atmospheric weather variables plus pavement and subsurface road temperature, road wetness, and pavement chemical concentration.
- Maintenance Decision Support System (MDSS) – this tool automatically combines weather model output with a road model, road maintenance rules of practice, and maintenance resource data for maintenance vehicles and snowplow incident management.

Project Goals and Objectives

MDOT completed RWMIS pre-deployment plans for five of the State's seven regions. As part of this process, MDOT performed a benefit cost analysis (BCA) for the RWMIS deployment in four regions: North, Bay, Grand, and Superior. In order to provide comparable benefits and costs within the analysis, MDOT carefully selected key measures of effectiveness (MOE) to fully capture the benefits of the program. These measures included:

- Travel time.
- Safety.
- Operating costs.

[7] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Methodology

Data outputs were obtained from the statewide travel demand model to use as inputs into the Intelligent Transportation Systems Deployment Analysis System (IDAS) model. The model data included both network files and travel demand files representing daily volumes for 2010. The project team used a combination of national default values, such as accident rates, vehicle fuel efficiency, emissions rates, etc.; values developed for the Southeast Michigan ITS Deployment Study conducted from 2000 to 2002; and values estimated based on research conducted specifically for the project as the estimated impact of the ITS deployment. Annualized capital costs were added to operational and maintenance costs to estimate annual expenditures.

The principal benefits expected from RWMIS deployment were reduction in crashes and travel time savings. The data available to estimate these benefits is scarce due to limited national deployments. As more systems are deployed nationwide, more accurate data on crash reductions and time savings will be available. For this study the researchers relied on the earlier MDOT studies and additional primary research conducted for this study. In order to estimate the deployment benefits, assumptions about crash frequencies and total trips were input into the regional transportation demand model (TDM) and IDAS. A full citation of the MDOT study is provided at the end of this case discussion.

Model Run Results

The benefit cost analysis conducted for the RWMIS deployment included capital costs (which were annualized to compute the net benefits and benefit cost ratios) and annual operations and maintenance (O&M) costs for each region. In each case, the benefits and costs are measured against a no deployment base case. Care must always be taken when selecting the base case condition. This was a deploy/no deploy evaluation, but the analysts could have considered what other actions might have been taken in the absence of the deployment. Such actions could alter the cost and benefits available from RWMIS. The number of ESS to be deployed was estimated at 15 in the Bay Region, 34 in the Superior Region and 50 in the North Region (no information was available for the Grand Region).[8] The costs were as follows (in 2007 dollars):

- North: Total Capital Cost: $4,020,000, Annual O&M Cost: $460,000.
- Bay: Total Capital Cost: $2,060,000, Annual O&M Cost: $256,000.
- Grand: Total Capital Cost: $2,272,000, Annual O&M Cost: $233,500.
- Superior: Total Capital Cost: $3,463,000, Annual O&M cost: $358,000.

Rural RWMIS deployments show estimated benefit cost ratios of 2.8 to 7.0 depending upon the region. Table 12 below shows the benefits and costs of proposed RWMIS. The benefit cost ratios are higher in the Bay and Grand regions where fewer Environmental Sensor Stations are proposed but where more motorists are served by the system. Travel time savings provide a significant proportion of the benefits in these regions. In the more rural North and Superior

[8] For more information on the geographical breakout of MDOT regions, visit MDOT's "Superior Region by County" web page, available at: http://michigan.gov/mdot/0,1607,7-151-9615_36946-119651--,00.html (accessed August 17, 2014).

regions, a higher proportion of benefits are found in crash reduction and operating costs, with less in travel time savings due to significantly lower traffic volumes.

Table 12. Benefit cost analysis from Michigan Department of Transportation's regional pre-deployment studies.

Benefits and Costs	North	Bay	Grand	Superior
Travel Time Savings	$354,000	$2,289,700	$1,036,000	$573,000
Crash Reduction	$1,519,000	$968,000	$1,269,000	$1,630,000
Operating Costs	$565,000	$94,000	$115,000	$203,000
Total Annual Benefits	$2,438,000	$3,351,700	$2,420,000	$2,406,000
Annualized Cost	$870,000	$482,000	$471,000	$713,000
Net Benefits	$1,568,000	$2,289,700	$1,949,000	$1,693,000
Benefit Cost Ratio	2.8	7.0	5.1	3.4

The results of the BCA showed rural road weather management information system deployments to be extremely efficient investments. The potential benefits include reduced travel time, 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 RWMIS.

Key Observations

This case evaluated two transportation system management and operations (TSMO) weather-related technologies in Michigan rural regions. MDOT used the IDAS BCA tool to assist with the agency's analysis. This decision was made in part due to MDOT's experience with the regional travel demand model and their ability to rerun the TDM to test alternatives.

Testing the deployment before expanding the system provided the sensitivity analysis decision makers needed before committing to system expansion. A BCA allows the user to examine the efficiency of the installation and compare it to alternative assumptions. This case study examined RWIS on four regions in Michigan before expanding the system. The BCA for each region provided the agency with a perspective on how the costs and benefits can vary by geography and other regional characteristics.

This case showed that winter maintenance 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.

Reference

Dan Krechmer, et.al. *Benefit–Cost Evaluation Techniques for Rural ITS Deployments*, January 2010.

CASE STUDY 4.2 – THE UTAH DEPARTMENT OF TRANSPORTATION WEATHER OPERATIONS/ ROAD WEATHER MANAGEMENT INFORMATION SYSTEM PROGRAM[9]

Strategy Type:	Surveillance, Monitoring and Prediction
Project Name:	Utah Department of Transportation (Utah DOT) Weather Operations/ Road Weather Management Information System (RWMIS) Program
Project Agency:	Utah DOT
Location:	Urban Setting
Geographic Extent:	Primary Transportation Corridors
Tool Used:	An Artificial Neural Network Model (ANN)

Project Technology or Strategy

The Utah Department of Transportation (DOT) implemented a weather operations program that assists the agency's operations, maintenance, and construction functions by providing detailed, often customized, area-specific weather forecasts. Established under the Utah DOT Traffic Management Division, the RWMIS program is responsible for deploying and operating a number of transportation systems management and operations (TSMO) strategies in the region, including the following:

- Road weather management information system (RWMIS).
- Regional traffic operations center (TOC).
- Incident management and freeway service patrols.
- Anti-icing system (spray systems).
- Communications (511/ CommuterLink/ variable message signs).
- Advanced traffic management system (ATMS).
- Other applications.

Project Goals and Objectives

The State of Utah expanded the number of its weather station installations as a result of hosting the 2002 Winter Olympics. During the Olympics, a report on hazardous weather potential was issued twice each day for the primary transportation corridors. After the Winter Olympics concluded, these efforts developed into Utah DOT's Weather Operations/RWMIS program. This program supports the agency's operations, maintenance, and construction functions by providing detailed, area-specific weather forecasts.

For the purposes of this project, the goal was to determine the benefits and costs associated with outputs from the weather operations program, specifically in the context of winter maintenance. For simplicity, the benefit cost analysis (BCA) considered only benefits related to a reduction in

[9] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

winter maintenance costs associated with materials and labor. Anecdotal evidence indicated that the program has supported improved anti-icing operations, which have likely reduced crash frequency and severity, thereby saving lives and reducing crash-related delay. However, these benefits were not quantified in this analysis.

Methodology

An artificial neural network (ANN) model of winter maintenance costs was developed. It calculated the labor and materials cost for a given maintenance/materials storage facility (shed) as a function of the following key factors:

- The shed's overall winter usage of Utah DOT weather operations service.
- The shed's overall evaluation of Utah DOT weather operations service.
- Level of anti-icing practice used by the shed.
- Level of maintenance of winter roadways managed by the shed.
- Vehicle miles traveled on winter roadways managed by the shed.
- A winter severity index for the area managed by the shed.

The model was developed based on winter maintenance cost data from Utah DOT maintenance sheds for winter 2004–2005 to estimate the cost-effectiveness of the State's Weather Operations/RWMIS program. The actual data from this season comprised the baseline for the BCA and included a mix of sheds that relied heavily on the program, used it occasionally, or did not use it. The baseline was compared with a "no program" alternative to reflect the material and labor cost savings in winter maintenance funds resulting from use of the weather operation program.

Model Run Results

It was estimated that the weather operations program in place saved Utah DOT more than $2.2 million during 2004–2005 from reduced winter maintenance costs. Given that the program costs approximately $200,000 to operate, the result translates into a benefit cost ratio of over 11:1. The analysis team collected operating and cost data from maintenance sheds across the State. These data and the use of RWMIS in selected sheds allowed the team to document how the use of RWMIS impacted operating costs. The model estimated the value and additional savings potential of the Utah DOT weather service to be 11–25 percent and 4–10 percent of the Utah DOT labor and materials costs for winter maintenance, respectively. It was unclear how labor costs might be impacted by program expansion, therefore ranges of potential savings on future deployments were estimated.

Anecdotal evidence indicated that the program has supported improved anti-icing operations, which have likely helped to reduce crash frequency and severity, thereby saving lives and reducing crash-related delay. However, these benefits were not quantified in the analysis.
The BCA results highlight the potential benefits that may be realized by an agency expanding the program and using improved weather information to direct its winter maintenance activities.

Key Observations

This analysis sought to quantify the benefits and costs of weather information by focusing on a case study of Utah DOT with its nationally unique Weather Operations/RWMIS program. Using an ANN)[10] approach, it is estimated that the benefit cost ratio associated with the program is greater than 11:1, based simply on the labor and materials cost savings associated with winter maintenance. The true benefit cost ratio of the program may be higher, as there are other program users whose economic benefits were not considered as a part of this study. Therefore, as shown in this case study, the Utah DOT weather operations program is quite cost-effective and has the potential for greater benefits in the future.

Using a combination of multiple TSMO strategies to add capacity offers an enormous potential benefit in reducing winter maintenance costs through improved weather information. In fact, potential benefits are likely greater than those mentioned. It would be valuable to have benefit–cost information on other sources of weather information more commonly used by transportation agencies, such as RWIS networks, decision-support systems, and private-sector forecasting services.

The approach used in this research shows that it is possible to quantify in economic terms the benefits of weather information for winter maintenance. From a modeling perspective, ANN was successful in finding some meaningful, logical results from the noisy data associated with winter maintenance cost activities over one season. It was able to estimate labor and materials costs precisely, and the model predicted changes in costs that were consistent with what would be expected under different traffic volume and winter severity characteristics.

Reference

Christopher Strong and Xianming Shi, "Benefit Cost Analysis of Weather Information for Winter Maintenance," *Transportation Research Record: Journal of the Transportation Research Board*, 2055(2008): 119–127.

[10] An artificial neural network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system, which is composed of a large number of highly interconnected processing elements working in unison to identify and solve specific problems. As a result, ANNs are able to learn by example.

CASE STUDY 4.3 – IMPLEMENTING A BRIDGE CONDITION MONITORING SYSTEM FOR WATER SCOUR[11]

Strategy Type:	Surveillance, Monitoring and Prediction
Project Name:	Bridge Condition Monitoring System for Water Scour
Project Agency:	Hypothetical Agency
Location:	Hypothetical Bridge Site
Geographic Extent:	One Bridge
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC)

Project Technology or Strategy

Scour refers to the erosion that results from flowing water, which excavates and carries away material from stream beds and banks. Different materials scour at different rates; for example, flowing water erodes loose soils rapidly, whereas cemented soils are more likely to resists the scouring effect. Determining the magnitude of scour is complicated because of the cyclical nature of the scour process. Scour can be deepest near the peak of a flood, but hardly visible as floodwaters recede and scour holes refill with sediment.[12]

Bridge scour is the erosion of sand and rock around bridge foundations, piles, abutments or piers and is the primary cause of bridge failure in the United States. There are more than 20,000 highway bridges that are rated "scour critical."[13] Selected bridges have been monitored for more than 10 years and valuable field data have been obtained from observing the effects of scour on these structures.

There are three basic types of fixed scour monitoring systems.[14] These include fixed instrumentation, portable instrumentation, and geophysical instrumentation. Fixed instrumentation monitors are firmly attached to one or more piers. They usually connect to a data logger to communicate remotely, or their data can be downloaded manually onsite.

This analysis assumes the implementation of fixed scour monitoring systems. They offer several advantages over the other systems, such as providing a constant flow of data to agencies, or offering multiple features that portable or geophysical instruments do not offer. Note that cost values can differ among three types of systems.

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[11] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

[12] FHWA, "Evaluating Scour at Bridges, Third Edition," *Hydraulic Engineering Circular No. 18*, FHWA NHI 01-001 (Washington, DC: 1995). Available at: http://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif12003.pdf.

[13] B.E. Hunt, *NCHRP Synthesis 396: Monitoring Scour Critical Bridges* (Washington, DC: Transportation Research Board of the National Academies: 2009). Available at http://www.trb.org/Publications/Blurbs/162822.aspx.

[14] S. Stein, *Risk-Based Management Guidelines for Scour at Bridges with Unknown Foundations*. Phase II Final Report. NCHRP 24-25 (Web-only document 107), Transportation Research Board, 2006.

Project Goals and Objectives

The primary goal of this case study is to analyze the feasibility of a bridge scour monitoring system at a hypothetical site using fixed monitoring technology. The results of a National Cooperative Highway Research Program (NCHRP) study on bridge scour monitoring were used in this BCA case study to determine the benefits and costs of implementing a fixed scour monitoring system in a hypothetical State. This case study demonstrates how transportation professionals can conduct a BCA to evaluate this type of strategy.

Methodology

The NCHRP survey data used in this case study provided cost information for 11 States, representing 41 bridge sites. The survey found that installation costs were often not available and labor costs were usually combined with other construction costs. Costs can vary due to various factors such as site conditions, type of installation, monitoring instrument, number of sites, and contract type. Bridge owners and operators were less likely to provide data on the costs of installation, operation, maintenance, and repairs.

Costs: The hypothetical State is assumed to implement a monitoring system on one bridge. This case is intended to demonstrate a feasibility analysis using BCA for one bridge out of the more than 20,000 highway bridges in the United States that are rated “scour critical.”

An average cost of $15,000 for a fixed scour monitoring system is used for a single bridge. This figure was determined through the evaluation of midpoints of the NCHRP survey responses. Furthermore, this example assumes that one instrument per site (including remote technology) can supply sufficient information to the agency to make informed decisions to address the condition of the bridge. Most sites offer multiple locations where monitoring systems can be implemented, and it is not uncommon that multiple systems are put into place at a single bridge. However, for the purpose of this analysis, it is assumed that one system per bridge is sufficient.

In this example, implementation costs of the new scour monitoring systems are input into the TOPS-BC. They replace the default data for other road weather management (RWM) strategies available in the tool. The tool provides several cost line items on its cost pages for other RWM strategies, separated into *Basic Infrastructure Equipment and Costs* and *Incremental Deployment Equipment*. The first section includes all costs that constitute basic infrastructure needs of an agency for a specific project. The default information for other RWM strategies included in TOPS-BC was replaced for this study with the NCHRP estimate mentioned above. The second category includes all equipment items that are needed on an incremental basis; the size of the planned system determines the quantity of incremental equipment.

The cost item necessary for this analysis was added to the model in the Basic Infrastructure Equipment and Costs section, since only one bridge is in the focus of the analysis. Figure 11 shows the cost sheet within TOPS-BC with the above assumptions- no incremental deployment equipment, and one cost item in the first cost section. Furthermore, this analysis utilizes the assumption of a Texas Department of Transportation (TxDOT) study indicating that 25 percent of the capital costs associated with system monitoring are necessary for operation and maintenance.[15] The calculation therefore results in average annual costs of $18,750.

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count	Unit Costs
Basic Infrastructure Equipment and Costs							
Bridge Scour Monitoring System	25	$ 15,000	$ 3,750	$ 18,750	1	1 per Bridge	$ 15,000
TOTAL Infrastructure Cost		$ 15,000	$ 3,750	$ 18,750			
Incremental Deployment Equipment - Please See Chart on the Right for Application-Specific Information							
TOTAL Incremental Cost		$ -	$ -	$ -			
INPUT Enter Number of Infrastructure Deployments	1	$ 18,750					
INPUT Enter Number of Incremental Deployments	1	$ -					
INPUT Enter Year of Deployment	2020						
Average Annual Cost $ 18,750							

Figure 11. Screenshot. Tool for Operations Benefit/Cost cost estimate for a bridge condition monitoring system for water scour.

Benefits: In order to estimate the benefits of a bridge monitoring system in the hypothetical State, the analysis utilizes historical data on bridge failures within the United States. Based on the literature, the average number of bridge failures is 1 in 4,700 annually.[16] Therefore, the annual number of bridge failures in the State is assumed to be 0.000213. Finally, it is assumed that each bridge failure in the State is related to some loss of life. The average number of fatalities in the case of a bridge failure based on four examples mentioned in literature is 26.[17] However, this analysis assumes a more conservative number of 10 fatalities for bridge failures in this State. For this reason, the factor of 0.000213 is multiplied by 10.

The resulting amount of annual fatalities in the hypothetical State that can be averted using this safety strategy is 0.00213. This number is then multiplied by the default monetary value of an avoided fatality listed on the benefit sheet within TOPS-BC. The tool allows the analyst to enter user-specific benefits when such values are available. The result of this analysis is entered into the cell under user-specific benefits. Figure 12 shows the safety section of the benefit calculation sheet within the tool. It does not show the user-specific benefits, since these were derived separately. However, the illustration includes the default value of a statistical life utilized by TOPS-BC as well as the result of the safety analysis. The analysis calculates the total average annual benefits of this strategy for a single bridge at about $22,890.

[15] TxDOT, *Remote Bridge Scour Monitoring: A Prioritization and Implementation Guideline*, TX-00/0-3970-1, (Texas DOT: 1999), p. 68. Available at https://ctr.utexas.edu/wp-content/uploads/pubs/3970_1.pdf.

[16] Wesley Cook, "Bridge Failure Rates, Consequences, and Predictive Trends," graduate dissertation, Utah State University, Paper 2163 (2014). Available at http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3187&context=etd.

[17] Ibid.

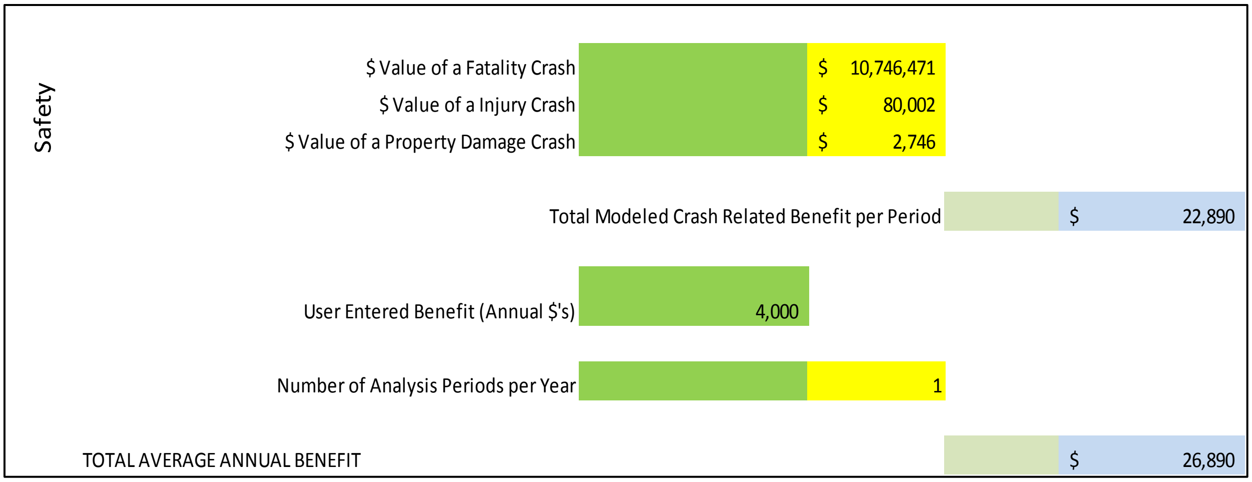

Figure 12. Screenshot. Tool for Operations Benefit/Cost safety benefit estimate for a bridge condition monitoring system for water scour.

Additionally, it is reasonable to assume that a remote water scour monitoring system eliminates the need for on-site visits by DOT staff. According to TxDOT, the cost for an on-site visit is at least $8,000.[18] Additionally, Washington State DOT estimates that on-site visits are regularly performed on bridges with high scour-risk; these inspections take place at least every other year.[19] Therefore, considering the assumptions made above, this analysis adds $4,000 per year to the previously calculated safety benefits using the user-specific cell in TOPS-BC. This analysis focuses on a single year, and on-site inspection costs by TxDOT are assumed to be valid for a 2-year cycle, which is why the previously mentioned $8,000 is divided by 2 years. Note that the preset number of analysis periods per year in TOPS-BC is 250, one for each weekday of the year, but since this analysis takes an annual approach, this value was set to 1.

Note that this analysis does not take into consideration possible benefits occurring from reduced operating and maintenance costs of bridges. The benefits of continuous scour monitoring are the reduction of the probability of scour-related damages or failure. The earlier a scour problem is recognized, the less expensive the costs of remedial action.[20] Monitoring also increases the likelihood of scour issue recognition during floods when periodic or special manual inspections are not feasible.[21] Electronic monitoring is acceptable to get a bridge judged scour critical removed from the list of scour critical bridges, but not as a substitute for federally mandated inspections at specified intervals.

The benefits of continuous monitoring include 1) early warning of impending failure during flooding, allowing the closure of the bridge; 2) a reduced probability of damage or failure; and 3)

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[18] TxDOT, *Remote Bridge Scour Monitoring: A Prioritization and Implementation Guideline*, TX-00/0-3970-1, (Texas DOT: 1999), p. 16.

[19] Washington State Department of Transportation, "Scour Repairs: Bridge Scour Mitigation Program" web page. Available at https://www.wsdot.wa.gov/Bridge/Reporting/ScourRepairs.htm.

[20] TxDOT, *Remote Bridge Scour Monitoring: A Prioritization and Implementation Guideline*, TX-00/0-3970-1, (Texas DOT: 1999).

[21] Ibid. p. 63.

real-time data for calibrating scour prediction equations.[22] Continuous monitoring also reduces the chances that a traffic agency will need to close a bridge prematurely during an incident—a clear benefit to users.

Model Run Results

This section sums up the results of the benefit cost analysis of the bridge scour monitoring system implemented on a hypothetical bridge. As stated above, the case study analyzes a specific set of costs and benefits for demonstration purposes. A full benefit cost analysis will include a wide range of additional costs and benefits that are not separately listed or analyzed in this study. The results of benefit and cost estimations are summarized within the tool on a single page. This gives the analyst a concise overview of all estimations and results. Figure 13 shows the benefit/cost summary of this project using TOPS-BC. For this case study, safety and inspection benefits were calculated manually and input as *Safety* and *User Entered* line items under the Annual Benefits category. The other annual benefits shown in Figure 13 are not estimated. The benefits of the system exceed its costs, as total benefits are $26,890 compared to $18,750 in costs for the installation of a bridge scour monitoring system on a single bridge. These results generate a benefit/cost ratio of 1.43, as shown on the summary table.

Benefit/Cost Summary

Annual Benefits		**Road Weather Management**
Travel Time	$	0
Travel Time Savings: Non-Recurring Delay	$	0
Energy	$	0
Safety	$	22,890
Other	$	0
User Entered	$	4,000
Total Annual Benefits	**$**	26,890
Annual Costs	**$**	18,750
Benefit/Cost Comparison		
Net Benefit	**$**	8,140
Benefit Cost Ratio		1.43

Figure 13. Screenshot. Benefit cost analysis results for a bridge condition monitoring system for water scour.

[22] TxDOT, *Remote Bridge Scour Monitoring: A Prioritization and Implementation Guideline*, TX-00/0-3970-1, (Texas DOT: 1999).

References

B.E. Hunt, *NCHRP Synthesis 396: Monitoring Scour Critical Bridges*, "Chapter 4: Experience with Scour Monitoring Systems," (Washington, D.C.: Transportation Research Board of the National Academies: 2009). Available at: http://www.trb.org/Publications/Blurbs/162822.aspx.

Wesley Cook, *Bridge Failure Rates, Consequences, and Predictive Trends* (2014), available at http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3187&context=etd.

WSDOT, *Scour Repairs*, available at https://www.wsdot.wa.gov/Bridge/Reporting/ScourRepairs.htm.

TxDOT, *Remote Bridge Scour Monitoring (1999)*, available at https://ctr.utexas.edu/wp-content/uploads/pubs/3970_1.pdf.

CASE STUDY 4.4 – ROAD WEATHER INFORMATION SYSTEM DEPLOYMENT IN IDAHO[23]

Strategy Type:	Surveillance, Monitoring and Prediction
Project Name:	Road Weather Information System Deployment (RWIS)
Project Agency:	Idaho Transportation Department (ITD)
Location:	Idaho State
Geographic Extent:	Statewide
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC)

Project Technology or Strategy

In the past few years the ITD has invested over $15 million in expanding and modernizing its RWIS network at strategic locations statewide. Non-invasive pavement sensors have been installed at nearly every site that report pavement temperature, layer type (water, ice, snow), layer thickness, and "grip" (the coefficient of friction). The current RWIS inventory statewide is 130 sites with three additional new sites under construction. ITD has developed a winter performance management program to quantify how well the maintenance crews are maintaining safe roads during and after winter storm events. The winter performance measures track the success of the road treatments, and the percentage of time the grip measurement was maintained in the safe driving range (grip >0.6) when the road surface temperature was below freezing and precipitation is present.

The deployment of RWIS using state of the art non-invasive pavement sensors together with the atmospheric sensors has advanced the capabilities of ITD maintenance crews to better plan their winter storm response, both in chemical treatment selection and application timing. The results of the winter maintenance activities are now measured through a Winter Performance Measurement Program that evaluates how well each maintenance crew is doing with regards to achieving and maintaining safe grip on the roads during and after storm events.

This case study examines how the benefits and costs of the system and the process implemented by ITD can be weighed against each other using TOPS-BC.[24] Additionally, this analysis highlights the usefulness of RWIS deployment and how it can impact highway safety. This case mainly utilizes information provided by ITD in a report published in 2014 on the effectiveness of the RWIS system in Idaho.[25] Note that due to the report's sole focus on safety benefits, this analysis mainly includes safety benefits and does not consider other benefits associated with the system.

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[23] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

[24] FHWA, Tool for Operations Benefit Cost Analysis, http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

[25] Robert Koeberlein, Dennis Jensen, Miranda Forcier (ITD): *Relationship of Winter Road Weather Monitoring to Winter Driving Crash Statistics* (2014), http://docs.trb.org/prp/15-0242.pdf.

Project Goals and Objectives

This case study analyzes the costs and benefits of RWIS deployment in Idaho using TOPS-BC. The BCA aims to achieve several goals:

1. Examine the cost-effectiveness of statewide RWIS deployment.
2. Show how TOPS-BC can be used to perform BCA of a road weather management (RWM) strategy.
3. Provide guidance on how RWIS implementations can be analyzed and evaluated.

Methodology

ITD deployed various RWIS sites over three years, from 2010 to 2013. As Table 13 displays, ITD deployed 9 RWIS sites from 2011-2012 and 24 new sites from 2012-2013. Since TOPS-BC considers one distinct set of assumptions at a time, it is run twice for this analysis, once for each of the two periods of RWIS deployment. Table 13 shows the observed reduction of 75 crashes for 2011-2012 as well as a reduction of 154 crashes for 2012-2013. Also shown in Table 14 is the estimated average value per crash of $72,700 in Idaho for both seasons, based on 674 reported crashes involving fatalities, serious injury, and property damage. Note that this average was calculated specifically for the State of Idaho. To perform this analysis in a different State or region, area-specific data must be used.

Table 13. Idaho Transportation Department road weather information system inventory by winter season.

Season	Road Weather Information System Sites Deployed	Total
2010-2011	Pre-deployment season (baseline)	0
2011-2012	9	9
2012-2013	24	33

Table 14. Idaho Transportation Department road weather information system crash reduction benefits by winter season.

Season	Crash Reduction	Value per Crash
2011-2012	75	$72,700
2012-2013	154	$72,700
Total	229	-

The benefits and costs of both seasons, 2011-2012 and 2012-2013, were evaluated by ITD using a project-specific spreadsheet tool. In this case, the benefits and costs are re-evaluated in TOPS-BC and the same results are achieved. TOPS-BC offers the ability to evaluate about 14 operations strategies and technologies using common assumptions. This allows the analyst to not only evaluate a specific project, but to compare preset alternatives. Benefits result from the number of reduced crashes multiplied by the value per crash. Costs result from the number of RWIS sites deployed in the respective year multiplied by $125,000 in installation costs for each site, and operating and maintenance costs of $5,500 per year per site. Both cost components are added up and annualized over 10 years. This calculation results in annualized costs of $162,000 for the season 2011-2012. The following section shows the cost and benefit estimation results for the Season 2011-2012 and how they were generated using TOPS-BC. Additionally, the results section briefly mentions similar benefits and costs for 2012-2013.

Costs: To use TOPS-BC for this BCA, the necessary cost components have to be established. As stated earlier, the tool can be downloaded from FHWA's website. Figure 14 shows the Opening Screen of TOPS-BC. By clicking on Estimate Life-Cycle Costs the user is redirected to a menu where he can select numerous cost sheets. Since the tool is developed in MS Excel, the user can adjust and modify the contents of all sheets within TOPS-BC. However, there are some cells in those sheets that the user cannot change.

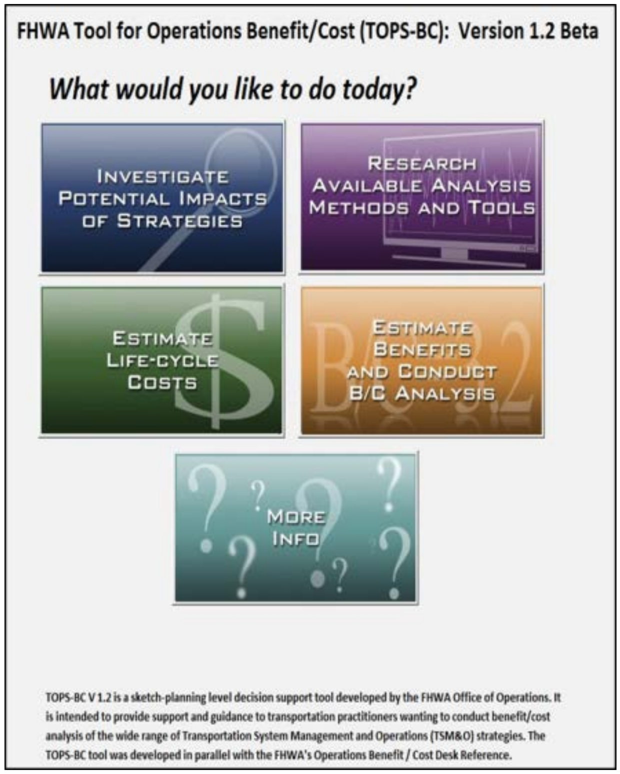

Figure 14. Screenshot. Tool for Operations Benefit/Cost opening screen.

In an RWM cost sheet within the tool, a new line was inserted for the new cost item "RWIS Site Deployment." The number of sites, capital costs, and operations and maintenance costs for both seasons were adopted from the ITD report. Figure 15 shows the cost sheet within TOPS-BC for the first season of 2011-2012. The benefits and costs methodologies are analogous for the season 2012-2013, hence not specifically displayed in this case study. The results section summarizes the outcomes of both seasons, 2011-2012 and 2012-2013. As the figure shows, the annualized costs over 10 years for Season 2011-2012 are $162,000 which matches the costs estimated by ITD. The next section explains the benefit estimation using TOPS-BC.

Incremental Deployment Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count	Unit Costs
RWIS Site Deployment	10	$ 1,125,000	$ 49,500	$ 162,000	9	Depending on RWIS	$ 125,000
TOTAL Incremental Costs		$ 1,125,000	$ 49,500	$ 162,000			

Figure 15. Screenshot. Tool for Operations Benefit/Cost cost sheet for the Idaho Transportation Department road weather information system, 2011-2012.

Benefits: The second step of the BCA is estimating benefits. TOPS-BC includes preset dollar values for various benefit calculation components. These preset parameters include different monetary values for fatalities, injuries, and property damage incidents. However, the ITD study and report used a fixed dollar amount of $72,700 in order to estimate the safety benefits of the RWIS system which represents the average cost per crash in Idaho, including fatality, injury, and property damage crashes. In TOPS-BC, the total reduction of 75 incidents for the season 2011-2012 needed to be separated into fatalities, injuries, and property damage. This separation was necessary, since TOPS-BC bases the benefit calculation on a distribution among these three types of impacts. Additionally, it is good practice to split up incidents into these three categories when using TOPS-BC, since the dollar values assigned to each impact vary substantially. This analysis adopts the standard distribution TOPS-BC uses among property damage, injuries, and fatalities, and applies it to the total reduction of 75 crashes. These factors are then utilized in the benefit calculation. This process guarantees that fatalities, injuries, and property damages are appropriately weighed for the benefit calculation. Table 15 shows the results of distributing 75 crashes in those three categories using TOPS-BC.

Table 15. Distribution of crash reduction for the Idaho Transportation Department road weather information system, 2011-2012.

Total Reduction 2011-2012	Distribution	Percent of Total	Tool for Operations Benefit/Cost Factor
Fatality Crashes	0.36	0.48	0.00088
Injury Crashes	32.85	43.80	0.07904
Property Damage	41.79	55.72	0.10055
Total	75	55.72	0.10055

Model Run Results

Finally, the analysis compares the results of the benefits calculation with the results of the cost calculations.

