Evaluation Methods and Techniques

May 2024

U.S. Department of Transportation

Federal Highway Administration

Foreword

The Federal Highway Administration (FHWA) Office of Operations presents these evaluation methods and techniques in support of the Advanced Transportation Technologies and Innovative Mobility Deployment Program, also known as the Advanced Transportation Technology and Innovation (ATTAIN) Program. ATTAIN grant recipients must report the benefits (e.g., safety, mobility, and environmental); costs; and effectiveness of their technology deployments; as well as lessons learned and recommendations for future deployment strategies (23 U.S.C. 503(c)(4)(F)). The FHWA designed this document to assist program grant recipients in fulfilling these reporting requirements. It offers an overview of the evaluation, including best practices related to designing and executing an evaluation. It also discusses methods and analytic techniques, including best practices on benefit-cost analysis, survey and interview methods, and emissions and energy measurement. Additionally, this document provides technology-specific information on evaluating adaptive signal control, connected vehicles, and automated vehicles.

Cover photo: Alyson West, A view of Wacker Drive at dusk, n.d. PBIC Image Library (https://www.pedbikeimages.org/details.php?picid=2291, last accessed March 7, 2024.

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This document is an update to the Evaluation Methods and Techniques (FHWA-HOP-19-053) that was prepared for the Advanced Transportation and Congestion Management Technologies Deployment Program and published in December 2019. The document is to assist intelligent transportation system (ITS) deployers in designing and executing robust evaluations that measure the impacts of their ITS technology deployments. The document offers an overview of the evaluation, including best practices related to designing and executing an evaluation. The document also discusses methods and analytic techniques, including information on benefit-cost analysis, survey and interview methods, and emissions and energy measurement. Additionally, the document provides technology-specific information on evaluating adaptive signal control, connected vehicles, and automated vehicles. Finally, it seeks to provide deployers with a suggested set of performance measures.</td></tr>
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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)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		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 (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		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. (Revised March 2003)

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation or Acronym	Definition
ADS	automated driving system
ASCT	adaptive signal control technology
ATCMTD	Advanced Transportation and Congestion Management Technologies Deployment
ATIS	advanced traveler information system
ATSPM	automated traffic signal performance measures
ATTAIN	Advanced Transportation Technology and Innovation
ATTIMD	Advanced Transportation Technologies and Innovative Mobility Deployment
AV	automated vehicle
BCA	benefit-cost analysis
BIL	Bipartisan Infrastructure Law
BSM	basic safety messages
CACC	cooperative adaptive cruise control
CARB	California Air Resources Board
CMAQ	Congestion Mitigation and Air Quality
CV	connected vehicle
DMP	data management plan
EDR	event data recorder
EMFAC	California Air Resources Board Emissions Factor Model
EPA	Environmental Protection Agency
FAST Act	Fixing America's Surface Transportation Act
FHWA	Federal Highway Administration
GPS	Global Positioning System
ICM	integrated corridor management
IRB	institutional review board
ITS	intelligent transportation system
MOVES	Motor Vehicle Emission Simulator
ODD	operational design domain
PEMS	portable emissions measurement system
PII	personally identifiable information
PM	performance measure
SIP	State Implementation Plan
TNC	transportation network company
TPM	Transportation Performance Management
TSP	transit signal priority
TTR	travel time reliability
USDOT	U.S. Department of Transportation
VHT	vehicle hours traveled
VMT	vehicle miles traveled

Abbreviation or Acronym	Definition
VOC	vehicle operating cost
V2I	vehicle-to-infrastructure
V2P	vehicle-to-pedestrian
V2V	vehicle-to-vehicle

CHAPTER 1. INTRODUCTION

Section 13006(b) of the Bipartisan Infrastructure Law (BIL), enacted as the Infrastructure Investment and Jobs Act (IIJA), Pub. L. No. 117-58 (2021), established the Advanced Transportation Technologies and Innovative Mobility Deployment (ATTIMD) Program, also known as the Advanced Transportation Technology and Innovation (ATTAIN) Program, to provide competitive grants to deploy, install, and operate advanced technologies.[1] The ATTAIN Program replaces the Advanced Transportation Congestion Management Technologies Deployment (ATCMTD) Program, which was established under the Fixing America's Surface Transportation (FAST) Act, Pub. L. No. 114–94 (2015), and which awarded grants in fiscal years 2016 through 2021.

The primary goal of these demonstrations is to improve safety, efficiency, system performance, and infrastructure return on investment. BIL requires the Secretary of the U.S. Department of Transportation (USDOT) to request applications each fiscal year (2022 through 2026) and to award grants to at least 5 and not more than 10 eligible entities (23 U.S.C. 503(c)(4)(D)). The legislation also mandates reporting requirements for the grantees, including Annual Reports that describe how the project costs compare with the benefits and that provide data on the benefits and effectiveness of the deployments, as well as lessons learned and recommendations for future deployment strategies.[2] The Federal Highway Administration (FHWA) designed this *Evaluation Methods and Techniques* report to assist grantees in designing and executing robust evaluations that enable them to fulfill the **reporting requirements of 23 United States Code (U.S.C.) 503(c)(4)(F).** This document is an update to the *Evaluation Methods and Techniques* (FHWA-HOP-19-053) that was prepared for the Advanced Transportation and Congestion Management Technologies Deployment Program and published in December 2019.

In addition to the grantees' Annual Reports, beginning 3 years after the first grant award and annually thereafter, the Secretary must post on the USDOT website a program report on the effectiveness of the grant recipients in meeting their projected deployment plans, including data on safety, mobility, environmental quality, system performance, and other outcomes.[3]

This *Evaluation Methods and Techniques* report seeks to provide grantees with a suggested set of performance measures (PMs) that address the reporting requirements of 23 U.S.C. 503(c)(4)(F). To the extent that grantees use the same or similar measures to assess deployment outcomes, researchers may become able to synthesize findings across multiple projects and to obtain a better understanding of the impacts of the deployments across multiple technologies and sites.

How To Use This Document

The *Evaluation Methods and Techniques* report contains information on a range of topics. To better guide readers to information most useful to them, the following section briefly describes each chapter and the target audience.

