Use Case: Adaptive Signal Control Benefit-Cost Analysis

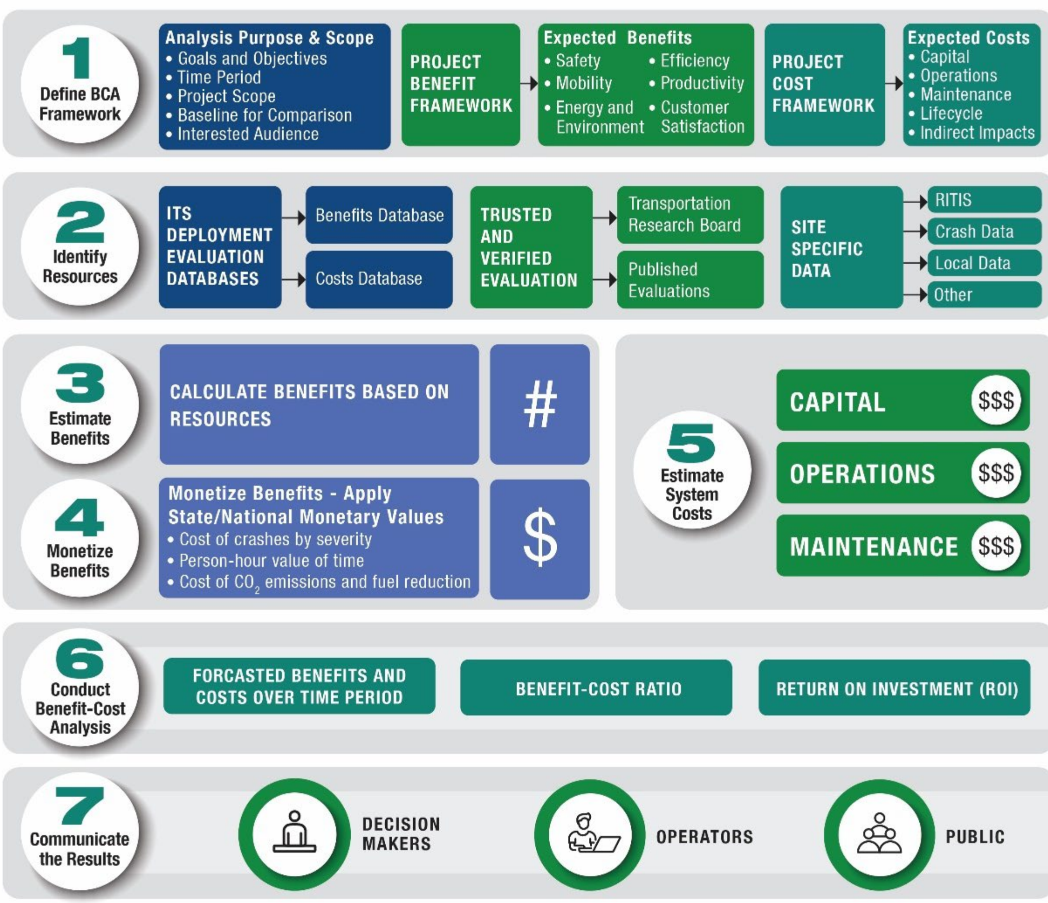
Intelligent Transportation Systems (ITS) Strategy Description

This document serves as a use case for conducting Benefit-Cost Analysis for a hypothetical adaptive signal control project. Adaptive signal control adjusts the timing of red, yellow, and green lights to accommodate changing traffic patterns and ease traffic congestion. The main benefits of adaptive signal control systems compared to conventional signal systems are that they can: (i) continuously distribute green time equitably for all traffic movements; (ii) improve travel time reliability by progressively moving vehicles through traffic signals; (iii) reduce congestion by creating smoother flow; and (iv) prolong the effectiveness of traffic signal timing. By receiving and processing data from strategically placed sensors, adaptive signal control can more effectively manage the flow of traffic through intersections. (Source: FHWA Every Day Counts: Adaptive Signal Control Technology).