Figure 16 shows the sections of TOPS-BC that compare benefits and costs for the Season 2011-2012 and Season 2012-2013 respectively. Both sections indicate that RWIS site deployment in Idaho was cost effective, since the resulting benefit cost ratio (BCR) for the season of 2011-2012 is 34 to 1 and the resulting BCR for 2012-2013 is 19 to 1.

Benefit/Cost Summary		Road Weather Management Strategies
Annual Benefits		
Travel Time	$	0
Travel Time Savings: Non-Recurring Delay	$	0
Energy	$	0
Safety	$	0
Other	$	0
User Entered	$	5,452,500
Total Annual Benefits	$	5,452,500
Annual Costs	$	162,000
Benefit/Cost Comparison		
Net Benefit	$	5,290,500
Benefit Cost Ratio		33.66

Benefit/Cost Summary		Road Weather Management Strategies
Annual Benefits		
Travel Time	$	0
Travel Time Savings: Non-Recurring Delay	$	0
Energy	$	0
Safety	$	0
Other	$	0
User Entered	$	11,195,800
Total Annual Benefits	$	11,195,800
Annual Costs	$	594,000
Benefit/Cost Comparison		
Net Benefit	$	10,601,800
Benefit Cost Ratio		18.85

Figure 16. Screenshot. Benefit cost ratio for season 2011-2012 and 2012-2013.

Key Observations

This case study evaluates the deployment of Road Weather Information System sites in Idaho as an RWM BCA example. Please note that this case study merely analyzes a specific set of costs and benefits for demonstration purposes. A full benefit cost analysis will include a wide range of additional costs and benefits that are not separately listed or analyzed in this write up. TOPS-BC was used to assist with the analysis. Data assumptions from the 2014 ITD report are cited earlier. This study demonstrates that RWIS deployment costs can be recovered by the benefits of enhanced road safety and reduced crash frequency on the highways.

Reference

R. Koeberlein, D. Jensen, and M. Forcier, "Relationship of Winter Road Weather Monitoring to Winter Driving Crash Statistics," (October 24, 2014). Available at: http://docs.trb.org/prp/15-0242.pdf.

CASE STUDY 4.5 – HIGH WATER DETECTION SYSTEM IN TEXAS[26]

Strategy Type:	Surveillance, Monitoring and Prediction
Project Name:	High Water Detection System
Project Agency:	City of Dallas
Location:	Dallas, Texas
Geographic Extent:	Dallas Metropolitan Area
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC)

Project Technology or Strategy

Flash flooding is the leading cause of weather-related deaths in the United States. Roughly 200 deaths occur annually due to flash floods, and even though there can be great variability from year to year, more than half of flood-related drownings involve a vehicle. Texas usually has the most flood fatalities, with South Central Texas known as Flash Flood Alley because it represents the area most prone to this type of flooding in the State. In the entire United States, 176 persons were killed by flooding in 2015, and 112 of these fatalities (about 64 percent) involved vehicles. Forty eight of the 176 flood-related fatalities occurred in Texas, including 25 vehicle-related fatalities.

Drivers enter flooded roadways for various reasons; one of the most common is that they don't realize how deep the water is and think they can make it through. This is especially true if the water is muddy or if visibility is low, such as during adverse weather conditions or at night time. The Federal Emergency Management Agency (FEMA) has validated the following facts:

- As little as 6 inches of water will reach the bottom of most passenger cars, causing loss of control and potential stalling.
- Only 1 foot of water will float many vehicles.
- It takes only 2 feet of rushing water to carry away most vehicles, including SUVs and pickups.

In light of these circumstances, high water detection systems (HWDS) are installed in stream beds at road and stream crossing locations with a history or potential for flooding. An HWDS consists of the following generic components:

- A stand pipe installed in the stream bed or measuring device attached to the crossing structure (bridge or culvert).
- Wired or wireless communications from the measuring system to the local computer.
- Wired or wireless communications from the local computer to advanced warning signs.
- Advanced warning signs, with flashers.
- Central/Master software.
- Cellular communications from the systems to a contracted operations center.
- Internet-based communications from the contracted operations center to agency's network.

[26] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Project Goals and Objectives

In May 1995, a rain event caused widespread flooding in Dallas, Texas, resulting in seven roadway fatalities. Following this incident, the city deployed an automated system to monitor water levels at over 40 stream locations near roads and to warn motorists of high water until maintenance personnel can barricade dangerous roads. The system's main goal is to allow the public, emergency responders, TransGuide Website operators, Texas Department of Transportation (TxDOT) and other agencies, as well as the media to monitor road conditions during adverse weather events using HWDS. The system monitors water levels in stream beds and transmits the data to computers. In of the event of a flood, the computers activate flashers on warning signs along the roadway leading to the stream crossing. The computers also transmit information to traffic management centers and operations centers, and the information appears publicly on the regional website for current road conditions. Conditions are categorized as "flooded," "not flooded," or "no data available."

TxDOT staff can access detailed information regarding the status of the system, operational history, and previous water levels. These resources support the decision-making processes of agencies as to whether a roadway is flooded and maintenance crews can be dispatched to barricade flooded roads. Moreover, drivers are able to make informed decisions on whether a planned trip is safe and if they will be able to reach their destination on time.

Methodology

Costs: This analysis utilizes a cost estimate of $75,000 for initial installation of each water level detection system. This estimate is based on a report by TxDOT, and is applied to the TOPS-BC tool cost page.[27] Note that mobility costs associated with road closures regularly occur when a water level detection system indicates that such action is necessary. However, these costs are not included in this analysis.

Figure 17 shows the cost page in TOPS-BC. It includes the cost estimate of $75,000 for a single water level detection system. This figure was then applied to 40 locations, resulting in total capital costs of $3,000,000. This analysis assumes a life-cycle of 10 years for each system, as well as operations and maintenance costs of 20 percent of the annualized capital costs. The result is an annual cost estimate of $360,000. No incremental equipment is listed on the cost sheet for this analysis.

[27] FHWA, *Best Practices for Road Weather Management*, FHWA-HOP-12-046, Washington, DC: 2012, p.73. Available at: https://ops.fhwa.dot.gov/publications/fhwahop12046/.

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count		Unit Costs
Basic Infrastructure Equipment and Costs								
Urban Freeway RSE w/ wireline	10	$ 3,000,000	$ 60,000	$ 360,000	40		-	$ 75,000
TOTAL Infrastructure Cost		$ 3,000,000	$ 60,000	$ 360,000				
INPUT Enter Number of Infrastructure Deployments	1	$ 360,000						
INPUT Enter Number of Incremental Deployments	0	-						
INPUT Enter Year of Deployment	2020							
Average Annual Cost $ 360,000								

Figure 17. Screenshot. Cost estimation for the Texas high water detection system.

Benefits: For the benefit estimation, this analysis uses data from year 1995 as benchmark, in which 7 fatalities occurred in Dallas due to widespread flooding events. However, this benefit cost analysis takes a conservative approach and assumes that the flooding event of 1995 was an outlier. According to reports by the Dallas Fire Department, no such incident took place in 20 years prior to 1995.[28] In addition, this analysis assumes that the effectiveness of water level sensors is not 100 percent; the technology is not capable of preventing the assumed amount of fatalities according to the benchmark. This is why the benefits of this analysis are estimated based on the assumption that four out of seven likely fatalities can be avoided over a 20 year period due to the implementation of the HWDS network. This assumption results in a factor of 0.2. This factor was then applied to the default dollar value of a fatality avoided which is used in TOPS-BC. Figure 18 shows the benefit estimation sheet in TOPS-BC, displaying the monetary values of the safety benefits after the application of the previously mentioned factor. The value of safety benefits resulting from these assumptions is approximately $2.08 million.

$ Value of a Fatality Crash		$ 10,433,467	
$ Value of a Injury Crash		$ 77,671	
$ Value of a Property Damage Crash		$ 2,666	
Total Modeled Crash Related Benefit per Period			$ 2,086,693
User Entered Benefit (Annual $'s)			
Number of Analysis Periods per Year		1	
TOTAL AVERAGE ANNUAL BENEFIT			$ 2,086,693

Figure 18. Screenshot. Benefit estimation for the Texas high water detection system.

[28] "Flooding Rages in Texas; at Least 15 People Killed," *St. Louis Post-Dispatch*, May 7, 1995. Available at https://www.questia.com/newspaper/1P2-32936223/flooding-rages-in-texas-at-least-15-people-killed.

Model Run Results

This section summarizes the results of the BCA of the Dallas HWDS. Note that this case study merely analyzes a specific set of costs and benefits for demonstration purposes. A full benefit cost analysis will include a wide range of additional costs and benefits that are not separately listed or analyzed in this case study.

TOPS-BC displays the results and summary of benefit and cost estimations on a single sheet called *Summary of my Deployments*. Figure 19 shows the benefit/cost summary which indicates that the benefits exceed the costs of the system. Note that the analysis did not consider additional safety and other benefits associated with the system. The BCA results in net benefits of about $1.7 million for 10 years and a benefit/cost ratio of 5.8. Benefits and costs, as well as benefit cost ratios, can differ for different sets of assumptions or regions in Texas and the United States.

Benefit/Cost Summary		
Annual Benefits		**Water Level Sensors**
Travel Time	$	0
Travel Time Savings: Non-Recurring Delay	$	0
Energy	$	0
Safety	$	2,086,693
Other	$	0
User Entered	$	0
Total Annual Benefits	$	2,086,693
Annual Costs	$	360,000
Benefit/Cost Comparison		
Net Benefit	$	1,726,693
Benefit Cost Ratio		5.80

Figure 19. Screenshot. Benefit cost analysis results for the Texas high water detection system.

References

United States Department of Transportation – FHWA, "Texas DOT High Water Detection System," *Best Practices for Road Weather Management*, Version 3.0, June 2012, available at http://ops.fhwa.dot.gov/publications/fhwahop12046/fhwahop12046.pdf

Lawrence, D., *Innovations in Flood Warning: What's Happening in Dallas?* presented at the 12th Conference and Exposition of the Southwest Association of ALERT Systems, 2000.

FHWA, Best Practices for Road Weather Management, available at http://www.ops.fhwa.dot.gov/publications/fhwahop12046/fhwahop12046.pdf

"Flooding Rages in Texas; at Least 15 People Killed," available at https://www.questia.com/newspaper/1P2-32936223/flooding-rages-in-texas-at-least-15-people-killed

CHAPTER 5. CASE STUDIES FOR INFORMATION DISSEMINATION

Table 16. Case studies for information dissemination.

#	Case Name	Benefit/Cost Analysis Model	Actual or Hypothetical Case
5.1	Rural Intelligent Transportation System Deployment - Oregon's Automated Wind Warning System	Custom In-House Analysis	Actual
5.2	Salt Lake City's Traffic Operations Center Study	An Artificial Neural Network Model	Actual
5.3	Motorist Advisory and Warning using Connected Vehicles	Tool for Operations Benefit/Cost Beta Connected Vehicle	Hypothetical
5.4	Information for Freight Carriers using Connected Vehicles	Tool for Operations Benefit/Cost Beta Connected Vehicle	Hypothetical

Note: Use the hyperlinks in this table to jump directly to the case study.

CASE STUDY 5.1 – RURAL INTELLIGENT TRANSPORTATION SYSTEM DEPLOYMENT – OREGON'S AUTOMATED WIND WARNING SYSTEM[29]

Strategy Type:	Information Dissemination
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 COATS Study Area (US Route 101)
Geographic Extent:	Two Selected Regions
Tool Used:	Custom In-House Analysis

Project Technology or Strategy

To address localized high cross-wind challenges, ODOT and Caltrans have used ITS installations to alert motorists of dangerously windy conditions automatically. Such a system is known as an automated wind warning system, or 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 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").
- On the Yaquina Bay Bridge (US Route 101) between mileposts 141.27 (southbound) and 142.08 (northbound) 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 ODOT TripChek Web site. The warning messages were deactivated when wind speeds dropped below threshold levels.

[29] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

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, the ODOT ITS Unit designed and deployed the AWWS to reduce the number of road closures on US Route 101 and improve efficiency. As part of this process, ODOT performed a benefit cost analysis (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 (MOE) 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.
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 17 summarizes the objectives and MOEs proposed for this evaluation.

Table 17. Goals, objectives and measures of effectiveness for the rural California / Oregon advanced transportation systems automated wind warning system.

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

Table 17. Goals, objectives and measures of effectiveness for the rural California / Oregon advanced transportation systems automated wind warning system (continuation).

Goal	Objectives	Potential Measures of Effectiveness	Data Source
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

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.

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 18, labor and equipment cost savings were calculated using average durations of road closures for two systems—the 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 18. 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

Table 18. Labor and equipment cost savings for automated wind warning systems (continuation).

Cost Category	South Coast		Yaquina Bay Bridge	
	Per Closure	Per Year	Per Closure	Per Year
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**

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 delays 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 19, 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 19. Average delay costs per road closure (South Coast system).

Average Delay per Closure	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**

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 of 7 percent.
- 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 20.

Table 20. Benefit cost calculations for automated wind warning systems.

	South Coast		Yaquina Bay Bridge	
	Average*	High**	Average*	High**
Number of Closures per year	**5**	**10**	**30**	**30**
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	

Table 20. Benefit cost calculations for automated wind warning systems (continuation).

	South Coast		Yaquina Bay Bridge	
	Average*	High**	Average*	High**
Number of Closures per year	**5**	**10**	**30**	**30**
Benefit Cost Ratio* **				
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	

* "Average" scenario includes average number of wind events and average traffic volumes.
** "High" Scenario includes high number of wind events and high traffic volumes.
*** Benefit-cost ratio is calculated based on "average" benefits.

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 7 years for the Yaquina Bay Bridge system and 12 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 a two 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.

Reference

Kumar, Manjunathan, and Christopher Strong, *Comparative Evaluation of Automated Wind Warning Systems*, USDOT Research and Innovative Technology Administration, February 2006.

CASE STUDY 5.2 – SALT LAKE CITY'S TRAFFIC OPERATIONS CENTER STUDY[30]

Strategy Type:	Information Dissemination
Project Name:	Utah DOT's Weather Operations/ Road Weather Management Information System (RWMIS) Program
Project Agency:	Utah Department of Transportation (UDOT)
Location:	Urban Setting
Geographic Extent:	Primary Transportation Corridors
Tool Used:	An Artificial Neural Network Model (ANN)

Project Technology or Strategy

The UDOT Traffic Management Division established the weather operations component, known as the traffic operations center (TOC), featuring four staff meteorologists stationed in it providing year-round weather support for winter maintenance, road construction and rehabilitation projects, TOC operations, the Highway Avalanche Safety Program, planning, risk management, training, and incident management. With the staffed meteorologists, quality control of weather forecasts is ensured.

Weather briefings are conducted in the TOC on a daily basis, involving TOC personnel, area supervisors, and maintenance foremen. In addition, the program provides tailored crew-specific forecasts in a text format for all 82 maintenance sheds.

Project Goals and Objectives

Being a part of UDOT's Weather Operations program, TOC installations aimed to provide road and weather information with improved quality and accessibility to UDOT personnel and other stakeholders. This is expected to have a positive impact on UDOT's goals and objectives, in terms of overall safety, mobility, efficiency, productivity, environmental conservation, and customer satisfaction. As a part of the process, UDOT conducted the BCA to quantify the benefits of UDOT's TOC weather service to winter maintenance activities. Labor and materials cost (in U.S. dollars) at the maintenance shed level was considered to be a key MOE indicator.

Methodology

The project approach included surveying UDOT maintenance and construction personnel and analyzing data on labor and materials cost for winter maintenance along with other related data for the maintenance sheds in order to evaluate both the intangible and tangible benefits of the UDOT's TOC weather service to winter maintenance. The assumption is that the maintenance sheds that have more confidence in the UDOT weather service and use it more frequently might save money through better planning and proactive operations.

[30] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

By examining the labor and materials cost for winter maintenance in the 2004-2005 season for 77 UDOT sheds, this study adopted a complex data mining approach to establish the shed winter maintenance cost as a function of UDOT's TOC weather service usage, evaluation of UDOT weather service, level-of maintenance, seasonal vehicle-miles traveled, anti-icing levels, and winter severity index.[31] Once the empirical artificial neural network model (ANN model) was validated, it was used to predict the shed-level labor and materials cost of 77 UDOT sheds under three different scenarios: (1) all the sheds used non-UDOT weather service providers on a daily basis as the only source for weather information, (2) used poorer quality weather service providers than they currently use on a weekly basis, and (3) used the UDOT weather service as the primary source to a maximum level. As such, the ANN model was used to quantify the benefits of UDOT's TOC weather service to winter maintenance (in the form of cost savings). This evaluation included the benefits for only certain groups of users (specifically, central maintenance, field maintenance and construction).

Model Run Results

The case shows that having a weather meteorologist work in a TOC can increase the accuracy of local weather forecast information resulting in improved operations and cost savings benefits. The benefit cost analysis (BCA) determined that the TOC had an estimated benefit of more than $2.2 million in 2004 to 2005 from UDOT's reduced winter maintenance costs. Given that the program costs approximately $200,000 to operate, the result translates into a benefit cost ratio of over 10:1. The BCA results highlight the potential benefits that may be realized by an agency expanding the TOC installations and using improved weather information to direct its winter maintenance activities.

Key Observations

The BCA sought to quantify the benefits and costs of weather information by focusing on a case study of Utah DOT's TOC deployments. Using an artificial neural network approach, it is estimated that the benefit cost ratio associated with the program is over 10:1, based simply on the labor and materials cost savings associated with winter maintenance.

As this research did not include the full extent of the range of costs and benefits resulting from this program, there are limitations to these findings. The true benefit cost ratio of the program may be higher, for there are other program users whose economic benefits were not considered as a part of this study.

Reference

Xianming Shi, Katie O'Keefe, Shaowei Wang, Christopher Strong, *Evaluation of Utah Department of Transportation's Weather Operations/RWMIS Program: Phase I*, The Western Transportation Institute for the Utah DOT, February 2007.

[31] This study adapted a multiplayer feed-forward artificial neural network (ANN) paradigm to assess the large amounts of data collected and to associate it with impact of deployment on shed operating costs. More information on this system can be found in the referenced report at the end of this Case.

CASE STUDY 5.3 – MOTORIST ADVISORY AND WARNING (CONNECTED VEHICLE APPLICATION)[32]

Strategy Type:	Information Dissemination
Project Name:	Motorist Advisory and Warning using Connected Vehicles (CV)
Project Agency:	Hypothetical Agency
Location:	Hypothetical State
Geographic Extent:	Statewide
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC) Beta CV

Project Technology or Strategy

The Road Weather Motorist Advisory and Warning application provides the capability of collecting road weather data from connected vehicles and using that data to develop short-term warnings or advisories that can be provided to individual motorists. The information may come from either vehicles operated by the general public and commercial or specialty vehicles and public fleet vehicles. The raw data will be processed in a traffic management or control center to generate segment-based traffic and road condition information. The processing will also include road weather motorist alert algorithms to generate appropriate short, medium and long-term messages that will be pushed to traveler information systems and made available to the public and other users of information.[33]

Project Goals and Objectives

Road-weather connected vehicle data will support advanced warning on deteriorating traffic and road weather conditions on specific roadway segments to travelers before and during their trips. By utilizing these data, roadway users will be readily informed about adverse weather conditions along their route and can react in time, either by not making the trip or adjusting their travel plans and driving behavior.

Methodology

Costs: We used the information from the 2013 *Road Weather Management Connected Vehicle Applications* report[34] to perform a benefit cost analysis (BCA) on the Motorist Advisory and Warning application. Based on this data, new cost line items were added to the existing cost sheet within TOPS-BC.[35] Figure 20 shows the different cost items that were added. The illustration is taken from a spreadsheet within TOPS-BC that calculates the costs of specific CV strategies. Basic Infrastructure refers to the required common infrastructure investments to

[32] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

[33] Connected Vehicle Reference Implementation Architecture, *Enhanced Maintenance Decision Support System*.

[34] FHWA, *Road Weather Management Connected Vehicle Applications*, available at http://ntl.bts.gov/lib/54000/54400/54480/Road_Weather_Connected_Vehicle_Applications_Benefit-508-v8.pdf.

[35] FHWA, *Tool for Operations Benefit/Cost Analysis*, available at http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

support multiple CV transportation systems management and operations (TSMO) projects while the Incremental Deployment section includes cost items that are application-specific. The Basic Infrastructure and Incremental Deployment sections include estimated annualized costs, operations and maintenance costs, item-specific counts and the user-selected quantities used in this analysis.

Since the case study CV deployments, including motorist advisory and warning, are assumed to take place in a hypothetical State, the distinction between necessary basic CV infrastructure investments and incremental/strategy-specific deployments needs to be clear. For the purpose of this analysis, each CV deployment BCA assumes that the respective State or metropolitan planning organization needs to acquire both basic infrastructure and incremental/ strategy specific infrastructure. However, since the basic deployment investment supports many projects and strategies, only a portion of the total basic infrastructure cost is assigned to a specific CV technology. The percentage assumes that a set of CV technologies are deployed and the specific technology’s basic infrastructure cost equals that technology’s share of expected benefits in the set of deployed technologies. This cost assignment would vary depending on the full set of CV technologies deployed and supported by the basic infrastructure investment. For the motorist advisory and warning case study, the assumed percentage of total basic infrastructure costs is 26 percent.

The CV BCA report focused on the entire United States, so for the individual CV case studies in this compendium the hypothetical State is assumed to have 2 percent (1 of 50 States) of the total U.S. population. The basic infrastructure quantities used in the analysis were derived from that assumption and are shown in Figure 20. When the new cost items are entered into TOPS-BC, the CV BCA report is used to identify which cost elements are needed to perform the appropriate cost analysis. If users want to analyze a specific Connected Vehicle Application deployment strategy, the table allows for a quick identification of the cost items needed.

This CV application, Motorist Advisory and Warning, has several basic infrastructure cost items that need to be taken into consideration when conducting a BCA. The following cost items were considered for this analysis, and are also listed in Figure 20:

- Urban freeway roadside equipment (wireline & wireless).
- Urban signal roadside equipment (wireline & wireless).
- Rural interstate equipment (with & without power grid connection).
- Application development.
- System integration and Back Office costs.
- On-board equipment on agency vehicles.

Figure 20 shows the cost sheet within TOPS-BC for this application. In addition to the basic infrastructure costs listed above, the figure also shows quantities and dollar values for a cost item specific for the education and outreach strategy.

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count	Unit Costs
Basic Infrastructure Equipment and Costs							
Urban Freeway RSE w/ wireline	**25**	$ 230,400	$ 5,760	$ 14,976	**24**	**1 per Mile**	$ 9,600
Urban Freeway RSE wireless	**25**	$ 1,948,800	$ 48,720	$ 126,672	**96**	**1 per Mile**	$ 20,300
Urban Signal RSE w/ wireline	**25**	$ 2,331,600	$ 58,290	$ 151,554	**201**	**2/3 of signals**	$ 11,600
Urban Signal RSE wireless	**25**	$ 17,951,500	$ 448,788	$ 1,166,848	**805**	**2/3 of signals**	$ 22,300
Rural Interstate w/ powergrid connection	**25**	$ 7,647,300	$ 191,183	$ 497,075	**261**	**1 per 2 Miles**	$ 29,300
Rural Interstate w/o powergrid connection	**25**	$ 2,411,500	$ 60,288	$ 156,748	**65**	**1 per 2 Miles**	$ 37,100
Application Development Costs	1	$ 191,746	$ -	$ 191,746	**1**	**1 per Application**	$ 191,746
System Integration & Backoffice	35	$ 25,886	$ 3,835	$ 4,575	**1**	**1 per Application per TMC**	$ 25,886
Vehicle On-Board Equipment	1	$ 4,800,000	$ 288,000	$ 5,088,000	**48,000**	**1 per Vehicle**	$ 100
TOTAL Infrastructure Cost		$ 37,538,732	$ 1,104,862	$ 7,398,192			
Incremental Deployment Equipment - Please See Chart on the Right for Application-Specific Information							
Vehicle Data Translator (This Item is RWM-specific only)	25	$ -	$ -	$ -		**1 per TMC**	$ 1,000,000
Maintenance Vehicle Costs	5	$ -	$ -	$ -		**1 per Maintenance Vehicle**	$ 30,000
Dynamic Message Sign	10	$ -	$ -	$ -		***VSL ONLY***	$ 82,000
Education & Outreach	1	$ 288,000	$ -	$ 288,000	**6,400,000**	**1 per capita**	$ 0.045
TOTAL Incremental Cost		$ 288,000	$ -	$ 288,000			
INPUT Enter Number of Infrastructure Deployments	1	$ **1,923,530**					
INPUT Enter Number of Incremental Deployments	1	$ **288,000**					
INPUT Enter Year of Deployment	2020						
Average Annual Cost $ 2,211,530							

Figure 20. Screenshot. Annualized costs for motorist advisories and warnings.

Education and outreach are necessary to inform the public about the implementation of the strategy. It is calculated on a per capita-basis, which means a cost occurs for every individual in the service area. Since the hypothetical State is assumed to have 2 percent of the U.S. population, this analysis uses the value of 6.4 million inhabitants, assuming that the U.S. population is 320 million.

Finally, the number of infrastructure and incremental deployments was set to 1 each, because the extent of the roadway structure for the entire CV system and for this strategy in particular is already considered in the quantities shown in each cost line. The system is assumed to be operational in 2020. As Figure 20 shows, these assumptions result in average annual costs of about $2.21 million.

Benefits: In order to estimate the benefits of this strategy, we utilized data from the CV BCA report[36] which estimates the effectiveness of this strategy to be 20 percent (i.e., crashes are likely to be reduced by 20 percent when the strategy is in place). Alongside this assumption is the assumed increase in capacity due to a lower amount of incidents that slow down traffic. The report set this number to 10 percent for all applications.

Furthermore, crashes include three different types of incidents: property damage only, injury, and fatality. Since TOPS-BC calculates the number of each of these types of incidents for all weather conditions and not just for adverse weather conditions, these values needed to be adjusted. For the purpose of this analysis, and based on the CV BCA report, we assume that 24 percent of incidents are related to adverse weather conditions. Hence this analysis applies to 24 percent of property damage only, injury, and fatality incidents.

[36] FHWA, *Road Weather Management Connected Vehicle Applications*, available at http://ntl.bts.gov/lib/54000/54400/54480/Road_Weather_Connected_Vehicle_Applications_Benefit-508-v8.pdf.

Figure 21 shows the CV benefit sheet within the tool. The adjusted values for property damage only, injury and fatality were entered into the green cells in the Facility Performance section of the tool. The green cells can be changed by the user and override the default values used by TOPS-BC. The capacity increase and crash reduction assumptions were implemented below the section Impacts due to Strategy. These values were also entered in the green cells, since TOPS-BC regularly does not consider any changes in capacity and uses a different crash reduction rate. For this reason, the given data within the tools were overridden. These data could come from travel demand models, freeway simulations, counts or other sources. Note that other agency benefits—for example, benefits from reduced maintenance costs due to the Motorist Advisory and Warning—are not reflected in the benefit estimation. Analysts are encouraged to independently calculate such benefits and add them into the TOPS-BC estimates.

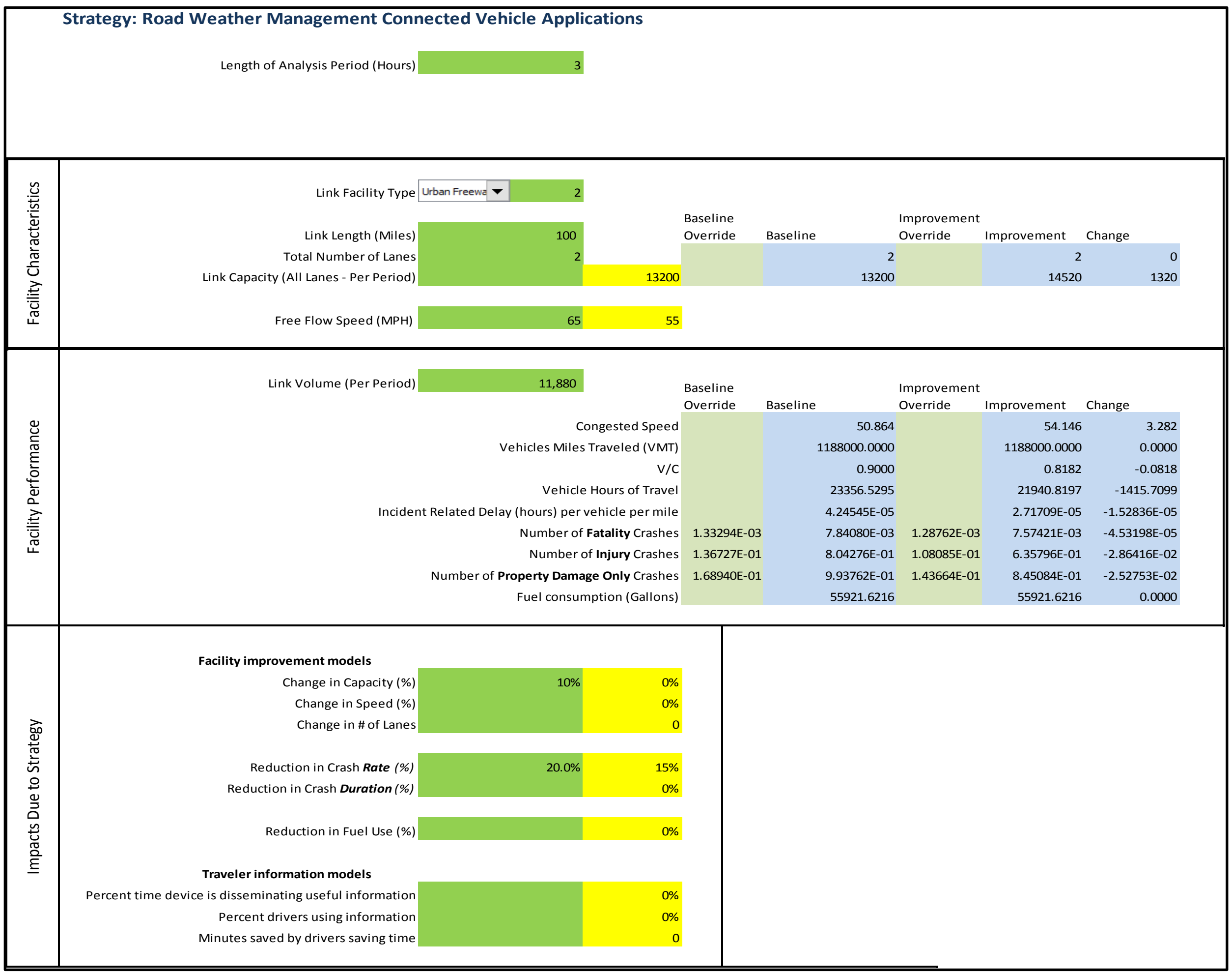

Figure 21. Screenshot. Benefit estimation assumptions for motorist advisory and warning system.

Finally, Figure 22 shows the lower half of the CV benefit estimation page. It includes additional sections on travel time, energy and other safety benefits. The user is able to refine any TOPS-BC calculation using these sections in case more specific data is at hand. Through this flexible user interface, the user can generate refined and more accurate results. The total average annual benefit is calculated automatically by TOPS-BC and can be found the bottom of the benefit estimation sheet. The total average annual benefit for this application is $13.32 million.

Travel Time	Average Person Hours of Travel Saved per Period		2364.2355
	$ Value of Person Hour (per hour) "On-the-Clock" Auto	$ 32.46	
	$ Value of Person Hour (per hour) Other Auto	$ 16.23	
	$ Value of Vehicle Hour (per hour) Truck	$ 32.46	
	Total Recurring Travel Time Benefit per Period		$ 49,882.46
ATIS Time Savings	Total hours saved due to ATIS deployments		0.00
Travel Time Savings: Non-Recurring Delay	Average Total Person Hours of Non-Recurring Delay Saved per Period		30.3221
	alue of Person Hour (per hour of ***Delay***) "On-the-Clock" Auto	$ 32.46	
	$ Value of Person Hour (per hour of ***Delay***) Other Auto	$ 16.23	
	$ Value of Vehicle Hour (per hour of ***Delay***) Truck	$ 32.46	
	Total Non-Recurring Delay Benefit per Period		$ 639.76
Energy	Average cost per gallon of fuel (excluding taxes)	$ 4.25	
	Total Fuel Savings Benefit		$ -
Safety	$ Value of a Fatality Crash	$ 10,433,467	
	$ Value of a Injury Crash	$ 77,671	
	$ Value of a Property Damage Crash	$ 2,666	
	Total Modeled Crash Related Benefit per Period		$ 2,765
	User Entered Benefit (Annual $'s)		
	Number of Analysis Periods per Year	250	
	TOTAL AVERAGE ANNUAL BENEFIT		$ 13,321,771

Figure 22. Screenshot. Benefit estimation results for motorist advisory and warning system.

Model Run Results

Finally, the analysis compares the results of the benefits calculation with the results of the cost calculations. This case study merely analyzes a specific set of costs and benefits for demonstration purposes. A full benefit cost analysis will include a wide range of additional costs and benefits that are not separately listed or analyzed in this case study; for example, vehicle operating cost reductions and an increased feeling of safety for roadway users.

Figure 23 shows the section of TOPS-BC that compares benefits and costs for the connected vehicle strategy motorist advisory and warning. The illustration indicates that the deployment of a motorist advisory and warning system in a hypothetical State considering the underlying assumptions is cost effective, since the resulting BCR for the strategy is 6.02. The resulting net benefits for this analysis are about $11.1 million.

