U.S. Department of Transportation

Use Case: Smart Work Zone Benefit-Cost Analysis

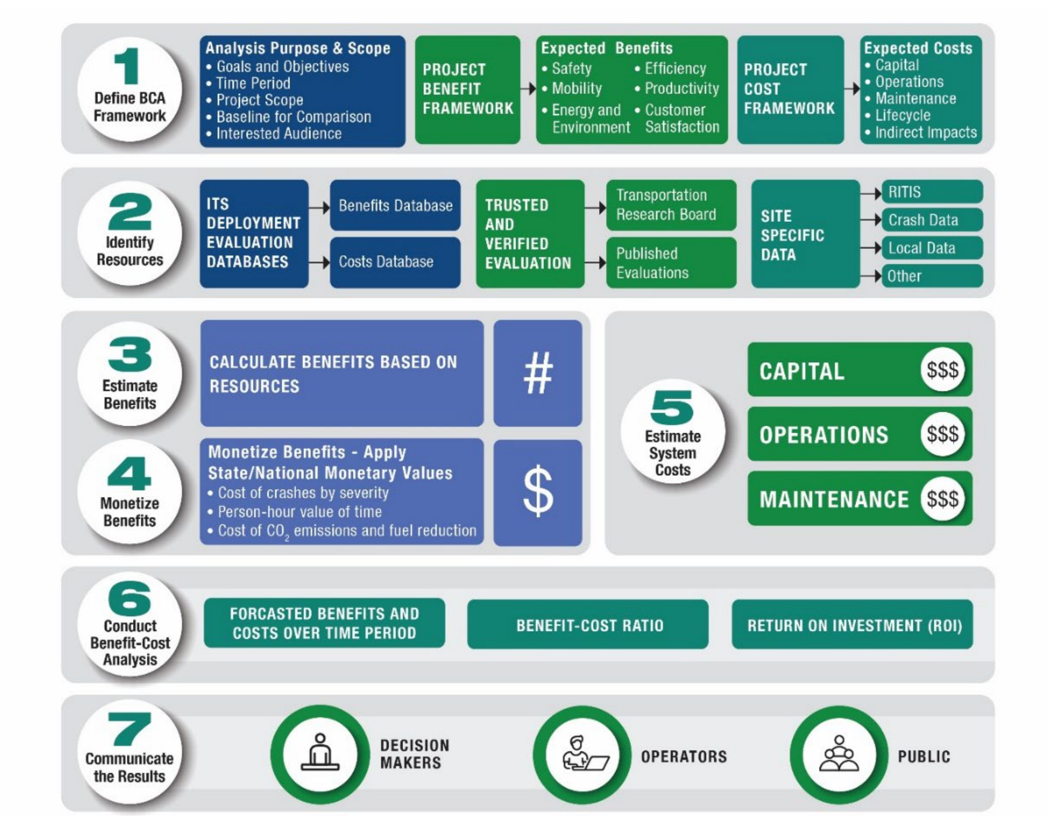
Intelligent Transportation Systems (ITS) Strategy Description

This document serves as a use case for conducting Benefit-Cost Analysis (BCA) for a hypothetical smart work zone project. Maintenance and construction activities are a necessary part of upgrading transportation infrastructure to meet today's needs. To support these construction and maintenance activities, work zones are required and may involve lane closures and detours. Passing through work zones can present both safety and mobility challenges. Effective work zone management involves carefully balancing safety and mobility to ensure that the negative impacts on traffic flows are minimized and unnecessary congestion is avoided, but also to make sure that the safety of motorists and workers is not compromised. Specific deployments and applications of smart work zones vary by agency and project. For the purposes of this use case, it is assumed that an agency is investigating the deployment of a smart work zone that includes the following: queue warning and traveler information on portable dynamic message signs (DMS), portable Bluetooth detection to monitor traffic speed, portable cameras that can be attached to DMS, as well as software upgrades to implement the smart work zone. This use case assumes a 4-mile work zone corridor along a freeway with work performed during non-peak hours.

This use case is for a hypothetical smart work zone project. Users should apply their own site-specific data to determine benefit-cost analysis (BCA) for their specific project.

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 conducted 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 is focused on a work zone project for a 4-mile corridor along a major interstate in one direction with work performed between 7PM and 7AM.
- **Goals and Objectives for the Project.** For the proposed 4-mile corridor, congestion is present during the time of construction. 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).
- **Time Period for Analysis.** Analysis was performed over a time period of 4 years. This is consistent with the expected duration of the corridor construction. This timeframe is long enough to capture the major impacts of the investment and aligns with the lifespan of construction.
- **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 smart work zone deployments 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.** 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.