This use case is for a hypothetical adaptative signal control corridor. Users should apply their own site-specific data to determine benefit-cost analysis (BCA) for their specific project(s).

Methodology

This use case applies the methodology from **A Guide for Leveraging ITS Deployment Evaluation Tools for Benefit-Cost Analysis**. The methodology is depicted in the graphic below.



Source: Kimley-Horn

Figure 1. Benefit-Cost Analysis Methodology

Applying the Methodology

The following steps provide an overview of the methodology utilized for the benefit-cost analysis.

1 Define BCA Framework — Step 1: Define BCA Framework

The first step in the process is to establish the framework for the study. The following information was defined prior to beginning the analysis:

Scope of the Project. The use case includes an adaptive signal control project for a 10-mile corridor with 44 intersections along an urban arterial. While the agency implementing the project considered traditional traffic signal timing optimization processes in the past, there is interest in applying more advanced strategies to enhance mobility on the corridor.

Goals and Objectives for the Project. For the proposed 10-mile corridor, congestion is present in both directions of the corridor throughout the day. Crashes are also prominent along this corridor. Finally, the corridor is located in a non-attainment area – an area considered to have air quality worse than the National Ambient Air Quality Standards as defined in the Clean Air Act Amendments of 1970 (P.L. 91-604, Sec. 109). Implementing adaptive signal control is expected to improve safety, enhance mobility, and reduce emissions (and fuel use).

Time Period for Analysis. A timeframe of 10 years was used for the analysis. This timeframe is based on the expected lifetime of an adaptive signal control system. This timeframe is long enough to capture the major impacts of the investment and aligns with the lifespan of the major assets. ITS projects typically have a shorter timeframe (7-15 years) than highway construction projects given the need to replace equipment.

Note: *Projects involving the initial construction of highways typically use an analysis period of 30 years.*

Evaluation Baseline Comparison. A “no-build alternative” served as the baseline used to measure the incremental benefits and costs of the proposed project.

A framework for project costs and benefits was also established. The framework identifies the types of project costs and benefits that will be assessed:

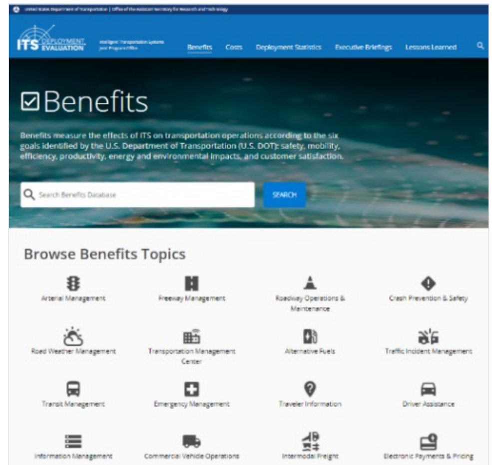
- **Types of Project Costs.** The types of potential project costs include planning and engineering costs, direct capital costs (i.e., costs for infrastructure, software, etc.), integration costs, operations and maintenance costs, and future lifecycle costs.
- **Types of Expected Benefits.** The ITS project aligns with agency goals to improve safety, enhance mobility, and reduce transportation impacts on the environment. Types of benefits expected from this project include:
  - **Safety.** Estimated reduction of crashes based on adaptive signals similar to the proposed implementation and current crash data that an agency might have available.
  - **Mobility.** Estimated reduction of travel time along the corridor based on similar implementations that have been studied and corridor-specific data.
  - **Energy and Environment.** Estimated reduction of emissions and fuel consumption realized because of the reduction of travel time.

2 Identify Resources — Step 2: Identify Resources

Resources guiding the benefit-cost analysis were identified through readily available sources.

Research Resources

The ITS Deployment Evaluation Databases – Benefits Database (see Figure 2) includes research resources documenting benefits for adaptive signal control. In addition, data are available from trusted and verified resources to support analysis of both benefits and costs. Specific resources are cited within the following analysis and provided as references at the end of the example.