Benefit/Cost Summary		
Annual Benefits		**CV Motorist Advisories and Warnings**
Travel Time	$	12,470,615
Travel Time Savings: Non-Recurring Delay	$	159,940
Energy	$	0
Safety	$	691,250
Other	$	0
User Entered	$	
Total Annual Benefits	**$**	13,321,771
Annual Costs	**$**	2,211,530
Benefit/Cost Comparison		
Net Benefit	**$**	11,110,241
Benefit Cost Ratio		6.02

Figure 23. Screenshot. Results for connected vehicle motorist advisory and warning system.

CASE STUDY 5.4 – INFORMATION FOR FREIGHT CARRIERS (CONNECTED VEHICLE APPLICATION)[37]

Strategy Type:	Information Dissemination
Project Name:	Information for Freight Carriers using Connected Vehicles (CV)
Project Agency:	Hypothetical Agency
Location:	Hypothetical State
Geographic Extent:	Statewide
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC) Beta CV

Project Technology or Strategy

The road weather information for freight carriers application is a special case of the road weather advisory and warning for motorists that is focused on freight carriers. This application provides the capability to collect road weather data from connected vehicles and use that data to develop short-term warnings or advisories that can be provided to individual commercial vehicles or to commercial vehicle dispatchers. The information may come from either vehicles operated by the general public, commercial entities, or specialty vehicles and public fleet vehicles. The raw data will be processed in a traffic management or control center to generate segment-based traffic and road weather information for truck drivers. The processing will also include a road weather commercial vehicle alerts algorithm to generate messages that will be pushed to traveler information systems and made available to commercial vehicle drivers and dispatchers.[38]

Project Goals and Objectives

Road-weather connected vehicle data will provide information on deteriorating traffic and road weather conditions on specific highway segments to both truck drivers and their dispatchers. This information can be used to improve scheduling decisions and parking availability and delivery schedules. Likely outcomes are a reduced number of crashes and unplanned delays, as well as higher reliability of delivery times.

Methodology

Costs: We used the information from the 2013 *Road Weather Management Connected Vehicle Applications* report[39] to perform a benefit cost analysis (BCA) for the information for freight carriers application. Based on this data, new cost line items were added to the existing cost sheet within TOPS-BC.[40]

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[37] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

[38] Connected Vehicle Reference Implementation Architecture, *Enhanced Maintenance Decision Support System*.

[39] FHWA, *Road Weather Management Connected Vehicle Applications*, available at http://ntl.bts.gov/lib/54000/54400/54480/Road_Weather_Connected_Vehicle_Applications_Benefit-508-v8.pdf.

[40] FHWA, *Tool for Operations Benefit/Cost Analysis*, available at http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

Figure 24 shows the different cost items that were added. The illustration is taken from a spreadsheet within TOPS-BC that calculates the costs of specific CV strategies. Basic Infrastructure refers to the required common infrastructure investments to support multiple CV transportation systems management and operations (TSMO) projects while the Incremental Deployment section includes cost items that are application-specific. The Basic Infrastructure and Incremental Deployment sections include estimated annualized costs, operations and maintenance costs, item-specific counts and the user-selected quantities used in this analysis.

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count	Unit Costs
Basic Infrastructure Equipment and Costs							
Urban Freeway RSE w/ wireline	**25**	$ 230,400	$ 5,760	$ 14,976	**24**	**1 per Mile**	$ 9,600
Urban Freeway RSE wireless	**25**	$ 1,948,800	$ 48,720	$ 126,672	**96**	**1 per Mile**	$ 20,300
Urban Signal RSE w/ wireline	**25**	$ 2,331,600	$ 58,290	$ 151,554	**201**	**2/3 of signals**	$ 11,600
Urban Signal RSE wireless	**25**	$ 17,951,500	$ 448,788	$ 1,166,848	**805**	**2/3 of signals**	$ 22,300
Rural Interstate w/ powergrid connection	**25**	$ 7,647,300	$ 191,183	$ 497,075	**261**	**1 per 2 Miles**	$ 29,300
Rural Interstate w/o powergrid connection	**25**	$ 2,411,500	$ 60,288	$ 156,748	**65**	**1 per 2 Miles**	$ 37,100
Application Development Costs	1	$ 191,746	$ -	$ 191,746	**1**	**1 per Application**	$ 191,746
System Integration & Backoffice	35	$ 25,886	$ 3,835	$ 4,575	**1**	**1 per Application per TMC**	$ 25,886
Vehicle On-Board Equipment	1	$ 4,800,000	$ 288,000	$ 5,088,000	**48,000**	**1 per Vehicle**	$ 100
TOTAL Infrastructure Cost		$ 37,538,732	$ 1,104,862	$ 7,398,192			
Incremental Deployment Equipment - Please See Chart on the Right for Application-Specific Information							
Vehicle Data Translator (This Item is RWM-specific only)	25	$ -	$ -	$ -		**1 per TMC**	$ 1,000,000
Maintenance Vehicle Costs	5	$ -	$ -	$ -		**1 per Maintenance Vehicle**	$ 30,000
Dynamic Message Sign	10	$ -	$ -	$ -		***VSL ONLY***	$ 82,000
Education & Outreach	1	$ -	$ -	$ -		**1 per capita**	$ 0.045
TOTAL Incremental Cost		$ -	$ -	$ -			
INPUT Enter Number of Infrastructure Deployments	1	**$ 1,109,729**					
INPUT Enter Number of Incremental Deployments	1	$ -					
INPUT Enter Year of Deployment	2020						
Average Annual Cost $ 1,109,729							

Figure 24. Screenshot. Annualized costs for information for freight carriers.

Since the case study CV deployments, including Information for Freight Carriers, are assumed to take place in a hypothetical State, the distinction between necessary basic CV infrastructure investments and incremental/strategy-specific deployments needs to be clear. For the purpose of this analysis, each CV deployment BCA assumes that the respective State or metropolitan planning organization (MPO) needs to acquire both basic infrastructure and incremental/ strategy specific infrastructure. However, since the basic deployment investment supports many projects and strategies, only a portion of the total basic infrastructure cost is assigned to a specific CV technology. The percentage assumes that a set of CV technologies are deployed and the specific technology's basic infrastructure cost equals that technology's share of expected benefits in the set of deployed technologies. This cost assignment would vary depending on the full set of CV technologies deployed and supported by the basic infrastructure investment. For the Information for Freight Carriers case study, the assumed percentage of total basic infrastructure costs is 26 percent.

The CV BCA report focused on the entire United States, so for the individual CV case studies in this compendium the hypothetical State is assumed to have 2 percent (1 of 50 States) of the total U.S. population. The basic infrastructure quantities used in the analysis were derived from that assumption and are shown in Figure 24. When the new cost items are entered into TOPS-BC, the CV BCA report is used to identify which cost elements are needed to perform the appropriate cost analysis. If users want to analyze a specific Connected Vehicle Application deployment strategy, the table allows for a quick identification of the cost items needed.

As displayed in Figure 24, this application has several basic cost items that need to be taken into consideration when conducting a BCA. The cost items listed below were considered for this analysis:

- Urban freeway roadside equipment (wireline & wireless).
- Urban signal roadside equipment (wireline & wireless).
- Rural interstate equipment (with & without power grid connection).
- Application development.
- System integration and back office costs.
- On-board equipment.

Since these cost items are needed for all CV applications, they are discussed in other case studies in this compendium. This CV strategy does not require any other incremental cost items. In order to implement CV Information for Freight Carriers, it is sufficient for the agency to implement basic CV. Figure 24 shows the total annualized costs resulting from the TOPS-BC calculations.

Finally, the number of infrastructure and incremental deployments was set to 1 each, because the extent of the roadway structure for the entire CV system and for this strategy in particular is already considered in the quantities shown in each cost line. The project is assumed to be in place in 2020. As Figure 24 shows, these assumptions result in annualized incremental costs of about $1.1 million.

Benefits: In order to estimate the benefits of this strategy, we utilized the data from the CV BCA report which estimates the effectiveness of this strategy to be 7 percent. This means that crashes are likely to be reduced by 7 percent when the strategy is in place. Alongside this assumption is the assumed increase in capacity due to a lower amount of incidents that slow down traffic. The report set this number to 10 percent for all applications.

Furthermore, this analysis makes use of the parameters sheet in TOPS-BC. Using this sheet, the user is able to modify certain preset parameters that influence the calculation of benefits and costs. One of these parameters is the percentage of different vehicles present in traffic mix.

Figure 25 shows the parameters page within the tool. Note that the orange cells represent the percentage of trucks in the traffic mix. For this analysis, this percentage was set to 100 percent, since trucks are the primary beneficiary of this strategy. This change in the parameter page will result in TOPS-BC calculating and displaying truck related benefits only.

Benefit Estimation Parameters

General Parameters

Year of Dollars Displayed	
Year of Dollar Display	2016
Inflation Rate	3%
Adjustment Factor	1.19
Annualization Factor	
Number of Periods per Year	250
Net Present Value Calculation	
Default Time Horizon (Years)	20
Traffic Mix	
Percentage Trucks	100%
Percentage "On-the-Clock" Travel Purpose (A	20%
Average Auto Occupancy	1.67
Discount Rate	
Discount Rate (for 20 year analysis)	7.0%

Benefit Valuations

Recurring Travel Time (per hour)	
"On the Clock" Travel Time	$ 33.43
Other Auto Travel Time	$ 16.72
Truck Travel Time	$ 33.43
Non-Recurring Travel Time (per hour)	
"On the Clock" Travel Time	$ 33.43
Other Auto Travel Time	$ 16.72
Truck Travel Time	$ 33.43
Crashes (per occurrence)	
Fatality	$ 10,746,471
Injury	$ 80,002
Property Damage Only (PDO)	$ 2,746
Fuel Use	
Per Gallon (Excluding Taxes)	$ 4.38
Non-fuel Operating Costs (per VMT)	

Speed/Flow Relationships

	V/C Ratio	I 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

Figure 25. Screenshot. Tool for Operations Benefit/Cost parameters sheet modification for information for freight carriers.

Additionally, crashes include three different types of incidents: property damage only, injury, and fatality. Since TOPS-BC calculates the number of each of these types of incidents for all weather conditions and not just for adverse weather conditions, these values needed to be adjusted. For the purpose of this analysis, and based on the CV BCA report, it is assumed that 24 percent of incidents are related to adverse weather conditions. Hence this analysis applies to 24 percent of property damage only, injury, and fatality incidents. Furthermore, since trucks make up a lower share within the traffic mix than cars do, the amount of vehicle-miles-traveled (VMT) used for the calculation was adjusted. This analysis assumes that trucks only make up 1/3 of all VMT, which is why the amount of VMT calculated by TOPS-BC was overridden in the green cells.

Figure 26 shows the CV benefit sheet within the tool. The adjusted values for property damage only, injury, and fatality were entered into the green cells in the Facility Performance section of the tool. The green cells can be changed by the user and override the default values used by TOPS-BC. The capacity increase and crash reduction assumptions were implemented below the section Impacts due to Strategy. These values were also entered in the green cells, since TOPS-BC regularly does not consider any changes in capacity and uses a different crash reduction rate. For this reason, the given data within the tools were overridden. These data could come from travel demand models, freeway simulations, counts or other sources. Note that other agency benefits, such as benefits from reduced maintenance costs due to the Information for Freight Carriers are not reflected in the benefit estimation. Analysts are encouraged to independently calculate such benefits and add them into the TOPS-BC estimates.

Strategy: Road Weather Management Connected Vehicle Applications

Length of Analysis Period (Hours)	3	

Facility Characteristics

			Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Facility Type	Urban Freewa 2						
Link Length (Miles)	100						
Total Number of Lanes	2			2		2	0
Link Capacity (All Lanes - Per Period)		13200		13200		14520	1320
Free Flow Speed (MPH)	65	55					

Facility Performance

Link Volume (Per Period)	11,880		

	Baseline Override	Baseline	Improvement Override	Improvement	Change
Congested Speed		50.864		54.146	3.282
Vehicles Miles Traveled (VMT)	396000.0000	1188000.0000	396000.0000	1188000.0000	0.0000
V/C		0.9000		0.8182	-0.0818
Vehicle Hours of Travel		7785.5098		7313.6066	-471.9033
Incident Related Delay (hours) per vehicle per mile		4.24545E-05		2.71709E-05	-1.52836E-05
Number of **Fatality** Crashes	4.44312E-04	2.61360E-03	4.29205E-04	2.52474E-03	-1.51066E-05
Number of **Injury** Crashes	4.55756E-02	2.68092E-01	3.60285E-02	2.11932E-01	-9.54719E-03
Number of **Property Damage Only** Crashes	5.63132E-02	3.31254E-01	4.78881E-02	2.81695E-01	-8.42510E-03
Fuel consumption (Gallons)		21405.4054		21405.4054	0.0000

Impacts Due to Strategy

Facility improvement models		
Change in Capacity (%)	10%	0%
Change in Speed (%)		0%
Change in # of Lanes		0
Reduction in Crash ***Rate*** (%)	20.0%	15%
Reduction in Crash ***Duration*** (%)		0%
Reduction in Fuel Use (%)		0%
Traveler information models		
Percent time device is disseminating useful information		0%
Percent drivers using information		0%
Minutes saved by drivers saving time		0

Figure 26. Screenshot. Benefit estimation assumptions for information for freight carriers.

Finally, Figure 27 shows the lower half of the CV benefit estimation page. It includes additional sections on travel time, energy, and other safety benefits. The user is able to refine any TOPS-BC calculation using these sections in case more specific data is at hand. Through this flexible user interface, the user can generate refined and more accurate results. The total average annual benefit is calculated automatically by TOPS-BC and can be found the bottom of the benefit estimation sheet. The total average annual benefit for this application is $7.76 million.

Travel Time	Average Person Hours of Travel Saved per Period		788.0785
	$ Value of Person Hour (per hour) "On-the-Clock" Auto	$ 33.43	
	$ Value of Person Hour (per hour) Other Auto	$ 16.72	
	$ Value of Vehicle Hour (per hour) Truck	$ 33.43	
	Total Recurring Travel Time Benefit per Period		$ 28,983.05
ATIS Time Savings	Total hours saved due to ATIS deployments		0.00
Travel Time Savings: Non-Recurring Delay	Average Total Person Hours of Non-Recurring Delay Saved per Period		30.3221
	alue of Person Hour (per hour of ***Delay***) "On-the-Clock" Auto	$ 33.43	
	$ Value of Person Hour (per hour of ***Delay***) Other Auto	$ 16.72	
	$ Value of Vehicle Hour (per hour of ***Delay***) Truck	$ 33.43	
	Total Non-Recurring Delay Benefit per Period		$ 1,115.15
Energy	Average cost per gallon of fuel (excluding taxes)	$ 4.38	
	Total Fuel Savings Benefit		$ -
Safety	$ Value of a Fatality Crash	$ 10,746,471	
	$ Value of a Injury Crash	$ 80,002	
	$ Value of a Property Damage Crash	$ 2,746	
	Total Modeled Crash Related Benefit per Period		$ 949
	User Entered Benefit (Annual $'s)		
	Number of Analysis Periods per Year	250	
	TOTAL AVERAGE ANNUAL BENEFIT		$ 7,761,869

Figure 27. Screenshot. Benefit estimation results for information for freight carriers.

Model Run Results

In this section, the analysis compares the results of the benefits calculation with the results of the cost calculations. Note that this case study merely analyzes a specific set of costs and benefits for demonstration purposes. A full benefit cost analysis will include a wide range of additional costs and benefits that are not separately listed or analyzed in this case study.

Figure 28 shows the section of TOPS-BC that compares benefits and costs for the connected vehicle strategy "CV Information for Freight Carriers." The illustration indicates that the deployment of an information system for freight carriers in the hypothetical State is cost effective, since the resulting BCR for the strategy is almost 7. The resulting net benefits for this analysis are about $6.65 million.

Benefit/Cost Summary		
Annual Benefits		**CV Information for Freight Carriers**
Travel Time	$	7,245,763
Travel Time Savings: Non-Recurring Delay	$	278,788
Energy	$	0
Safety	$	237,250
Other	$	0
User Entered	$	
Total Annual Benefits	**$**	7,761,869
Annual Costs	**$**	1,109,729
Benefit/Cost Comparison		
Net Benefit	**$**	6,652,140
Benefit Cost Ratio		6.99

Figure 28. Screenshot. Results for the Connected Vehicle Information for Freight Carriers strategy.

CHAPTER 6. CASE STUDIES FOR DECISION SUPPORT, CONTROL, AND TREATMENT

Table 21. Case studies for decision support, control, and treatment.

#	Case Name	BCA Model	Actual or Hypothetical Case
6.1	Minnesota Department of Transportation Gate Operations	Custom In-House Analysis	Actual
6.2	Hypothetical Road Closure Feasibility	Tool for Operations Benefit/Cost	Hypothetical
6.3	Hypothetical Freeway Systems: Dynamic Traffic Signal (DTS) Control Systems Deployment and Feasibility	Tool for Operations Benefit/Cost	Actual
6.4	Weather Responsive Signal Timing using Connected Vehicles	Tool for Operations Benefit/Cost Beta Connected Vehicle	Hypothetical
6.5	Road Condition Reporting Application	Tool for Operations Benefit/Cost	Actual
6.6	Weather Responsive Active Traffic Management System in Oregon	Tool for Operations Benefit/Cost	Actual
6.7	Variable Speed Limit (VSL) using Connected Vehicles	Tool for Operations Benefit/Cost Beta Connected Vehicle	Hypothetical

Note: Use the hyperlinks in this table to jump directly to the case study.

CASE STUDY 6.1 – MINNESOTA DEPARTMENT OF TRANSPORTATION GATE OPERATIONS[41]

Strategy Type:	Decision Support, Control & Treatment
Project Name:	The Minnesota Department of Transportation (MNDOT) Freeway Gate Closure System
Project Agency:	MNDOT
Location:	Urban Freeway
Geographic Extent:	Interstate 90, Minnesota
Tool Used:	Custom In-House Analysis

Project Technology or Strategy

MNDOT developed an operational procedure known as the freeway gate closure system for directing traffic off Interstates and prohibiting access during unsafe driving conditions such as severe snowstorms and major incidents. This procedure involves using gates both on the mainline to direct traffic off an Interstate and at entrance ramps to block traffic accessing an Interstate. While using gates is a relatively new technique for closing roadways to travel in Minnesota, neighboring States such as North and South Dakota have used gates for a number of years.

During severe snowstorms and major incidents, mainline gates divert traffic from highways, and gates located on entrance ramps prohibit highway access. Generally, MNDOT personnel report to gate locations and activate warning signs with amber lights. Gate arms are then swung or lowered into place and gate arm lights are illuminated. Once gate arms are deployed, law enforcement personnel man gate locations for 1–2 hours. MNDOT's practice includes closing the Interstate to all traffic and prohibiting access to the Interstate when towns ahead cannot accommodate additional stranded vehicles.

Project Goals and Objectives

During a 1998 snow storm, MNDOT reduced roadway clearance costs by 18 percent on I-90 by activating a freeway gate closure system to limit vehicle interference and reduce snow compaction problems that increase work for plows.

Between March and August 1999, MNDOT's Office of Advanced Transportation Systems (OATS) conducted a BCA that compared potential savings to estimated costs to document past procedures and to identify current operational issues associated with gate systems.

Gates were first used in Minnesota on Interstate 94 during the winter of 1996/97 and today 65 gates are used in three of MNDOT's eight Districts. In MNDOT District 4, 22 gates are used on portions of Interstate 94 and Highways 10 & 210, and in Districts 6 & 7, 43 gates are used on portions of Interstate I-90.

[41] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

As the use of gates has spread in Minnesota, MNDOT has become increasingly interested in documenting the experience to date with the gates and identifying any opportunities to enhance gate operations, particularly through the utilization of intelligent transportation systems (ITS). As a result, MNDOT undertook this study to document past experience, identify issues and to recommend enhancements to the current operations. MNDOT hired the consulting firm of BRWM, Inc. to assist with the study that was conducted between March and August 1999. In order to provide comparable benefits and costs within the analysis, MNDOT carefully selected key MOEs to fully capture the benefits of the program. These measures included:

- Travel time.
- Safety.
- Costs (deployment costs and operations and maintenance costs).

Methodology

This benefit-cost analysis (BCA) for the proposed gate use on I-90 focuses on the cost of deployment along with the associated benefits due to savings in delays and reductions in accidents. The annual frequency of snow- and ice- related accidents and hourly volume data were used in the analysis. Total system costs were calculated assuming deployment costs of $159,700 plus 5 percent operations and maintenance costs over 10 years.

Costs - Travel Delay Associated Costs. Table 22 presents the average delay and associated costs each year due to the closure of I-90 in MNDOT District 7. The analysis assumes one closure per year for a period of 3 hours affecting a percentage of average annual daily traffic (AADT). The AADT was calculated to be 8,000 (6,900 for passenger vehicles and 1,100 for heavy trucks) using values along I-90 from the 1994 MNDOT District 7 Trunk Highway Traffic Volume Map.

Table 22. Average annual delay and associated costs due to closure of I-90.

	High Volume Scenario	Low Volume Scenario
Passenger Vehicles		
Average Number Delayed per Closure [a]	1,258	557
Average Value of Time per Hour [b]	$ 11.90	$ 11.90
Average Annual Cost [c]	$ 44,911.00	$ 19,885.00
Heavy Trucks		
Average Number Delayed per Closure[a]	550	275
Average Value of Time per Hour [b]	$ 20.00	$ 20.00
Average Annual Cost [c]	$ 33,000.00	$ 16,500.00
Average Annual Cost of Delay	$ 77,911.00	$ 36,385.00

[a] Assumes one closure per year affecting 18 and 8 percent of trucks and 8 and 4 percent of cars for the high and low volume scenarios, respectively.

[b] The values of time per hour were derived from the default values of MicroBENCOST, microcomputer based model developed by the Texas Transportation Institute at Texas A&M University. The default values were updated using the CPI. The value of time for heavy trucks is an average of values for different truck types.

[c] The average annual cost is calculated assuming a 3-hour delay.

Benefit - Travel Delay Cost Savings: Hourly distributions were obtained from automatic traffic recorder (ATR) data for 1994, Station 227 E&W, located east of Alden in Freeborn County. The high-volume scenario assumes the closure occurs during the highest volume 3 hours of the day, from 3 p.m. to 6 p.m. with 22.6 percent of AADT. This calculates to 1,808 total vehicles delayed, with 550 assumed to be trucks.

Assuming a certain minimum volume of traffic is required to justify closing the interstate, the hours of 6 a.m. to 9 a.m. with a volume of 10.4 percent AADT were used for the low volume scenario. This calculates to 832 total vehicles delayed, with 275 assumed to be trucks.

The potential annual delay and accident cost savings as a result of deploying gates on I-90 are found in Table 24 and Table 24. Once again, a range is presented because it is not possible to pinpoint the actual reductions in delay and accidents that will occur due to the deployment of gates on I-90.

Table 23. Potential annual delay savings due to I-90 gates.

Estimated Savings from	High Volume Scenario	Low Volume Scenario
10% Reduction in Delay (18 minutes)	$7,791	$3,639
20% Reduction in Delay (36 minutes)	$15,582	$7,277
30% Reduction in Delay (54 minutes)	$23,373	$10,916
40% Reduction in Delay (72 minutes)	$31,164	$14,554
50% Reduction in Delay (90 minutes)	$38,956	$18,193
60% Reduction in Delay (108 minutes)	$46,747	$21,831
70% Reduction in Delay (126 minutes)	$54,538	$25,470

Accident Cost Savings: There are approximately 80 snow- and ice- related crashes per year on this segment of I-90. The average cost per accident is estimated to be $7,876. This assumes 81.38 percent of the accidents are property damage only with a total cost of $2,700 each, and 18.62 percent are personal injury with a total cost of $30,500 each. These accident costs are the values currently being used by MNDOT. The values are based on the average cost of accidents obtained from the four largest insurance carriers in Minnesota.

Table 24. Potential annual accident cost savings due to I-90 gates.

Estimated Savings from:	Value
1% Reduction in Accidents (Eliminate 0.8 accidents)	$ 6,301
2% Reduction in Accidents (Eliminate 1.6 accidents)	$ 12,602
3% Reduction in Accidents (Eliminate 2.4 accidents)	$ 18,902
4% Reduction in Accidents (Eliminate 3.2 accident)	$ 25,203
5% Reduction in Accidents (Eliminate 4 accidents)	$ 31,504
Average Annual Cost of Accidents During Adverse Weather	$ 630,080

Model Run Results

The report documents potential savings attributed to a reduction in delays experienced by both passenger vehicles and heavy trucks. Based on AADT recorded by MNDOT in District 7, a delay of 3 hours on I-90 can cost between $36,400 during a low-volume period up to $78,000 during a high-volume period.

In addition to a reduction in delays, cost estimates for a reduction in the number of accidents are also presented. Potential savings for accident reduction use an estimated average cost per accident calculated to be $7,900. This figure is based on values currently used by MNDOT to estimate accident costs. There are approximately 80 snow- and ice-related crashes per year on the segment of I-90 controlled by gates. A 5 percent reduction (4 accidents) in accidents annually will lead to an estimated annual savings of $31,504.

These potential savings were compared with the estimated costs of gates. Based on information from District 7B, the cost for materials and installation of 43 gates averaged approximately $3,700 per gate.

The potential ranges of benefit cost ratios published in the report are summarized in Table 25. Benefits outweighed the costs when the accident reduction is at least 3 percent for both low and high volumes and when the reduction in high-volume delay is 40 percent, even if there is no reduction in accidents.

Table 25. Range of I-90 gate system benefits/cost ratios.

Reduction in Delay	Road Volume	Expected Accident Reduction (percent)	10-Year Delay Savings & Accident Reduction* (dollars)	Deployment & Annual Operations and Maintenance Costs	Benefit/ Cost Ratio**
10%	Low	0	28,096	221,360	0.13
20%	High	1	168,981	221,360	0.76
20%	High	2	217,636	221,360	0.98
30%	Low	3	230,253	221,360	1.04
40%	High	0	240,651	221,360	1.09
40%	Low	3	258,350	221,360	1.17
20%	High	3	266,290	221,360	1.20
50%	Low	4	335,101	221,360	1.51
40%	High	4	435,270	221,360	1.97
70%	High	5	664,414	221,360	3.00

Note: Discount rate = 5%
*The range of benefits goes from a low of $28,096 with a 10% reduction in delay in the low volume scenario and no reduction in accidents to $664,414 with a 70% reduction in delay in the high volume scenario and a 5% reduction in accidents.
** Assuming deployment costs of $159,700 +5% operations & maintenance costs over 10 year for 39 manually operated gates.

Key Observations

This case showed that MNDOT and law enforcement personnel's gate closure projects are cost effective. After installing and using the gates, there is unanimous support for keeping the gates and enhancing how they are used. The gates provide a clear and indisputable notice that the road is closed and travel is prohibited. However, there is some frustration over roadways being closed when it appears the roadway is clear enough for traffic to make short trips between exits. When conducting a BCA, it is often useful to consider a range of alternatives and potential outcomes. This can provide insight into the project characteristics that drive either costs or benefits. In this analysis the authors show benefits associated with changes in assumed delay and accident rates.

Reference

BRW, Inc., *Documentation and Assessment of MNDOT Gate Operations* (Minnesota DOT: October 1999). Available at:
http://www.dot.state.mn.us/guidestar/1996_2000/i90_i94_gate_closure/gatereport.pdf

CASE STUDY 6.2 – HYPOTHETICAL ROAD CLOSURE FEASIBILITY[42]

Strategy Type:	Decision Support, Control & Treatment
Project Name:	Modeling Road Closure Impacts During Winter Weather
Project Agency:	State Transportation Agency
Location:	Rural Interstate Highways
Geographic Extent:	113 Miles of Freeway
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC)

Project Technology or Strategy

Severe winter weather makes travel unsafe and dramatically increases crash rates. Road closure strategies should allow users to avoid crash costs and eliminate costs associated with rescuing stranded motorists when conditions become unsafe due to winter weather. Some of the Snow Belt States recently gated entrances to physically close sections of rural freeways during severe winter storms. The benefits of efficient road closure strategies are the delay time savings and avoided safety costs. The costs of road closures are installation costs, operational costs, and some other costs, including the delays that are imposed on motorists and motor carriers who would have made the trip had the road not been closed.

Project Goals and Objectives

The purpose of this hypothetical example is to examine the benefits and costs of winter weather road closure and develop a framework for their analysis. The benefit side of the analysis focuses on the safety issues related to road closures and the value of travel time. The cost of a road closure is concerned with infrastructure costs and operations and maintenance costs.

Methodology

The data used in this hypothetical scenario is similar to the data presented in the benefit cost analysis (BCA) on a gate closure system developed and published by Minnesota DOT (see Case Study 6.1). The analysis assumes one closure per year for a period of 3 hours affecting a percentage of average annual daily traffic (AADT). The AADT was calculated to be 8,000 (6,900 for passenger vehicles and 1,100 for heavy trucks) using values along the urban freeway from the 1994 State Trunk Highway Traffic Volume Map. The values of time per hour are available as default inputs in TOPS-BC. The default values were updated using an assumed 2.5 percent annual growth rate. The value of time for heavy trucks is an average of values for different truck types. The average annual cost is calculated assuming a 3-hour delay.

As it is not possible to pinpoint the actual reductions in delay and accidents that will occur due to road closures, a range of hourly distributions is presented. The high volume scenario assumes the closure occurs during the highest volume 3 hours of the day, from 3 p.m. to 6 p.m. with 22.6 percent of AADT. This calculates to 1,808 total vehicles delayed, with 550 assumed to be trucks. Assuming a certain minimum volume of traffic is required to justify closing the interstate, the

[42] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

hours of 6 a.m. to 9 a.m. with a volume of 10.4 percent AADT were used for the low volume scenario. This calculates to 832 total vehicles delayed, 275 of which were assumed to be trucks.

There are approximately 80 snow- and ice-related crashes per year on this segment of freeway. The average cost per accident is calculated to be $7,876. This assumes 81.38 percent of the accidents are property damage only with a total cost of $2,700 each, and 18.62 percent are personal injury with a total cost of $30,500 each. The values are based on the average cost of accidents obtained from the four largest insurance carriers in a typical mid-western State.

The total cost assumes deployment costs of $159,700 plus 5 percent operations and maintenance costs over 10 years. Assuming deployment costs of $159,700 + 5 percent operations and maintenance costs for 39 manually operated gates.

Benefit Cost Analysis: A BCA can be used to determine whether to implement this type of road closure strategy. This section will describe how to run a BCA using TOPS-BC. In this case, we will use information from the previous study to run this analysis.

In this hypothetical example, 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 road closure application, the user must supply much of these data. The information can be collected from other departments of transportation (DOT) that have implemented road closure programs or the data can be produced from engineering estimates. A search of the Federal Highway Administration (FHWA) Intelligent Transportation Systems (ITS) Database may provide much of this information.

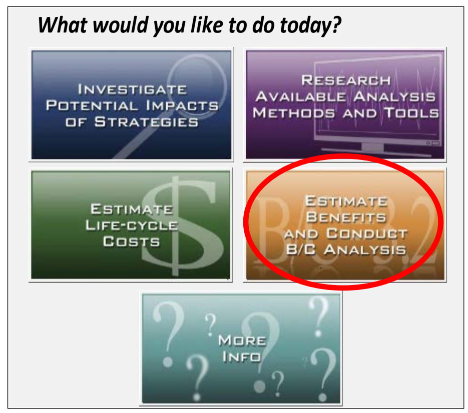

Figure 29. Screenshot. Tool for Operations Benefit/Cost start page – estimate benefits and conduct benefit cost analysis function.

To set up TOPS-BC to conduct this analysis, the user will open the spreadsheet modeling tool to the start page (Figure 29) and click on "Estimate Life-Cycle Costs." Then, in the left hand column of the Cost Page (Figure 30), 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 road closure systems. If no road closure costs are displayed, users can input cost data from available information on the specific project or they may locate information on the FHWA ITS Cost database. (http://www.itscosts.its.dot.gov/its/benecost.nsf/ByLink/CostDocs).

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 measure 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 the dollar value of other benefits. You may have data to support their inclusion; simply add the estimated value of these benefits to the "User Entered Benefit."

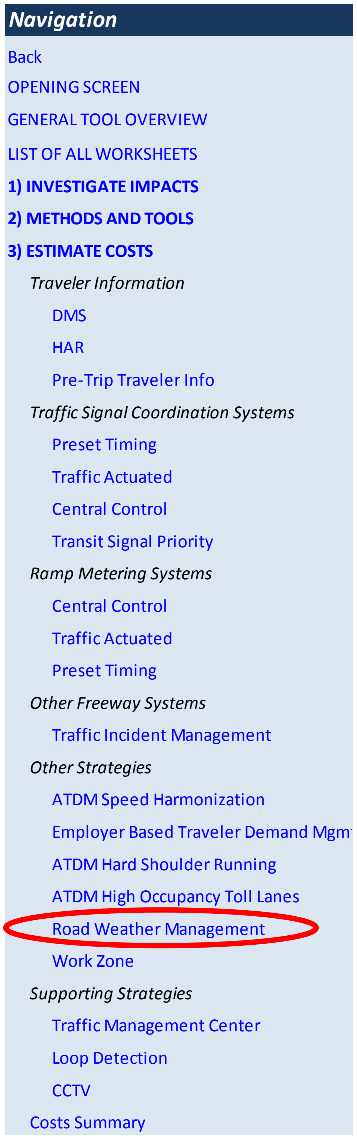

Figure 30. Screenshot. Tool for Operations Benefit/Cost navigation column for estimating costs – road weather management strategies.