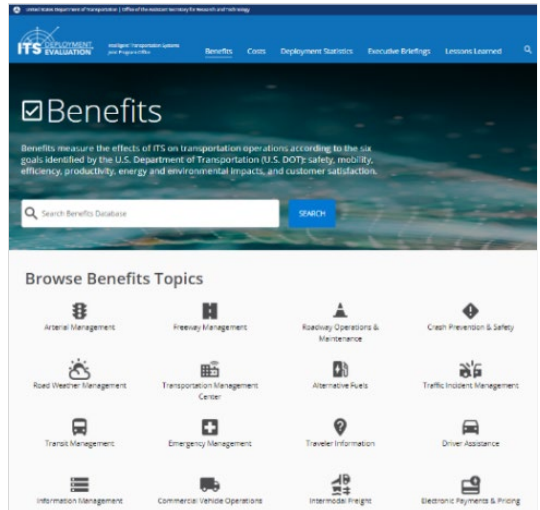
Step 2: Identify Resources

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 smart work zones. In addition, data is available from trusted and verified resources to support analysis of both, benefits and costs.

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 delay, traffic volumes, and crash data – that can be used as inputs in determining the benefits of smart work zones. Site-specific data used for the use case include:

- Crash data obtained from a statewide database for a period of 3 years categorized by severity and analyzed using a yearly average (property damage only (PDO), injury, and fatality).
- Travel time data from Regional Integrated Transportation Information System (RITIS), identified by non-peak AM and PM hours. 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).

Step 3: Estimate Benefits

Smart work zones are implemented to reduce work zone related delays and enhance safety when maintenance and construction activities occur along the roadway. 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. The smart work zone use case estimated benefits include:

- **Safety.** Estimated reduction of crashes.
- **Mobility.** Estimated reduction of travel time.
- **Energy and Environment.** Estimated reduction of emissions and fuel consumption.

Details of the calculations and assumptions are included in the example contained later in this document.

4 Monetize Benefits

Step 4: Monetize Benefits

Estimating the monetary value of strategy deployment benefits provides the ability to analyze and compare benefits and costs. Using the estimated benefits from Step 3, the monetary value of the smart work zone use case can be 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. 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.** Value of CO_2 emission reductions and fuel savings were 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.

5 Estimate System Costs

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. The smart work zone use case system capital, operations, and maintenance costs are estimated by system component:

- Software updates and TMC upgrades
- Portable DMS with portable cameras
- Speed detection on trailers

Cost information from the ITS Deployment Evaluation Databases – Costs Database was referenced for the smart work zone use case for non-recurring, capital component costs. These system components costs were converted to present values by estimating inflation factors. Recurring, operations and maintenance component costs were estimated by calculating 10% of capital costs – a rule of thumb used by many agencies.

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 to current dollars.

6 Conduct Benefit-Cost Analysis

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 4-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 the 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 4-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 was 10.2:1 and the ROI was 924%. Both the BCR and ROI show a positive return on investment for the proposed project. For comparative purposes, roadway construction projects that build new capacity typically have a BCR of 2:1.

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.

7 Communicate the Results

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 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.

Smart Work Zone Benefit-Cost Analysis

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

This section documents the benefit-cost analysis for the example smart work zone use case. 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.

Estimating and Monetizing Benefits

The following analysis was performed to estimate and monetize the benefits for a smart work zone.

Benefits: Safety

2 Identify Resources	Corridor Length =	4	Miles
	Corridor average annual PDO crashes (7PM-7AM) =	37	PDO Crashes
	Corridor average annual injury crashes (7PM-7AM) =	18	Injury Crashes
	Corridor average annual fatality crashes (7PM-7AM) =	0.7	Fatal Crashes
	Average percent reduction of crashes using proposed strategy [8] =	18%	
3 Estimate Benefits	Estimated annual reduction of PDO crashes =	7	PDO Crashes
	Estimated annual reduction of injury crashes =	3	Injury Crashes
	Estimated annual reduction of fatal crashes =	0.1	Fatal Crashes
	Estimated Safety Benefit =	**10**	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 =	**$2,440,000**	

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

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

Benefits: Mobility

2 Identify Resources	Vehicle-Hour travel time (7PM-7AM) [RITIS] =	6,000	Vehicle-Hours
	Reduction in corridor travel time during non-peak hour [9] =	10%	
	Percent passenger vehicles (i.e., cars, SUVs, etc.)	90%	
	Percent trucks	10%	
	Average vehicle occupancy [2] =	1.7	Persons Per vehicle
3 Estimate Benefits	**Estimated Mobility Benefit =**	**1,020**	Person-Hours Travel Time Savings
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 =	**$ 26,700**	

Est. Mobility Benefit = (travel time between 7PM-7AM) x (percent reduction in travel time) x (average vehicle occupancy)

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

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.

Benefits: Energy and Environment

3 Estimate Benefits

Fuel Reduction		
Veh-hours of travel time savings per year =	1,020	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)	**217**	Gallons
CO_2 Emission Reduction		
Average CO_2 emitted per gallon of gasoline burned [6] =	0.0089	Metric Tons / Gallons
Average CO_2 emitted per gallon of diesel burned [6] =	0.0102	Metric Tons / Gal
Estimated Energy and Environment Benefit = (Average CO_2 emission reduction due to travel time savings)	**2**	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	$ per Gallon
Annual Fuel Reduction Benefit =	$ 715	
Average cost per metric ton of CO_2 [7] =	$ 21.71	$ per Metric Ton
Annual CO_2 Benefit =	$ 42	
Monetized Annual Energy and Environment Benefit =	**$ 757**	

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 smart work zone 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 along the corridor. Capital costs were obtained from the ITS Deployment Evaluation Cost Database [10]. To adjust the costs to 2020 dollars, an Inflation Factor was used. Recurring, operations and maintenance component costs are estimated by calculating 10% of capital costs.