Evaluation Overview (Chapter 2. Evaluation Overview): This chapter provides a suggested framework for designing evaluations based on evaluation best practices. An emphasis is placed

[1] 23 U.S.C. 503(c)(4)
[2] 23 U.S.C. 503(c)(4)(F).
[3] 23 U.S.C. 503(c)(4)(G).

on performance measurement and linking PMs to goals and objectives. While evaluation team members are likely familiar with the information, they may find the templates useful. In particular, both evaluation team members and project team members should consult the section on Annual Reports, which provides information for completing reporting requirements.

Performance measures (Chapter 3. Performance Measures): Both the project team and the evaluation team may use this chapter, which presents PMs for key goal areas of the ATTAIN Program, as described in 23 U.S.C. 503(c)(4)(F,G). Where available—particularly for the areas of safety, congestion and mobility, and environmental impacts—PMs are drawn from USDOT guidance. Although the list is not exhaustive and the use of these specific PMs is not required, grantees are encouraged to use the PMs presented in this chapter to satisfy statutory reporting requirements. Using these PMs will enable USDOT to synthesize findings more easily across project sites for the program-level report.

Methods and Analytic Techniques (Chapter 4. Methods and Analytic Techniques): This chapter includes three key topics: **Benefit–Cost Analysis (BCA)**, **Survey and Interview Methods**, and **Emissions and Energy Measurement**. These subchapters are designed primarily for evaluation team members, as the information is presented at some level of detail. However, project team members may also find these chapters informative. Each of the following subsections also includes a set of references for more detailed information:

- **Benefit-Cost Analysis**: This analytic method is the recommended approach for comparing project benefits and costs. The subchapter is based largely on USDOT guidance and provides best practices in performing BCA.
- **Surveys and Interviews**: This subsection provides best-practice information on a range of survey-related topics, including sampling, sample size, recruitment, and questionnaire design.
- **Emissions and Energy Measurement**: This subsection presents different methods and resources for addressing the measurement of emissions and energy and is geared toward projects that have identified this as one of their goal areas.

Technology-Specific Information (Chapter 5. Technology-Specific Information): This chapter outlines considerations and lessons learned with respect to evaluating specific technologies—namely, **Adaptive Signal Control, Connected Vehicles**, and **Automated Vehicles**. For projects that are deploying any of these technologies, project team members as well as evaluation team members may obtain some useful insights regarding the evaluation of these technologies. A list of references for each subsection is also included.

This document will be updated as appropriate, based on the needs of the grantees.

CHAPTER 2. EVALUATION OVERVIEW

Why Evaluate?

An evaluation is a systematic assessment of how well a project or program is meeting established goals and objectives. Evaluations involve collecting and analyzing data to inform specific evaluation questions related to project impacts and performance.[1] This performance information enables project managers to:

- Report progress and make improvements, as necessary, to ensure the achievement of longer term impacts.
- Assess and communicate the effectiveness of new technologies.

Researchers can use evaluations at different points in the project lifecycle. For example, researchers conduct some evaluations during implementation to assess whether a technology is operating as planned, whereas they conduct others postimplementation to assess the outcomes and impacts of a technology. Figure 1 shows where ATTAIN Program evaluation activities fit in the project lifecycle. During the preimplementation phase, as the project design is underway, deployers must also conduct evaluation planning. The remainder of this chapter describes these key evaluation-planning activities. During the implementation phase, as deployers test and implement the technology, the deployers should also test the data collection methods and complete any baseline data collection (baseline data also may have been collected during preimplementation). Once the technology has been implemented, deployers should collect postdeployment data for the duration of the evaluation period. Grantees should report interim as well as final evaluation and performance measurement findings in their Annual Reports (see Appendix B: Annual Report Template for the Annual Report template).

	Preimplementation	Implementation	Postimplementation
Project activities	• Design project	• Pilot technology • Fully implement technology	• Maintain operations
Evaluation activities	• Establish evaluation team • Develop evaluation design • Identify data collection and management procedures	• Pilot test data collection methods • Establish a baseline for field tests	• Collect, analyze, and synthesize data • Develop conclusions and recommendations
ATTAIN outputs	• Develop evaluation plan • Develop data management plan • Submit Annual Reports (updates on measures and progress)	• Collect data for baseline measures • Submit Annual Reports (updates on measures and progress)	• Submit Annual Reports • Write and submit final evaluation report

Source: FHWA.

Figure 1. Graphic. Project lifecycle.[2]

This document focuses primarily on outcome evaluations that assess whether a program or project has achieved its results-oriented objectives. However, ATTAIN grantees should consider

[1]Evaluations commonly use evaluation questions or evaluation hypotheses to link project performance to goals and objectives. For simplicity, this document describes the use of evaluation questions.

[2]Source: John A. Volpe National Transportation Systems Center, U.S. Department of Transportation.

ways to measure interim progress toward their outcomes. Early measurement will inform interim improvements, as necessary, and provide input into the required Annual Reports that document the benefits, costs, and effectiveness (among other measures) of the technologies being deployed.

Researchers should systematically plan and execute evaluations to ensure findings are credible and actionable. The remainder of this section describes this systematic approach to an evaluation. When planning evaluations, researchers should consider constraints that might affect the ability to conduct evaluation activities. In particular, evaluations should consider the financial and staff resources available for the assessment.

Assembling an Evaluation Team

The first step in conducting a project evaluation is assembling an evaluation team. Researchers can conduct evaluations by using an internal evaluation team, independent evaluators (such as consultants), or a mix of both. Deployers should bring evaluators on board as early as possible so that the design of the evaluation can occur as the deployers are planning deployment and the project generates sufficient data to support the evaluation. Given the reporting requirements in the BIL, an independent evaluator should be used to design and manage ATTAIN evaluations.

> Independent evaluators bring:
> - Objectivity
> - Technical expertise
>
> Help ensure the results are:
> - Credible
> - Unbiased

Due to the complex nature of systems and technologies ATTAIN funds, evaluators should work closely with the ATTAIN project team.[3] Evaluators should have regular access to the project team members who are implementing the technology and collecting the data. The project team should set up regular opportunities for the evaluators to work with data providers during and after the data collection period. Data issues are common, and deployers may find it best to troubleshoot these issues collaboratively.