Entering your own data allows you to make the analysis as specific as possible 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.

In this case we have some specific site characteristics including length, number of lanes, and other characteristics. We also enter specific data about the performance of the facility, the value of reliability and the value of crash avoidance we are analyzing as TOPS-BC model doesn't provide default values for these parameters in the case of road weather management.

Cost data inputs are located on the road weather management (RWM) cost sheet in TOPS-BC (Figure 31). We will modify the capital infrastructure equipment costs to reflect the installation of 39 closure gates. We have also added costs for incremental deployment equipment. However, we have shown there will be 0 incremental deployments, as for this analysis we are assuming that the 39 closure gates are installed concurrently and that the variable message signs and remote weather station are already in place. If they were not, then we would need to add costs for the incremental deployment of these systems.

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 - Road Closure

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrastructure Equipment				
Closure Gate Installation	10	$ 159,700	$ 7,985	$ 23,955
				$ -
				$ -
				$ -
				$ -
TOTAL Infrastructure Cost		$ 159,700	$ 7,985	$ 23,955
Incremental Deployment Equipment				
Incremental costs for road weather management deployments are extremely variable depending on the type of dep				
User should enter and edit costs appropriate to their planned strategy. Example costs include:				
Operator Cost	25	$ 750	$ 900	$ 930
Variable Message Sign	25	$ 92,500	$ 4,400	$ 8,100
Variable Message Sign Tower	25	$ 125,000	$ 275	$ 5,275
Remote Weather Station	25	$ 40,000	$ 2,500	$ 4,100
TOTAL Incremental Cost		$ 258,250	$ 8,075	$ 18,405
INPUT Enter Number of Infrastructure Deployments	1			**$ 23,955**
INPUT Enter Number of Incremental Deployments	0			**$ -**
INPUT Enter Year of Deployment	2014			
Average Annual Cost				**$ 23,955**

Figure 31. Screenshot. Cost estimate sheet from Tool for Operations Benefit/Cost for winter road closure analysis.

Once the cost estimate is in place, return to the Navigation Column on the far left and click on the Benefit section for Road Weather Management Figure 32). Here we will enter our safety data to complete the benefit side of the benefit cost ratio. For this case, we will assume that the number of injury crashes is reduced from 1 to zero and the number of property damage only crashes is reduced from 5 to zero (see red circles and arrows in Figure 33).

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 attributes. This gives the user a range of estimated benefits and costs. One can also test the value assumptions. For example, an alternative set of crash costs by type (fatality, injury or property damage) that only reflects local crash cost experience would improve the applicability of this tool for an individual project.

Figure 32. Screenshot. Tool for Operations Benefit/Cost navigation column for estimating benefits – road weather management strategies.

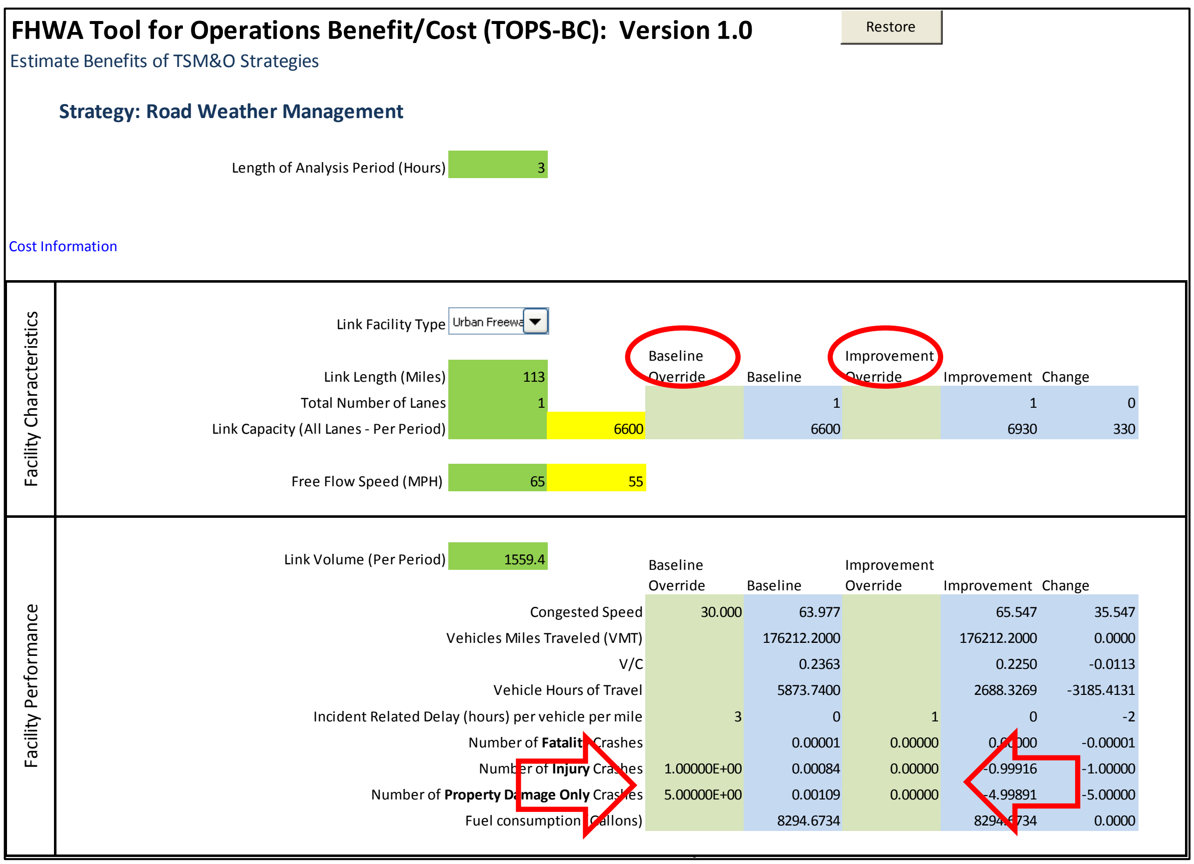

Figure 33. Screenshot. Benefit estimate sheet from Tool for Operations Benefit/Cost for winter road closure analysis.

Safety	$ Value of a Fatality Crash		$ 9,000,000		
	$ Value of a Injury Crash		$ 73,955		
	$ Value of a Property Damage Crash		$ 2,539		
	Total Modeled Crash Related Benefit per Period				$ 86,753.98
	User Entered Benefit (Annual $'s)				
	Number of Analysis Periods per Year	1	250		
TOTAL AVERAGE ANNUAL BENEFIT					$ 86,797

Figure 34. Screenshot. Benefit estimate sheet from Tool for Operations Benefit/Cost for winter road closure analysis (continued).

Model Run Results

To view the results of the BCA, go to the left-hand navigation column and click My Deployments. The results are displayed in the middle of the page. They are reproduced in Figure 35.

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

		Road Weather Management	Total Benefits
Annual Benefits			
Travel Time	$	0	0
Travel Time Reliability	$	0	0
Energy	$	0	0
Safety	$	86,754	86,754
Other	$	0	0
User Entered	$	0	0
Total Annual Benefits	$	86,754	86,754
Annual Costs	$	23,955	23,955
Benefit/Cost Comparison			
Net Benefit	$	62,799	62,799
Benefit Cost Ratio		3.62	3.62

Figure 35. Screenshot. Benefit cost analysis summary sheet (partial) from the Tool for Operations Benefit/Cost for winter road closure analysis.

The TOPS-BC cost effectiveness analysis indicates that the average annual cost for this road closure policy will be $23,955 with total annual benefits from crash reductions are valued at $62,879. Other benefits for delay reduction, energy savings, maintenance crew deployment efficiencies, etc. would add to the total estimated benefits and would be included in the results display.

Benefits: The primary benefits of road closure deployments are the reduction in crashes. The reduction in crashes provides a net annual benefit of about $62,879. 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.

In this case, TOPS-BC estimates that the project benefits exceed the costs. This is a result of the reduction in crashes compared to the base case. As a result, we have increased the benefits provided to users per dollar of system costs. In economic parlance, we would say that the RWM investments and strategies evaluated would improve the operating efficiency for the system under study. Previous studies also demonstrated that with the freeway closed to travel there was less compaction due to vehicle travel, resulting in faster clearing times. Additionally, there were little or no stranded vehicles that interfered with State plowing operations on the freeway.

Key Observations

This case discussed development of a TOPS-BC analysis model to test the feasibility of a road closure on rural interstate freeway in response to dangerous road weather conditions. Although this model is just a prototype, it provides a framework for the development of a tool that could be used to measure effectiveness in reducing delay times and safety costs (as measured by crash reductions), thereby providing an agency with objective and predictable measures for determining whether a closure is necessary.

CASE STUDY 6.3 – HYPOTHETICAL FREEWAY SYSTEMS: DYNAMIC TRAFFIC SIGNAL CONTROL SYSTEMS DEPLOYMENT AND FEASIBILITY[43]

Strategy Type:	Decision Support, Control & Treatment
Project Name:	Dynamic Traffic Signal Control of Freeway
Location:	Hypothetical Freeway
Geographic Extent:	Five Mile Corridor
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC) for Life Cycle Cost and Benefit Cost Analysis

Project Technology or Strategy

Dynamic traffic signal (DTS) control involves placing a traffic signal linked to detectors at freeway onramps to regulate the flow of traffic entering the mainline facility and smoothing the flow of traffic during an inclement weather condition. DTS may be implemented with minimal cycle lengths, which simply break up platoons of vehicles entering the facility for an average day, or may be operated more aggressively with longer cycle lengths designed to function as gate regulators whose purpose is to maintain lower volumes on a freeway facility. DTS may be deployed at single isolated locations or regionwide and are intended to improve road weather operations as a means of 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

In this hypothetical scenario, a Midwestern traffic management agency wishes to deploy DTS on seven interchanges along a 5-mile corridor of a major interstate. The overall goal of the DTS program is to help decrease crashes and travel time delay while minimizing operational and management costs on freeway weather management. In this case we will use actual data from a previous study, but use the TOPS-BC tool to analyze the data. The objective of the case is to demonstrate the use of TOPS-BC to produce the project evaluation that is needed.

Methodology

Data is collected and analyzed prior to and after deployment of the DTS system to evaluate effectiveness.

The data used for the analysis consists of loop detector speed and volume data and accident and incident management data. The study focuses on morning peak period (6 a.m. to 8 a.m.) and afternoon peak period (4 p.m. to 6 p.m.). This scenario assumes the 2010-2011 period for an initial evaluation. Historical data for a 24-month period prior to the implementation of the metering system will be used for the "before" period. The "after" period will use data collected over a 12-month period following the activation. For the Long Term Impacts Evaluation, we use

[43] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

archived data from morning and afternoon peak hours for the all no-holiday weekdays following the activation of the system.

The results of the evaluation indicates that the DTS control systems will benefit traffic flow on the freeway and will meet or exceed the initially identified objectives for the system.

Benefit Cost Analysis: A BCA can be used to determine whether to implement DTS technology. TOPS-BC provides input defaults for most variables that would be used in the evaluation of a new DTS system. If a planner was looking at a system similar to this DTS 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. 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, traffic levels, wait times, etc. Each of the items shown in Table 26 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 include the value of time or reliability, the price of fuel, the cost of crashes, or the dollar value of other benefits you may have calculated, such as vehicle emissions. TOPS-BC estimates fuel and emissions savings from changes in vehicle miles traveled (VMT) and assumptions about average fuel efficiency of the fleet. Some deployments may also reduce fuel consumption by changing the vehicle speed profile, but estimating this effect is beyond TOPS-BC.

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 26 illustrates both user-supplied data inputs and TOPS-BC-supplied inputs.

Table 26. Input variables and user supplied data for dynamic traffic signal control systems.

Required Input Variables	User Supplied Data Inputs	Tool for Operations Benefit/Cost 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)		26,400
Free Flow Speed (MPH)	65	55

Table 26. Input variables and user supplied data for dynamic traffic signal control systems (continuation).

Required Input Variables	User Supplied Data Inputs	Tool for Operations Benefit/Cost Supplied Inputs
Number of DTS	15	1
Average Link Length (Miles)	0.25	0.25
Average DTS Link Capacity (All Lanes - for the time period of analysis)		4,800
Average DTS Free Flow Speed (MPH)		35
Facility Performance		
Freeway Link Volume (during time period of analysis)	21,120	14,000
Average DTS Link Volume (during time period of analysis)	3,840	5,200
Impacts Due To Strategy		
Change in Freeway Link Capacity (%)	20	12%
Reduction in Freeway Crash Rate (%)	20	12%
Reduction in Freeway Crash Duration (%)	-	0%
Reduction in Fuel Use (%)	-	10%

Note: User supplied inputs over ride TOPS-BC Supplied Input Defaults.

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 performed a literature review for the impacts of traffic-actuated road weather ITS and provides a consensus 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 which can be found on the *Parameters* page in the TOPS-BC model.[44]

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 that in this particular deployment, the freeway travel speeds increased by 20 percent and the number of crashes 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 percentage for speed and volume increases and crash reductions. 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. One

[44] For more information on modifying the TOPS-BC *Parameters* page, see case 7-10.

can also test the value assumptions. For example, an alternative set of crash costs by type (fatality, injury or property damage only) that reflects local crash cost experience would improve the applicability of this tool for a specific project.

The three primary benefits of DTS deployments are improvements in travel time, travel time reliability, and crashes. Each project plan is different, and the realized benefits can be impacted by the plan. By varying the assumptions in the plan, benefit cost analysis (BCA) models allow you to see how plan assumptions will impact the expected benefits.

Travel Time. Travel time is usually calculated based on estimated link speeds in the corridor, both for the freeway and interstate links. Speeds may be estimated using the speed-flow relationship from the *Highway Capacity Manual* (HCM) 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 interstate links. For the improvement scenario, average capacities are adjusted based on default impact percentages. BCA models usually provide these defaults, although 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 second Strategic Highway Research Program (SHRP2 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 DTS strategy on incident-related delay is two-fold: it is impacted by both the change in facility capacity (discussed under the Travel Time impact above) as well as 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. The incident delay factor is multiplied by the VMT estimated for the facility. 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. Additionally, according to the SHRP2 research,[45] the resulting recurring delay and incident delay values are applied in an additional algorithm along with the volume/capacity ratio to factor total non-recurring delay for the facility. 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

[45] See for example: http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/Pages/Reliability_Projects_302.aspx.

all these calculations for you with data you provide about your project and its expected effects on performance.

Crashes. This data represents the benefit from the reduction in crashes that results 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 into 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 DTS strategies, including the reduction in vehicle emissions and fuel use beyond a change in travel demand. This is a change in vehicle efficiency caused by a change in vehicle operating profiles. 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). 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

The TOPS-BC cost effectiveness analysis indicates that the first year cost for this DTS introduction will be $1.687 million with a continuing annual cost of $93,250 for a 20-year analysis period and with an additional cost every 5 years of $97,500 for software and system upgrades. This results in a 20 year net present value of just over $2 million, or a levelized annual cost of $172,600 with a 5 percent discount rate.

If the deployment were already complete, we could then use the actual cost experience in this case if we believed it to be more accurate than the average cost shown by TOPS-BC. Note: Be cautious in overriding the default cost numbers. These values were developed from several reports on this technology and are thought to be accurate representations. Costs shown in a single report may not be comparable to the default values as they may not include all deployment costs.

Benefits: TOPS-BC estimates benefits from the DTS 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. 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 27. Benefit cost summary.

Annual Benefit Type	Dollar Value
Total Annual Benefits	**$7,994,382**
Travel Time	$7,497,256
Travel Time Reliability	$36,835
Energy	$456,072
Safety	$4,218
Other	$0
User Entered	$0
Total Annual Costs	**$172,600**
Benefit/Cost Comparison	
Net Benefit	$7,821,782
Benefit Cost Ratio	46.32

Key Observations

This case identifies the introduction of a series of DTS control systems on an Interstate that is highly exposed to weather conditions. 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 DTS 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 6.4 – WEATHER RESPONSIVE SIGNAL TIMING (CONNECTED VEHICLE APPLICATION)[46]

Strategy Type:	Decision Support, Control and Treatment
Project Name:	Weather Responsive Signal Timing using Connected Vehicles (CV)
Project Agency:	Hypothetical Agency
Location:	Hypothetical State
Geographic Extent:	Statewide
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC) Beta CV

Project Technology or Strategy

Weather events can reduce the effectiveness of traffic signal timing plans and reduce arterial mobility. Several research studies found that in adverse weather average speeds declined by 16 percent to 40 percent, free-flow speed was reduced by 10 percent to 30 percent, traffic volumes were 15 percent to 30 percent lower, saturation flow rate fell by 2 percent to 21 percent, travel time delay increased by 11 percent to 50 percent, and there was 5 percent to 50 percent more start-up delay. Weather-related delays can be mitigated by implementing signal timing plans designed for slick pavement conditions and slower travel speeds. Investigations of traffic parameters sensitive to adverse weather assist analysts in developing weather-responsive traffic signal timing plans. Several of these benefit studies revealed that weather-responsive signal timing can improve arterial mobility by increasing average speed and reducing delay.[47]

Project Goals and Objectives

Road-weather connected vehicle data can be used to optimize signal timing for safety and mobility during adverse weather conditions. This means that high volume routes will have longer green phases. This technology can also be applied to ramp meters, with the reverse effect: ramp meters would allow a smaller number of cars on freeways and highways, because the risk of crashes decreases with lower traffic volume. Ramp meters can thus decrease delays on freeways during adverse weather conditions by controlling the entry volume and movement of traffic from the ramps.

Methodology

Costs: We used the information from the 2013 *Road Weather Management Connected Vehicle Applications* report[48] to perform a benefit cost analysis (BCA) of the weather responsive signal timing application. Based on this data, new cost line items were added to the existing cost sheet

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[46] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

[47] Lynette C. Goodwin and Paul A. Pisano, "Weather-Responsive Traffic Signal Control," *ITE Journal*, June 2004.

[48] FHWA, *Road Weather Management Connected Vehicle Applications*, available at http://ntl.bts.gov/lib/54000/54400/54480/Road_Weather_Connected_Vehicle_Applications_Benefit-508-v8.pdf.

within TOPS-BC.[49] Figure 36 shows the different cost items that were added. The exhibit is taken from a spreadsheet within TOPS-BC that calculates the costs of specific CV strategies. Basic infrastructure refers to the required common infrastructure investments to support multiple CV transportation systems management and operations (TSMO) projects while the Incremental Deployment section includes cost items that are application-specific. The basic infrastructure and incremental deployment sections include estimated annualized costs, operations and maintenance costs, item-specific counts and the user-selected quantities used in this analysis.

Since the case study CV deployments, including weather responsive signal timing, are assumed to take place in a hypothetical State, the distinction between necessary basic CV infrastructure investments and incremental/strategy-specific deployments needs to be clear. For the purpose of this analysis, each CV deployment BCA assumes that the respective State or metropolitan planning organization (MPO) needs to acquire both basic infrastructure and incremental/ strategy specific infrastructure. However, since the basic deployment investment supports many projects and strategies, only a portion of the total basic infrastructure cost is assigned to a specific CV technology. The percentage assumes that a set of CV technologies are deployed and the specific technology's basic infrastructure cost equals that technology's share of expected benefits in the set of deployed technologies. This cost assignment would vary depending on the full set of CV technologies deployed and supported by the basic infrastructure investment. For the weather responsive signal timing case study, the assumed percentage of total basic infrastructure costs is 26 percent.

The 2013 CV report referenced above focused on the entire United States, so for the individual CV case studies in this compendium the hypothetical State is assumed to have 2 percent (1 of 50 States) of the total U.S. population. The basic infrastructure quantities used in the analysis were derived from that assumption and are shown in Figure 36. When the new cost items are entered into TOPS-BC, the 2013 CV report is used to identify which cost elements are needed to perform the appropriate cost analysis. If users want to analyze a specific connected vehicle application deployment strategy, the table allows for a quick identification of the cost items needed.

This weather responsive signal timing application has several basic infrastructure cost items that need to be taken into consideration when conducting a BCA. These cost items are considered for this analysis and are listed below:

- Urban freeway roadside equipment (wireline & wireless).
- Urban signal roadside equipment (wireline & wireless).
- Rural interstate equipment (with & without power grid connection).
- Application development.
- System integration and back office costs.
- On-board equipment on agency vehicles.

[49] FHWA, *Tool for Operations Benefit/Cost Analysis*, available at http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count	Unit Costs
Basic Infrastructure Equipment and Costs							
Urban Freeway RSE w/ wireline	**25**	$ 230,400	$ 5,760	$ 14,976	**24**	**1 per Mile**	$ 9,600
Urban Freeway RSE wireless	**25**	$ 1,948,800	$ 48,720	$ 126,672	**96**	**1 per Mile**	$ 20,300
Urban Signal RSE w/ wireline	**25**	$ 2,331,600	$ 58,290	$ 151,554	**201**	**2/3 of signals**	$ 11,600
Urban Signal RSE wireless	**25**	$ 17,951,500	$ 448,788	$ 1,166,848	**805**	**2/3 of signals**	$ 22,300
Rural Interstate w/ powergrid connection	**25**	$ 7,647,300	$ 191,183	$ 497,075	**261**	**1 per 2 Miles**	$ 29,300
Rural Interstate w/o powergrid connection	**25**	$ 2,411,500	$ 60,288	$ 156,748	**65**	**1 per 2 Miles**	$ 37,100
Application Development Costs	1	$ 191,746	$ -	$ 191,746	**1**	**1 per Application**	$ 191,746
System Integration & Backoffice	35	$ 25,886	$ 3,835	$ 4,575	**1**	**1 per Application per TMC**	$ 25,886
Vehicle On-Board Equipment	1	$ 4,800,000	$ 288,000	$ 5,088,000	**48,000**	**1 per Vehicle**	$ 100
TOTAL Infrastructure Cost		$ 37,538,732	$ 1,104,862	$ 7,398,192			
Incremental Deployment Equipment - ***Please See Chart <u>on the Right</u> for Application-Specific Information***							
Vehicle Data Translator (This Item is RWM-specific only)	25	$ -	$ -	$ -		**1 per TMC**	$ 1,000,000
Maintenance Vehicle Costs	5	$ -	$ -	$ -		**1 per Maintenance Vehicle**	$ 30,000
Dynamic Message Sign	10	$ -	$ -	$ -		***VSL ONLY***	$ 82,000
Education & Outreach	1	$ 288,000	$ -	$ 288,000	**6,400,000**	**1 per capita**	$ 0.045
TOTAL Incremental Cost		$ 288,000	$ -	$ 288,000			
INPUT Enter Number of Infrastructure Deployments	1	**$ 443,892**					
INPUT Enter Number of Incremental Deployments	1	**$ 288,000**					
INPUT Enter Year of Deployment	2020						
Average Annual Cost $ 731,892							

Figure 36. Screenshot. Annualized costs for weather responsive signal timing.

Additionally, there is one incremental cost item necessary for this CV application, education and outreach, which are necessary to inform the public about the implementation of the strategy. It is calculated on a per capita-basis, which means a cost occurs for every individual in the service area. Since the hypothetical State is assumed to have 2 percent of the U.S. population, this analysis uses the value of 6.4 million inhabitants, assuming that the U.S. population is 320 million.

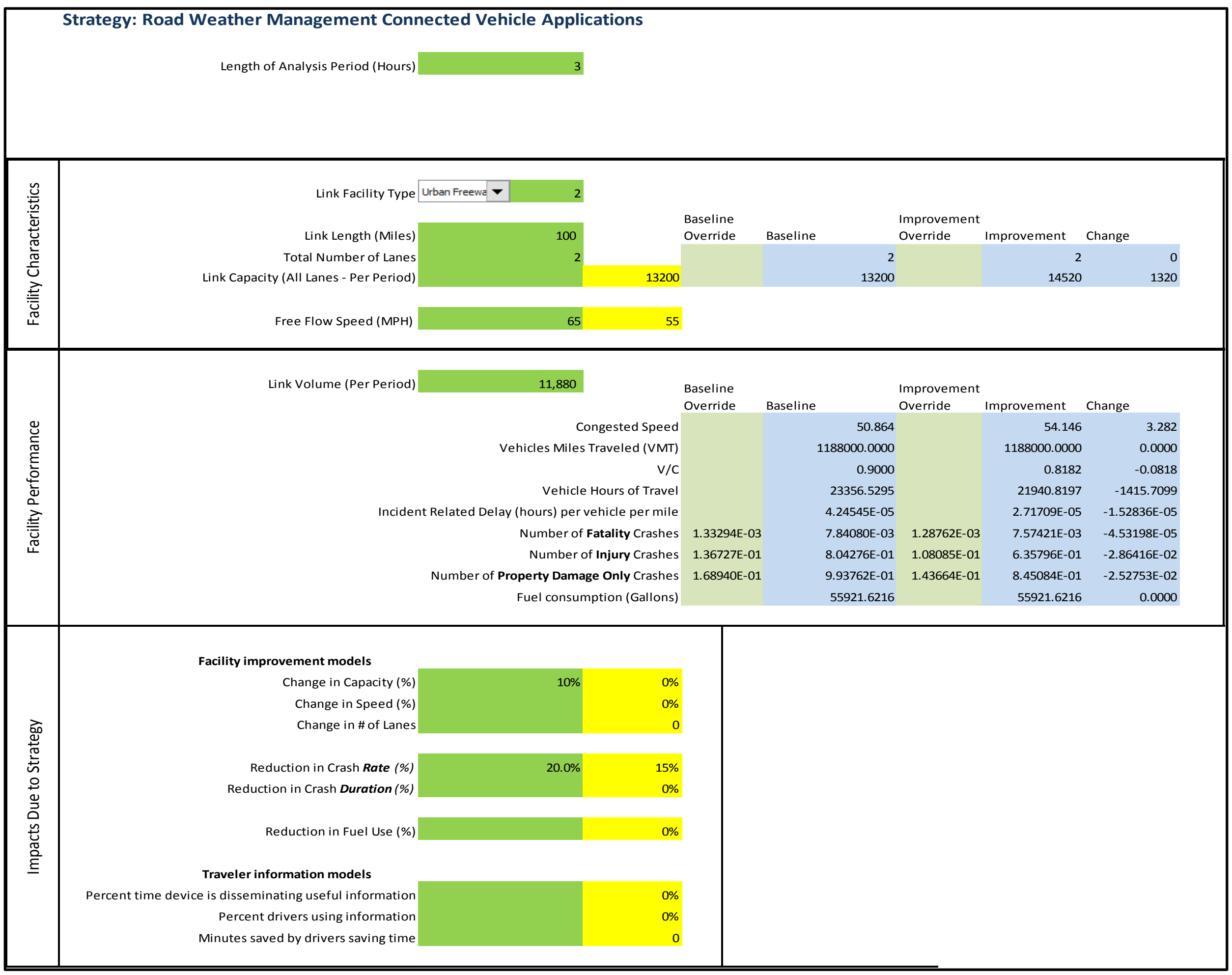
The following section focuses on the dollar values for basic infrastructure costs of a CV environment as well as the incremental cost item specific to this strategy. Figure 36 shows the annualized costs of this strategy as they were calculated using TOPS-BC.

Finally, the number of infrastructure and incremental deployments was set to 1 each, because the extent of the roadway structure for the entire CV system and for this strategy in particular is already considered in the quantities shown in each cost line. The project is assumed to be in place in 2020. As Figure 36 shows, these assumptions result in annualized incremental costs of $731,892.

Benefits: In order to estimate the benefits of this strategy, we utilized the data from the CV BCA report which estimates the effectiveness of this strategy to be 7 percent. This means that crashes are likely to be reduced by 7 percent when the strategy is in place. Alongside this assumption is the assumed increase in capacity due to a lower amount of incidents that slow down traffic. The report set this number to 10 percent for all applications.

Furthermore, crashes include three different types of incidents: property damage only, injury and fatality. Since TOPS-BC calculates the number of each of these types of incidents for all weather conditions and not just for adverse weather conditions, these values needed to be adjusted. For the purpose of this analysis, and based on the CV BCA report, it is assumed that 24 percent of incidents are related to adverse weather conditions. Hence this analysis applies to 24 percent of property damage only, injury, and fatality incidents.

Figure 37 shows the CV benefit sheet within the tool. The adjusted values for property damage only, injury and fatality were entered into the green cells in the Facility Performance section of the tool. The green cells can be changed by the user and override the default values used by TOPS-BC. The capacity increase and crash reduction assumptions were implemented below the section Impacts due to Strategy. These values were also entered in the green cells, since TOPS-BC regularly does not consider any changes in capacity and uses a different crash reduction rate. For this reason, the given data within the tools were overridden. These data could come from travel demand models, freeway simulations, counts or other sources. Note that other agency benefits, such as benefits from reduced maintenance costs due to the weather responsive signal timing are not reflected in the benefit estimation. Analysts are encouraged to independently calculate such benefits and add them into the TOPS-BC estimates.



Strategy: Road Weather Management Connected Vehicle Applications

Length of Analysis Period (Hours)	3	

Facility Characteristics

			Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Facility Type	Urban Freewa 2						
Link Length (Miles)	100						
Total Number of Lanes	2			2		2	0
Link Capacity (All Lanes - Per Period)		13200		13200		14520	1320
Free Flow Speed (MPH)	65	55					

Facility Performance

	Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Volume (Per Period) 11,880					
Congested Speed		50.864		54.146	3.282
Vehicles Miles Traveled (VMT)		1188000.0000		1188000.0000	0.0000
V/C		0.9000		0.8182	-0.0818
Vehicle Hours of Travel		23356.5295		21940.8197	-1415.7099
Incident Related Delay (hours) per vehicle per mile		4.24545E-05		2.71709E-05	-1.52836E-05
Number of **Fatality** Crashes	1.33294E-03	7.84080E-03	1.28762E-03	7.57421E-03	-4.53198E-05
Number of **Injury** Crashes	1.36727E-01	8.04276E-01	1.08085E-01	6.35796E-01	-2.86416E-02
Number of **Property Damage Only** Crashes	1.68940E-01	9.93762E-01	1.43664E-01	8.45084E-01	-2.52753E-02
Fuel consumption (Gallons)		55921.6216		55921.6216	0.0000

Impacts Due to Strategy

Facility improvement models		
Change in Capacity (%)	10%	0%
Change in Speed (%)		0%
Change in # of Lanes		0
Reduction in Crash ***Rate*** (%)	20.0%	15%
Reduction in Crash ***Duration*** (%)		0%
Reduction in Fuel Use (%)		0%
Traveler information models		
Percent time device is disseminating useful information		0%
Percent drivers using information		0%
Minutes saved by drivers saving time		0

Figure 37. Screenshot. Benefit estimation assumptions for weather responsive signal timing.

Finally, Figure 38 shows the lower half of the CV benefit estimation page. It includes additional sections on travel time, energy and other safety benefits. The user is able to refine any TOPS-BC calculation using these sections in case more specific data is at hand. Through this flexible user interface, the user can generate refined and more accurate results. The total average annual benefit is calculated automatically by TOPS-BC and can be found at the bottom of the benefit estimation sheet. The total average annual benefit for this application is $13.32 million.

Travel Time	Average Person Hours of Travel Saved per Period		2364.2355
	$ Value of Person Hour (per hour) "On-the-Clock" Auto	$ 32.46	
	$ Value of Person Hour (per hour) Other Auto	$ 16.23	
	$ Value of Vehicle Hour (per hour) Truck	$ 32.46	
	Total Recurring Travel Time Benefit per Period		$ 49,882.46
ATIS Time Savings	Total hours saved due to ATIS deployments		0.00
Travel Time Savings: Non-Recurring Delay	Average Total Person Hours of Non-Recurring Delay Saved per Period		30.3221
	alue of Person Hour (per hour of ***Delay***) "On-the-Clock" Auto	$ 32.46	
	$ Value of Person Hour (per hour of ***Delay***) Other Auto	$ 16.23	
	$ Value of Vehicle Hour (per hour of ***Delay***) Truck	$ 32.46	
	Total Non-Recurring Delay Benefit per Period		$ 639.76
Energy	Average cost per gallon of fuel (excluding taxes)	$ 4.25	
	Total Fuel Savings Benefit		$ -
Safety	$ Value of a Fatality Crash	$ 10,433,467	
	$ Value of a Injury Crash	$ 77,671	
	$ Value of a Property Damage Crash	$ 2,666	
	Total Modeled Crash Related Benefit per Period		$ 2,765
	User Entered Benefit (Annual $'s)		
	Number of Analysis Periods per Year	250	
	TOTAL AVERAGE ANNUAL BENEFIT		$ 13,321,771

Figure 38. Screenshot. Benefit estimation results for weather responsive signal timing.

There is limited data on the effectiveness of weather-responsive signal timing. The CV BCA report states that the number of incidents that occur in signalized intersections is about 6 percent of all crashes. The final benefits of this application are therefore estimated to be 6 percent of the total benefits of the application. The total benefits of this application are therefore 6 percent of the $13,321,771 shown in Figure 38, resulting in a total benefit of $799,306.

Model Run Results

Finally, the analysis compares the results of the benefits calculation with the results of the cost calculations. Note that this case study merely analyzes a specific set of costs and benefits for demonstration purposes. A full benefit cost analysis will include a wide range of additional costs and benefits that are not separately listed or analyzed in this case study.

Figure 39 shows the section of TOPS-BC that compares benefits and costs for the connected vehicle strategy Weather Responsive Signal Timing. The exhibit indicates that the deployment of a Weather Responsive Signal Timing in a hypothetical State considering the underlying assumptions is cost effective, since the resulting BCR for the strategy is estimated at 1.09. The resulting net benefits for this analysis account for $67,417.

