



# Use Case: Transit Signal Priority Benefit-Cost Analysis

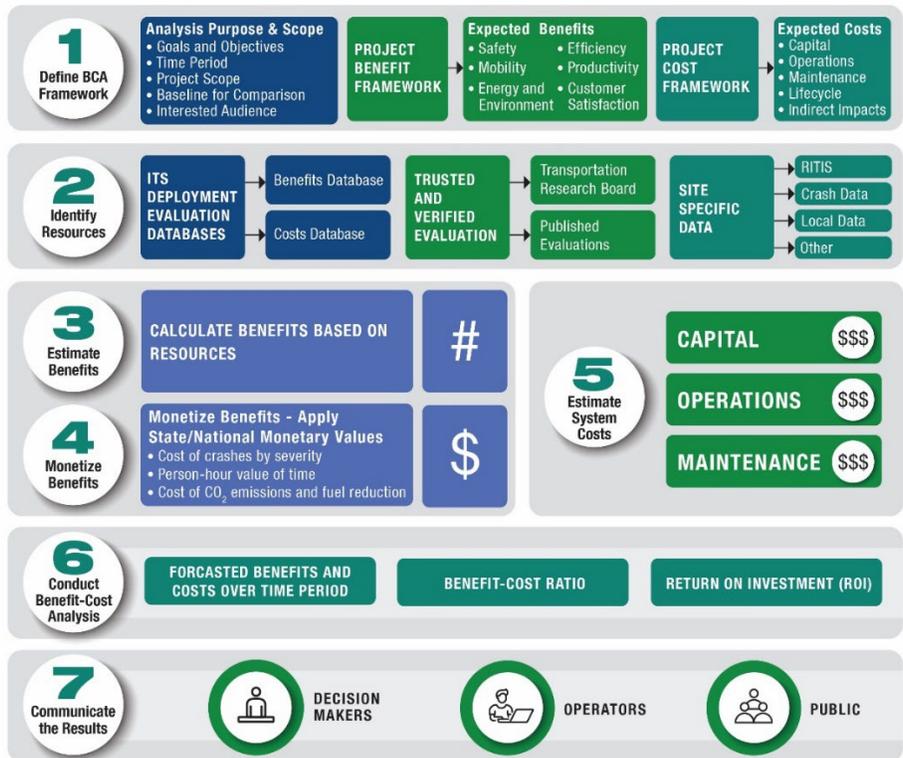
## Intelligent Transportation Systems (ITS) Strategy Description

This document serves as a use case for conducting Benefit-Cost Analysis (BCA) for a hypothetical transit signal priority project. Transit signal priority (TSP) is an operational strategy that is applied to reduce the delay transit vehicles experience at traffic signals. TSP involves communication between buses and traffic signals so that a signal can alter its timing to give priority to transit operations. Priority may be accomplished through a number of methods, such as extending greens on identified phases, altering phase sequences, and including special phases without interrupting the coordination of green lights between adjacent intersections (Source: [FHWA Traffic Signal Timing Manual](#)). Specific deployments and applications of TSP vary by agency and project. For the purposes of this use case, it is assumed that an agency is investigating the deployment of TSP that includes equipment installed on transit vehicles to request priority, equipment installed at the traffic signal to receive priority requests, and algorithms and equipment that interact with the signal controller to grant priority. This use case assumes a 25-mile deployment corridor that serves multiple transit routes with 105 signalized intersections along an urban arterial. TSP is planned for approximately 60 transit vehicles.

**This use case is for a hypothetical transit signal priority (TSP) 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.



### 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 a TSP project in an urban setting that includes 105 roadside units and a fleet of 60 heavy duty buses powered with diesel.
- **Goals and Objectives for the Project.** This project is intended to reduce transit delay, increase transit reliability, and decrease impacts on the energy and environment.
- **Time Period for Analysis.** A timeframe of 10 years was used for the analysis. 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 enhance mobility and reduce transportation impacts on the environment. Types of benefits expected from this project include:
  - **Mobility.** Estimated reduction of transit 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.



### 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 TSP. 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.

#### Data Resources

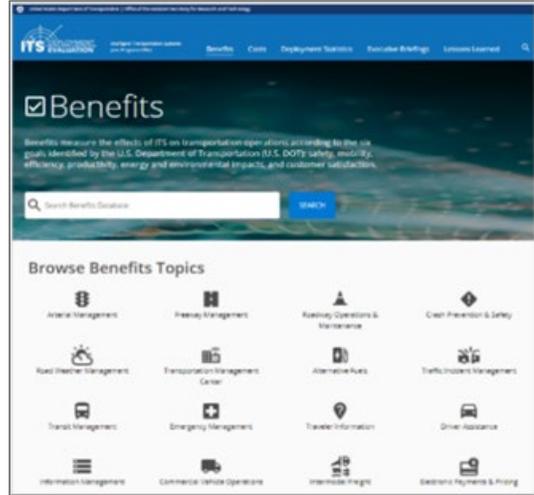
There are various types of site-specific data for the corridor – such as travel time and existing bus service routes and schedules – that can be used as inputs in determining the benefits of TSP.