Evaluation Planning Process

Developing an evaluation plan puts grantees in the best position to identify and collect the data needed to assess the impacts of their ATTAIN technology deployments. This plan is a blueprint for the evaluation; it includes the specifics of the evaluation design and execution, as well as a description of the project and its stakeholders. Table 1 describes the activities involved in evaluation planning and execution, each of which this chapter discusses. Several templates are also included to assist grantees in structuring and documenting their evaluation and performance measurement plans.

[3] "Project team" refers to the team members involved in deploying the technology and may include staff from different organizations. "Evaluation team" refers to those who design and conduct the evaluation.

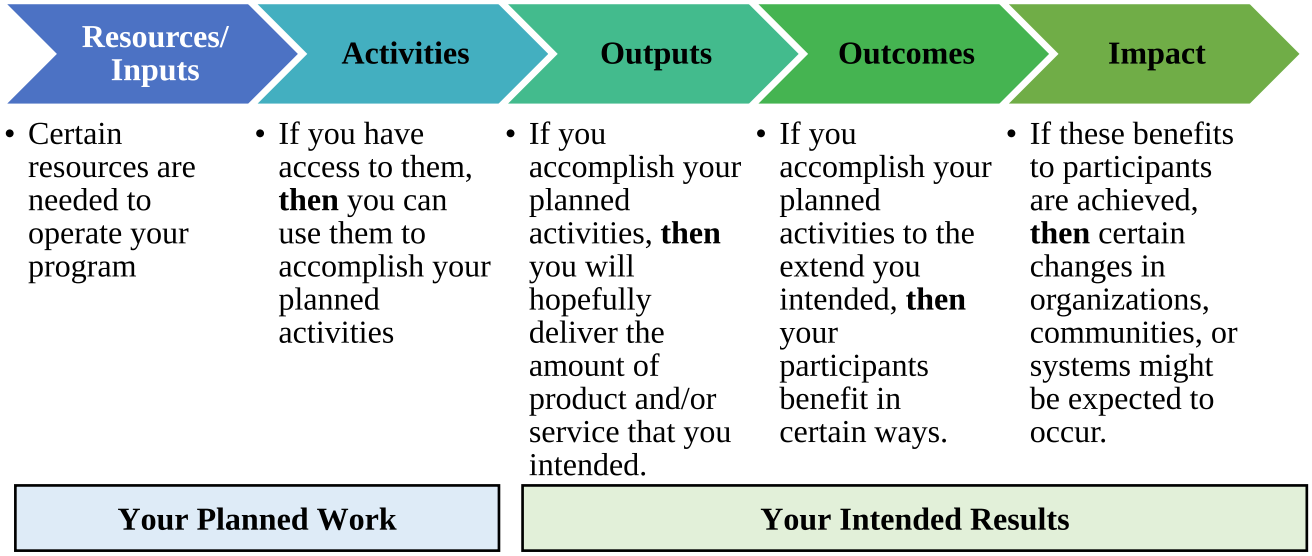
Table 1. Evaluation planning and execution.

Phase	Activities
Evaluation planning	• Set evaluation goals and objectives • Develop evaluation questions and hypotheses • Identify performance measures • Develop evaluation design • Develop data management procedures • Design analysis plan
Evaluation execution	• Test data collection methods • Acquire or collect data • Analyze data and draw conclusions • Develop annual reports

Set Evaluation Goals and Objectives

Guiding an evaluation is an agreed-upon set of project goals and objectives to drive the evaluation design. These should represent the core of what the project is trying to achieve. A logic model can be a helpful tool for evaluation teams to use as they identify goals, objectives, and related information needs. A logic model is a systematic and visual way to present relationships among the project resources, the planned activities, and the changes or results that the project hopes to achieve. In short, a logic model illustrates how the program's activities can achieve its goals. A logic model generally includes resources or inputs, activities, outputs, outcomes, and impacts (see figure 2, based on the project or program logic model developed by the W.K. Kellogg Foundation). [4]

[4] W.K. Kellogg Foundation. 2004. https://www.researchgate.net/figure/A-Simple-Logic-Model-W-K-Kellogg-Foundation-2004_fig1_230557767.



Source: W.K. Kellogg Foundation.

Figure 2. Graphic. Project or program logic model.

The following W.K. Kellogg Foundation document contains additional details on logic models: https://www.betterevaluation.org/sites/default/files/2021-11/Kellogg_Foundation_Logic_Model_Guide.pdf

ATTAIN project goals align with the priorities established in BIL. These priorities relate to the use of advanced transportation technologies to improve safety, mobility, environment, system performance, and infrastructure return on investment as well as to address transportation equity.

Table 2 includes some priority goal areas listed in the BIL (i.e., as described in 23 U.S.C. 503(c)(4)(F) and 23 U.S.C. 503(c)(4)(G), which outline the requirements for the Annual Reports and the program level reports, respectively), along with potential objectives that deployers should consider in the development of project goals and objectives (see Chapter 3. Performance Measures for a set of suggested PMs for each goal area).

When developing project goals, the evaluation team should clearly address the ATTAIN goals. Most project goals should be outcome based and reflect social benefits.[5] Output-based goals may be used to supplement outcome-based goals, but such goals generally address technical performance or intermediate targets that serve as indicators for outcomes.[6] For each goal, the objectives should clearly indicate the expected direction of change or level (e.g., reduce travel speeds and achieve a minimum of 85-percent detection rate).

[5] For example, improved safety, improved mobility, reduced environmental impacts, effectiveness of real-time information, reduced costs, improved access to transportation alternatives, and economic benefits.

[6] For example, improved network performance, extended asset life, enhanced monitoring of assets, and incentivized travelers to share or shift trips.

Table 2. Advanced Transportation Technology and Innovation Bipartisan Infrastructure Law example goals and objectives.