Source: USDOT

Figure 2. ITS Benefits Database

Data Resources

There are various types of site-specific data for the corridor – such as travel times, traffic volumes, and crash data – that can be used as inputs in determining the benefits of adaptive signal control. Site-specific data used for the use case include:

- Crash data obtained from a statewide database for a period of 1-year categorized by severity (property damage only (PDO), injury, and fatality).
- Travel time data from the Regional Integrated Transportation Information System (RITIS), identified by peak AM and PM hours per direction. RITIS is a tool developed and managed by the University of Maryland's Center for Advanced Transportation Technology (CATT) Laboratory.

Note: To analyze costs and benefits, it is necessary to have costs and monetized benefits on a common unit basis. The BCA should be conducted in real dollars using a specified base year. Expenditures that occurred in prior years may need to be adjusted. If data collected in this step is obtained from studies conducted in earlier years, it may be required to adjust costs to current dollars by accounting for inflation. Inflation is the increase in prices for goods and services over time. If adjustments need to be made, practitioners should clearly define their methodologies for converting them to current dollars such as using the Inflation Factors provided by the Bureau of Economic Analysis or other inflationary factors like Consumer Price Index (CPI) and Producer Price Index (PPI).

3 Estimate Benefits — Step 3: Estimate Benefits

The adaptive signal control is being considered for deployment to reduce delay and increase throughput along an existing facility by optimizing traffic flow. This technology is also expected to provide safety and energy and environmental benefits.

The information identified in Step 2 is used to calculate the benefits for the ITS strategy being assessed. Benefits data obtained from the ITS Deployment Evaluation Benefits Database and site-specific data available on the corridor are used to estimate the safety, mobility, and energy and environmental benefits of the strategy.

Estimated benefits for the proposed project include:

- **Safety.** Estimated reduction of crashes based on similar adaptive signal deployments and current crash data along the 10-mile corridor.
- **Mobility.** Estimated reduction of travel time based on similar adaptive signal deployments and current vehicular delay data along the 10-mile corridor.

- **Energy and Environment.** Estimated reduction of emissions and fuel consumption related to reduction of travel time and associated greenhouse gases and reduction of idle time.

Annual benefits are calculated using data from Step 2. Details of the calculations and assumptions for this use case are included later in the document.

Step 4: Monetize Benefits

Estimating the monetary values of a strategy's benefits provides the ability to analyze and compare benefits and costs. Using the estimated benefits from Step 3, the monetary values were estimated by applying state and national monetary values of the following:

- **Safety.** Value of preventing crashes by type (i.e., property damage only [PDO], injury, fatality). National, state, or local sources provide costs of crashes by relevant crash type.
- **Mobility.** Person-hour value of time categorized by personal and commercial vehicular travel or transit traveler wait time. User Delay Cost Reports are based on the cost per hour for passenger and commercial vehicles, updated annually. Delay cost values were obtained from RITIS which uses values from the Texas Transportation Institute (TTI) that are based on the passenger value of time and commercial operating cost. Sources are referenced in the example below.
- **Energy and Environmental.** Cost of CO_2 emission reductions and fuel savings can be derived using data that estimates the amount of fuel burned when a vehicle is idling – and the amount of emissions associated with the fuel burned. To determine the monetary value of the benefits, costs of gasoline and costs of emissions from trusted and verified sources such as the U.S. Environmental Protection Agency (EPA) can be applied to the energy and environmental costs.

The completion of this step results in monetized benefits for each applicable benefit area (i.e., safety, mobility, etc.). Monetized benefits are in current dollars.

Step 5: Estimate System Costs

ITS strategy costs can be estimated using a variety of resources depending on access to current agency construction bids, vendor quotes, and relevant information within the ITS Deployment Evaluation Databases – Costs Database. For this project, capital, operations, and maintenance costs were estimated by the following system component as defined in the Costs Database:

- Signalized Intersection Upgrades

National Cooperative Highway Research Program (NCHRP) data were referenced for non-recurring, capital component costs. These data were converted to net present value numbers by estimating inflation factors. Recurring, operations and maintenance component costs were estimated by calculating 15% of capital costs for the signalized intersection components. This accounts for enhanced detection maintenance and software service costs.