Site-specific data used for the use case include:

- Existing corridor transit travel time.
- Number of bus trips along the corridor.
- Transit route schedules.

**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).



Source: USDOT

Figure 2. ITS Benefits Database



### Step 3: Estimate Benefits

Transit signal priority is deployed to reduce dwell times at traffic signals for transit vehicles, helping to reduce transit travel times, improve schedule adherence, improve transit efficiency, and increase road network efficiency as measured by person mobility. The information identified in Step 2 is used to calculate the benefits for the ITS strategy being assessed.

The transit signal priority use case estimated benefits include:

- **Mobility.** Estimated reduction of travel time for transit vehicles. For simplicity, it was assumed that there is little or no net change to travel times for other vehicles.
- **Energy and Environment.** Estimated reduction of emissions and fuel consumption.

Benefits data obtained from the [ITS Deployment Evaluation Benefits Database](#) and site-specific data available on the corridor are used to estimate the mobility and energy and environmental benefits of the strategy.

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



### 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 transit signal priority use case can be estimated by applying state and national monetary values of the following:

- **Mobility.** Reduced costs of operating a bus per transit travel time saved. Trusted data sources were used to quantify this value. 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. Sources are referenced in the example below.



- **Energy and Environmental.** Cost of CO<sub>2</sub> emission reductions and fuel savings can be derived using data that estimates the amount of fuel burned when a bus is idling – and the amount of emissions associated with the fuel burned. To determine the monetary value of the benefits, 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., mobility, energy and environmental, 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](#). The transit signal priority use case system capital, operations, and maintenance costs are estimated by system component:

- Field connected vehicle equipment
- Transit on-board connected vehicle equipment

These data were converted to present value numbers by applying inflation factors. The [ITS Deployment Evaluation Databases – Costs Database](#) is referenced for the transit signal priority use case for non-recurring, capital component costs. Recurring, operations and maintenance component costs are estimated by calculating 10% of capital costs for the ITS strategy system components with an additional \$10,000 per year for anticipated software service costs. A 10% estimate is a standard rule of thumb used by many agencies. In addition, it was assumed that transit bus components would need to be replaced after 5 years of use.

**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 in order 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., 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 (2020 for this example). 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 their 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) =  $\sum \text{benefits} \div \sum \text{costs} : 1$
- Return-on-Investment (ROI) =  $(\sum \text{benefits} - \sum \text{costs}) \div (\sum \text{costs}) \times 100\%$

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 transit signal priority project were calculated and demonstrated a positive impact is expected for the example project. The BCR was 3.6:1 and the ROI was 259%. 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.



## 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.



## Transit Signal Priority Benefit-Cost Analysis

This section documents the benefit-cost analysis for the transit signal priority 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 the benefits for a transit signal priority project.

#### Benefits: Mobility

	Average reduction in transit travel time [1] =	32.9%		
	(assumed average of transit results from AZ and VA scenarios and Volume-to-Capacity ratio (V/C) = 0.5)			
	Corridor existing transit travel time [10] =	41	Minutes per Trip	
	Number of bus trips along corridor per weekday =	304	Trips per Day	
	Average number of working days a year =	260	Days per Year	
	Transit travel time savings per year =	17,650	Hours per Year	
	<b>Estimated Mobility Benefit =</b>	<b>17,650</b>	<b>Annual Transit Travel Time Savings (Hours)</b>	<i>Est. Mobility Benefit = (reduction in transit travel time) x (average transit travel time) x (no. of trips per day) x (no. of trips per year)</i>
	Average cost of operating a bus per hour [2] =	\$ 93.61	Per Hour	
	<b>Monetized Annual Mobility Benefit =</b>	<b>\$ 1,652,143</b>		<i>Monetized Benefit = (annual transit travel time savings) x (average bus operating cost per hour)</i>

#### 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.

	<b>Emissions Reduction</b>		
	Emission rates for urban diesel buses [3]:		
	NOx =	61.113	Gram per Hour
	VOC =	2.700	Gram per Hour
	PM2.5 =	1.069	Gram per Hour
	CO <sub>2</sub> [4] =	4,484	Gram per Hour
	Transit travel time savings per year = (calculated above)	17,650	Annual Transit Travel Time Savings (Hours)