Goal Area	Objectives
Improved safety	• Reduce traffic-related fatalities • Reduce traffic-related injuries • Reduce traffic crashes
Improved mobility	• Reduce traffic congestion • Reduce travel delay • Improve travel time, speeds, or travel reliability
Reduced environmental impacts	• Reduce transportation-related emissions • Increase occupancy per vehicle
Improved network performance (optimized multimodal system performance)	• Optimize multimodal system performance • Optimize system efficiency
Improved access to transportation alternatives	• Improve access to transportation alternatives for underserved communities
Effectiveness of real-time transportation information	• Provide the public with access to real-time integrated traffic, transit, and multimodal transportation information to make more informed travel decisions
Reduced costs	• Provide cost savings for transportation agencies, businesses, and the traveling public • Demonstrate that benefits outweigh costs
Other benefits	• Provide other benefits for transportation users and the general public • Demonstrate improved agency efficiency • Develop lessons learned and recommendations for future deployment strategies

Develop Evaluation Questions

Once goals and objectives have been established, evaluation teams can develop specific research questions or hypotheses. These questions will be addressed through data collection, analysis, and interpretation. At least one—and, ideally, several—evaluation questions should support each goal. When designing evaluation questions, evaluation teams are encouraged to consider the following:

- Design questions that are specific about changes in safety, network performance, behavior, etc., that the team expects as a result of the project activity.
- Avoid using polar questions (i.e., yes–no responses).
- Address one aspect of performance with each question; use multiple evaluation questions rather than a few general ones.
- Use simple, straightforward language.

Generally, evaluation questions indicate either explicitly or implicitly a desired outcome or impact (e.g., reduced traffic crashes and improved travel time reliability (TTR)). If the desired outcome or impact is not achieved, however, the evaluation should describe the actual results and address reasons—or potential reasons—that may account for the difference between the desired and the actual results.

Table 3 provides a template for organizing evaluation goals, objectives, and questions (a limited set of examples is included for descriptive purposes only).

Table 3. Template with example evaluation goals, objectives, and evaluation questions.

Goal Area	Objective	Evaluation Questions
Improved safety	Reduce traffic crashes	To what extent has connected-vehicle (CV) application X reduced traffic crashes along corridor Y? What proportion of drivers using CV application X rated the safety warnings as helpful?
Improved mobility	Improve travel times	What impact did adaptive signal control have on travel times along corridor Y?
Effectiveness of real-time transportation information	Provide the public with access to real-time integrated traffic, transit, and multimodal transportation information to make more informed travel decisions	Did most application users indicate that the travel time information helped improve their commute decisionmaking?
Reduced costs	Provide cost savings for transportation agencies	What was the benefit-cost ratio of the adaptive signal control deployment?
Shared institutional insights	Lessons learned	What lessons learned did project managers identify to facilitate future successful deployments of CV?

Note: Examples are included for illustrative purposes only.

Identify Performance Measures

As grantees develop their evaluation questions, they may begin identifying the PMs or information that will address each evaluation question. The PMs will assess whether improvements and progress have been made on the safety, mobility, environmental, and other goal areas of the ATTAIN Program as described in the BIL).

In developing PMs:

- Determine whether the information needed is qualitative or quantitative in nature.

- Be specific (e.g., noting rates versus counts, geographic scope, and time of day if applicable).
- To the extent possible, evaluators can monetize select quantitative measures for use in benefit-cost analysis (see Chapter 4. Methods and Analytic Techniques on benefit-cost analysis for more information).
- Ensure that researchers can collect or otherwise acquire the data necessary for the measures.
- Include outcome measures and do not rely solely on output measures.

As with developing project goals, evaluations should consider distinguishing between outcome-based measures and output-based measures when designing PMs. Output-based measures provide an intermediary measure (e.g., number of roadside units deployed or number of safety messages received by the driver), and outcome-based measures demonstrate the impact (e.g., reduction in crash rate and improved TTR). To the extent possible, grantee evaluations should focus on outcome-based PMs. However, project outcomes can be difficult to measure due to a number of factors, including the relative rarity of the event (e.g., crashes at an intersection) or a short postdeployment evaluation period. In such cases, evaluators can use output-based measures, coupled with other qualitative feedback, such as interviews, to demonstrate impacts.

Chapter 3. Performance Measures provides additional information on PMs, including suggested measures specific to fulfilling the requirements in the BIL.

Develop Evaluation Design

While identifying the evaluation questions and PMs, grantees should also be developing an appropriate evaluation design that describes how, within the constraints of time and cost, they will collect data that address the evaluation questions. This process entails identifying the experimental design, the sources of information or methods used for collecting the data, and the resulting data elements.

Experimental Design

The experimental design frames the logic for the ways the data will be collected. Evaluations of technology deployments often use a **before–after design**, whereby predeployment data (i.e., baseline data) are compared with data that are collected following the deployment of the technology. For certain evaluation questions, however, it may be appropriate to collect data only during the after period. For example, for measures related to user satisfaction with a technology, the design could include surveys only in the postdeployment period.

More robust designs, such as randomized experimental and quasi-experimental designs, use a control group that does not receive the treatment of a program’s activities to account for potential confounding factors (see Data Limitations or Constraints for more information on confounding factors). The same data collection procedures are used for both the treatment and control groups, but the expectation is that the hypothesized outcome (improved safety, mobility, etc.) occurs only within the treatment group and not the control group.

Evaluation designs are applied to the different methods or information sources (see next section) that are used in the evaluation.

Data Collection Methodology

The evaluation team should consider the appropriate method(s) for addressing each of their evaluation questions. For any given evaluation question, multiple methods may be available to address it. For example, agency efficiency evaluation questions may include an analysis of agency operations data as well as qualitative interviews with agency personnel. In addition, evaluators may use the same method to address multiple evaluation questions. Evaluators may use vehicle field test data (e.g., CV data) to inform both mobility and safety-related evaluation questions.

When developing data collection methods, evaluators should consider the specific **data elements** that will be gathered from each method and whether those data elements meet the needs of the evaluation (e.g., address the evaluation questions or are available in the units required for the performance metric). Data elements will be either quantitative or qualitative and can take many forms (e.g., speed data, crash data, survey responses, and interview responses).

Table 4 highlights examples of key methods, their data sources, and data collection considerations for each method.

Table 4. Examples of data collection methods.

Information Sources or Method	Data Sources	Data Collection Considerations
Field test	• Roadside infrastructure (e.g., sensors) • Vehicle probes or onboard units (e.g., connected-vehicle or automated-vehicle data) • Third-party data sources	• Field test location and scope • Data collection period • Data elements to be collected, including unit of analysis • Data collection frequency and interval (hourly, daily, peak period, etc.) • Data requirements related to modeling or simulation, if applicable • Data management (e.g., storage and quality control) • Data security (e.g., protecting privacy)
Surveys or interviews[7]	• Survey responses • Interview responses	• Target population and sampling procedures • Participant recruitment and contact procedures • Expected sample size • Methods for encouraging survey response • Survey administration period • Key topics to be addressed in a survey, interview guides, or both
Internal agency data	• Information management systems • Operations data (e.g., response times, system downtime, and maintenance data), website tracking, reports, documents, etc.	• Data collection period • Data elements to be collected, including unit of analysis • Frequency and interval (hourly, daily, etc.) • Accuracy and completeness of internal agency data

[7]See Chapter 4. Methods and Analytic Techniques, Survey and Interview Methods.