Note: In many instances, cost data collected during Step 2 will be collected from a variety of sources and studies. These sources and studies are likely to include costs from different time periods. It is important to put these values into a common, apples-to-apples framework that adjusts for costs over time. All relevant costs should have a common temporal footing. This is done by converting past costs into a present value amount. For example, if costs are obtained for ITS equipment from a report in 2017, dollars should be adjusted for current dollars.

Step 6: Conduct Benefit-Cost Analysis

Step 6 uses the monetized results from Steps 4 and 5 to determine a Benefit-Cost Ratio (BCR) and Return on Investment (ROI) for the project. Costs and benefits were identified for each year of the time horizon to calculate the BCR and ROI.

ITS and Transportation Systems Management and Operations (TSMO) projects incur a stream of expenditures and benefits over time. Initial capital costs may occur in the early project years with operations and maintenance (O&M) costs continuing over the project life. Benefits start accruing once the project is implemented and accrue over time (i.e., for the duration of the time horizon). The estimated monetized applicable benefits (e.g., safety, mobility, energy & environmental) are extrapolated over the 10-year time horizon. Likewise, the capital, operations, and maintenance costs are also estimated for the same time horizon.

All costs and benefits are stated in **real dollars** using a common base year. Cost elements that were expended in prior years were updated to the recommended base year. Any future year constant dollar costs were appropriately discounted to the baseline analysis year to allow for comparisons with other BCA elements. Costs and benefits for future years are adjusted for discounting over the time period. In accordance with OMB Circular A-94, a discount rate of 7% was applied to discount streams of benefits and costs to the present value in their BCA.

Once costs and benefits are calculated for the time-period, the benefit-cost analysis is reported as:

- Benefit-Cost Ratio (BCR) $= \sum benefits \div \sum costs : 1$
- Return-on-Investment (ROI) $= (\sum benefits - \sum costs) \div (\sum costs) \times 100\%$

It was assumed that capital investment will be maintained during the 10-year horizon, therefore capital replacement costs are not included. Step 6 concludes with the calculation of the BCR and ROI. A BCR greater than 1:1 and a ROI greater than zero shows a positive return. The BCR and ROI for the adaptive signal control project were calculated and demonstrated a positive impact is expected for the example project. The BCR was 32.6:1 and the ROI was 3162%. Both the BCR and ROI show a positive return on investment for the proposed project.

Note: While the equation listed above is common for ROI, there are additional definitions/equations used. Net Present Value (NPV) is another metric that may be useful. To calculate NPV, all benefits and costs over an alternative's lifecycle are discounted to the present, and the costs are subtracted from the benefits. If benefits exceed costs, NPV is positive and the project is considered economically sound.

Step 7: Communicate the Results

Communicating the results of benefit-cost analysis provides an opportunity to demonstrate the value of ITS deployments in a tangible way. When communicating the results, the audience with whom the analysis results are being shared with should be considered to ensure that the information is relevant and relatable. An infographic was developed and included in the example that summarizes the key results for these audiences.

- **Decision Makers.** Decision makers are responsible for prioritizing projects and determining where funds are invested. This group may consider using BCR or ROI as a way to compare all transportation projects including, traditional roadway projects and ITS deployments. Demonstrating fiscal responsibility with BCR and ROI is a good way to communicate with this group. Results may help decision makers better assess and align ITS and TSMO projects with traditional roadway capacity improvement or multi-modal projects.
- **Operators.** Operators optimize the management of their systems and monitor performance metrics. Communicating key performance indicators (KPI) such as crashes or hours of travel time reduced is relevant to how an operator will increase the efficiency of their system.

- **Public.** Communicating benefits in a way that is relatable and tangible to the public is critical to demonstrating the value and gaining support for ITS deployments. Sharing with the public how many additional hours a year they will be able to spend with family and friends or how much fuel they will save is a good way to communicate with this group.