Benefit/Cost Summary		
Annual Benefits		**CV Weather Responsive Signal Timing**
Travel Time	$	748,237
Travel Time Savings: Non-Recurring Delay	$	9,596
Energy	$	0
Safety	$	41,475
Other	$	0
User Entered	$	
Total Annual Benefits	**$**	799,308
Annual Costs	**$**	731,892
Benefit/Cost Comparison		
Net Benefit	**$**	67,417
Benefit Cost Ratio		1.09

Figure 39. Screenshot. Results for weather responsive signal timing.

CASE STUDY 6.5 – ROAD CONDITION REPORTING APPLICATION IN WYOMING[50]

Strategy Type:	Decision Support, Control and Treatment
Project Name:	Road Condition Reporting Application
Project Agency:	Wyoming Department of Transportation (WYDOT)
Location:	Wyoming
Geographic Extent:	Statewide
BCA Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC)

Project Technology or Strategy

The recently completed weather responsive traffic management (WRTM) implementation project by the Wyoming DOT (WYDOT) included the development of a new mobile software application ("App") to improve the way maintenance staff report road conditions from the field. The App is used by WYDOT maintenance personnel to report road weather information to the traffic management center (TMC) it recommends variable speed limit changes, reports snow performance measures, and identifies a number of different traffic incidents including crashes and road hazards. Maintenance workers use the App, which was built to run on a tablet computer, to share information such as road conditions reported to the public, variable speed limits, weather information, messages posted on dynamic message signs, and map-based asset locations. The App can also be used to exchange email-type messages. The App was installed on 20 tablets, mostly in plow trucks.

Project Goals and Objectives

The project goal was to develop a new software application to enhance the way maintenance personnel report road and weather conditions to headquarters and the traffic management center, recommend changes to variable speed limits, and report traffic incidents such as road hazards or crashes. Previously, these data were gathered manually and communicated via radio. The specific project objectives, which the App helped WYDOT to achieve, are to improve:

- Efficiency of road condition reporting.
- Proficiency of the TMC operations in taking actions based on the reported road conditions.
- Timeliness of updated traveler information.
- Situational awareness of maintenance staff in the field regarding road weather conditions.

Methodology

The evaluation of the condition reporting tool conducted by WYDOT and the Federal Highway Administration (FHWA) focused on quantitative and qualitative assessments of the changes in reporting and information processing related to road and traffic conditions. While the

[50] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

quantitative analysis primarily focused on comparing time spent by TMC operators to process such information, the qualitative analysis gathered data through two separate surveys: one completed by TMC operators and the other completed by maintenance employees.[51] In general, the App improved the effectiveness and efficiency of road condition reporting and traffic management center activities during weather events. WYDOT plans to expand the App's usage during the winter of 2016 to as many as 150 vehicles. There was no benefit cost analsys (BCA) conducted as part of the project evaluation. The following analysis can serve as a hypothetical example of how BCA can be used to evaluate this type of project.

The expanded version of TOPS-BC (Version 1.2 Beta for Connected Vehicles) developed by the FHWA for demonstration purposes is used to analyze this case study, since the App developed by WYDOT can be evaluated like a connected vehicle application.

Costs: For this case study, development costs for the WYDOT software application are estimated using data available in TOPS-BC. On the cost sheet for Version 1.2, the tool provides several cost line items separated into *Basic Infrastructure Equipment and Costs* and *Incremental Deployment Equipment*. The first section includes all costs that constitute basic infrastructure needs of an agency for all connected vehicle applications. Note that the information included in TOPS-BC is based on a study that estimated the benefits and costs of a nationwide connected vehicle deployment. Therefore, this case study only uses a fraction of the costs included in the tool. The second category includes all equipment items that are needed on an incremental basis; the size of the planned system determines the quantity of incremental equipment.

For the cost estimation of the software application implemented by WYDOT, this analysis assumes significantly lower costs than the initial tool development for the nationwide study. These reduced costs are assumed for two reasons: (1) WYDOT already has technologies and procedures in place to acquire and report road weather conditions during adverse weather. It is unlikely that the full range of listed basic infrastructure and incremental costs in TOPS-BC was actually needed for this project, and (2) the information in TOPS-BC is based on a paper which performed a BCA of nationwide connected vehicle deployment. In contrast, this case study focuses on a software application deployment. It is reasonable to assume that this project does not require as extensive investments as the national estimate. Since these costs are unknown, this case study utilized a selected percentage of the standard *Application Development Costs* that is included as a cost line item within TOPS-BC. Figure 40 shows the cost page within the tool, the different line items of *Basic Infrastructure Equipment* and *Incremental Deployment Equipment*, as well as the total assumed costs for this strategy. The standard *Application Development Costs* within the tool for national deployment are $10,000,000. For this case study it is assumed that only a small percentage (0.25 percent) of that amount applies to the WYDOT road condition reporting app. This results in annual costs of $25,000. Furthermore this cost estimation considers on-board equipment (OBE) for 20 vehicles as mentioned in the introduction, amounting to additional $2,120. The total average annual costs for this project thus are $27,120.

[51] FHWA, *Wyoming Department of Transportation (WYDOT) Road Condition Reporting Application for Weather Responsive Traffic Management*, FHWA-JPO-16-26 (Washington, DC: 2015), p. 27. Available at: http://ntl.bts.gov/lib/56000/56800/56890/FHWA-JPO-16-266_v2.pdf.

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count	Unit Costs
Basic Infrastructure Equipment and Costs							
Urban Freeway RSE w/ wireline	**25**	$ -	$ -	$ -		**1 per Mile**	$ 9,600
Urban Freeway RSE wireless	**25**	$ -	$ -	$ -		**1 per Mile**	$ 20,300
Urban Signal RSE w/ wireline	**25**	$ -	$ -	$ -		**2/3 of signals**	$ 11,600
Urban Signal RSE wireless	**25**	$ -	$ -	$ -		**2/3 of signals**	$ 22,300
Rural Interstate w/ powergrid connection	**25**	$ -	$ -	$ -		**1 per 2 Miles**	$ 29,300
Rural Interstate w/o powergrid connection	**25**	$ -	$ -	$ -		**1 per 2 Miles**	$ 37,100
TOTAL Infrastructure Cost		$ -	$ -	$ -			
Incremental Deployment Equipment - Please See Chart on the Right for Application-Specific Information							
Application Development Costs	1	$ 25,000	$ -	$ 25,000	**0.25%**	**1 per Application**	$ 10,000,000
System Integration & Backoffice	35	$ -	$ -	$ -		**1 per Application per TMC**	$ 25,886
Vehicle On-Board Equipment	1	$ 2,000	$ 120	$ 2,120	**20**	**1 per Vehicle**	$ 100
Vehicle Data Translator (This Item is RWM-specific only)	25	$ -	$ -	$ -		**1 per TMC**	$ 1,000,000
Maintenance Vehicle Costs	5	$ -	$ -	$ -		**1 per Maintenance Vehicle**	$ 30,000
Dynamic Message Sign	10	$ -	$ -	$ -		***VSL ONLY***	$ 82,000
Education & Outreach	1	$ -	$ -	$ -		**1 per capita**	$ 0.045
TOTAL Incremental Cost		$ 27,000	$ 120	$ 27,120			
INPUT Enter Number of Infrastructure Deployments	1	$ -					
INPUT Enter Number of Incremental Deployments	1	**$ 27,120**					
INPUT Enter Year of Deployment	2020						
Average Annual Cost $ 27,120							

Figure 40. Screenshot. Wyoming road condition reporting application cost estimation sheet and results as displayed within the Tool for Operations Benefit/Cost.

Benefits: As resulting benefits of this strategy, significant TMC operator time savings were calculated from the automation of several key tasks – data logging and traveler information system updates. Based on road reports including storm days and non-storm days from January 2014 to December 2014, WYDOT estimates that using the App can result in more than one person-year of time savings for agency staff.[52]

This analysis assumes the monetized amount of one person-year to be an average salary of $60,000 annually. This amount is counted as an agency benefit, because, based on the source, the agency can save one person-year of time savings. Finally, this analysis also accounts for 20 percent of the annual salary for possible fringe benefits related to this person-year of staff savings.

This case study demonstrates the process for estimating costs and benefits and performing a BCA using TOPS-BC for connected vehicle strategies. It does not consider a range of other benefits potentially applicable to this strategy, such as safety benefits, travel time savings, travel time reliability benefits, or other agency efficiency gains. If the user wants to perform a comprehensive BCA of this particular road weather management strategy or a related strategy, it is essential to include the benefits mentioned above, which are not considered explicitly in this case study.

TOPS-BC allows the analyst to input unique, user-specific annual benefits on its benefit sheets. This feature was utilized for this analysis, since the monetary amount of benefits is mainly based

[52] FHWA, *Wyoming Department of Transportation (WYDOT) Road Condition Reporting Application for Weather Responsive Traffic Management*, FHWA-JPO-16-26 (Washington, DC: 2015), p. 27. Available at: http://ntl.bts.gov/lib/56000/56800/56890/FHWA-JPO-16-266_v2.pdf.

on a national estimate. As a last step, $60,000 is multiplied by 1.2 in order to account for the 20 percent of assumed fringe benefits, resulting in a total of $72,000 of average annual benefits.

Model Run Results

Figure 41 shows the benefit/cost summary of the WYDOT Road Condition Reporting Application using TOPS-BC. Since the benefit estimation is based on national connected vehicle deployment estimates, there are only user entered benefits to be considered for this analysis. The costs of this project only represent a fraction of its benefits, since total costs are $27,120 compared to $72,000 of benefits for each year of deployment. These results generate a benefit cost ratio of 2.65, as the exhibit indicates. Additional benefits associated with this strategy and the resulting improved traveler information, traffic management and maintenance operations are not included in the analysis.

Benefit/Cost Summary		
Annual Benefits		**Wyoming Software Application**
Travel Time	$	0
Travel Time Savings: Non-Recurring Delay	$	0
Energy	$	0
Safety	$	0
Other	$	0
User Entered	$	60,000
Total Annual Benefits	**$**	72,000
Annual Costs	**$**	27,120
Benefit/Cost Comparison		
Net Benefit	**$**	44,880
Benefit Cost Ratio		2.65

Figure 41. Screenshot. Benefit cost analysis results for the Wyoming road condition reporting application as displayed within the Tool for Operations Benefit/Cost.

Key Observations

This case study serves to demonstrate how TOPS-BC can be used to analyze improvements in road reporting systems. Users are encouraged to improve any assumptions utilized in this analysis based on their own region-specific data and other available databases. Through this effort, the results generated by TOPS-BC become more refined as more data is fed into the tool. More detailed and in-depth analyses of such a procedure may result in different benefit cost ratios and net benefits. The tool offers various features that support such analyses, and its results can give the user a first impression on the cost efficiency of agency procedure and traffic improvement strategies.

References

Federal Highway Administration, *Wyoming Department of Transportation (WYDOT) Road Condition Reporting Application for Weather Responsive Traffic Management*, Final Report, US DOT, FHWA-JPO-16-266, October 2015.

CASE STUDY 6.6 – WEATHER RESPONSIVE ACTIVE TRAFFIC MANAGEMENT SYSTEM IN OREGON[53]

Strategy Type:	Decision Support, Control and Treatment
Project Name:	Weather Responsive Active Traffic Management System in Oregon
Project Agency:	Oregon Department of Transportation
Location:	Portland, Oregon
Geographic Extent:	SR-217 Corridor
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC)

Project Technology or Strategy

The Oregon Department of Transportation (ODOT) has avoided spending nearly $1 billion on capacity and interchange improvements by implementing a weather responsive active traffic management system on State Route 217 (OR217), a 7.5 mile limited access highway in Portland, Oregon. ODOT designed and implemented various cost-saving active traffic management (ATM) strategies to improve safety, reliability, and mobility. The ATM system includes a comprehensive application of automated technologies to improve operations and safety on the corridor.[54] The system manages traffic dynamically based on prevailing roadway conditions using integrated monitoring systems and coordinated responses. The project consisted of six interrelated systems: queue warning, congestion responsive variable speed, weather responsive variable speed, dynamic ramp-metering, travel time information, and curve warning. Key facets of the project included advisory speeds based on weather and traffic conditions, variable message signs on the sides of roadways and surface streets providing real-time travel time estimates, and queue warnings. In addition, it involved targeted shoulder use and shoulder widening to provide space for impaired vehicles and to improve emergency vehicle access.

Project Goals and Objectives

The project goals are to improve highway efficiency and safety as long-term solutions, avoiding high-cost investments of major construction by employing relatively low-cost ATM solutions. Oregon Route 217 is a heavily trafficked 7.5-mile limited access highway that runs north-south through the cities of Beaverton and Tigard between Interstate 5 and US 26. The roadway frequently operates at high capacity levels as traffic has more than doubled in the past thirty years, resulting in significantly decreased safety and reliability.[55] While studies have recommended capacity and interchange improvements costing nearly $1 billion, such as widening to six lanes, braiding ramps, and adding collector-distributor roadways, ODOT opted for the development of more cost-effective ATM improvements. The changes are designed to:

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[53] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

[54] Oregon Department of Transportation, *OR217: Active Traffic Management* (2015). Available at: http://www.nascio.org/portals/0/awards/nominations2015/2015/2015OR6-Oregon-ODOT-2015%20-%20OR217%20ATM%20Project.pdf.

[55] Ibid, p.3.

- Improve safety.
- Reduce secondary crashes.
- Provide real-time travel information.
- Increase highway efficiency without the high cost of major new construction.[56]

Methodology

In order to estimate the costs and benefits of the ATM system in Oregon, we utilized TOPS-BC.[57] This case study mainly serves to demonstrate the possibility for analyzing active transportation and demand management (ATDM) strategies deployed by ODOT to improve the traffic conditions on OR217. For this case study, we chose to analyze one of the six strategies deployed on the corridor, namely *weather-responsive variable speed limits*.

FHWA expanded TOPS-BC to Version 1.2, which includes an analysis sheet for variable speed limits along various types of operational strategies. This Oregon case study uses that version.

Costs: The costs of Oregon's weather responsive variable speed limits (VSL) project were estimated using the TOPS-BC cost sheet, which includes numerous line items that are unique to VSL. There are a number of default values for an initial VSL deployment within TOPS-BC, which are utilized for this cost estimation. Figure 42 shows the different cost items as they are listed within the tool. The costs are separated into two groups. The first is basic infrastructure equipment costs, which represent basic infrastructure investments necessary for the strategy. The second cost section, incremental deployment equipment costs, represents cost items associated with how extensively the system will be deployed. The quantities for this section were removed, since ODOT provided cost information on the total costs of the project as well as annual operations and maintenance (O&M) costs. The cost columns show annualized capital and O&M costs in three different columns, indicating that the tool can apply different cost values if needed. ODOT estimated the total costs for the ATM system at $8 to $10 million, so for this analysis we assumed a total cost of $9 million. Additional costs for the weather related VSL system are estimated to be $500,000. These two figures were combined in order to represent the project's total capital costs and then annualized over the average lifetime of the equipment, which is 25 years. Finally, ODOT estimated the O&M costs for the implemented system to be $50,000 annually. This amount was added to the previously tabulated annualized costs.

[56] ITS 2015 award nomination package, submitted by D. Mitchell, Regional Traffic Engineer (ODOT): "OR 217: Active Traffic Management," for the Best New Innovative Product, Service, or Application category.

[57] FHWA, *Tool for Operations Benefit/Cost Analysis*, available at: http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

Equipment		Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Unit	Unit Costs
Basic Infrastructure Equipment and Costs								
	Engineering Design	25	$ -	$ -	$ -		LS	$ -
	Software Module	20	$ -	$ -	$ -		LS	$ 300,000
	Traffic Engineering / Operations		$ -	$ -	$ -		hours	$ 175
	ATM TOC Hardware	25	$ -	$ -	$ -		LS	$ 50,000
	TOTAL Infrastructure Cost		$ 9,500,000	$ -	$ 380,000			
Incremental Deployment Equipment								
	Harden Shoulder	25	$ -	$ -	$ -		Lane-mile	$ 3,000,000
	Build Refuge Areas	25	$ -	$ -	$ -		Each	$ 250,000
	Re-striping	25	$ -	$ -	$ -		LF	$ 0.80
	Ramp Meters	25	$ -	$ -	$ -		Each	$ 30,000
	Arterial and Ramp Detection	25	$ -	$ -	$ -		-	$ 10,000
	Gantries with large DMS and CCTV	25	$ -	$ -	$ -		Each	$ 920,000
	Controller	25	$ -	$ -	$ -		Each	$ 25,000
	Speed Limit / Lane Control Sign on Gantry	25	$ -	$ -	$ -		Each	$ 10,000
	Detectors on Gantry or Pole	25	$ -	$ -	$ -		Each	$ 10,000
	Mast Arm Assembly w/ dynamic DLA and DSpL Signs	25	$ -	$ -	$ -		Each	$ 150,000
	Roadside DSpL Sign, Post, and Controller	25	$ -	$ -	$ -		Each	$ 20,000
	Camera Assembly	25	$ -	$ -	$ -		Each	$ 65,000
	Telecom/Power Duct Bank	25	$ -	$ -	$ -		Mile	$ 250,000
	Telecommunications (trunk to device)	25	$ -	$ -	$ -		Each	$ 40,000
	Power (trunk to device)	25	$ -	$ -	$ -		Each	$ 40,000
	On site Backup Generator / UPS	25	$ -	$ -	$ -		Each	$ 10,000
	TOTAL Incremental Cost			$ 50,000	$ 50,000			
INPUT	Enter Number of Infrastructure Deployments	1	**$ 380,000**					
INPUT	Enter Number of Incremental Deployments	1	**$ 50,000**					
INPUT	Enter Year of Deployment	2016						
	Average Annual Cost $ 430,000							

Figure 42. Screenshot. Cost estimation sheet in the Tool for Operations Benefit/Cost for the Oregon weather responsive active traffic management system.

The bottom of the cost sheet shows the number of infrastructure and incremental deployments, which depend on the extent of the VSL system. Since the VSL system was implemented only on OR 217, the number of infrastructure and incremental deployments was set to 1 each. Finally, the cost sheet shows an average annual cost of about $555,000 for the VSL deployment.

Benefits: This section describes the benefit estimation for the weather responsive VSL deployment. We made several assumptions for the benefit estimation. Figure 43 shows an extract from the VSL Benefit Estimation sheet within the Beta Version 1.2 of TOPS-BC and includes these default assumptions. Since the focus of TOPS-BC is on peak periods as opposed to the entire day, the length of the analysis period is set to three hours, as this constitutes a standard peak period in a metropolitan area. Subsequently, the link facility type is set to Type 2 – Urban Freeway. The total length of the link in the case study is 7.5 miles, based on information from Oregon DOT. The average number of lanes is set to 2.5; this is because the number of lanes on OR217 is 2, but auxiliary lanes are put in place between interchanges, which is why this analysis assumes half the capacity for the auxiliary lanes. The link capacity in the yellow cell is calculated by the tool based on the number of lanes, length of the analysis period, and the link facility type. Free flow speed is set to 60 instead of the standard value of 55, because the analysis assumes that the average roadway user exceeds the official speed limit on a regular basis and

Length of Analysis Period (Hours)	3	

Facility Characteristics

			Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Facility Type	Urban Freewa						
Link Length (Miles)	7.5						
Total Number of Lanes	2.5			2.5		2.5	0
Link Capacity (All Lanes - Per Period)		16500		16500		18150	1650
Free Flow Speed (MPH)	60	55					

Facility Performance

		Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Volume (Per Period)	15,675					
Congested Speed			44.428		48.298	3.870
Vehicles Miles Traveled (VMT)			117562.5000		117562.5000	0.0000
V/C			0.9500		0.8636	-0.0864
Vehicle Hours of Travel			2646.1386		2434.1292	-212.0095
Incident Related Delay (hours) per vehicle per mile			5.42391E-05		3.91877E-05	-1.50513E-05
Number of **Fatality** Crashes		1.86219E-04	7.75913E-04	1.79515E-04	7.47980E-04	-6.70388E-06
Number of **Injury** Crashes		1.95107E-02	8.12945E-02	1.69094E-02	7.04559E-02	-2.60125E-03
Number of **Property Damage Only** Crashes		2.47685E-02	1.03202E-01	2.14974E-02	8.95727E-02	-3.27109E-03
Fuel consumption (Gallons)			5533.9105		5533.9105	0.0000

Impacts Due to Strategy

Facility improvement models		
Change in Capacity (%)	10%	0%
Change in Speed (%)		0%
Change in # of Lanes		0
Reduction in Crash ***Rate*** *(%)*		15%
Reduction in Crash ***Duration*** *(%)*		0%
Reduction in Fuel Use (%)		0%
Traveler information models		
Percent time device is disseminating useful information		0%
Percent drivers using information		0%
Minutes saved by drivers saving time		0

Figure 43. Screenshot. Benefit estimation assumptions for the Oregon weather responsive active traffic management system.

ODOT provided similar information for this analysis. Finally, the link volume is set to 15,675 vehicles per period, analyzed in this write up.

The results of benefit and cost estimations are collected by TOPS-BC which is derived by calculating 95 percent of the link capacity. This assumption ensures that the traffic flow is heavy and close to the maximum capacity of the roadway structure for the peak period. Transportation demand management (TDM) simulations or traffic counts, if available, could be substituted for the flow estimate.

The crash values shown in the Facility Performance section include three different types of incidents: property damage only, injury, and fatality. TOPS-BC calculates the number of each incident type for all weather conditions, not just for adverse weather conditions. However, because the system being analyzed in Oregon is weather-responsive, these values had to be adjusted. Additional benefits could occur from the use of the other strategies mentioned earlier, but are not estimated here. For the purpose of this analysis, and based on a report by FHWA, it is assumed that 24 percent of incidents are related to adverse weather conditions.[58] Hence this analysis applies to 24 percent of property damage only, injury, and fatality incidents.

Finally, as a result of the implementation of all strategies in the ODOT ATM project, the assumption was made that these measures are going to free up 10 percent of additional capacity throughout peak periods. This is why the value of Change in Capacity in the Impacts due to Strategy section was set to 10 percent. Figure 43 shows the assumptions discussed above and gives an overview of what a benefit sheet within TOPS-BC looks like.

Model Run Results

This section summarizes the results of the BCA of the VSL project. Please note that this case study merely analyzes a specific set of costs and benefits for demonstration purposes. A full BCA will include a wide range of additional costs and benefits that are not separately listed or on a single page within the tool. This gives the user a concise overview of the all estimations and their results. This sheet is called *Summary of my Deployments* and provides a benefit cost summary. Figure 44 shows the benefit/cost summary for the weather responsive variable speed limit deployment in Oregon. Note that the heading states “transportation and demand management” because VSL falls into this category of traffic management and operations measures. As the exhibit shows, the benefits exceed the costs of this strategy alone, without considering the other five active transportation demand management strategies associated with the project. The BCA results in net benefits of about $1.52 million and a benefit cost ratio of 4.54. A more complete analysis would include all costs and benefits of the full Oregon DOT ATM deployment strategies on OR217.

[58] FHWA, *Road Weather Connected Vehicle Applications* (2013), available at http://ntl.bts.gov/lib/54000/54400/54480/Road_Weather_Connected_Vehicle_Applications_Benefit-508-v8.pdf.

Benefit/Cost Summary		
Annual Benefits		**Transportation and Demand Management**
Travel Time	$	1,867,536
Travel Time Savings: Non-Recurring Delay	$	15,587
Energy	$	0
Safety	$	70,177
Other	$	0
User Entered	$	0
Total Annual Benefits	**$**	1,953,300
Annual Costs	**$**	430,000
Benefit/Cost Comparison		
Net Benefit	**$**	1,523,300
Benefit Cost Ratio		4.54

Figure 44. Screenshot. Benefit cost analysis results for the Oregon weather responsive active traffic management system.

References

Oregon Department of Transportation, *OR217: Active Traffic Management* (2015). Available at: http://www.nascio.org/portals/0/awards/nominations2015/2015/2015OR6-Oregon-ODOT-2015%20-%20OR217%20ATM%20Project.pdf

FHWA, *Road Weather Connected Vehicle Applications* (2013), available at http://ntl.bts.gov/lib/54000/54400/54480/Road_Weather_Connected_Vehicle_Applications_Benefit-508-v8.pdf

ITS 2015 award nomination package, submitted by D. Mitchell, Regional Traffic Engineer (ODOT). “OR 217: Active Traffic Management,” for the Best New Innovative Product, Service, or Application category.

CASE STUDY 6.7 – VARIABLE SPEED LIMIT (CONNECTED VEHICLE APPLICATION)[59]

Strategy Type:	Decision Support, Control and Treatment
Project Name:	Variable Speed Limit (VSL) using Connected Vehicles (CV)
Project Agency:	Hypothetical Agency
Location:	Hypothetical State
Geographic Extent:	Statewide
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC) Beta CV

Project Technology or Strategy

The vision of intelligent vehicles has generated numerous concepts to control future traffic flow, one of which is the in-vehicle actuation of traffic control signals. Key to this concept is the use of intelligent vehicles as actuators for traffic control systems, replacing the traditional roadside systems. Traffic speeds are regulated through variable speed limit (VSL) gantries to resolve stop-and-go waves, while intelligent vehicles control accelerations to optimize their local driving situation specifically. In this scenario, each intelligent vehicle receives VSL commands from the traffic controller and implements them into its driving behavior. Simulations show that the connected VSL and vehicle control systems improve traffic efficiency and sustainability; for example, total time spent in the network and the average fuel consumption rate are reduced compared to scenarios with 100 percent human drivers and to scenarios with the same intelligent vehicle rates.[60]

Project Goals and Objectives

This case study shows how road-weather connected vehicle data can be used to activate VSL systems to provide real-time information on appropriate speeds for current conditions, as well as warn drivers of impending road weather events.

Methodology

Costs: We used the information from the 2013 *Road Weather Management Connected Vehicle Applications* report[61] to perform a benefit cost analysis (BCA) on the VSL application. Based on

[59] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

[60] Wang, Daamen, Hoogendoorn, van Arem, "Connected Variable Speed Limits Control and Vehicle Acceleration Control to Resolve Moving Jams," presented to the 94th Annual Meeting of Transportation Research Board, in Washington, D.C., January 2015. Available at: https://www.researchgate.net/publication/270892960_Connected_variable_speed_limits_control_and_vehicle_acceleration_control_to_resolve_moving_jams.

[61] FHWA, *Road Weather Management Connected Vehicle Applications*, FHWA-JPO-14-124. Available at http://ntl.bts.gov/lib/54000/54400/54480/Road_Weather_Connected_Vehicle_Applications_Benefit-508-v8.pdf.

this data, new cost line items were added to the existing cost sheet within TOPS-BC.[62] Figure 45 shows the different cost items that were added. The exhibit is taken from a spreadsheet within TOPS-BC that calculates the costs of specific CV strategies. Basic Infrastructure refers to the required common infrastructure investments to support multiple CV transportation system management and operations (TSMO) projects while the Incremental Deployment section includes cost items that are application-specific. The basic infrastructure and incremental deployment sections include estimated annualized costs, operations and maintenance costs, item-specific counts and the user-selected quantities used in this analysis.

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count	Unit Costs
Basic Infrastructure Equipment and Costs							
Urban Freeway RSE w/ wireline	25	$ 230,400	$ 5,760	$ 14,976	24	1 per Mile	$ 9,600
Urban Freeway RSE wireless	25	$ 1,948,800	$ 48,720	$ 126,672	96	1 per Mile	$ 20,300
Urban Signal RSE w/ wireline	25	$ 2,331,600	$ 58,290	$ 151,554	201	2/3 of signals	$ 11,600
Urban Signal RSE wireless	25	$ 17,951,500	$ 448,788	$ 1,166,848	805	2/3 of signals	$ 22,300
Rural Interstate w/ powergrid connection	25	$ 7,647,300	$ 191,183	$ 497,075	261	1 per 2 Miles	$ 29,300
Rural Interstate w/o powergrid connection	25	$ 2,411,500	$ 60,288	$ 156,748	65	1 per 2 Miles	$ 37,100
Application Development Costs	1	$ 191,746	$ -	$ 191,746	1	1 per Application	$ 191,746
System Integration & Backoffice	35	$ 25,886	$ 3,835	$ 4,575	1	1 per Application per TMC	$ 25,886
Vehicle On-Board Equipment	1	$ 4,800,000	$ 288,000	$ 5,088,000	48,000	1 per Vehicle	$ 100
TOTAL Infrastructure Cost		$ 37,538,732	$ 1,104,862	$ 7,398,192			
Incremental Deployment Equipment - Please See Chart on the Right for Application-Specific Information							
Vehicle Data Translator (This Item is RWM-specific only)	25	$ -	$ -	$ -		1 per TMC	$ 1,000,000
Maintenance Vehicle Costs	5	$ -	$ -	$ -		1 per Maintenance Vehicle	$ 30,000
Dynamic Message Sign	10	$ 4,100,000	$ -	$ 410,000	50	*VSL ONLY*	$ 82,000
Education & Outreach	1	$ 288,000	$ -	$ 288,000	6,400,000	1 per capita	$ 0.045
TOTAL Incremental Cost		$ 4,388,000	$ -	$ 698,000			
INPUT Enter Number of Infrastructure Deployments	1	$ 1,923,530					
INPUT Enter Number of Incremental Deployments	1	$ 698,000					
INPUT Enter Year of Deployment	2020						
Average Annual Cost		$ 2,621,530					

Figure 45. Screenshot. Annualized costs for variable speed limits for weather-responsive traffic management.

Since the case study CV deployments, including VSL, are assumed to take place in a hypothetical State, the distinction between necessary basic CV infrastructure investments and incremental or strategy-specific deployments needs to be clear. For the purpose of this analysis, each CV deployment BCA assumes that the respective State or metropolitan planning organization (MPO) needs to acquire both basic infrastructure and incremental or strategy-specific infrastructure. However, since the basic deployment investment supports many projects and strategies, only a portion of the total basic infrastructure cost is assigned to a specific CV technology. The percentage assumes that a set of CV technologies are deployed and the specific technology's basic infrastructure cost equals that technology's share of expected benefits in the set of deployed technologies. This cost assignment would vary depending on the full set of CV technologies deployed and supported by the basic infrastructure investment. For the VSL case study, the assumed percentage of total basic infrastructure costs is 26 percent.

The CV BCA report focused on the entire United States so for the individual CV case studies in this compendium the hypothetical State is assumed to have 2 percent (1 of 50 States) of the total

[62] FHWA, *Tool for Operations Benefit/Cost Analysis*, available at http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

U.S. population. The basic infrastructure quantities used in the analysis were derived from that assumption and are shown in Figure 45. When the new cost items are entered into TOPS-BC, the CV BCA report is used to identify which cost elements are needed to perform the appropriate cost analysis. If users want to analyze a specific connected vehicle application deployment strategy, the table allows for a quick identification of the cost items needed.

As illustrated in Figure 45, this CV application has several cost items that need to be taken into consideration when conducting a BCA. The following cost items were included in this case study:

- Urban freeway roadside equipment (wireline & wireless).
- Urban signal roadside equipment (wireline & wireless).
- Rural interstate equipment (with & without power grid connection).
- Application development.
- System integration and back office costs.
- On-board equipment on agency vehicles.

Figure 45 shows the cost sheet within TOPS-BC for this application. In addition to the basic infrastructure cost items mentioned above, the figure also shows quantities and dollar values for two cost items that are specific for this strategy:

- Variable speed limit sign (or dynamic message sign).
- Education and outreach.

Variable speed limit signs are necessary, since the speed limit will change depending on the weather and traffic conditions. For the hypothetical State, it is assumed that a total of 50 variable speed limit signs will be necessary throughout the network.

Education and outreach are necessary to inform the public about the implementation of the strategy. It is calculated on a per capita-basis, which means a cost occurs for every individual in the service area. Since the hypothetical State is assumed to have 2 percent of the U.S. population, this analysis uses the value of 6.4 million inhabitants, assuming that the U.S. population is 320 million.

Finally, the number of infrastructure and incremental deployments were each set to 1, because the extents of the roadway structure for the entire CV system and for this particular strategy area already considered in the quantities shown in every cost line. The VSL system is assumed to be operational in 2020. As Figure 45 shows, these assumptions result in annualized costs of about $2.62 million.

Benefits: In order to estimate the benefits of VSL strategy, we utilized again the data from the CV BCA report. According to these data, the effectiveness of this strategy is estimated to be 2 percent in the summer and 13 percent in the winter. This means that crashes are likely to be reduced by 2 percent and 13 percent in summer and winter respectively when the strategy is in place. Alongside this assumption is the assumed increase in capacity due to a lower amount of incidents that slow down traffic. The report set this number to 10 percent for all applications.

Furthermore, crashes include three different types of incidents: property damage only, injury and fatality. Since TOPS-BC calculates the number of each of these types of incidents for all weather conditions and not just for adverse weather conditions, these values needed to be adjusted. For the purpose of this analysis, and based on the CV BCA report, it is assumed that 24 percent of incidents are related to adverse weather conditions. Hence this analysis applies to 24 percent of property damage only, injury, and fatality incidents.

TOPS-BC is a sketch-planning level tool that calculates one distinct set of assumptions at a time. Since the levels of effectiveness vary between summer (2 percent) and winter (13 percent), the model is run twice for this application. Figure 46 shows the CV benefit sheet within the tool and the set of assumptions for this case study, including the rate of effectiveness for the summer. There is no specific figure included in this case study showing the winter rate of effectiveness, since the 2 percent value in Figure 46 was merely changed to 13 percent. Adjusted property damage only, injury and fatality values were input into the green cells in the Facility Performance section of the tool. The user can change the green cells and override the values calculated by TOPS-BC. The capacity increase and crash reduction assumptions were used below the section Impacts due to Strategy. These values were also used in the green cells, since TOPS-BC regularly does not consider any changes in capacity and uses a different crash reduction rate. For this reason, the given data within the tools were overridden.