Data Limitations or Constraints

For each evaluation question, it can be important to consider any limitations or constraints that may affect the ability to collect the data or may affect the data collected. Examples of **constraints** include:

- Technology functionality problems
- Low survey participation
- Poor agency documentation
- Limited data collection period

Identifying ways to mitigate these data limitations or constraints will enhance the ability to collect useful data.

The evaluation team also should consider whether confounding factors may affect the evaluation and should track such factors for the duration of the evaluation. A **confounding factor** is a variable that completely or partially accounts for the apparent association between an outcome and a treatment. Confounding factors are usually external to the evaluation; hence, they may be unanticipated or difficult to monitor. If grantees are using a before–after design without a control (i.e., a nonexperimental design), it may be particularly important to consider potential confounding factors that may be the causes of a change in the before–after data. Grantees should avoid attributing a change in outcomes to the technology deployment when it is due to some other factor. Evaluators should also identify potential mitigation approaches for each confounding factor.

Example confounding factors:

- Changes in travel demand
- Weather
- Traffic incidents
- Construction
- Changes in gas prices
- Changes in the economy (e.g., loss of or growth in jobs)
- Changes in legislation

As grantees are thinking through the key components of their evaluation, including the evaluation questions, PMs, data sources, data collection methodology, and data limitations, grantees should document this information in the Evaluation Plan. The following template (see Table 5) provides grantees with a useful tool for summarizing this evaluation information.

Table 5. Example methodology template.

Evaluation Questions and Hypotheses	Performance Measure	Information Source or Method	Data Element	Limitations and Constraints
What proportion of drivers using connected vehicle (CV) application X rated the safety warnings as helpful?	Percentage of respondents who reported safety warning was helpful	Survey	Survey response in postsurvey	Low response rate may be an issue
What impact did adaptive signal control have on travel times along corridor Y?	Percentage change in average travel times	Field test (vehicle probe data)	Pre- and postcomparisons of vehicle probe data	Weather incidents may affect the measurement
What lessons learned did project managers identify to facilitate future successful deployments of CV?	Lessons learned	Interviews	Responses to questions about lessons learned	Findings for one project may not generalize to other locations
What was the benefit-cost ratio of the adaptive signal control deployment?	Net present value	Benefit-cost analysis	Monetized estimates of project impacts	• Findings may yield incomplete data • Some impacts are difficult to quantify

Note: Examples are included for illustrative purposes only.

For projects whose data collection location, frequency, etc., may vary across the different technologies deployed, documenting these data collection characteristics or procedures may be useful. Table 6 gives an example for illustrative purposes only.

Table 6. Template for data collection procedures.

Data Element	Data Collection Frequency or Interval	Location	Data Collection Period	Data Collection Responsible Party
Traffic volumes	5 minutes	U.S. 80 corridor	January 1 – December 31, 2019	New Jersey DOT
Light rail ridership	Daily	Newark Broad Street	January 1 – December 31, 2019	New Jersey Transit

Develop Data Management Procedures

In most cases, grantees will be collecting significant amounts of data to support their evaluation and operations, and the grantees need to consider a number of data-related issues during evaluation planning. While grantees may document data management procedures in the Evaluation Plan, grantees are encouraged to develop a separate **data management plan** (DMP) during the preimplementation phase to describe how the project team will handle data both during and after the project. The grantee can update its DMP with more information as the project proceeds.

In planning for data management, grantees should consider how they will capture, transfer, store, and protect data. The evaluation team will need to work closely with the project team to ensure that these protocols are put in place before the data collection period. Data management protocols include the following:

- Processes to log and transfer data to the evaluation team.
- Data quality control procedures (e.g., data cleaning).
- Standards used for data and metadata format and content.
- Plans for data storage and archiving.
- Plans for data documentation (e.g., data dictionary and code book).
- Responsibilities of data manager.
- Data protection procedures.
- Data access and sharing.

Grantees must provide USDOT the results of their evaluation via their Annual Reports required by the BIL and as agreed to in their cooperative agreement with USDOT (for the template, see Appendix B: Annual Report Template) and grantees should reflect these results in their DMPs. Although not required, USDOT encourages grantees to make relevant data available to the USDOT and the public to further advance the objectives of the ATTAIN program. For example, projects may provide USDOT access to the underlying data used to determine the costs and benefits described in the report. The DMP should indicate whether project data contain confidential business information and personally identifiable information (PII), whether such data will be shared in a controlled-access environment, or removed before providing public or USDOT access.

The following link offers additional information on creating DMPs: https://ntl.bts.gov/public-access/creating-data-management-plans-extramural-research.

Design Analysis Plan

Grantees are encouraged to develop an analysis plan that describes how they are going to organize and analyze the evaluation data. Grantees may document the analysis plan as a section of the Evaluation Plan, in the DMP, or in a separate document.

Grantees must structure their analyses to answer the questions about whether change occurred and whether the grantees can attribute these changes to the deployment. During evaluation planning, the evaluation team must determine the types of analyses that it plans to conduct (e.g., statistical procedures), so that the team can design the evaluation to produce the required data. For each of the evaluation questions, the evaluation plan should provide sufficient detail on how the team will analyze the data.

Since evaluation data may come from multiple sources—such as experimental design (field tests), surveys, interviews, and historical data—the evaluation team may use different types of analyses in an evaluation. Analysis methods may include descriptive statistics and statistical comparisons, as well as qualitative summaries and comparisons (e.g., based on interview data). The evaluation team may also use modeling or simulation as analytic methods.

Execute the Evaluation Plan

Executing the evaluation includes collecting the data, analyzing the data, and developing the findings.

Acquire or Collect Data

During data collection, the project team captures the data that have been identified in the evaluation plan, which may include system performance data, vehicle or infrastructure data, and survey responses.