Adaptive Signal Control Benefit-Cost Analysis

This section documents the benefit-cost analysis for the example adaptive signal control project. The numbers included in this example are hypothetical. Users should apply their own site-specific data to estimate BCR and ROI for their projects rather than simply using the results in this document. Resources used in conducting the analysis are denoted by a number in brackets. In addition, resources in the examples are color-coded (see image to the right) to denote the source of the data or resource used.

User Provided Site Specific Data
Evaluation Database
Trusted/Verified Research and Resource

Estimating and Monetizing Benefits

The following analysis was performed to estimate and monetize the benefits for adaptive signal control.

Benefits: Safety

2 Identify Resources	Corridor length =	10	Miles
	Corridor average annual PDO crashes =	476	PDO Crashes
	Corridor average annual injury crashes =	251	Injury Crashes
	Corridor average annual fatality crashes =	1	Fatal Crashes
	Average percent reduction of crashes using proposed strategy [8] =	28.8%	
3 Estimate Benefits	Estimated annual reduction of PDO crashes =	137	PDO Crashes
	Estimated annual reduction of injury crashes =	72	Injury Crashes
	Estimated annual reduction of fatal crashes =	0.3	Fatal Crashes
	Estimated Safety Benefit =	**210**	Crashes Reduced
4 Monetize Benefits	Average cost of a property damage only crash [1] =	$ 3,745	
	Average cost of an injury collision per crash [1] =	$ 287,526	
	Average cost of a fatal collision per crash [1] =	$ 12,216,548	
	Monetized Annual Safety Benefit =	**$24,816,000**	

Safety Benefit = (corridor average annual crashes) x (reduction %)

Monetized Benefit = $\sum(cost\ of\ crash \times number\ of\ crashes)$

Benefits: Mobility

2 Identify Resources	Corridor peak veh-hour travel time (AM & PM) [RITIS] =	30	Minutes
	Corridor average peak hour volume =	1,200	Vehicles Per Hour
	Reduction in corridor travel time during peak hour (AM & PM) [9] =	10%	
	Annual number of weekdays =	260	
	Number of peak hours per day =	6	
	Percent passenger vehicles (i.e., cars, SUVs, etc.)	90%	
	Percent trucks	10%	
	Average vehicle occupancy [2] =	1.7	Persons Per Veh

3 Estimate Benefits

Estimated Mobility Benefit =	**159,120**	Annual Person-Hours Travel Time Savings

Est. Mobility Benefit = (peak travel time) x (peak volume) x (reduction in travel time) x (average vehicle occupancy) x (no. of peak hours per day) x (no. weekdays)

4 Monetize Benefits

Passenger hourly value of delay time [3] =	\$ 17.91	Per Person Per Hour
Commercial hourly value of delay time [3] =	\$ 100.49	Per Person Per Hour
Monetized Annual Mobility Benefit =	**\$ 4,163,900**	

Monetized Benefit = (% passenger vehicles) x [(Estimated Mobility Benefit) x passenger value of delay time)] + (% trucks) x [(Mobility Benefit) x (commercial value of delay time)]

Benefits: Energy and Environment

Estimated reduction of emissions and fuel consumption related to reduction of travel time and associated greenhouse gases and reduction of idle time. Therefore, energy and environmental benefits are derived from the mobility benefits, vehicle-hours travel time savings, calculated above.

3 Estimate Benefits

Fuel Reduction		
Veh-hours of travel time savings per year =	159,120	Vehicle-Hours
Average fuel consumption per hour of idle time [4] =	0.17	Gallons per Hour
Average diesel fuel consumption per hour of idle time [4] =	0.64	Gallons per Hour
Estimated Energy and Environment Benefit = (Average fuel consumption reduction per year)	**33,813**	Gallons
CO_2 Emission Reduction		
Average CO_2 emitted per gallon of gasoline burned [6] =	0.0089	Metric Tons / Gallon
Average CO_2 emitted per gallon of diesel burned [6] =	0.0102	Metric Tons / Gallon
Estimated Energy and Environment Benefit = (Average CO_2 emission reduction due to travel time savings)	**305**	Metric Tons