Finally, Figure 47 shows the lower half of the CV benefit estimation page for the summer assumptions. It includes additional sections on travel time, energy and other safety benefits. The user is able to refine any TOPS-BC calculation using these sections in case more specific data is available. Through this flexible user interface, the user can generate more refined and accurate results. The total average annual benefit is calculated automatically by TOPS-BC and can be found at the bottom of the benefit estimation sheet. The total annual benefit for this summer application is $13.2 million. The winter application yields an annual benefit of $13.52 million. For this case study, the average between these two numbers is used. The average annualized benefit for this application is $13.37 million.

Strategy: Road Weather Management Connected Vehicle Applications

Length of Analysis Period (Hours)	3	

Facility Characteristics

	Input	Default	Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Facility Type	Urban Freewa 2						
Link Length (Miles)	100						
Total Number of Lanes	2			2		2	0
Link Capacity (All Lanes - Per Period)		13200		13200		14520	1320
Free Flow Speed (MPH)	65	55					

Facility Performance

	Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Volume (Per Period) 11,880					
Congested Speed		50.864		54.146	3.282
Vehicles Miles Traveled (VMT)		1188000.0000		1188000.0000	0.0000
V/C		0.9000		0.8182	-0.0818
Vehicle Hours of Travel		23356.5295		21940.8197	-1415.7099
Incident Related Delay (hours) per vehicle per mile		4.24545E-05		4.07733E-05	-1.6812E-06
Number of **Fatality** Crashes	1.88179E-03	7.84080E-03	1.87276E-03	7.80316E-03	-9.03260E-06
Number of **Injury** Crashes	1.93026E-01	8.04276E-01	1.58227E-01	6.59281E-01	-3.47988E-02
Number of **Property Damage Only** Crashes	2.38503E-01	9.93762E-01	2.09784E-01	8.74102E-01	-2.87185E-02
Fuel consumption (Gallons)		55921.6216		55921.6216	0.0000

Impacts Due to Strategy

	Input	Default
Facility improvement models		
Change in Capacity (%)	10%	0%
Change in Speed (%)		0%
Change in # of Lanes		0
Reduction in Crash ***Rate*** *(%)*	2.0%	15%
Reduction in Crash ***Duration*** *(%)*		0%
Reduction in Fuel Use (%)		0%
Traveler information models		
Percent time device is disseminating useful information		0%
Percent drivers using information		0%
Minutes saved by drivers saving time		0

Figure 46. Screenshot. Benefit estimation assumptions for variable speed limits for weather-responsive traffic management (summer season).

Travel Time	Average Person Hours of Travel Saved per Period		2364.2355
	$ Value of Person Hour (per hour) "On-the-Clock" Auto	$ 32.46	
	$ Value of Person Hour (per hour) Other Auto	$ 16.23	
	$ Value of Vehicle Hour (per hour) Truck	$ 32.46	
	Total Recurring Travel Time Benefit per Period		$ 49,882.46
ATIS Time Savings	Total hours saved due to ATIS deployments		0.00
Travel Time Savings: Non-Recurring Delay	Average Total Person Hours of Non-Recurring Delay Saved per Period		3.3354
	alue of Person Hour (per hour of ***Delay***) "On-the-Clock" Auto	$ 32.46	
	$ Value of Person Hour (per hour of ***Delay***) Other Auto	$ 16.23	
	$ Value of Vehicle Hour (per hour of ***Delay***) Truck	$ 32.46	
	Total Non-Recurring Delay Benefit per Period		$ 70.37
Energy	Average cost per gallon of fuel (excluding taxes)	$ 4.25	
	Total Fuel Savings Benefit		$ -
Safety	$ Value of a Fatality Crash	$ 10,433,467	
	$ Value of a Injury Crash	$ 77,671	
	$ Value of a Property Damage Crash	$ 2,666	
	Total Modeled Crash Related Benefit per Period		$ 2,874
	User Entered Benefit (Annual $'s)		
	Number of Analysis Periods per Year	250	
	TOTAL AVERAGE ANNUAL BENEFIT		$ 13,206,629

Figure 47. Screenshot. Benefit estimation result for variable speed limits for weather-responsive traffic management.

Model Run Results

Finally, the analysis compares the benefits calculation with the cost calculations. This case study merely analyzes a specific set of costs and benefits for demonstration purposes. A full benefit cost analysis will include a wide range of additional costs and benefits that are not separately listed or analyzed in this case study, such as environmental benefits, energy savings, and vehicle operating cost reductions.

Figure 48 shows the section of TOPS-BC that compares benefits and costs for the CV variable speed limit strategy. The exhibit indicates that the deployment of a variable speed limit in a hypothetical State, all assumptions considered, is cost effective, since the resulting BCR for the strategy is 5.04. The resulting net benefits for this analysis are about $10.59 million.

Benefit/Cost Summary		
Annual Benefits		**CV Variable Speed Limit**
Travel Time	$	12,470,615
Travel Time Savings: Non-Recurring Delay	$	17,593
Energy	$	0
Safety	$	718,500
Other	$	0
User Entered	$	
Total Annual Benefits	**$**	13,206,629
Annual Costs	**$**	2,621,530
Benefit/Cost Comparison		
Net Benefit	**$**	10,585,099
Benefit Cost Ratio		5.04

Figure 48. Screenshot. Results for connected vehicle variable speed limit strategy.

CHAPTER 7. CASE STUDIES FOR WEATHER RESPONSE OR TREATMENT

Table 28. Case studies for weather response or treatment.

#	Case Name	Benefit/Cost Analysis Model	Actual or Hypothetical Case
7.1	Maintenance Decision Support System Implementation: The City and County of Denver	Custom Benefit/Cost Analysis Model – "with-without" Analysis	Actual
7.2	Pooled Fund Maintenance Decision Support System Implementation	Custom In-House Analysis	Actual
7.3	Hypothetical Maintenance Decision Support System Implementation	Tool for Operations Benefit/Cost	Hypothetical
7.4	Washington's Automated Anti-icing System Study	Washington Department of Transportation Benefit/Cost Worksheet for Collision Reduction	Actual
7.5	Bridge Prioritization for Installation of Anti-icing Systems in Nebraska	Custom Benefit/Cost Analysis Model	Actual
7.6	De-icing in Iowa	Tool for Operations Benefit/Cost	Hypothetical
7.7	Evaluation of North Dakota's Fixed Automated Spray Technology Systems	Custom In-House Analysis	Actual
7.8	Automatic Vehicle Location System Deployment in Kansas	Custom In-House Analysis	Actual
7.9	Hypothetical Study of the Use of Automatic Vehicle Location for Highway Maintenance Activities	Tool for Operations Benefit/Cost	Hypothetical
7.10	Enhanced Maintenance Decision Support System using Connected Vehicles	Tool for Operations Benefit/Cost Beta Connected Vehicle	Hypothetical

Note: Use the hyperlinks in this table to jump directly to the case study.

CASE STUDY 7.1 – MAINTENANCE DECISION SUPPORT SYSTEM IMPLEMENTATION: THE CITY AND COUNTY OF DENVER[63]

Strategy Type:	Weather Response or Treatment
Project Name:	A Maintenance Decision Support System (MDSS) Implementation: the City and County of Denver (C/C Denver)
Project Agency:	C/C Denver
Location:	Urban Setting Covered by C/C Denver
Geographic Extent:	Six Selected Work Districts (1780 Lane Miles)
Tool Used:	Custom Benefit Cost Analysis (BCA) Model – “with-without MDSS” Analysis

Project Technology or Strategy

MDSS usage has begun to extend beyond State departments of transportation (DOT) to include local agencies. This is appropriate, considering that there is an increasing trend in local expenditures and all local agencies combined spend more than all State DOTs on snow and ice removal activities. C/C Denver faces many of the same challenges as other local agencies around the country, including budgetary and technological constraints. Nevertheless, their street maintenance division was eager to participate in an evaluation of their use of an MDSS and learn ways to enhance their winter operations and make better use of the MDSS tool throughout their jurisdiction. A Federal prototype MDSS is being used by C/C Denver as a tool to assist their maintenance operations in forecasting road-weather conditions in their area and providing treatment recommendations.

Project Goals and Objectives

This example presents the actual results of a BCA for the use of MDSS by the City and County of Denver, Colorado over two winter periods: 2007-2008 and 2008-2009. In order to provide comparable benefits and costs within the analysis, C/C Denver carefully selected key MOEs to primarily focus on benefits to the implementing agency, including labor, equipment, and material savings. In this case we demonstrate how the agency used the available information and created a simple spreadsheet model the conduct the BCA. FHWA has developed a similar system, TOPS-BC, which provides a wealth of cost and benefit information along with the computations needed to estimate net present values and benefit cost ratios (BCR).

Figure 49 shows a benefit cost framework for focusing the evaluation of the BCA in terms of the primary pathways by which benefits and costs are expected to be experienced by C/C Denver. The area inside the red dotted box represents the costs and benefits evaluated by the agency in the BCA.

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[63] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

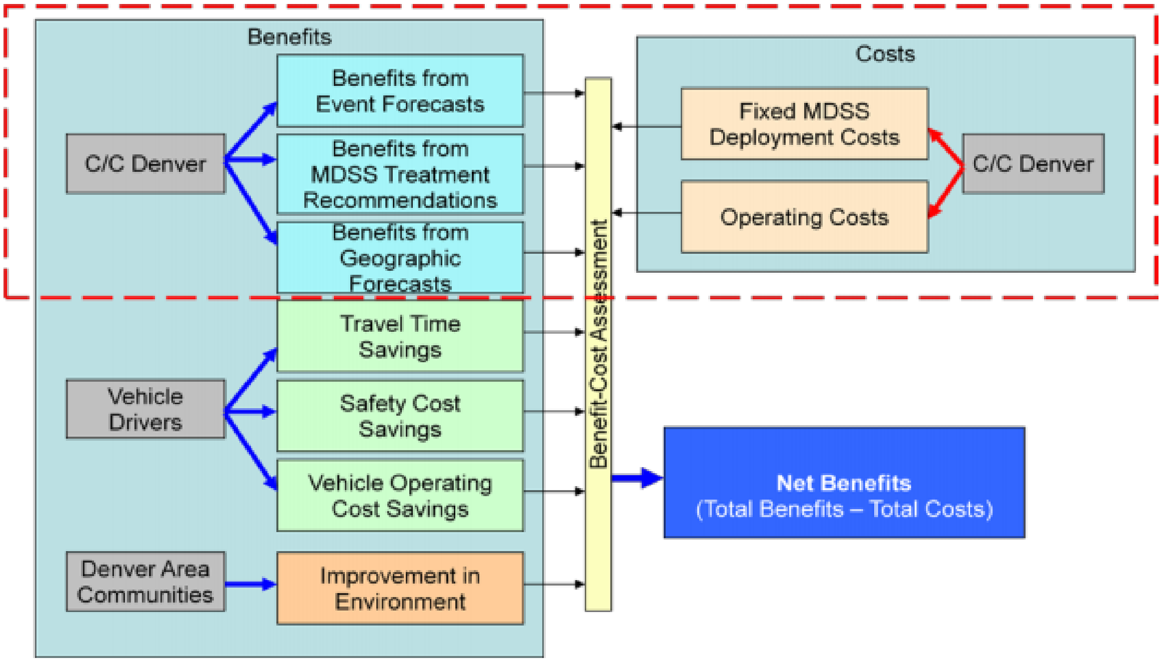

Figure 49. Diagram. The benefit cost analysis pathways framework.

Methodology

The evaluation was designed to be a "with-without MDSS" analysis intending to quantify the two benefit areas: (1) those resulting from atmospheric and pavement forecasts, and (2) those resulting from treatment recommendations.

The first benefit area examined tactical forecasts that are made prior to a storm event to indicate the expected start time of the storm and other attributes. Tactical decisions are initially made 24 to 48 hours before the event (at the snow meeting with the management staff) and during each shift.

Evaluation Hypothesis #1 **-** *By using the MDSS forecasts as a tactical decision support tool, C/C Denver will achieve reductions in shift hours or eliminate shift call-ins, thereby reducing labor hours and associated costs for winter maintenance.*

Over the past two winters combined, 69 snow events were tracked and reported by C/C Denver. MDSS forecasts were used for 56 of those events. For 13 events in the past two winters, MDSS was not used either because computer server problems prevented access to MDSS information, or C/C Denver supervisors were not able to compile the information. In the previous winter, MDSS was used for all but three events.

The evaluation design for assessing the second benefit area of the MDSS in offering treatment recommendations was a "with-without" design based on identified experimental plow routes on which crews used the MDSS forecasts and treatment recommendations and a matched set of control routes on which C/C Denver conducted operations without the use of the MDSS. Several major routes were selected where C/C Denver would follow the MDSS treatment recommendations to the best extent possible without jeopardizing public safety. The condition of selected experimental route segments where the MDSS would be used to guide treatments would then be compared with control route segments where treatments were determined using the existing procedures based on driver and supervisor decisions.

Evaluation Hypothesis #2 **-** *By using the MDSS updates and treatment recommendations, C/C Denver 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 conducted three times during the winter of 2008-2009. While ideally an entire winter of testing was desired, C/C Denver was able to complete the standard operating procedures for the evaluation design by January 20, 2009. Subsequent to that date, only seven events occurred, and most of them required primarily spot treatments rather than extended material use. The BCA model runs found that the treatment recommendations had minimal and inconclusive effects on C/C Denver's treatment strategies.

Model Run Results

The study team reviewed data from previous winter events, some when MDSS was fully operational and others when it was not. By studying the crash and travel outcomes as well as agency operation costs, researchers assigned costs and benefits to individual events with and without MDSS. Benefits were realized primarily by reductions in labor hours due to the tactical decision support offered by the MDSS, including the deployment of road crews, equipment, and materials. No benefits were realized by the MDSS in the treatment aspect. Overall, the treatment recommendations had minimal and inconclusive effects on C/C Denver's treatment strategies. Three tests revealed three different results across the control and experimental districts. The results from these three tests were not published.

Costs include one-time set-up costs and annual contract costs for the MDSS. Benefits and costs were adjusted to constant 2009 dollars using inflation rates from the Bureau of Labor Statistics. The budget cycle for C/C Denver is based on the calendar year, so benefits and costs reported are for events in specified calendar years.

Overall, the MDSS provided a net positive benefit cost trade-off, with the average annual benefits exceeding the costs. For every $1.00 that C/C Denver spent on the MDSS, it achieved $1.34 in return. The C/C Denver gained a net benefit (Net Benefit = Total Benefit - Total Costs) of $24,304 per year from the use of the MDSS.

Table 29 shows the overall net benefits of using the MDSS for C/C Denver. The costs and the benefits are in 2009 dollars and are based on the calendar year in which they were incurred. Costs incurred in 2006 include one-time system setup, calibration, and hardware costs. This savings is equivalent to about 10 percent of C/C Denver's discretionary overtime budget for the year, and management believes this more than justifies the investment in the MDSS.

Table 29. Net benefit calculation for maintenance decision support system (2009 dollars).

Costs and Savings	Year Incurred	Adjusted Dollars (2009)
System Costs Incurred by Agency (Current $)		
$82,315	2006	$90,769
$60,282	2007	$64,970
$55,295	2008	$57,424
Average Annual Cost	n/a	**$71,054**
Savings per Calendar Year due to MDSS (Current $)	**Year Incurred**	**Adjusted Dollars (2009)**
$62,000	2007	$66,222
$119,880	2008	$124,459
Average Annual Benefit	n/a	**$95,359**

n/a = not applicable.

Overall, C/C Denver found the MDSS to offer them valuable guidance in their efforts to fine tune their maintenance decisions before and during storms, and they fully intend to continue their investment in the MDSS into the future.

Key Observations

C/C Denver worked closely with the evaluation team and with the developer of the prototype MDSS, in their use of the MDSS over the past two winter periods to inform C/C Denver's winter road maintenance decisions and actions. The findings of this BCA pointed to a clear set of benefits, along with real cost savings, that strongly justify the value not only to State DOTs but also local DOTs of having an MDSS among the suite of tools and services they rely upon to support their road maintenance decisions. Although not directly assessed in this BCA, the benefits at the agency level that have been identified 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, this BCA provides an evaluation structure and insight into the effective uses of an MDSS in an urban setting that may be of value to other local agencies similar to C/C Denver.

Reference

Research and Innovative Technology Administration, *Benefit–Cost Assessment of a Maintenance Decision Support System (MDSS) Implementation: The City and County of Denver*, FHWA-JPO-10-018 (Washington, D.C.: 2009). Available at: http://ntl.bts.gov/lib/33000/33100/33156/denver_mdss_bca_report_final.pdf

CASE STUDY 7.2 – POOLED FUND MAINTENANCE DECISION SUPPORT SYSTEM IMPLEMENTATION[64]

Strategy Type:	Weather Response or Treatment
Project Name:	Maintenance Decision-Support System (MDSS) Pooled Fund Study
Project Agency:	South Dakota Department of Transportation (DOT)
Location:	Highways
Geographic Extent:	New Hampshire, Minnesota, Colorado
Tool Used:	Custom In-house Analysis

Project Technology or Strategy

Sixteen States have joined the MDSS Pooled Fund Study led by the South Dakota DOT to develop an enhanced maintenance decision-support system (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 winter operations at transportation agencies.

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.

[64] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

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 measures of effectiveness to focus primarily on benefits to the implementing agency and ultimate users, including:

- Reduced Material Use (Agency Benefit).
- Improved Traffic Safety (User Benefit).
- 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 30.

Table 30. Benefit and cost categories expected from a 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**		

Note: Bold indicates factors included in methodology.
LOS = level of service.

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.
- 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 50. The simulation outputs from selected route segments were extrapolated to other route segments in each State to achieve a statewide BCA.

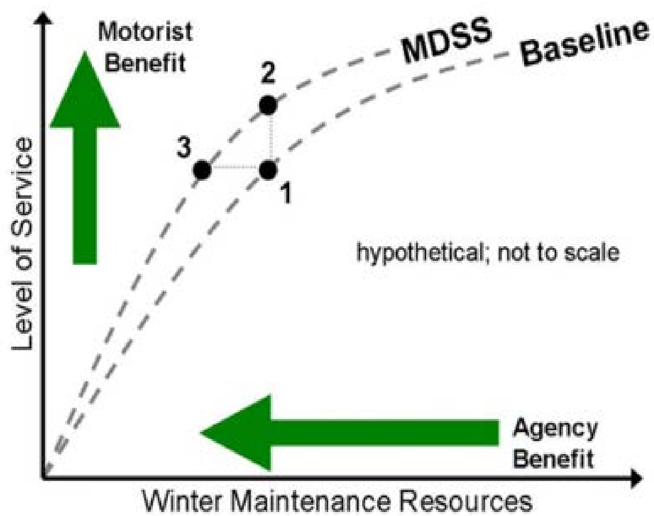

Figure 50. Graph. Benefit cost methodology and relationship between level of service and costs.

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 31. 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 31. Maintenance decision support system benefit cost summary.

Case State	Scenario	Benefits	User Savings (%)	Agency Savings (%)	Costs	Benefit Cost 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

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 50) than the other two cases. Thus, Table 31. Maintenance decision support system benefit cost summary 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.

Reference

South Dakota DOT, *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs*, SD2006-10-F (SDDOT: May 12, 2009). Available at: http://trid.trb.org/view.aspx?id=915012

CASE STUDY 7.3 – HYPOTHETICAL MAINTENANCE DECISION SUPPORT SYSTEM IMPLEMENTATION[65]

Strategy Type:	Weather Response or Treatment
Project Name	Maintenance Decision Support System (MDSS) Implementation
Location:	Urban Setting
Geographic Extent:	Statewide
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC) for Life Cycle Cost and Benefit Cost Analysis

Project Technology or Strategy

Several State departments of transportation (DOT) and municipal public works departments have deployed 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 benefit cost analysis (BCA) is to demonstrate how the TOPS-BC tool could support a road weather management (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.

<u>Evaluation Hypothesis #1</u> **–** *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.*

<u>Evaluation Hypothesis #2</u> **–** *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.*

[65] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

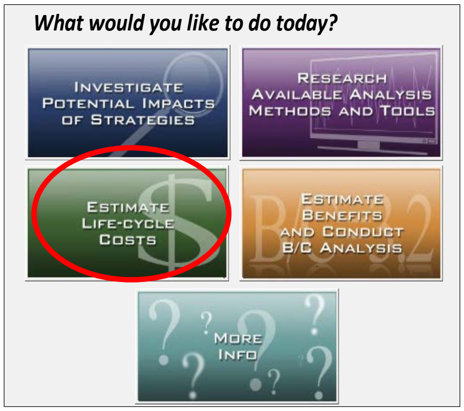

Figure 51. Screenshot. Tool for Operations Benefit/Cost start page – estimate life-cycle costs function.

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 for 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.

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 available information on the specific project or locate cost information on the FHWA Intelligent Transportation Systems (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

Figure 52. Screenshot. Tool for Operations Benefit/Cost navigation column for estimating costs – road weather management strategies.

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 an automatic vehicle location (AVL) technology to support the maintenance vehicle fleet as shown in Figure 53, 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.

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**

Figure 53. Screenshot. Tool for Operations Benefit/Cost cost table edited for maintenance decision support system cost inputs.

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 the 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.

Figure 54. Screenshot. Tool for Operations Benefit/Cost navigation column for estimating benefits – road weather management strategies.

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.0			
Estimate Benefits of TSM&O Strategies			
Strategy: Road Weather Management			
User Entered Benefit (Annual $'s)	$ 100,000.0		
Number of Analysis Periods per Year		250	
TOTAL AVERAGE ANNUAL BENEFIT			$ 100,000
Length of Analysis Period (Hours)	1		

Figure 55. Screenshot. Bottom of road weather management benefit spreadsheet.

Model Run Results

Now go back to the far left Navigation Column (Figure 56) and select, "My Deployments." In the middle of the sheet you will see the results as shown in Table 32.

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.

Figure 56. Screenshot. Tool for Operations Benefit/Cost navigation column for estimating benefits – my deployments.

Table 32. Benefit costs summary from the Tool for Operations Benefit/Cost “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	**2013**	**2014**
Active Strategies		
Road Weather Management	$100,000	$38,395

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.

Reference

Research and Innovative Technology Administration, *Benefit–Cost Assessment of a Maintenance Decision Support System (MDSS) Implementation: The City and County of Denver*, FHWA-JPO-10-018 (Washington, D.C.: 2009). Available at: http://ntl.bts.gov/lib/33000/33100/33156/denver_mdss_bca_report_final.pdf

CASE STUDY 7.4 – WASHINGTON'S AUTOMATED ANTI-ICING SYSTEM STUDY[66]

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)

Project Technology or Strategy

To address weather-related crashes on a section of Interstate 90 near Vantage, Washington, 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 transportation system management and operations (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 benefit cost analysis (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 measures of effectiveness in the BCA to be Safety.

[66] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

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. **It was estimated that 80 percent of the snow, ice, and wet pavement crashes would be eliminated.**[67] 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 and 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

[67] 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 to 80 percent of snow and ice crashes.

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 using a spreadsheet incorporating the present worth factor of a uniform series, as shown in Figure 57. The calculated cost benefit 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: 5. Annual Safety Benefits by Costs of Collision:

Collision Type	Cost			
a) Fatality	$ 800,000	a) (3a)(4a)	=	0
b) Disabling Injury	$ 800,000	b) (3b)(4b)	=	213,333
c) Evident Injury	$ 62,000	c) (3c)(4c)	=	16,533
d) Possible Injury	$ 33,000	d) (3d)(4d)	=	17,600
e) Property Damage Onl	$ 5,800	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

Figure 57. Screenshot. Washington State Department of Transportation 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.

Reference

Robert Stowe, "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, D.C., January 7-11, 2001.

CASE STUDY 7.5 – BRIDGE PRIORITIZATION FOR INSTALLATION OF ANTI-ICING SYSTEMS IN NEBRASKA[68]

Strategy Type:	Weather Response or Treatment
Project Name:	Nebraska's Bridge Prioritization for Installation of Automatic Anti-icing Systems Study
Project Agency:	The Nebraska Department of Roads (NDOR)
Location:	Bridges
Geographic Extent:	Statewide
Tool Used:	Custom Benefit Cost Analysis (BCA) Model

Project Technology or Strategy

During severe winter conditions, bridges freeze before the surrounding roadways, often catching unsuspecting drivers off guard. To mitigate this issue, the NDOR evaluated installing automatic bridge deck anti-icing systems on various bridges statewide. Bridge deck anti-icing systems are one type of the road weather treatment strategies, which supply de-icing liquid chemicals to bridge decks when icing conditions are detected, thereby preventing moisture from freezing on the bridge deck.

Project Goals and Objectives

The NDOR was interested in installing automatic bridge deck anti-icing systems as a safety enhancement. However, the presence of 2,193 bridges in Nebraska and the limited availability of funding created a need for prioritization in installing automatic anti-icing systems. Therefore, the NDOR along with the University of Nebraska-Lincoln initiated the BCA to prioritize bridges for the installation of anti-icing systems, with the objective of developing a decision-aid tool that could aid NDOR with the prioritization of bridges for most effective installation. As part of the process, NDOR selected accidents avoided as the key measure of effectiveness, and cost estimation was based on the purchase price of such systems.

Methodology

To achieve the project objective, NDOR extensively reviewed literature on automatic bridge deck anti-icing systems as well as the experiences of various transportation agencies with such systems. Based on this review, a two-step methodology was developed to guide the construction of an appropriate database and the development of the decision-aid tool for bridge prioritization. Data from diverse sources were integrated in a geographic information system (GIS) to construct the needed database and a benefit cost method was conducted as the decision-aid tool.

Figure 58 presents the methodology used for database construction from various sources and development of the decision-aid tool. Database construction was accomplished in a GIS while the decision-aid tool was developed in a spreadsheet. The data utilized included bridge

[68] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

inventory, State accident data, weather information, traffic information, maintenance yard information, and Nebraska streets, rivers, and streams data. Additional elements were added to the integrated data to enhance its effectiveness for use by the decision-aid tool, which utilized the integrated database to provide prioritized lists of candidate bridges for the installation of automatic bridge deck anti-icing systems.

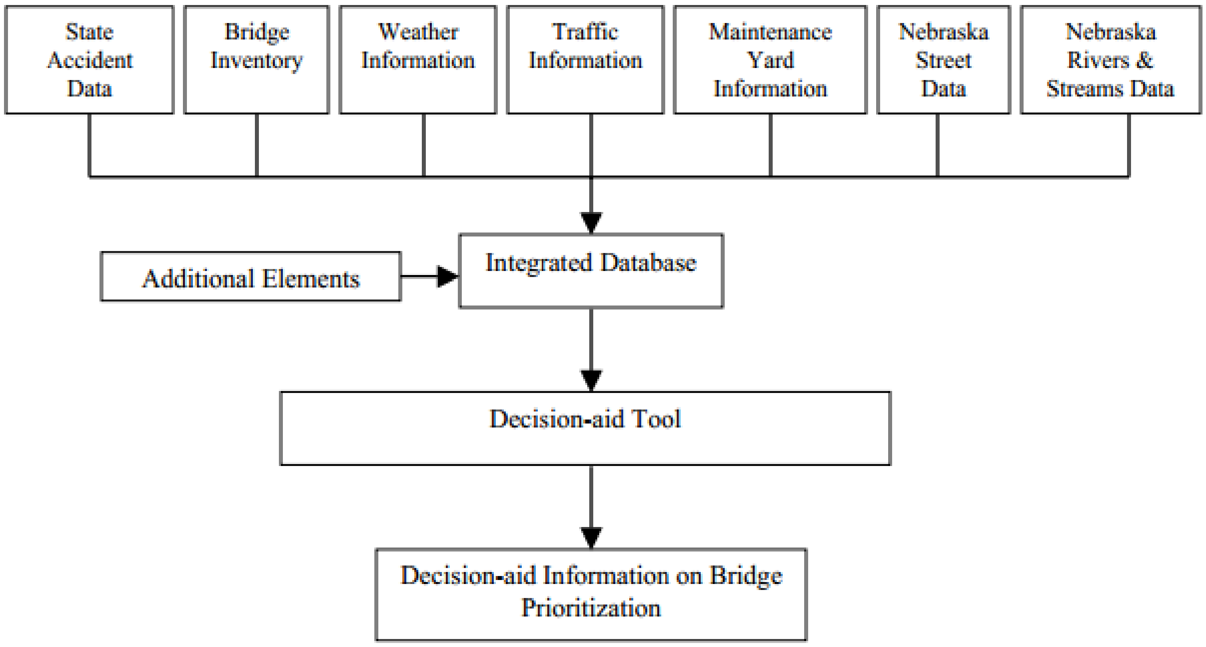

Figure 58. Diagram. Adopted research methodology.

In the BCA, bridges were prioritized based on the ratio of benefits generated from the installation of anti-icing systems and the associated costs. Bridges with higher benefit cost ratios were given higher priorities. Benefits and costs were quantified in monetary terms; estimation of benefits involved looking at avoided accidents due to installation of automatic anti-icing systems while estimation of costs was based on the purchase cost of such systems. Based on information gleaned from the literature, it was assumed that installation of anti-icing systems would result in a 60 percent reduction in accidents. Benefits were then calculated by using accident costs for different injury levels. Avoided traffic delays due to fewer accidents would also contribute to benefits; however, data required to estimate traffic delays due to accidents were not readily available and, therefore, benefits from avoided traffic delays were not included in this method.

Amongst the various criteria considered important in the installation of automatic anti-icing systems, the prioritization by simple accident frequency provided the most realistic and useful results for Nebraska. As such, the decision-aid tool was modified to first limit candidate bridges to those that experienced 13 or more accidents during the study period and then prioritized those bridges on simple accident frequency.

Model Run Results

Using the BCA model, NDOR examined the experiences of several transportation agencies that deploy such systems. It found that:

- In Minnesota, the installation of automatic anti-icing systems reduced crashes at three sites:
  - Interstate 35 Bridge near Duluth by 56 percent. The benefit- cost ratio was 2.0:1.
  - Truck Hwy 61 Bridge near Winona by 100 percent. The benefit- cost ratio was 3.1:1.
  - An intersection in Dresbach by 100 percent. The benefit-to-cost ratio was 2.7:1.
- In Minnesota, another anti-icing system installed on I-35W at the Mississippi River Bridge resulted in a 68 percent reduction in winter season crashes and a benefit cost ratio of 3.4:1.

In summary:

- Accident frequency reduction varies from 25 to 100 percent.
- Benefit Cost ratios of such systems are in the range of 1.8:1 to 3.4:1.

Finally, NDOR generated two priority lists, one each for Omaha and non-Omaha bridges, based on this method. NDOR will consider bridges at the top of these lists for the installation of automatic bridge deck anti-icing systems.

Key Observations

Through the BCA, the Nebraska study proved that the bridge deck automatic anti-icing system technology has the potential to reduce accidents on bridge decks statewide significantly. In the end, NDOR used a relatively straightforward ranking by accident frequency in the production of the two priority lists of candidate bridges. The major benefit of these systems was crash reduction and consequent improvement in travel times. Lacking data and a modeling framework that would incorporate benefits other than crash reduction, NDOR opted for a process that only considered crash frequency. Such a decision system may prove functional for NDOR, but as resources continue to be limited, NDOR may want to include these other benefits in its decision process. Instruments like the Intelligent Transportation System Deployment Analysis System, the Tool for Operations Benefit/Cost and the Clear Roads BCA Toolkit now offer user-friendly systems to support the inclusion of all identified agency and user benefits in the deployment decision process.

The bridge deck automatic anti-icing systems were experimental in Nebraska. The methodology and database integration processes presented in this case should be useful to transportation agencies contemplating installation of similar anti-icing systems for highway mobility and safety enhancement.

Reference

Khattak, A.P., Geza Pesti. "Bridge Prioritization for Installation of Automatic Anti-icing Systems in Nebraska," Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Iowa State University, August 2001.

CASE STUDY 7.6 – DE-ICING IN IOWA[69]

Strategy Type:	Weather Response or Treatment
Project Name	De-icing
Project Agency:	Iowa Department of Transportation (DOT)
Location	Iowa State
Geographic Extent:	Statewide
Tool Used:	Clear Roads Benefit Cost Analysis (BCA) Toolkit

Project Technology or Strategy

De-icing is the practice of removing snow, ice and slush from a roadway surface. De-icers are employed (along with plowing) in this process to melt existing snow and ice, as well as to prevent snow and ice from forming a bond/freezing to pavements. De-icers can take on either a solid (granular) or liquid form. De-icer materials include road salt, calcium chloride, calcium magnesium acetate (CMA), magnesium chloride, potassium chloride, sodium acetate, and others. Additionally, some agencies employ abrasives, such as sand or similar grit materials, to improve surface friction; these materials do not however, perform a de-icer function (unless combined with a de-icer product, such as road salt).

According to the Iowa DOT, the State uses rock salt as the primary material to combat winter storms. The department uses approximately 200,000 tons of rock salt annually to keep Iowa highways clear of snow and ice. De-icing material is deployed using trucks.

Project Goals and Objectives

To determine cost-effective strategies for winter maintenance practices, equipment and operations agencies must quantify the value of each strategy's benefits and compare it to the costs of implementation. The Clear Roads Pooled Fund tool kit was developed to facilitate and streamline BCA for various winter maintenance strategies. The Clear Roads pooled fund project began in early 2004 in response to a need for real world testing in the field of winter highway operations. This ongoing research program has already attracted 26 member States and is funding practical, usable winter maintenance research.