Pilot Studies

Before the start of data collection, conducting a data collection pilot that tests the end-to-end data collection pipeline is recommended, particularly for new systems or tools (i.e., new systems or tools that have no previously established data collection mechanism to our knowledge). For example, for automated-vehicle (AV) or connected-vehicle (CV) projects involving the collection of vehicle data, the pilot test should include logging data in its final format, offloading the data from the technology, vehicles, and equipment; processing the data; and transmitting the data to where the evaluators will use them. Evaluators should be part of this feedback loop to make sure that the data are acceptable, including providing feedback on the format of sample datasets before the end-to-end test.

In addition to a pilot study that tests the data collection protocols, the project team should conduct **system acceptance testing** whereby the team assesses whether the technology functions as designed. To the extent that issues arise with the functionality of the technology, the evaluator may need to delay postimplementation data collection until the issue has been corrected. During the post-, or after-, data collection period, the deployer should not make any technology adjustments; otherwise, such technology adjustments will introduce a confounding factor.

For projects involving surveys, a pilot involves testing the completed survey with a small set of respondents before the full launch. Such testing will enable the project and evaluation teams to work through any issues with questions regarding relevance or interpretability, survey length, or other problems (e.g., data coding, processing, and storage) before the full survey launch. Testing also ensures that once the data collection begins, the evaluators are confident that the data will meet their evaluation needs.

During the data collection pilot, the teams should generate complete data documentation to accompany the data. Generating complete data documentation is a general best practice but may be particularly important if an independent evaluator will be conducting the evaluation, if staff turnover may occur on the project, or if data will be made available to others in the future. At a minimum, data documentation should include:

- Data dictionaries, including definitions of each data element, enumeration codes, units, default values, etc.
- Contextual descriptions of the data from each source (e.g., how were the data collected and why might someone want to use the data in this table).

When possible, grantees should leverage insights from previous projects—including USDOT-funded intelligent transportation system (ITS) research—to determine the right data formats and documentation to support evaluation. For example, data and documentation from past and current ITS research projects are available through USDOT's ITS DataHub at https://www.its.dot.gov/data/.

Analyze Data and Draw Conclusions
Data analysis techniques and methods will vary greatly, depending on the evaluation design and the type of data that are collected. For all deployments, however, grantees must structure analyses to answer the following two questions:

- Did the desired changes (i.e., in safety, mobility, etc.) occur?
- If changes occurred, were they the results of the deployment?

During evaluation planning, the evaluation team must determine the types of analyses that it plans to conduct (e.g., statistical procedures), so that the team can design the evaluation to produce the required data.

Develop Annual Report(s)
The BIL requires that grantees submit Annual Reports. This *Evaluation Methods and Techniques* document provides information on how to structure an evaluation that will produce the data needed to meet this reporting requirement. In accordance with 23 U.S.C. 503(c)(4)(F), *"For each eligible entity that receives a grant under this paragraph, not later than one year after the entity receives the grant, and each year thereafter, the entity shall submit a report to the Secretary that describes—*

i. *Deployment and operational costs of the project compared to the benefits and savings the project provides; and*

ii. *How the project has met the original expectations projected in the deployment plan submitted with the application, such as—*
   I. *Data on how the project has helped reduce traffic crashes, congestion, costs, and other benefits of the deployed systems;*
   II. *Data on the effect of measuring and improving transportation system performance through the deployment of advanced technologies;*
   III. *The effectiveness of providing real-time integrated traffic, transit, and multimodal transportation information to the public to make informed travel decisions; and*
   IV. *Lessons learned and recommendations for future deployment strategies to optimize transportation mobility, efficiency, multimodal system performance, and payment system performance."*

An Annual Report template was designed to assist grantees in meeting their annual reporting requirement (see Appendix B: Annual Report Template). While evaluation-related activities are underway, grantees are asked to provide annual updates on their activities, organized by specific goal areas. In addition to a general summary of evaluation-related activities, these updates may include the status of baseline data collection if applicable, data collection challenges, and evaluation milestones. Once data collection is completed, grantees are asked to report on their findings for each relevant goal area and to note any particularly innovative or noteworthy findings. To collect the information specified in the BIL, the template includes additional questions on how the project has met original expectations, a comparison of the benefits and costs of the project, lessons learned, and recommendations for deployment strategies.

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CHAPTER 3. PERFORMANCE MEASURES

This chapter provides a set of suggested PMs to assist ATTAIN Program grantees in meeting the reporting requirements of BIL. As outlined in 23 U.S.C. 503(c)(4)(F), grantees must produce Annual Reports that describe the findings from their deployments, including data on benefits, costs, effectiveness, and lessons learned (see Develop Annual Report(s) for specific BIL reporting requirements).

In addition, 23 U.S.C. 503(c)(4)(G) requires the Secretary of Transportation to submit a program level report (not later than 3 years after the date of the first grant award and each year thereafter) that describes how the program has:

- Reduced traffic-related fatalities and injuries.
- Reduced traffic congestion and improved TTR.
- Reduced transportation-related emissions.
- Optimized multimodal system performance.
- Improved access to transportation alternatives.
- Improved integration of payment systems;
- Provided the public with access to real-time integrated traffic, transit, and multimodal transportation information to make informed travel decisions.
- Provided cost savings to transportation agencies, businesses, and the traveling public.
- Provided other benefits to transportation users and the general public.

The PMs are intended to provide ATTAIN grantees with a core set of measures. In developing the set of suggested PMs, several key criteria were used. Namely, the measures should be:

- Based on USDOT or other Federal guidance (as available),[1]
- Appropriate for a broad range of technologies, and
- Able to be monetized for the purposes of BCA.

While the measures tend to be quantitative and outcome-based, measures that rely on qualitative data are also presented, as ATTAIN grantees will want to include PMs that reflect a mix of both quantitative and qualitative data. In designing their evaluations, the ATTAIN grantees should start with the PMs described below; however, the list is not exhaustive. Grantees may want to include additional PMs that are tailored to their specific deployments and that provide insight into the safety, mobility, agency efficiency, and other impacts of their technology deployments. The projects will not necessarily address all the performance areas. PMs should be selected based on the technology being deployed, the anticipated impacts, and data availability.

[1]In cases where USDOT or other Federal guidance was not available, new measures were designed.

Resources
The Performance Measure References at the end of this chapter list a number of useful resources, such as FHWA's Transportation Performance Management (TPM) Toolbox, which includes the TPM Guidebook and Resources (see https://www.tpmtools.org/about/). TPM measures and targets may provide grantees with sources of data to meet the grant performance measurement requirements.