Fuel Reduction = (reduction in travel time) x [(% passenger vehicles) x (fuel consumed idling) + (% trucks) x (diesel consumed idling)]

CO_2 Reduction = Fuel Reduction per Year x [(% passenger vehicles) x (CO_2 emitted per gallon of gasoline) + (% truck) x (CO_2 emitted per gallon of diesel)]

4 Monetize Benefits

Average cost of fuel within region [5] =	\$ 3.30	\$ / Gallon
Annual Fuel Reduction Benefit =	\$ 111,400	
Average cost per metric ton of CO_2 [7] =	\$ 20.00	\$ / Metric Ton
Annual CO_2 Benefit =	\$ 6,100	
Monetized Annual Energy and Environment Benefit =	**\$ 117,500**	

Monetized Benefit = (fuel reduction benefit) x (cost of fuel) + (CO_2 reduction benefit) x (cost of CO_2)

Estimating Costs

The following analysis was performed to estimate costs for the adaptive signal control project. Project costs include direct capital costs (i.e., costs for infrastructure, software) and operations and maintenance costs as well as future lifecycle costs with an assumed base year of 2020.

When estimating costs, it was assumed that there is existing fiber and adequate closed-circuit television (CCTV) coverage along the proposed corridor. Capital costs were obtained from the ITS Deployment Evaluation Cost Database [10]. The costs used for the analysis were from 2010. To adjust the costs to 2020 dollars, an Inflation Factor was used. Annual operations and maintenance costs were assumed to be 15% of the capital costs to account for enhanced detection maintenance and software service costs.

System Costs: Adaptive Signal Control

5 Estimate System Costs

System Component	Unit	Qty	Capital (Unit)	Annual O&M (Unit)
Signalized Intersection Upgrade - detection, controller upgrades, and controller software	Each	44	$ 77,057	$ 11,559
Total System Costs =			**$ 3,390,508**	**$ 508,576**

Costs adjusted to 2020 Dollars using Inflation Factor

Benefit Cost Analysis (BCA) and Return-on-Investment (ROI)

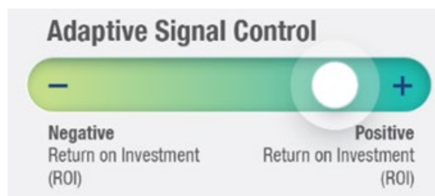
The annual monetized benefits and costs were used to calculate the BCR and ROI over a 10-year period. Capital costs were used for the first year and an annual O&M cost was applied for future years that accounted for inflation.

Benefits and costs for future years considered a discount rate of 7% starting in Year 2 (*t*=1). In the calculations below, the discount rate is applied to determine the present value (PV) for each year, Y1 (*t*=0) through Y10 (*t*=9). The discount rate recognizes that a dollar today is worth more than a dollar five years from now, even if there is no inflation because today's dollar can be used productively in the ensuing five years, yielding a value greater than the initial dollar. Future benefits and costs are discounted to reflect this fact.

Benefit-Cost Analysis: Adaptive Signal Control

6 Conduct Benefit-Cost Analysis

Annual Monetized Benefits:	
Safety	$ 24,816,000
Mobility	$ 4,163,900
Energy and Environment	$ 117,500
Total Annual Benefit	$ 29,097,400
Total System Costs:	
Capital	$ 3,390,508
Annual O&M	$ 508,576
Adjustment Rates:	
Real Discount Rate (i)	**7%**