The following case study, reproduced and adapted with permission from the Clear Roads Pooled Fund's *Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations: User Manual*, presents the results of a BCA completed with the toolkit for de-icing operations.[70]

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[69] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

[70] David Veneziano, Xianming Shi, and Lisa Ballard, Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations: User Manual" (Clear Roads Pooled Fund: November 2010). Available at: http://clearroads.org/cba-toolkit/documents/user-manual/user-manual.pdf. Additional information on the Clear Roads Pooled Fund and resources are available at http://clearroads.org.

Methodology

For this example, data provided by the Iowa DOT will be employed. Table 33 represents the basic project parameters information that the user must have available for input during the course of the evaluation.

Table 33. Sample de-icing project parameters.

Discount Rate	7.0 %
Analysis period	10 years
Number of equipped trucks	900
Total trucks	900
Number of facilities (sheds/garage) with brine making infrastructure	0
Loaded labor cost per hour (shop rate)	21
Average labor hours per storm event per vehicle	12
Average labor hours per storm to produce materials	0
Annual hours per vehicle to maintain de-icing-specific equipment	10
Annual number of storm events	20
Average de-icer application rate (tons or gallons per lane mile)	0.050
Lane miles covered per storm (all trucks)	24,867

To begin, the user will select the "Anti-icing" link under the Operations heading on the Technology Selection page. This is displayed in Figure 59.

Project Parameters

Once anti-icing has been selected for evaluation, the user will be directed to the Project Parameters page. Here the user will define basic information for report purposes, including their name, their agency, and a brief project description. Note that certain items are set to default values, including the date, discount rate (7 percent), and life cycle (5 years in this example, although the toolkit defaults to a life cycle of 12 years). However, the user is encouraged to employ the values presently of their respective agency. For this example, the 7 percent rate and 5-year life cycle will be employed, as they are reasonable for demonstration purposes.

Figure 59. Screenshot. Clear Roads benefit-cost analysis tool anti-icing selection.

Note that when establishing an interest rate and service life for an item, different approaches will yield different benefit cost ratios. For example, if a low interest rate and longer life are employed/assumed for an item, a higher benefit cost ratio will typically result. The same is true for when a high interest rate and long life are employed, as the costs and benefits of that item are being accrued over a longer time frame. Conversely, when a high or low interest rate is combined with a short life for an item, benefit cost ratios will fall.

In addition to basic reporting information, this page also requires the user to enter specific data input parameters for later calculations. These include:

- **Number of equipped trucks**. In this example, four trucks will be equipped for anti-icing.
- **Total number of trucks**. For this example, there is a total fleet of 23 trucks.
- **Number of brine-making facilities**. For this example, there will be one facility.
- **Loaded labor cost**. For this example, the loaded labor cost is $14.42.
- **Average labor hours per storm**. For this example, an assumed labor hours per storm figure of 12 hours is employed.
- **Current annual material cost (de-icing activities only)**. For this example, the current cost of materials is $320,673.
- **Hours to produce brine material**. For this example, an average of 2 hours per brine batch is used.
- **Hours spent annually maintaining anti-icing equipment per vehicle**. For this example, a figure of 25 hours is used, based on practitioner feedback.
- **Annual number of storm events**. For this example, an assumed value of 12 events is employed.
- **Anticipated anti-icer application rate (gallons per mile)**. For this example, an assumed value of 50 gallons per mile is used.
- **Lane miles covered by jurisdiction**. For this example, the total lane miles covered by this subdistrict is 679.
- **Annual number of storm related crashes**. For this example, a total of 0 crashes is employed.
- **Average crash cost**. For this example, the cost of $33,700 is employed.

These various data items are entered into their respective places on the project parameters screen, with the user selecting the next arrow at the bottom of the screen when complete. The Tab key may be used to progress through the data entry boxes.

Note that when entering values in, commas and dollar signs should not be included. For example, a material cost should be entered as 373186, as opposed to $373,186. The completed data entry is displayed in Figure 60.

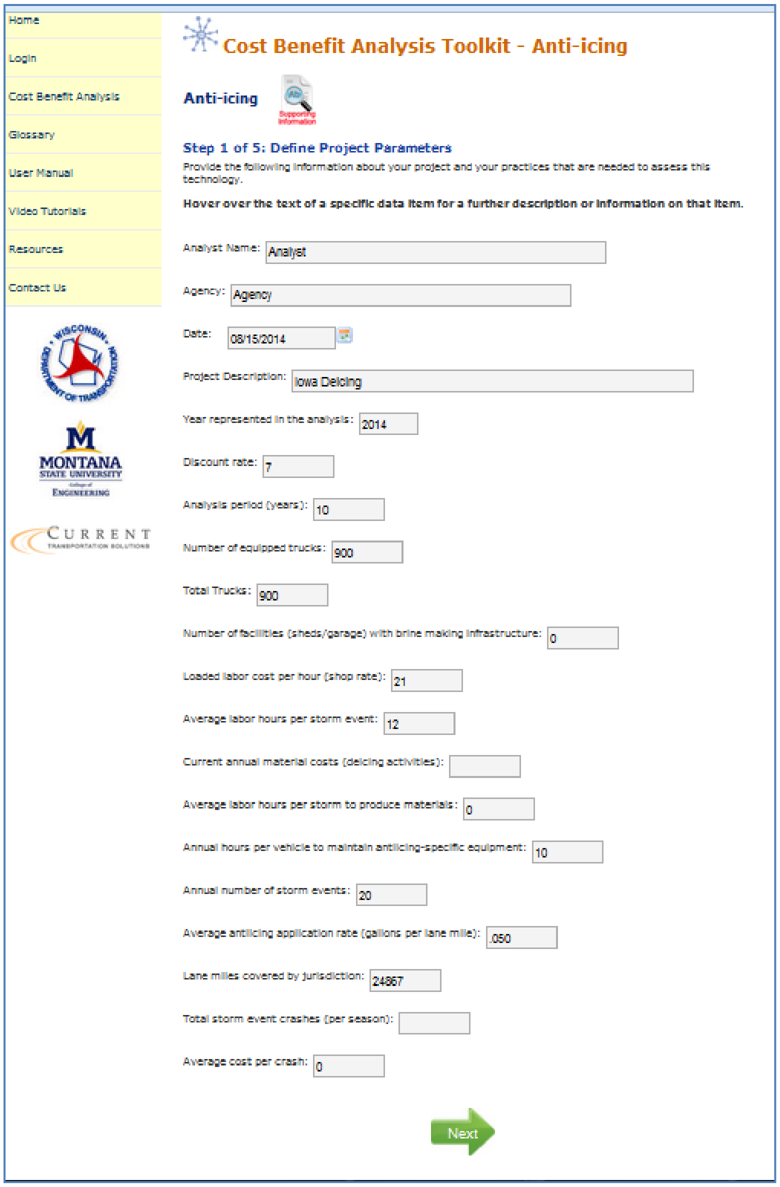

Figure 60. Screenshot. Clear Roads anti-icing benefit cost analysis tool project parameters page.

Costs Entry. Following the entry of initial project parameters, the user is required to enter costs associated with their prospective project. Toolkit costs are divided into three categories: agency costs, user costs, and society costs. Agency costs are those associated with the purchase, maintenance and use of the specific item. User costs are those carried by the motorist, such as delay or crash costs. Society costs are those associated with the entire society, such as environmental degradation (i.e. the impacts of salt on the environment).

For anti-icing, the initial steps for the user are to establish initial and annual costs to their agency. This is accomplished through the use of the two calculators provided under Agency costs. In clicking on the initial costs calculator icon, the user will be presented with a spreadsheet which determines the costs associated with the anti-icing equipment, its controller, and brine-making infrastructure. The spreadsheet is designed to automatically populate using the data entered by the user, as shown in Table 34. However, the user is encouraged to enter information, specifically manufacturer quotes, obtained specifically for their evaluation scenario. These specifics can be entered in any of the grayed boxes displayed by the spreadsheet. In the example below, the cost per vehicle for anti-icing equipment is $8,000, its controller $2,389, and brine-making infrastructure $20,000. Once the user has completed data entry or verified automated data population, the green check mark may be selected to return to the main cost screen. Upon doing so, the initial agency costs will appear on the page.

Table 34. Initial de-icing cost spreadsheet (automatically populated).

Items	Unit rate ($)	# of units	Unit	Amount ($)
De-Icing Equipment - Material Spreaders (Spinner, Gravity Drop, Etc.)	900	900	vehicles	810,000
De-Icing Equipment - Sprayers (Liquid De-Icing)	0	900	vehicles	0
Controller	2,389	900	vehicles	2,150,100
Infrastructure (Brine Making Equipment If Employing Liquid De-Icing Activities)	0	0	building	0
Other 1 (Define)	0	0		0
Other 2 (Define)	0	0		0
Total initial expenditure				**$2,960,100**

Next, the user will complete a similar procedure for annual costs. The Annual costs calculator is selected, and the user will be presented with spreadsheet automatically populated with the project parameters. In this case the user will need to enter the annual cost of brine materials, brine plant maintenance and corrosion/environmental costs. The calculator automatically populates the spreadsheet with the costs associated with brine production and annual vehicle maintenance. For this example, the annual brine material cost is estimated to be $0.07 per gallon, brine plant maintenance $2,000, and corrosion/environmental costs $0 per ton of material used. Note that for this example, no environmental/corrosion costs were employed because such costs would greatly outweigh any benefits achieved given the small expenditures on materials and labor at the subdistrict level, as well as in the absence of expected crash savings, producing a benefit cost ratio of much less than 1.0 (in reality, 0.0). Additionally, the user may enter the annual cost of sanding/grit materials used, as these would be reduced or eliminated by anti-icing. In this example, it is assumed that no such costs exist. Once the user has examined the spreadsheet, they should select the green check mark to return to the main cost page, which will be updated automatically.

Table 35. Annual de-icing cost spreadsheet (manually populated).

Items	Unit costs per year	# of units	Unit	Amount ($)
Material costs (year)	0	24,867	gallons	0
Production costs (liquid de-icers)	0	20	storms	0

Table 35. Annual de-icing cost spreadsheet (manually populated). (continuation)

Items	Unit costs per year	# of units	Unit	Amount ($)
Equipment maintenance	214	900	vehicles	192,780
Brine plant maintenance	0	0	years	0
Corrosion/environmental cost per ton	0	24,867	tons	0
Other 1 (define)	0	0		0
Other 2 (define)	0	0		
Cost of Alternative				
Minus cost of sanding and gritting	0	1	years	0
Total Annual Operations & Maintenance Costs				**$192,780**

In the case of anti-icing, no tangible societal costs have been identified. As a result, the user will not need to enter any information for these items, unless they choose to do so. At present, the toolkit is set up to accept a brief description of what the cost being entered is, as well as what the value of that cost is. Note that if the user chooses to add a societal or user cost, they will need to determine the entire value associated with it; the toolkit cannot calculate such costs given the lack of published information on the subject. Each cost button works in an identical fashion.

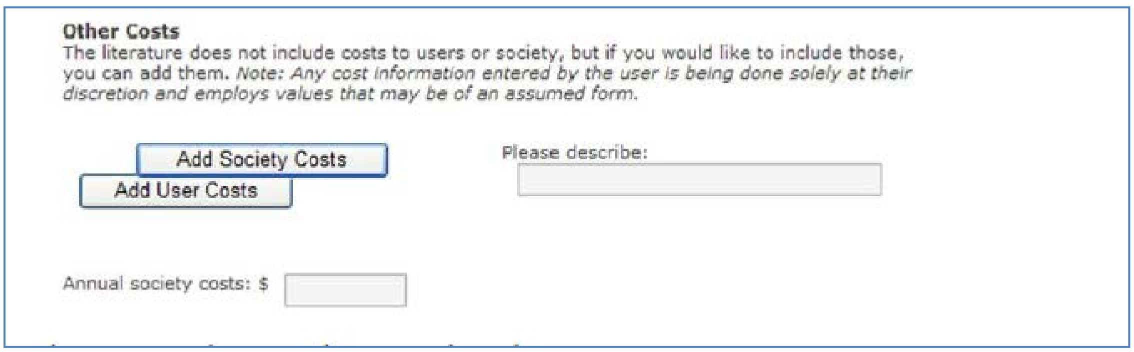

Figure 61. Screenshot. Clear Roads anti-icing benefit cost analysis tool other cost buttons selected.

Once any potential societal or user costs have been entered, the cost entry page is complete. At the bottom of the page, a summary of the annualized costs associated with the anti-icing are displayed, as shown in Figure 62.

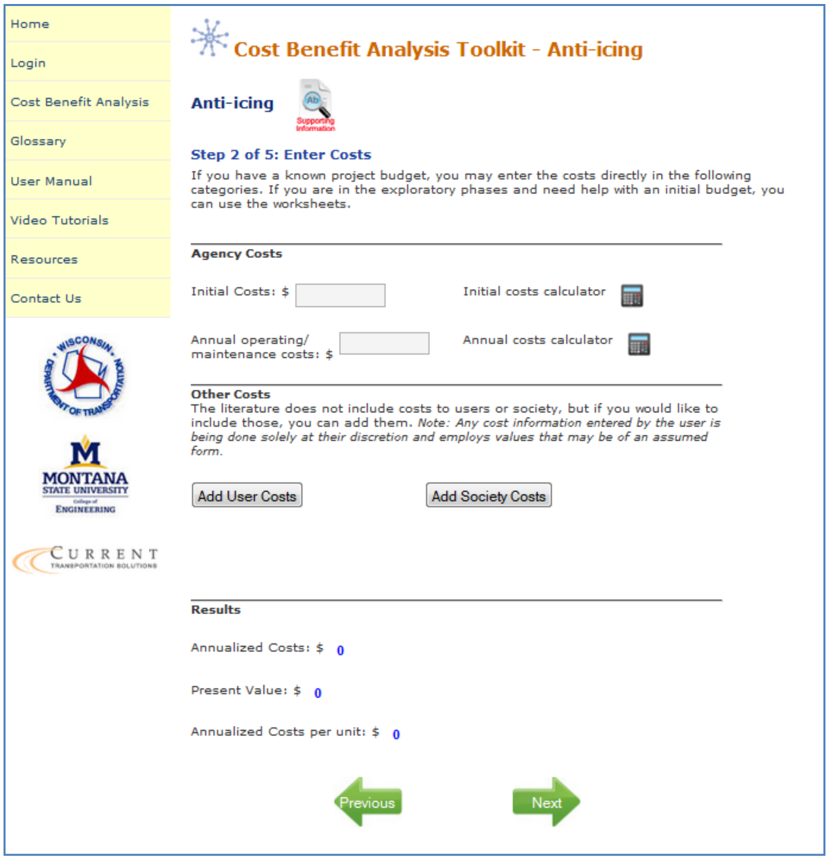

Figure 62. Screenshot. Clear Roads anti-icing benefit cost analysis tool cost page.

Benefits Entry. Next, the user will be presented with a screen associated with step 3 of 5, simply labeled "Benefits." This screen presents the user with a list of quantified and non-quantified benefits associated with anti-icing. A screen shot of these benefits is presented in Figure 63. At this point, the user should select the next arrow and proceed to screen 4 of 5, "Benefit Quantification."

Figure 63. Clear Roads anti-icing benefit cost analysis tool benefits page.

The "Benefit Quantification" screen allows the user to specify agency, user and society benefits. Agency benefits are the expected savings that an agency might expect through the use of an item. User benefits are savings that motorists might receive, such as reduced crashes or improved mobility. Societal benefits are savings such as reduced damage to the environment.

When quantifying benefits, the user will often only be able to quantify those at the agency level. This is because of the lack of existing, published research detailing the accrued user and societal benefits of many toolkit items. In this example, the primary quantified benefits are material and labor savings. A conservative value of 15 percent material cost savings has been employed, while a labor savings of 50 percent has been employed based on past reported savings by agencies.

In the case of anti-icing, user benefits, specifically crash reductions, have also been quantified. To include this benefit, the user will select the user benefits calculator by clicking inside the user benefits textbox. For anti-icing, a conservative crash reduction of 10 percent has been employed, although no crashes were reported for this example. The user benefits calculator is shown in Figure 64.

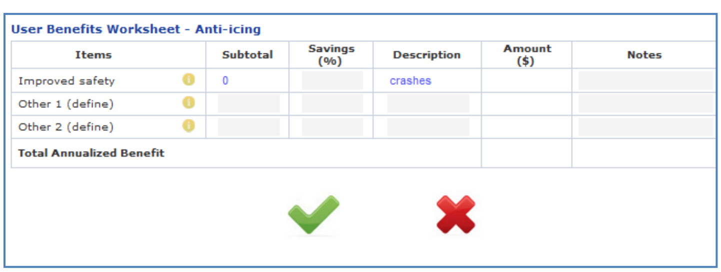

Figure 64. Clear Roads anti-icing user benefits calculator.

No known tangible societal benefits have been quantified for anti-icing. Of course, if any societal benefits are known to the user, a cumulative dollar value for these may be entered in the appropriate text box on the present screen. Once all data entry related to quantified benefits is complete, the user is presented with calculations of the agency and total benefit cost ratios. The agency ratio is derived strictly from the costs and benefits associated with the agency's expenditures and savings. The total ratio is derived from the agency's costs and benefits, as well as the costs and benefits associated with users and society.

Once the user has completed all data entry, including any modifications which may have required using the previous arrow, they may proceed to screen 5 of 5, the "Results" page. The user should note that they need to be absolutely certain they are finished entering or modifying input data, as there is no mechanism to move back from the report page without losing all entered data.

Benefit Cost Evaluation. The final screen presents the results of the analysis in a report format. This includes a description of the item, its components, complimentary items (other items it can be used in conjunction with), and a summary of the potential benefits the item offers. Additionally, the report presents the project parameter, cost and benefit data entered by the user. This includes all values and text entered, as well as the results of calculations made by the toolkit. Finally, the user is presented with the calculated benefit cost ratios for both the agency and in total (including user and societal inputs, if available). Due to the length of this report, a screen shot of this final page cannot be presented here. However, a key input and output information tables are presented in Tables 36 through 41.

Table 36. Agency de-icing strategy benefits.

Annualized	$0
Present Value	$0
Annualized Benefit per Truck	$0

Table 37. User (motorist) benefits from a de-icing strategy – part 1.

Items	Unit rate ($)	Costs	Unit	Amount ($)
Improved safety and mobility	0	0	De-icing Cost	0
Other 1 (define)	5	4,653,720	De-icing Cost	20,941,740
Other 2 (define)	0	0		0
Total Annualized Benefit				**$20,941,740**

Table 38. User (motorist) benefits from a de-icing strategy – part 2.

Annualized	$20,941,740
Present Value	$147,086,018
Annualized Benefit per Truck	$23,269

Table 39. Societal benefits from a de-icing strategy.

Annualized	$0
Present Value	$0
Annualized Benefit per Truck	$0

Table 40. Total benefits from a de-icing strategy.

Annualized	$20,941,740
Present Value	$147,086,018
Annualized Benefit per Truck	$23,269

Table 41. De-icing strategy benefit cost ratio.

Agency benefits	0.0
Total benefits	34.1

As the results indicate, the benefit cost ratio is 34.1. The agency incurred costs of infrastructure requirements, operation and maintenance and material costs associated with anti-icing are outweighed by the benefits experienced by motorists.

While step 5 presents the results of the analysis in a report format, it does so as part of the website itself. In most cases, the user will likely wish to present the final output in a Word or .pdf document. As part of the second phase of the toolkit development, an option to create a Word version of the project report has been added. Report documents can be accessed in html format via the printer icon and Word via the Word icon. The toolkit does not have the direct capability to save files in a .pdf format. The html formatted report accessed by the printer icon can be directly printed to a .pdf if the user has that capability on the machine they are accessing the toolkit on. The Word file may be converted directly into a PDF if the user holds a license for a PDF maker.

Key Observations

This chapter has presented a step by step overview of the process employed in using the cost-benefit toolkit to evaluate anti-icing. The agency parameters and values (monetary values and percentages) used as inputs are for demonstration purposes only. These values, as well as the benefit cost ratios consequently generated only represent a potential outcome under a theoretical scenario and do not represent a recommended configuration for anti-icing. Rather, they are intended to provide prospective users with an overview of the process necessary to complete an analysis using the toolkit.

For more information on the Clear Roads pooled fund tool kit, please visit: http://www.clearroads.org.

References

David Veneziano, Xianming Shi, and Lisa Ballard, *Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations: User Manual* (Clear Roads Pooled Fund: November 2010). http://clearroads.org/cba-toolkit/documents/user-manual/user-manual.pdf

Clear Roads Pooled Fund, "Cost-Benefit Analysis Toolkit for Winter Maintenance Practices Equipment and Operations" web page, available at: http://clearroads.org/cba-toolkit/terms.html.

CASE STUDY 7.7 – EVALUATION OF NORTH DAKOTA'S FIXED AUTOMATED SPRAY TECHNOLOGY SYSTEMS[71]

Strategy Type:	Weather Response or Treatment
Project Name:	North Dakota's Fixed Automated Spray Technology (FAST) Systems
Project Agency:	The North Dakota Department of Transportation (NDDOT) – Fargo District
Location:	Urban Highway Operations
Geographic Extent:	2670 Feet of Roadway and Bridge Decking
Tool Used:	Custom In-House Analysis

Project Technology or Strategy

The NDDOT installed two FAST systems, which are also known as roadway anti-icing systems, to eliminate or reduce the formation of frost, ice, and snow on the road surface through the use of chemical agents. These systems are used to improve roadway safety and reduce maintenance costs compared to traditional manual surface treatments (sand, salt, etc.).

Frost, ice, and snow on roadways create dangerous driving conditions. Bridge decks can be especially dangerous because the cold air flowing underneath the structure can freeze moisture on the deck, which may not freeze on adjacent roadways. Therefore, road crews must treat roads and bridges with sand, salt, or other chemicals to improve traction and melt the accumulated ice/snow. Because manual treatments of bridge decks can be expensive and unfeasible at times, transportation departments can deploy automated anti-icing systems.

Project Goals and Objectives

The NDDOT has installed two fixed automated spray technology (FAST) systems. One system is installed at the Interstate 29 (I-29) Buxton Bridge (near Buxton, ND), while the second installation is at the Interstate 94 (I-94) Red River Bridge between Fargo, ND, and Moorhead, MN. As part of this process, NDDOT performed a benefit cost analysis (BCA) for the two existing FAST installations to assist in determining if additional systems are feasible. In order to provide comparable benefits and costs within the analysis, NDDOT carefully selected the following key measures of effectiveness to fully capture the benefits of the program:

- Safety.
- Installation costs.
- Operation and maintenance costs.

[71] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

Methodology

Fixed automated spray technology systems are intended to provide several qualitative and quantitative benefits for both motorists and transportation departments.

The main quantitative benefit of FAST systems relates to reductions in societal costs from crash occurrences. Societal costs include the loss of life and quality of life, loss of productivity, legal costs, and property damage costs. The crash analyses in this section will be based on crash vehicles (the number of vehicles involved in each crash category) and factored for average annual daily traffic (AADT).

In addition, transportation agencies can experience reductions in maintenance costs by using less staff, equipment, and material (sand, salt, etc.). **Since frost typically develops late at night or early in the morning, which is outside of normal working hours, FAST systems reduce staff overtime, truck costs, and material/chemical costs.**

The main costs of FAST systems include initial implementation, anti-icing chemicals, and annual maintenance. Manual application costs include the cost of the operator, truck, and chemical/material (GEOMELT® or sand/salt). If treatment occurs after normal hours of operation, overtime pay is required.

The cost analyses for manual and automated treatment methods will be based on the spray applications for the winter of 2007. The actual cost savings of reduced manual treatments is difficult to determine since maintenance staff also would be treating other road surfaces, especially during freeze conditions. However, manual treatments for frost and freeze conditions that occur outside of normal hours of operation will be considered as a quantitative benefit of the FAST system. **The labor costs for these treatments would include overtime and would have a 3-hour minimum.**

Model Run Results

Buxton Bridge FAST System– Benefit/Costs: Due to the reduction in crashes attributed to the installation of the FAST system on Buxton Bridge, there is an annual safety benefit of $78,735. Reduced maintenance costs from NDDOT employees no longer needing to manually spray the area, particularly after normal hours of operation, saves NDDOT $31,860 per year in staff overtime, truck, and material/chemicals costs. The Buxton Bridge FAST system costs over the 20-year lifecycle are nearly $400,000, including installation, maintenance and replacement, utilities, and chemical costs. Dollar values in this study are in 2002 dollars, but can be adjusted to any year by applying an appropriate price index. See Chapter 2 of this Compendium for a discussion of discount rates and inflation. This results in a 20-year net benefit of $1,257,869. The Buxton Bridge FAST system shows an estimated benefit cost ratio of 4.3 over a 20-year lifecycle. A summary of the system benefits and costs include:

<u>System Costs</u>

- Installation: $168,531 (2002 dollars).
- Maintenance: $1,000/year (plus pump replacements of $5,000 at year 7 and 14).

- Utilities: $1,162/year.
- Chemical: $9,471/year (1,155 gallons).

System Benefits

- Crash reduction: $78,735/year (1.39 non-incapacitating injuries/year and 1.81 property damage crashes/year).
- Manual treatment cost reduction: $31,860/year (78 frost treatments and 81 freeze treatments).

Benefit Cost Ratio

- 4.3 (net benefits of $1,257,869).

Red River Bridge FAST System– Benefit/Costs: Due to the reduction in crashes attributed to the installation of the FAST system on Red River Bridge, there is an annual safety benefit of $162,578. Reduced congestion due to lower crash rates also attributes to $4,060 annually in benefits. Reduced maintenance costs due to employees of NDDOT and the Minnesota Department of Transportation (MNDOT) no longer needing to manually spray the area, particularly after normal hours of operation, saves NDDOT and MNDOT $48,983 per year in staff overtime, truck, and material/chemicals costs. The Red River Bridge FAST system costs over the 20-year lifecycle are $2,520,963, including installation, maintenance and replacement, utilities, and chemical costs. This results in a 20-year net benefit of $675,184. The Red River Bridge FAST shows an estimated benefit cost ratio of 1.3 over a 20 year lifecycle. A summary of the system benefits and costs are shown below:

System Costs

- Installation: $1,320,000 (2005 dollars).
- Maintenance: $2,000/year (plus pump replacements of $5,000 at year 7 and 14).
- Utilities: $2,955/year .
- Chemical: $66,703/year (8,135 gallons).

System Benefits

- Crash reduction: $162,578/year (2.40 non-incapacitating injuries, 1.31 possible injuries, and 4.36 property damage crashes).
- Manual treatment reduction: $48,983/year (102 frost treatments and 53 freeze treatments).
- Traffic congestion savings: $4,060/year.

Benefit Cost Ratio

- 1.3[72] (net benefits of $675,184).

The NDDOT – Fargo District believes the two FAST systems are very effective in treating the bridge structures, especially for frost conditions. Both systems have operated as expected in terms of spraying at the appropriate time and applying the proper amount of chemical agent.

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[72] Using a 20-year design life, the lower benefit cost ratio of the Red River Bridge FAST system, when compared to the Buxton Bridge FAST system, is a result of the significantly higher installation cost. The higher installation cost causes the chemical agent costs to have a smaller impact on the BCA.

Key Observations

The benefit cost analyses produced favorable results for both FAST system installations. The major benefits of the FAST systems relate to reductions in societal (resulting from vehicle crashes) and transportation agency costs (maintenance activities). The costs for FAST systems include initial implementation, anti-icing chemicals, and annual maintenance. The two ND FAST system installations appear to be working as intended based on the results from the benefit cost analyses. Several factors contribute to these successful systems, such as selecting appropriate locations for FAST systems (primarily based on winter crash data); and having knowledgeable and dedicated staff to assist in the design and implementation of the system, monitor its operation, and perform the required maintenance procedures.

Reference

Shawn Birst and Mohamed Smadi, *Evaluation of North Dakota's Fixed Automated Spray Technology Systems* (Advanced Traffic Analysis Center, Upper Great Plains Transportation Institute, North Dakota State University: October 2009). Available at: http://www.ugpti.org/pubs/pdf/DP219.pdf

Case Study 7.8 – Automatic Vehicle Location System Deployment In Kansas[73]

Strategy Type:	Weather Response or Treatment
Project Name:	Study of the Use of an Automatic Vehicle Location (AVL) System for Highway Maintenance Activities
Project Agency:	Kansas Department of Transportation (KDOT)
Location:	Highways
Geographic Extent:	Statewide
Tool Used:	Custom In-House Analysis

Project Technology or Strategy

Several State DOTs and municipal public works departments have implemented AVL and found it to be a valuable tool for maintenance and operations activities. AVL systems are a fleet management tool that integrates several technologies to allow a fleet manager or dispatcher to see the location of their vehicles at any given time. Many systems can also indicate the status of each vehicle.

Project Goals and Objectives

Sponsored by the Kansas DOT, the University of Kansas conducted a study of the use of AVL for highway maintenance activities, especially snow removal. As part of the process, the study included a BCA associated with implementing AVL in their maintenance and operations. Toward this end, researchers carefully selected key measures of effectiveness to identify strategies that would achieve the following objectives:

- Improved fleet management (continuous location of snowplow fleet operations).
- Reduced system costs (capital and operations and maintenance).
- Increased safety for the vehicle operator (reduced snow-related crashes).
- Ability to detect and minimize waste and fraud.
- Improved communications efficiency (reduced paper work, ability to capture statistical data).

Methodology

To evaluate the cost-effectiveness of AVL for highway maintenance, cost data and qualitative and perceived benefits data were collected from State and local transportation agencies in the United States and Canada. Initially, all 50 State DOTs, all Canadian provinces, and 6 municipal public works departments were contacted to evaluate their experience with AVL for highway maintenance. Researchers found that 15 agencies were actively using AVL to track highway maintenance vehicles, and eight of them were State DOTs. Questionnaires and follow-up emails

[73] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

and telephone calls were provided to these agencies to further explore the technologies being used, benefits and costs experienced, and obstacles encountered.

The benefit cost analysis (BCA) included four components:

- Determination of life-cycle costs.
- Methodological approach to cost/benefit analysis.
- Quantification of risks.
- Assignment of dollar values to intangible benefits.

Two risk perspectives were examined: very low risk translated into conservative assumptions and low risk translated into moderate (but somewhat conservative) assumptions. Costs remained constant across the scenarios.

Expected Costs: This study assumed that KDOT's existing 800 MHz radio system would be used, and a dedicated channel would be added for data transmissions. The implementation cost for the dedicated data channel was approximately $750,000 for a pilot project and $6 million for a statewide deployment. The KDOT Bureau of Maintenance and Construction provided these estimates based on current equipment costs. Costs will vary based on the specific deployment anticipated.

In vehicles, expenditures included an in-vehicle unit (IVU) consisting of a GPS receiver, a data modem, and a mobile data terminal (MDT). These were estimated to cost approximately $3,500, including installation. A total of 24 units were considered for the pilot project—23 maintenance vehicles and one paint truck. Road and air temperature sensors were estimated to cost $600 per vehicle.

The operating costs generally involve the monthly fees for the cellular digital packet data (CDPD) connection, if a CDPD based communication system is used. For an implementation of AVL using KDOT's radio system, operation and maintenance costs are comprised primarily of maintenance and repair for the radio system's dedicated data channel, the in-vehicle units, and the base station equipment.

Annual maintenance costs were estimated to be the purchase price of the equipment divided by the typical service life. Only equipment unique to the AVL system was considered. That is, the cost of maintaining the 800 MHz radio system is a cost that would be incurred regardless of whether or not an AVL system was implemented. Consequently, the implementation of AVL adds no incremental cost to the maintenance of the existing radio system. As stated earlier, the cost of the in-vehicle units is estimated to be $3,500 each. Assuming one base station at each area office with an initial cost of $7,000, also with a service life of 7 years, the annual maintenance cost of the base stations would be $26,000.

The incremental maintenance costs incurred by the addition of a dedicated data channel were estimated based on the KDOT Replacement Life Cycle of 12 years, assuming that an average of 1/12 of the equipment will be replaced each year. Under this assumption, each year's maintenance would be equal to the cost of the entire system times the percentage of the system deployed divided by 12. The total annual maintenance cost of the system, once fully deployed, would be $818,500.

Expected Benefits: The nature of the expected benefits can be drawn from the experience of other agencies combined with the operational characteristics of KDOT maintenance crews. Expected benefits include the following:

- More timely response to emergencies.
- Improved resource management by analyzing past activities to improve efficiency.
- Reduced snow-related accidents due to reductions in snow removal times.
- Increased security for drivers.
- Reduced legal costs from tort claims allegedly involving KDOT maintenance vehicles.
- Reduced material costs with more efficient application strategies.
- Reduced time associated with routine paperwork.
- More timely pavement condition information.
- Enhanced locational accuracy of various inventories and map segments.

Model Run Results

Three implementation scenarios were considered. After the pilot test completion in 2004, the aggressive implementation schedule assumes one district is added to the system each year until the system is complete. The moderate implementation schedule assumes full implementation occurs over 10 years, and the conservative implementation schedule assumes full implementation occurs over 20 years.

The assessment indicated that the application of AVL in highway maintenance has a benefit-to-cost ratio ranging from 2.6:1 using conservative assumptions, to 24:1 (or higher) using moderate assumptions. A moderate estimate of the net present value of statewide implementation ranges from $233 million to more than $433 million over 20 years, depending on the implementation schedule. The annual efficiency savings for the department are estimated to be nearly twice the annual maintenance cost of the system. Overall, the analysis conducted suggests that AVL can provide a significant benefit to highway maintenance operations.