The remainder of this chapter presents PMs for the following key goal areas outlined in the BIL:[2]

- Improved Safety
- Improved Mobility and Reduce Traffic Congestion
- Reduced Environmental Impacts
- Improved Multimodal or System Performance
- Improved Access to Transportation Alternatives
- Effectiveness of Providing Real-Time Integrated Multimodal Transportation Information to the Public for Making Informed Travel Decisions
- Reduced Costs and Improved Return on Investment
- Other Benefits and Lessons Learned

Improve Safety
Table 7 presents a number of safety-related PMs organized by mode of transportation. While they are generally prioritized within each mode, grantees should consider the measures that are most relevant to their specific deployments. That is, the selection of PMs depends on the technologies being deployed and what problem(s) they are trying to solve. Grantees should carefully consider the specific type of safety benefits they anticipate from the technology deployment.

Nearly all the PMs involve a measure of change (e.g., in crashes, fatalities, or injuries), which is based on a comparison of data between a baseline (predeployment) period and a postdeployment period. The preferred type of measure is a rate because it adjusts for the level of exposure; however, there may be cases in which counts are the only data available (e.g., for bicycle or pedestrian measures).

FHWA adopted the following five safety-related PMs as part of the TPM program:

- Number of fatalities (23 CFR 490.207(a)(1))
- Rate of fatalities per 100 million vehicle miles traveled (VMT) (23 CFR 490.207(a)(2))
- Number of serious injuries (23 CFR 490.207(a)(3))
- Rate of serious injuries per 100 million VMT (23 CFR 490.207(a)(4))
- Number of nonmotorized fatalities and nonmotorized serious injuries (23 CFR 490.207(a)(5))

[2] 23 U.S.C. 503(c)(4)(G)

These PMs are covered within the following, more detailed list of PMs. The Safety Performance Management Final Rule, codified under 23 CFR part 490, subpart B, also established methodological guidelines for reporting these measures, which grantees may find useful.[3]

Grantees should consider the use of multiple measures to understand the safety impacts of the deployed technologies. In addition to crash records or field test data on crash precursors, survey data can provide a complement to—but not a substitute for—these other data sources, providing useful data on users' (e.g., drivers' and transit operators') experiences or attitudes.

Grantees should consider the geographic scope when developing PMs. The measures included in Table 7 can be used at any geographic level (intersection, corridor, or region). However, as geographic scope decreases, random variation tends to increase, and thus intersection or even corridor-level analysis can be highly variable from year to year. Any comparisons at these lower levels should be made with care. When reporting the performance measurement findings, grantees should clearly convey the geographic scope of the measures.

Table 7. Performance measures for improving safety.

	Performance Measures
Performance Measure Number	**Vehicle**
1	(Rate) Crashes per Vehicle Miles Traveled (VMT)
2	(Rate) Fatalities per VMT
3	(Rate) Injuries per VMT
4	(Count) Number of crashes
5	(Count) Number of fatalities
6	(Count) Number of injuries
7	(Rate) Secondary crashes[4] per VMT
8	(Count) Number of secondary crashes
9	Crash precursors (e.g., time to collision and hard braking)
10	Percentage of drivers who feel safer (i.e., from crashes) while driving [along X corridor] [survey or interview]
11	Percentage of drivers who indicate that [X warning or feature etc.] is very helpful or somewhat helpful. [survey or interview]

[3]See https://www.fhwa.dot.gov/tpm/guidance/safety_performance.pdf for guidance documents on the Safety Performance Management Final Rule.

[4]"Secondary crashes" refers to the number of additional crashes—starting from the time of detection of the primary incident—within either the incident scene or its queue, including the opposite direction, resulting from the original incident (Jodoin and Vásconez 2010).

Table 7. Performance measures for improving safety (continuation).

	Performance Measures
Performance Measure Number	**Transit**
12	(Rate) Transit crashes per vehicle revenue miles or passenger miles traveled
13	(Rate) Fatalities or injuries per passenger miles traveled
14	(Count) Number of transit passenger fatalities, injuries, or both
15	Percentage of transit vehicle operators who indicate that [X warning or feature etc.] is very helpful or somewhat helpful [survey or interview]
Performance Measure Number	**Nonmotorized**
16	(Count) Number of bicycle crashes, injuries, or fatalities[5]
17	(Count) Number of pedestrian crashes, injuries, or fatalities
18	Percentage of bicyclists or pedestrians who feel safer (i.e., from crashes) [crossing at X intersection or traveling along Y corridor] [survey or interview]

Improve Mobility and Reduce Congestion

This section highlights mobility and congestion-related PMs. The measures are organized by transportation mode and are generally prioritized within the mode. Grantees' selections of PMs, however, will depend on the technologies being deployed and what problem(s) the grantees are trying to solve. Grantees should give careful thought to the specific type of mobility benefits they anticipate from the technology deployment.

Preferred measures include **travel time, average speed, and TTR**. While TTR can be important to travelers, there is no uniform standard on how to measure it. Standard deviation of travel time (or travel time index) is the most common method for measuring TTR, but grantees may also use variance or other measures. The least preferred measure is vehicle volume or throughput, as it does not directly measure mobility benefits.

In developing the list of suggested PMs for measuring ATTAIN mobility impacts (table 8), the TPM measures described in the National Performance Management Measures: Assessing Performance of the National Highway System, Freight Movement on the Interstate System, and Congestion Management and Air Quality (CMAQ) Improvement Program rule were

[5]Grantees may also consider using exposure-adjusted rates for pedestrian or bicyclist measures (e.g., change in bicycle crashes per 1,000 cyclists); however, since many agencies do not routinely capture the relevant exposure data, it may require a special data collection effort during both the baseline and postdeployment periods.

incorporated.[6] The suggested PMs include measures of TTR, peak-hour excessive delay, and non-single-occupancy-vehicle (SOV) travel.

It is anticipated that grantees will be collecting the data to measure mobility and reduced-congestion benefits through field tests (i.e., new data collection) and possibly through modeling or simulation. Surveys may provide a complementary source of data on user experience or satisfaction, but surveys should not be a substitute for field test data.