Source: Kimley-Horn

Discount Rate Applied to Benefit and Costs

Year			Year		
Y1	Annual Monetized Benefit	$ 29,097,400	Y6	PV Annual Monetized Benefit	$ 20,746,044
Y1	Estimated Cost	$ 3,390,508	Y6	PV Estimated Cost	$ 362,608
Y2	PV Annual Monetized Benefit	$ 27,193,832	Y7	PV Annual Monetized Benefit	$ 19,388,826
Y2	PV Estimated Cost	$ 475,305	Y7	PV Estimated Cost	$ 338,886
Y3	PV Annual Monetized Benefit	$ 25,414,796	Y8	PV Annual Monetized Benefit	$ 18,120,398
Y3	PV Estimated Cost	$ 444,210	Y8	PV Estimated Cost	$ 316,716
Y4	PV Annual Monetized Benefit	$ 23,752,146	Y9	PV Annual Monetized Benefit	$ 16,934,952
Y4	PV Estimated Cost	$ 415,150	Y9	PV Estimated Cost	$ 295,996
Y5	PV Annual Monetized Benefit	$ 22,198,267	Y10	PV Annual Monetized Benefit	$ 15,827,058
Y5	PV Estimated Cost	$ 387,990	Y10	PV Estimated Cost	$ 276,632

PV 10-Year Monetized Benefits	$ 218,673,719
PV 10-Year Estimated Costs	$ 6,704,000

10-Year Benefit-Cost Ratio (BCR) =	**32.6:1**
10-Year Return on Investment (ROI) =	**3162%**

Present Value (PV) =

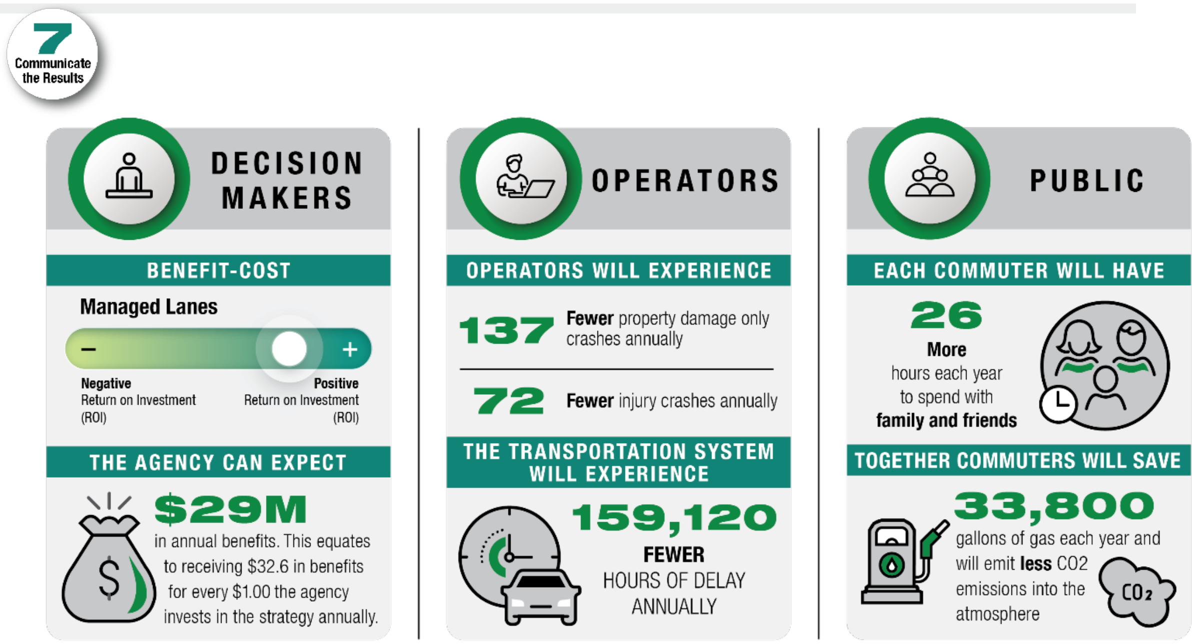
$$\sum \frac{Future\ Value}{(1+i)t}$$

where,
i = rate of return
t = number of periods

Communicating the Results

Communicating the results of benefit-cost analysis provides an opportunity to prove the value of ITS deployments which can sometimes be difficult to demonstrate in a tangible way. It is important to consider the audience with whom the analysis results are being shared such that the information is relevant and relatable.

Communicate the Results: Adaptive Signal Control



Source: Kimley-Horn

Figure 3. Adaptive Signal Control Benefit-Cost Analysis Results

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