System Costs: Smart Work Zones

5 Estimate System Costs

System Component	Unit	Qty	Capital (Unit)	Annual O&M (Unit)
Software and TMC Costs	--	1	$ 341,950	$ 34,195
Portable dynamic message sign (DMS) with trailer *Assumption: One per 3/4 of a mile*	Each	6	$ 21,711	$ 2,171
Portable cameras mounted on DMS or radar trailer *Assumption: approx. one per mile*	Each	4	$ 10,856	$ 1,086
Radar detection to detect vehicle speed (on trailer) *Assumption: One per 1/3 of a mile*	Each	12	$ 14,655	$ 1,466
		Total Costs =	**$ 691,500**	**$ 69,150**

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 4-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 Y4 (*t*=3). 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: Smart Work Zone

6 Conduct Benefit-Cost Analysis

Annual Monetized Benefits:		
Safety	$	2,440,000
Mobility	$	26,700
Energy and Environment	$	757
Total Annual Benefit	$	2,467,457
Total System Costs:		
Capital	$	691,500
Annual O&M	$	69,150
Adjustment Rates:		
Real Discount Rate (i)		7%

Source: Kimley-Horn

Discount Rate Applied to Benefit and Costs

Year (2020)

Y1	Annual Monetized Benefit	$	2,467,457	Y3	PV Annual Monetized Benefit	$	2,155,173
Y1	Estimated Cost	$	691,500	Y3	PV Estimated Cost	$	60,398
Y2	PV Annual Monetized Benefit	$	2,306,035	Y4	PV Annual Monetized Benefit	$	2,014,180
Y2	PV Estimated Cost	$	64,626	Y4	PV Estimated Cost	$	56,447

4-Year Monetized Benefits = $8,942,845

4-Year Estimated Costs = $872,971

Present Value (PV) =

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

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

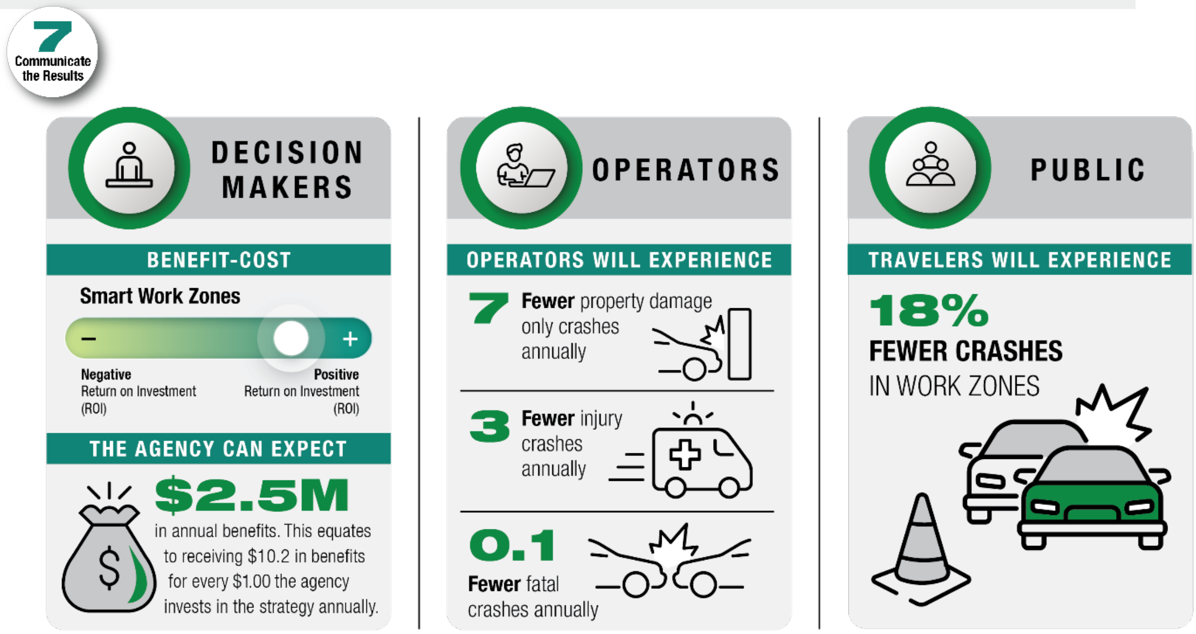
4-Year Benefit-Cost Ratio (BCR) = 10.2:1

4-Year Return on Investment (ROI) = 924%

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: Smart Work Zones



Source: Kimley-Horn

Figure 3. Smart Work Zones Benefit-Cost Analysis Results

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