**Estimated Energy and Environment Benefit = (Emissions)**

NOx =	<b>1,078.62</b>	Kilogram per Year
VOC =	<b>47.65</b>	Kilogram per Year
PM2.5 =	<b>18.87</b>	Kilogram per Year
CO <sub>2</sub> =	<b>79,141</b>	Kilogram per Year

**Fuel Consumption**

Average fuel consumption per minute of idle time [5] =	<b>0.97</b>	Gallons per Hour
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**Estimated Energy and Environment Benefit = (Fuel Consumption)**

<b>17,120</b>	Gallons
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$$\text{Fuel Reduction} = (\text{urban diesel bus fuel consumption per idle time}) \times (\text{annual transit travel time savings})$$



**Emissions Reduction**

Emissions Cost per metric ton [7]:

Emissions Cost NOx =	<b>\$ 6,700</b>	Per Metric Ton
Emissions Cost VOC =	<b>\$ 1,700</b>	Per Metric Ton
Emissions Cost PM2.5 =	<b>\$ 306,500</b>	Per Metric Ton
Emissions Social Cost CO <sub>2</sub> , 2020 [6] =	<b>\$ 22</b>	Per Metric Ton

**Monetized Annual Energy and Environment Benefit = (Emissions)**

<b>\$ 14,809</b>
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Average cost of diesel fuel in a representative area [8] =	<b>\$ 3.30</b>	Per Gallon
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**Monetized Annual Energy and Environment Benefit = (Fuel Consumption)**

<b>\$ 56,411</b>
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<b>Monetized Annual Energy and Environment Benefit = \$ 71,220</b>
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$$\text{Emission Reduction} = (\text{urban diesel bus emission rate}) \times (\text{annual transit travel time savings})$$

$$\text{Monetized Benefit} = (\text{emission reduction benefit}) \times (\text{emission costs}) + (\text{fuel reduction benefit}) \times (\text{cost of fuel})$$

## Estimating Costs

The following analysis was performed to estimate costs for the transit signal priority 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 [9]. 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 for the ITS strategy system components with an additional \$10,000 per year for anticipated software service costs. In addition, it was assumed that transit bus components would need to be replaced after 5 years of use; of which the additional cost is evenly distributed throughout the life of the project.



### System Costs: Transit Signal Priority



System Component	Unit	Qty	Capital (Unit)	Annual O&M (Unit)
<b>Field Equipment</b> - Roadside units (RSU), MAP message development, edge processing, software, and cybersecurity. <i>Capital Resources: ITS Deployment Evaluation Cost</i> <i>O&amp;M Resources: 10% of capital cost + software service costs Database [9]</i>	Each	105	\$ 14,000	\$ 1,495
<b>Transit Bus Equipment</b> - Onboard units (OBU), human-machine interface (HMI), and cybersecurity. <i>Capital Resources: ITS Deployment Evaluation Cost Database [9]</i> <i>O&amp;M Resources: 10% of capital cost + capital replacement cost at year 6</i>	Each	60	\$ 8,100	\$ 1,620

O&M cost includes OBU replacement at year 6

Costs adjusted to 2020 Dollars using Inflation Factor

**Total System Costs = \$ 1,956,000 \$ 254,200**

### 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: Transit Signal Priority



**Annual Monetized Benefits:**

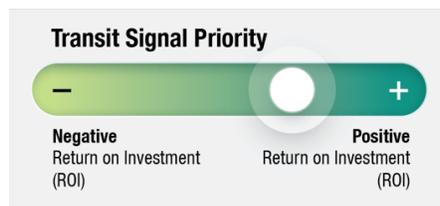
Mobility	\$ 1,652,143
Energy and Environment	\$ 71,220
<b>Total Benefits</b>	<b>\$ 1,723,363</b>

**Total System Costs:**

Capital	\$ 1,956,000
Annual O&M	\$ 254,200

**Adjustment Rates:**

Real Discount Rate (i)	7%
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Source: Kimley-Horn

Discount Rate Applied to Benefit and Costs



Year			Year		
Y1	Annual Monetized Benefit	\$ 1,723,363	Y6	PV Annual Monetized Benefit	\$ 1,228,734
Y1	Estimated Cost	\$ 1,956,000	Y6	PV Estimated Cost	\$ 181,241
Y2	PV Annual Monetized Benefit	\$ 1,610,620	Y7	PV Annual Monetized Benefit	\$ 1,148,350
Y2	PV Estimated Cost	\$ 237,570	Y7	PV Estimated Cost	\$ 169,384
Y3	PV Annual Monetized Benefit	\$ 1,505,252	Y8	PV Annual Monetized Benefit	\$ 1,073,224
Y3	PV Estimated Cost	\$ 222,028	Y8	PV Estimated Cost	\$ 158,303
Y4	PV Annual Monetized Benefit	\$ 1,406,778	Y9	PV Annual Monetized Benefit	\$ 1,003,013
Y4	PV Estimated Cost	\$ 207,503	Y9	PV Estimated Cost	\$ 147,947
Y5	PV Annual Monetized Benefit	\$ 1,314,745	Y10	PV Annual Monetized Benefit	\$ 937,395
Y5	PV Estimated Cost	\$ 193,928	Y10	PV Estimated Cost	\$ 138,268