Key Observations

The study showed that the potential for AVL to improve the efficiency and effectiveness of highway maintenance operations appears to be significant. Because the technology is well established and there is some precedent among transportation agencies from which to learn, AVL implementation can be cost-effectively accomplished with a high level of confidence that the system will prove beneficial. The agency and user cost savings afforded by AVL make the technology a very appealing tool for highway maintenance activities, and the state of the practice is ready to support reliable deployment. With proper attention to planning and evaluation, AVL can help KDOT and other transportation agencies further improve the quality of highway transportation.

This case demonstrates some of the fundamental building blocks of a BCA. The study team developed clear project objectives and selected alternative deployment strategies that allowed the comparison of different management decisions. In this case, both strategies proved to be efficient, even when very conservative assumptions were made for the input data. The completion of this analysis allows management not only to compare alternative AVL deployments, but to compare the benefits of an AVL deployment to other TSMO investments.

Reference

Eric Meyer and I. Ahmed, “Benefit Cost Assessment of Automatic Vehicle Location (AVL) in Highway Maintenance,” presented to the 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., January 2004.

CASE STUDY 7.9 – HYPOTHETICAL STUDY OF THE USE OF AUTOMATIC VEHICLE LOCATION FOR HIGHWAY MAINTENANCE ACTIVITIES[74]

Strategy Type:	Weather Response or Treatment
Project Name	Automatic Vehicle Location (AVL) for Winter Maintenance
Location:	Highways
Geographic Extent:	Statewide
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC) for Life Cycle Cost and Benefit Cost Analysis (BCA)

Project Technology or Strategy

Several State DOTs and municipal public works departments have implemented AVL system and found it to be a valuable tool for maintenance and operations activities. AVL systems are a fleet management tool that integrates several technologies to allow a fleet manager or dispatcher to see the location of their vehicles at any given time. Many systems can also indicate the status of each vehicle.

Project Goals and Objectives

This case study assumes a hypothetical Midwestern traffic management agency is conducting a study on the use of AVL for highway maintenance activities, especially snow removal. The overall goal of the system is to facilitate the following:

- Continuous location of snowplow fleet operations.
- Ability to identify vehicles with abnormal behavior.
- Increase safety for the vehicle operator.
- Ability to detect and minimize waste and fraud.
- Ability to capture statistical data.
- Improved communications efficiency.

Methodology

To evaluate the cost-effectiveness of AVL for highway maintenance, cost data, and qualitative and perceived benefits data were collected from State and local transportation agencies in the United States and Canada. Questionnaires and follow-up emails and telephone calls were provided to these agencies to further explore the technologies being used, benefits and costs experienced, and obstacles encountered. In this case study we used these data to demonstrate a BCA of AVL for road weather maintenance (RWM) in TOPS-BC.

The BCA includes four components:

[74] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

- Determination of life-cycle costs.
- Methodological approach to cost/benefit analysis.
- Quantification of risks.
- Assignment of dollar values to intangible benefits.

A moderate implementation plan assumes full implementation occurs over 10 years.

Benefit Cost Analysis: A BCA to determine whether to implement the AVL strategy can be conducted using TOPS-BC. TOPS-BC provides the framework for conducting a BCA of an RWM alternative like AVL. For many technologies, TOPS-BC provides a rich database of likely TSMO costs and benefits. FHWA also periodically adds new information to TOPS-BC, including both entirely new technologies as well as new benefit and cost information on technologies already in the system.

In this case, the user can utilize the TOPS-BC spreadsheets to set up the BCA, to estimate annualized costs 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 an RWM AVL application, the user must supply much of this data. The information can be collected from other DOTs that have implemented AVL programs or the data can be produced from engineering estimates. A search of the Federal Highway Administration (FHWA) Intelligent Transportation System (ITS) Database may provide much of this information.

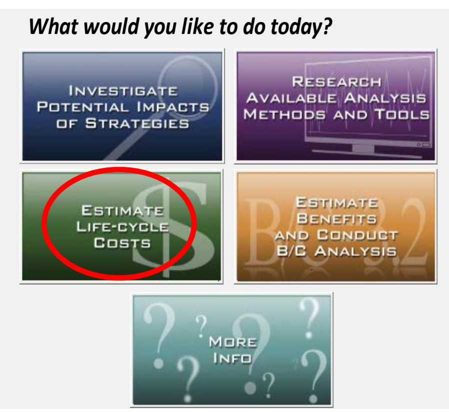
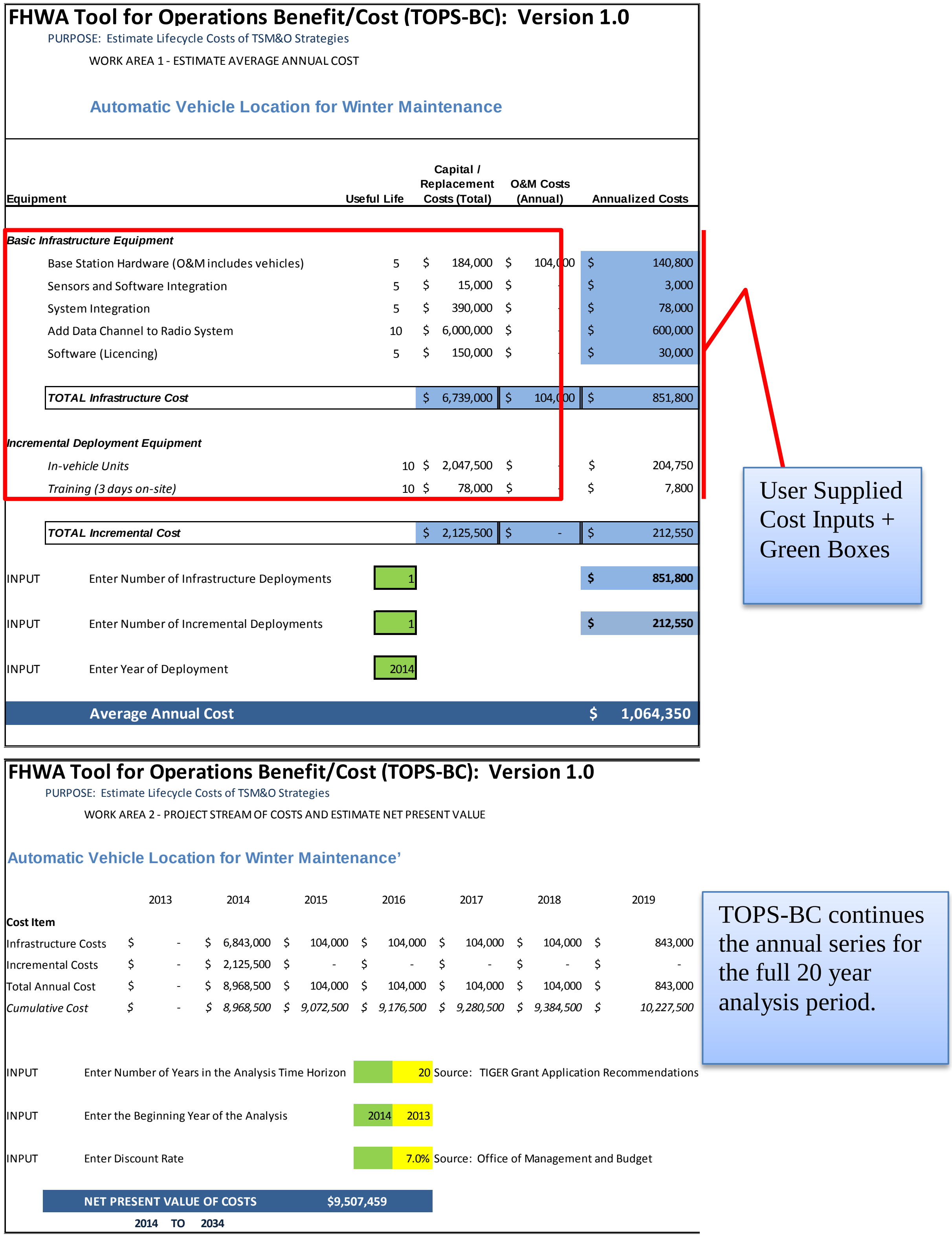


Figure 65. Screenshot. Tool for Operations Benefit/Cost start page – estimate life-cycle costs.

To set up TOPS-BC to conduct this analysis, the user will open the spreadsheet modeling tool to the start page (Figure 65) and click on "Estimate Life-Cycle Costs" and in the left hand column of the Cost Page, 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 AVL systems. If no AVL costs are displayed, the user can input cost data from available information on the specific project or may locate 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," shown in Figure 66 with new user provided AVL cost data included. This worksheet has all the analysis capabilities present in all other strategy worksheets, but lacks any default equipment or cost data. You may copy the data in this worksheet in its entirety and paste it into a new worksheet. This new worksheet may then be renamed and populated with your customized defined equipment and cost data as shown in Figure 67, to create new strategies, assuming that the new data is entered in the same format (e.g., equipment name, capital cost, useful life, annual operations and maintenance costs).



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

Automatic Vehicle Location for Winter Maintenance

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrastructure Equipment				
Base Station Hardware (O&M includes vehicles)	5	$ 184,000	$ 104,000	$ 140,800
Sensors and Software Integration	5	$ 15,000	$ -	$ 3,000
System Integration	5	$ 390,000	$ -	$ 78,000
Add Data Channel to Radio System	10	$ 6,000,000	$ -	$ 600,000
Software (Licencing)	5	$ 150,000	$ -	$ 30,000
TOTAL Infrastructure Cost		$ 6,739,000	$ 104,000	$ 851,800
Incremental Deployment Equipment				
In-vehicle Units	10	$ 2,047,500	$ -	$ 204,750
Training (3 days on-site)	10	$ 78,000	$ -	$ 7,800
TOTAL Incremental Cost		$ 2,125,500	$ -	$ 212,550
INPUT Enter Number of Infrastructure Deployments	1			**$ 851,800**
INPUT Enter Number of Incremental Deployments	1			**$ 212,550**
INPUT Enter Year of Deployment	2014			
Average Annual Cost				**$ 1,064,350**

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

PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies

WORK AREA 2 - PROJECT STREAM OF COSTS AND ESTIMATE NET PRESENT VALUE

Automatic Vehicle Location for Winter Maintenance'

Cost Item	2013	2014	2015	2016	2017	2018	2019
Infrastructure Costs	$ -	$ 6,843,000	$ 104,000	$ 104,000	$ 104,000	$ 104,000	$ 843,000
Incremental Costs	$ -	$ 2,125,500	$ -	$ -	$ -	$ -	$ -
Total Annual Cost	$ -	$ 8,968,500	$ 104,000	$ 104,000	$ 104,000	$ 104,000	$ 843,000
Cumulative Cost	*$ -*	*$ 8,968,500*	*$ 9,072,500*	*$ 9,176,500*	*$ 9,280,500*	*$ 9,384,500*	*$ 10,227,500*

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 $9,507,459

2014 TO 2034

Figure 66. Screenshot. Tool for Operations Benefit/Cost new cost estimation worksheet for road weather management automatic vehicle location statewide deployment.

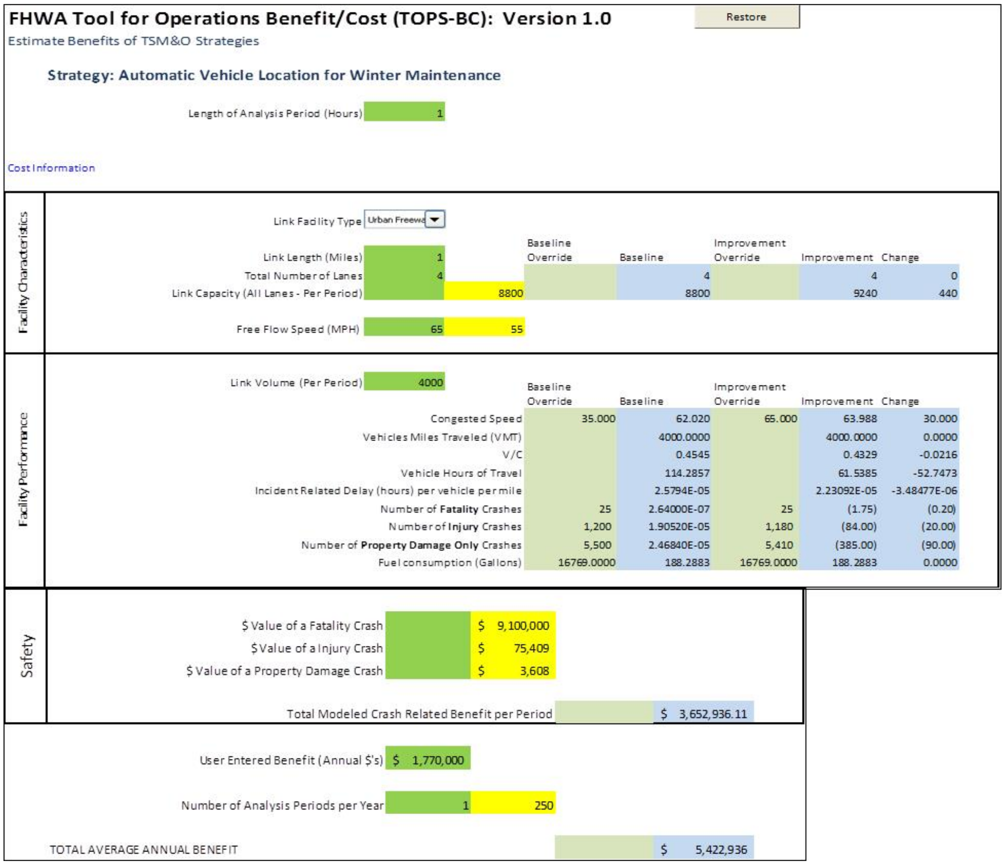


Figure 67. Screenshot. Input variables and user-supplied data for use of automatic vehicle location for highway maintenance activities.

Unneeded rows may be deleted. You will need to manually modify the navigation capabilities and link the new worksheet to the "Summary" sheet or other worksheets where they intend to use the output cost data. These procedures are explained in the TOPS-BC User's Manual. It can be found 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 Table 42, 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 (NPV) of cost for use in a BCA (more information about calculating NPV can be found in Chapter 2 – Fundamentals of Benefit Cost Analysis). The user also provides a start date, an analysis period and a discount rate.

Table 42. Automated vehicle location system cost estimate for statewide deployment.

Cost Line Item	Cost per Unit	Number of Units	Total Cost
Base Station Hardware	$7,000/area	26 (1/area)	$184,000
Software (Licensing)	$25,000 for first computer, $5,000 per additional	26 (1/area)	$150,000
Sensors and Software Integration	$15,000 (software)	NA	$15,000

Table 42. Automated vehicle location system cost estimate for statewide deployment. (Continued)

Cost Line Item	Cost per Unit	Number of Units	Total Cost
In-Vehicle Units	$3,500/unit	585 units	$2,047,500
Training (3 days onsite)	$3,000/area	26 areas	$78,000
Repair and Maintenance	$4,000/year/area	27 areas	$104,000
System Integration	$15,000/area	28 areas	$390,000
Add Data Channel to Radio System	NA	NA	$6,000,000
Total Expenditure			**$8,968,500**

Note: These estimates are provided as representative. In actuality, the costs will be unique based on each deployment's characteristics.

The deployment of an AVL system is expected to provide a range of benefits. These include:

- More timely response to emergencies.
- Improved resource management by analyzing past activities to improve efficiency.
- Reduced snow-related accidents due to reductions in snow removal times.
- Increased security for drivers.
- Reduced legal costs from tort claims allegedly involving maintenance vehicles.
- Reduced material costs with more efficient application strategies.
- Reduced time associated with routine paperwork.
- More timely pavement condition information.
- Enhanced locational accuracy of various inventories and map segments.
- Increased completeness of various inventories (e.g., pavement management systems).
- Automatic and continuous updates of pavement conditions for maintenance.
- Potential feed of near real-time information to advanced traveler information.
- Improved efficiency and effectiveness of roadside maintenance.
- Reduced fleet maintenance costs due to improved fleet management.

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 an existing deployment to the one we are considering or because we have more recent or project specific information than TOPS-BC provides. In this case, by using the navigation column again we can go to the benefit inputs page for RWM and input the data for TOPS-BC to calculate certain benefits or enter benefit values we have calculated outside of TOPS-BC. These values will be used in all calculations calling for these values in TOPS-BC.

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 data to support their inclusion simply to add the estimated value of these benefits to the "User Entered Benefit."

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. Figure 66 and Figure 67 illustrate both user-supplied data inputs (green) and TOPS-BC supplied inputs (yellow). While there are many benefits of AVL that should be estimated in a full BCA, in this case we will use TOPS-BC to calculate only the dollar benefits of a reduction in crashes. Some other hypothetical benefit estimates will be entered directly from a previous study for Kansas DOT and will be referred to as User Supplied Benefits. These include:

- Annual reductions in paperwork costs - $100,000.
- Annual savings from more efficient fleet management - $1,600,000.
- Annual operating efficiency - $70,000.

Figure 67 depicts the benefit calculation input page from TOPS-BC. In this case we are only using the Facility Performance and Safety sections of the inputs to describe the change in crash rates by crash type. If we had traffic data on before and after deployments, TOPS-BC could assist in calculating travel time savings or reliability benefits. In this case, we are just focused on the procedures for calculating safety benefits, and other benefits are added as User Estimated Benefits. The safety impacts we are assuming are input to the light green cells for: Number of Fatality Crashes, Number of Injury Crashes and Number of Property Damage Only Crashes. TOPS-BC uses this information to estimate the annual safety benefits from our AVL deployment. You should note that this analysis is overriding the usual VMT change based safety impacts with the safety impacts estimated for AVL in other studies. The override makes immaterial some usual TOPS-BC inputs such as the *Length of the Analysis Period* which is related to the peak traffic period. TOPS-BC requires a number in this cell to move forward with the analysis, but it is not used in this case due to the override.

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 of assumptions such as crash rates, prices and discount rates. For example, an alternative set of crash costs by type (fatality, injury or property damage) only that reflects local crash cost experience would improve the applicability of this tool for your project.

Model Run Results

The TOPS-BC Cost Effectiveness analysis indicates that the average annual cost for this AVL technology will be $1,064,350 with total annual benefits of $5,422,936 per period (Table 43) for a total annual net benefit of $4,358,586. This results in a benefit cost ratio of 5.10.

Table 43. Benefit cost summary.

Total Annual Benefits	$5,422,936
Safety	$3,652,936
Other, User Entered	$1,770,000
Total Annual Costs	**$1,064,350**
Net Benefit	**$4,358,586**
Benefit Cost Ratio	5.10

Benefits: The two primary benefits of AVL deployments are improvements in operating efficiency of the fleet and a reduction in expected crashes. Together they result in net annual benefits of about $5.5 million. Each project plan is different and the realized benefits can be impacted by the plan. By varying the assumptions in the plan, BCA models like TOPS-BC allow you to see how plan assumptions will impact the expected benefits.

In this case, TOPS-BC estimates that the project benefits exceed the costs. This results from the gain in operating efficiency for the system under study. This case study also demonstrated that with AVL there was better allocation of maintenance resources, resulting in less energy use.

Key Observations

This case discussed the development of a TOPS-BC analysis model that tested AVL feasibility on an urban interstate freeway. Although this model is just a prototype, it provides a framework for the development of a model which could be used as a measure of effectiveness in fuel costs and expected safety (as measured by crash reductions) of an AVL managed roadway, thereby providing an agency with objective and predictable measures for determining whether an AVL deployment is cost effective. Prior to and after the deployment, a State department of transportation can collect 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 agency cost 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 7.10 – ENHANCED MAINTENANCE DECISION SUPPORT SYSTEM (CONNECTED VEHICLE APPLICATION) [75]

Strategy Type:	Weather Response or Treatment
Project Name:	Enhanced Maintenance Decision Support System (EMDSS) Using Connected Vehicles (CV)
Project Agency:	Hypothetical Agency
Location:	Hypothetical State
Geographic Extent:	Statewide
Tool Used:	Tool for Operations Benefit/Cost (TOPS-BC) Beta CV

Project Technology or Strategy

The EMDSS application incorporates road weather data from connected vehicles into an agency's existing capabilities for maintenance decision making. The data may come from either vehicles operated by the general public and commercial entities, including passenger cars and trucks, or specialty vehicles and public fleet vehicles such as snowplows and maintenance trucks. The data is processed, either at the field or control center, to generate road segment-based outputs such as forecasts and treatment recommendations.[76]

Project Goals and Objectives

This CV application provides data to road managers to help optimize the treatment of roads using the additional information, resulting in improved maintenance operations and increased safety.

Methodology

Costs: We used the information from the 2013 *Road Weather Management Connected Vehicle Applications* report[77] (CV BCA report) to perform a benefit cost analysis (BCA) of the EMDSS application. Based on this data, new cost line items were added to the existing cost sheet within TOPS-BC.[78] Figure 68 shows the different cost items that were added. The exhibit is taken from a spreadsheet within TOPS-BC that calculates the costs of specific CV strategies. Basic Infrastructure refers to the required common infrastructure investments to support multiple CV transportation system management and operations (TSMO) projects while the Incremental Deployment section includes cost items that are application-specific. The Basic Infrastructure and Incremental Deployment sections include estimated annualized costs, operations and maintenance costs, item-specific counts, and the user-selected quantities used in this analysis.

[75] Chapters 2 and 3 of this Compendium contain a discussion of the fundamentals of BCAs and an introduction to BCA modeling tools. These sections also contain additional BCA references.

[76] Connected Vehicle Reference Implementation Architecture, *Enhanced Maintenance Decision Support System*.

[77] FHWA, *Road Weather Management Connected Vehicle Applications*, FHWA-JPO-14-124. Available at http://ntl.bts.gov/lib/54000/54400/54480/Road_Weather_Connected_Vehicle_Applications_Benefit-508-v8.pdf.

[78] FHWA, *Tool for Operations Benefit/Cost Analysis*, available at http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

Since the case study CV deployments, including EMDSS, are assumed to take place in a hypothetical State, the distinction between necessary basic CV infrastructure investments and incremental ***or*** strategy-specific deployments needs to be clear. For the purpose of this analysis, each CV deployment BCA assumes that the respective State or metropolitan planning organization needs to acquire both basic infrastructure and incremental or strategy-specific infrastructure. However, since the basic deployment investment supports many projects and strategies, only a portion of the total basic infrastructure cost is assigned to a specific CV technology. The percentage assumes that a set of CV technologies are deployed and the specific technology's basic infrastructure cost equals that technology's share of expected benefits in the set of deployed technologies. This cost assignment would vary depending on the full set of CV technologies deployed and supported by the basic infrastructure investment. For the EMDSS case study, the assumed percentage of total basic infrastructure costs is 26 percent.

The CV BCA report focused on the entire United States, so for the individual CV case studies in this compendium, the hypothetical State is assumed to have 2 percent (1 of 50 States) of the total U.S. population. The basic infrastructure quantities used in the analysis were derived from that assumption and are shown in Figure 68. When the new cost items are entered into TOPS-BC, the CV BCA report is used to identify which cost elements are needed to perform the appropriate cost analysis. If users want to analyze a specific connected vehicle application deployment strategy, the table allows for a quick identification of the cost items needed.

The EMDSS application has several cost items that need to be included in a BCA. The following basic infrastructure cost items are included in this case study:

- Urban freeway roadside equipment (wire line & wireless).
- Urban signal roadside equipment (wire line & wireless).
- Rural interstate equipment (with & without power grid connection).
- Application development.
- System integration and back office costs.
- On-board equipment on agency vehicles.

Figure 68 includes quantities and dollar values for two cost items that are specific to this strategy:

- Education and outreach.
- Equipment of maintenance vehicles.

Education and outreach are necessary to inform the public about the implementation of the strategy. It is calculated on a per capita-basis, which means a cost occurs for every individual in the service area. Since the hypothetical State is assumed to have 2 percent of the U.S. population, this analysis uses the value of 6.4 million inhabitants, assuming that the U.S. population is 320 million. Furthermore, the amount of maintenance vehicles is assumed to be in relation to the length of the segment that is analyzed. The relation of maintenance vehicles per distance is assumed to be one vehicle for every 5 miles of roadway. Since this analysis assumes the entire

CV environment will embrace about 100 miles of roadway, 20 maintenance vehicles are necessary for a successful deployment of an EMDSS.

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs	Quantity	Count	Unit Costs
Basic Infrastructure Equipment and Costs							
Urban Freeway RSE w/ wireline	25	$ 230,400	$ 5,760	$ 14,976	24	1 per Mile	$ 9,600
Urban Freeway RSE wireless	25	$ 1,948,800	$ 48,720	$ 126,672	96	1 per Mile	$ 20,300
Urban Signal RSE w/ wireline	25	$ 2,331,600	$ 58,290	$ 151,554	201	2/3 of signals	$ 11,600
Urban Signal RSE wireless	25	$ 17,951,500	$ 448,788	$ 1,166,848	805	2/3 of signals	$ 22,300
Rural Interstate w/ powergrid connection	25	$ 7,647,300	$ 191,183	$ 497,075	261	1 per 2 Miles	$ 29,300
Rural Interstate w/o powergrid connection	25	$ 2,411,500	$ 60,288	$ 156,748	65	1 per 2 Miles	$ 37,100
Application Development Costs	1	$ 191,746	$ -	$ 191,746	1	1 per Application	$ 191,746
System Integration & Backoffice	35	$ 25,886	$ 3,835	$ 4,575	1	1 per Application per TMC	$ 25,886
Vehicle On-Board Equipment	1	$ 4,800,000	$ 288,000	$ 5,088,000	48,000	1 per Vehicle	$ 100
TOTAL Infrastructure Cost		$ 37,538,732	$ 1,104,862	$ 7,398,192			
Incremental Deployment Equipment - Please See Chart on the Right for Application-Specific Information							
Vehicle Data Translator (This Item is RWM-specific only)	25	$ -	$ -	$ -		1 per TMC	$ 1,000,000
Maintenance Vehicle Costs	5	$ 600,000	$ 10,000	$ 130,000	20	1 per Maintenance Vehicle	$ 30,000
Dynamic Message Sign	10	$ -	$ -	$ -		*VSL ONLY*	$ 82,000
Education & Outreach	1	$ 288,000	$ -	$ 288,000	6,400,000	1 per capita	$ 0.045
TOTAL Incremental Cost		$ 888,000	$ 10,000	$ 418,000			
INPUT Enter Number of Infrastructure Deployments	1	$ 1,923,530					
INPUT Enter Number of Incremental Deployments	1	$ 418,000					
INPUT Enter Year of Deployment	2020						
Average Annual Cost $ 2,341,530							

Figure 68. Screenshot. Annualized costs for enhanced maintenance decision support system.

Finally, the number of infrastructure and incremental deployments was set to 1 each, because the extent of the roadway structure for the entire CV system and for this strategy in particular is already considered in the quantities shown in each cost line. The project is assumed to be in place in 2020. As Figure 68 shows, these assumptions result in annualized project costs of about $2.34 million.

Benefits: In order to estimate the benefits of this strategy, we utilized the data from the 2013 CV BCA report, which estimates the effectiveness of this strategy to be 7 percent. This means that crashes are likely to be reduced by 7 percent when the strategy is in place. Alongside this assumption is the assumed increase in capacity due to a lower amount of incidents that slow down traffic. The report set this number to 10 percent for all applications.

Furthermore, crashes include three different types of incidents: property damage only, injury and fatality. Since TOPS-BC calculates the number of each of these types of incidents for all weather conditions and not just for adverse weather conditions, these values needed to be adjusted. For the purpose of this analysis, and based on the CV BCA report, it is assumed that 24 percent of incidents are related to adverse weather conditions. Hence this analysis applies to 24 percent of property damage only, injury, and fatality incidents.

Figure 69 shows the CV benefit sheet within the tool. The adjusted values for property damage only, injury, and fatality crashes were entered into the green cells in the Facility Performance section of the tool. The green cells can be changed by the user and override the default values used by TOPS-BC. The capacity increase and crash reduction assumptions were implemented below the section Impacts due to Strategy. These values were also entered in the green cells, since TOPS-BC regularly does not consider any changes in capacity and uses a different crash reduction rate. For this reason, the given data within the tools were overridden. These data could come from travel demand models, freeway simulations, counts**,** or other sources. Note that other agency benefits, such as benefits from reduced maintenance costs due to the EMDSS are not reflected in the benefit estimation. We are aware that these savings are often the primary purpose for using EMDSS; for example**,** to reduce the amount of chemicals applied and number of plow passes. Analysts are encouraged to calculate such benefits independently and add them into the TOPS-BC estimates.

Strategy: Road Weather Management Connected Vehicle Applications

Length of Analysis Period (Hours)	3	

Facility Characteristics

			Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Facility Type	Urban Freewa 2						
Link Length (Miles)	100						
Total Number of Lanes	2			2		2	0
Link Capacity (All Lanes - Per Period)		13200		13200		14520	1320
Free Flow Speed (MPH)	65	55					

Facility Performance

Link Volume (Per Period)	11,880

	Baseline Override	Baseline	Improvement Override	Improvement	Change
Congested Speed		50.864		54.146	3.282
Vehicles Miles Traveled (VMT)		1188000.0000		1188000.0000	0.0000
V/C		0.9000		0.8182	-0.0818
Vehicle Hours of Travel		23356.5295		21940.8197	-1415.7099
Incident Related Delay (hours) per vehicle per mile		4.24545E-05		3.67189E-05	-5.7356E-06
Number of **Fatality** Crashes	1.88179E-03	7.84080E-03	1.85018E-03	7.70907E-03	-3.16141E-05
Number of **Injury** Crashes	1.93026E-01	8.04276E-01	1.55911E-01	6.49630E-01	-3.71151E-02
Number of **Property Damage Only** Crashes	2.38503E-01	9.93762E-01	2.06922E-01	8.62176E-01	-3.15805E-02
Fuel consumption (Gallons)		55921.6216		55921.6216	0.0000

Impacts Due to Strategy

Facility improvement models		
Change in Capacity (%)	10%	0%
Change in Speed (%)		0%
Change in # of Lanes		0
Reduction in Crash ***Rate*** (%)	7.0%	15%
Reduction in Crash ***Duration*** (%)		0%
Reduction in Fuel Use (%)		0%
Traveler information models		
Percent time device is disseminating useful information		0%
Percent drivers using information		0%
Minutes saved by drivers saving time		0

Figure 69. Screenshot. Benefit estimation assumptions for enhanced maintenance decision support system.

Finally, Figure 70 shows the lower half of the CV benefit estimation page. It includes additional sections on travel time, energy and other safety benefits. The user is able to refine any TOPS-BC calculation using these sections in case more specific data is at hand. Through this flexible user interface, the user can generate refined and more accurate results. The total average annual benefit is calculated automatically by TOPS-BC and can be found the bottom of the benefit estimation sheet. The total average annual benefit for this application is $13.35 million.

Travel Time	Average Person Hours of Travel Saved per Period		2364.2355
	$ Value of Person Hour (per hour) "On-the-Clock" Auto	$ 32.46	
	$ Value of Person Hour (per hour) Other Auto	$ 16.23	
	$ Value of Vehicle Hour (per hour) Truck	$ 32.46	
	Total Recurring Travel Time Benefit per Period		$ 49,882.46
ATIS Time Savings	Total hours saved due to ATIS deployments		0.00
Travel Time Savings: Non-Recurring Delay	Average Total Person Hours of Non-Recurring Delay Saved per Period		11.3792
	alue of Person Hour (per hour of ***Delay***) "On-the-Clock" Auto	$ 32.46	
	$ Value of Person Hour (per hour of ***Delay***) Other Auto	$ 16.23	
	$ Value of Vehicle Hour (per hour of ***Delay***) Truck	$ 32.46	
	Total Non-Recurring Delay Benefit per Period		$ 240.09
Energy	Average cost per gallon of fuel (excluding taxes)	$ 4.25	
	Total Fuel Savings Benefit		$ -
Safety	$ Value of a Fatality Crash	$ 10,433,467	
	$ Value of a Injury Crash	$ 77,671	
	$ Value of a Property Damage Crash	$ 2,666	
	Total Modeled Crash Related Benefit per Period		$ 3,297
	User Entered Benefit (Annual $'s)		
	Number of Analysis Periods per Year	250	
	TOTAL AVERAGE ANNUAL BENEFIT		$ 13,354,844

Figure 70. Screenshot. Benefit estimation result for enhanced maintenance decision support system.

Model Run Results

In this section, the analysis compares the results of the benefits calculation with the results of the cost calculations. Note that this case study merely analyzes a specific set of costs and benefits for demonstration purposes. A full benefit cost analysis will include a wide range of additional costs and benefits that are not separately listed or analyzed in this case study.

Figure 71 shows the section of TOPS-BC that compares benefits and costs for this CV EMDSS strategy. The exhibit indicates that the deployment of an Enhanced Maintenance Decision Support System in a hypothetical State, considering the various assumptions, is cost effective, since the resulting BCR for the strategy is 5.70. The resulting net benefits for this analysis are about $11.01 million.

Benefit/Cost Summary		
Annual Benefits		**Maintenance Decision Support System**
Travel Time	$	12,470,615
Travel Time Savings: Non-Recurring Delay	$	60,023
Energy	$	0
Safety	$	824,050
Other	$	0
User Entered	$	
Total Annual Benefits	**$**	13,354,844
Annual Costs	**$**	2,341,530
Benefit/Cost Comparison		
Net Benefit	**$**	11,013,314
Benefit Cost Ratio		5.70

Figure 71. Screenshot. Results for connected vehicle maintenance decision support system.

U.S. Department of Transportation
Federal Highway Administration

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