10-Year Monetized Benefits = \$ 12,951,473

10-Year Estimated Costs = \$ 3,612,172

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

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

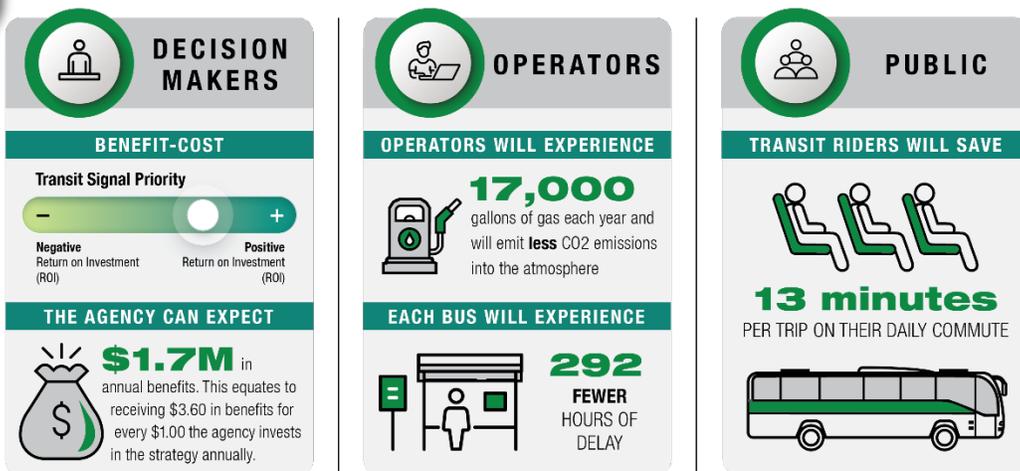


**10-Year Benefit-Cost Ratio (BCR) = 3.6:1**  
**10-Year Return on Investment (ROI) = 259%**

### 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: Transit Signal Priority



Source: Kimley-Horn

Figure 3. Transit Signal Priority Benefit-Cost Analysis Results



## References

1. FHWA. "Multi-Modal Intelligent Traffic Signal Systems (MMITSS) Impacts Assessment" (Page 63, Table 4-7). 2015. <https://rosap.ntl.bts.gov/view/dot/3557>
2. Federal Transit Administration. "2015 National Transit Summary and Trends" (Page 35). 2016. <https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/2015%20NTST.pdf>
3. U.S. Environmental Protection Agency. "Average In-Use Emissions from Urban Buses and School Buses" (Page 4). 2008. <https://nepis.epa.gov/Exe/ZyPDF.cgi/P100EVY1.PDF?Dockkey=P100EVY1.PDF>
4. West Virginia University. "Idle Emissions from Heavy-Duty Diesel Vehicles: review and recent data" (Page 1). 2006. <https://pubmed.ncbi.nlm.nih.gov/17063863/>
5. Argonne National Laboratory. "Idling Reduction Savings Calculator" (Page 2). 2018. [https://www.anl.gov/sites/www/files/2018-02/idling\\_worksheet.pdf](https://www.anl.gov/sites/www/files/2018-02/idling_worksheet.pdf)
6. Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866" (Page 4). 2016. [https://www.epa.gov/sites/default/files/2016-12/documents/sc\\_co2\\_tsd\\_august\\_2016.pdf](https://www.epa.gov/sites/default/files/2016-12/documents/sc_co2_tsd_august_2016.pdf)
7. National Highway Traffic Safety Administration. "Corporate Average Fuel Economy for MY 2017-MY 2025 Passenger Cars and Light Trucks" (Page 922). 2012. [https://www.epa.gov/sites/default/files/2016-12/documents/sc\\_co2\\_tsd\\_august\\_2016.pdf](https://www.epa.gov/sites/default/files/2016-12/documents/sc_co2_tsd_august_2016.pdf)
8. U.S. Energy Information Administration. "Gasoline and Diesel Fuel Update" (Page 1). 2021. <https://www.eia.gov/petroleum/gasdiesel/>
9. Gwinnett County. "Gwinnett County Connected Vehicle Technology Master Plan" (Pages 55, 93). 2019. <https://www.gwinnettcountry.com/static/departments/transportation/pdf/CVTechnologyMasterPlan2019.pdf>.
10. Center for Advanced Transportation Technology. Probe Data Analytics Suite – RITIS. 2020. <https://pda.ritis.org/suite/delay-analysis/>