In most cases, the PMs can be used at the intersection, corridor, or regional level, and grantees should consider geographic scope when developing PMs. For technologies deployed at intersections, grantees should consider measuring impacts at both the intersection and the corridor or regional level, as the impacts may differ (i.e., the problem may have shifted from one intersection to another location).

Time of day should also be considered. In cases where mobility impacts are anticipated to be greatest during peak hours, the PMs should focus on those peak hours.

Table 8. Performance measures to improve mobility and reduce congestion.

	Performance Measures
Performance Measure Number	**Vehicle**
1	Travel time: (Rate) Vehicle hours traveled (VHT) per vehicle miles traveled (VMT)
2	(Count) Average speed
3	(Rate) Travel Time Reliability (TTR) 23 CFR 490.507: Percentage of the person-miles traveled on the Interstate [non-Interstate national highway system] that are reliable (ratio of the 80th-percentile travel time to a normal travel time (50th percentile)). FHWA's National Performance Management Research Data Set is a potential data source for TTR, but grantees will need to assess the appropriateness of these data in meeting their evaluation needs.

[6]See https://www.fhwa.dot.gov/tpm/rule.cfm.

Table 8. Performance measures to improve mobility and reduce congestion (continuation).

	Performance Measures
Performance Measure Number	**Vehicle**
4	Delay per trip (travel time): • (Rate) Per vehicle or per person • (Count) Average or total Congestion Mitigation and Air Quality rule: Annual hours of peak-hour excessive delay per capita (person-hours) *Note: Delay accounts for the difference between actual and free-flow travel time.*
5	(Rate) Vehicle volume/throughput (vehicles/hour)
6	Percentage of travelers who report being very satisfied or somewhat satisfied with: • Their travel experience [along X corridor] • Their travel time [along X corridor] • The reliability of their travel time [along X corridor] • Travel speed [along X corridor] [survey or interview]
7	Percentage of travelers who report that their travel experience along X corridor (select appropriate measure): • Is less congested • Is more reliable • Takes less time [survey or interview]
Performance Measure Number	**Transit**
8	Average run time for transit *Note: Breaking data out by route can highlight particular locations with positive or negative impacts.*
9	On-time performance (% trips)
10	Total passenger delay or average passenger delay
11	Completion rate for transit service

Table 8. Performance measures to improve mobility and reduce congestion (continuation).

	Performance Measures
Performance Measure Number	**Transit**
12	Percentage of riders who are very satisfied or somewhat satisfied with the following aspects of service: • Travel time • On-time performance • Frequency of service • Location of stops • Wait times [survey or interview]
13	Percentage of transit vehicle operators who report that [travel time or TTR or average speeds] has improved along their routes [survey or interview]
14	Percentage of transit vehicle operators who are very satisfied with [travel time or TTR or average speed] along their routes [survey or interview]
Performance Measure Number	**Pedestrian/Bicycle/Rideshare**
15	Percentage of pedestrians or riders who feel [travel time or on-time performance, etc.] has improved [survey or interview]
16	Percentage of riders who perceive that the rideshare time estimates are very accurate or somewhat accurate [survey or interview]
Performance Measure Number	**Freight**[7]
17	Port turn time, including: • Reduced wait time (to enter the terminal) Reduced terminal time (time in terminal)
18	Truck TTR
Performance Measure Number	**Other**
19	Incident clearance time[8] (minutes)
20	23 CFR 490.707: Mode share of non-single-occupancy vehicle modes (including telework)

[7]Mobility measures described above, such as travel time, average speed, and delay, could also apply to freight. In addition, see *FHWA's Freight Performance Measure Primer*.

[8]Incident clearance time is defined by the span of time in minutes between the first recordable awareness of an incident by a responsible agency and the time at which the last responder has left the scene (Jodoin and Vásconez 2010).

For evaluations related to signalized control, including adaptive signal systems, grantees should consider specific PMs that capture the ability of the control mechanism to respond to traffic and improve mobility.

Table 9. Additional performance measures related to signalized control.

	Performance Measures
Performance Measure Number	**Volume and Capacity**
21	Saturation (by lane, approach, movement, or intersection)
22	Phase termination Percentage of terminations due to gap out, max out, etc.

Table 10. Additional performance measures related to signalized control (continuation).

	Performance Measures
Performance Measure Number	**Volume and Capacity**
23	Number of stops
24	% Arrival on green, % Arrival on red
25	Purdue Coordination Diagram (qualitative)

Many of these performance measures (and delay and speed measures) can be automatically produced using automated traffic signal performance measure (ATSPM) software. Data from modern traffic controllers can be analyzed using ATSPMs, significantly easing the burden of analysis and visualization for some studies. FHWA promoted ATSPMs as part of the fourth iteration of Every Day Counts (EDC-4).[9] Through a pooled-fund effort, open-source software[10] was developed which can take controller log information and automatically produce a wide variety of performance measures and create visualizations and statistics using those data. Several States have implemented these systems, with Utah DOT among the early adopting agencies (see Utah DOT's ATSPM website https://udottraffic.utah.gov/atspm/).

Reduce Environmental Impacts

The program objectives include reducing transportation-related emissions, and where applicable, grantees should consider evaluating environmental impacts of their technology deployments. Analysis should include applicable mobile-source emissions of regulated pollutants that are known to have adverse public health effects, such as ozone precursors (volatile organic

[9]For information on EDC-4: https://www.fhwa.dot.gov/innovation/everydaycounts/edc-4.cfm.

compounds and nitrogen oxides), carbon monoxide, and particulate matter with diameters of 2.5 and 10 microns or less (PM2.5 and PM10, respectively). Grantees could also report reductions in energy consumption and carbon dioxide equivalent using the PMs in Table 11.

Chapter 4. Methods and Analytic Techniques provides information about models and tools that grantees use for emissions and energy measurement. Additionally, the Emissions and Energy Measurement References provides links and useful resources.

Table 11. Performance measures for reduced environmental impacts.

	Performance Measures
Performance Measure Number	**Emissions**
1	Net project emissions in kilograms per day (kg/d)[11]
Performance Measure Number	**Energy[12]**
2	Energy reduction in Btu
3	Energy reduction in kJ
4	Energy reduction in gal of fuel saved

Improve Multimodal or System Performance

Given the complex nature of our transportation systems, defining and measuring improved network performance can be challenging Below are a few suggested performance measures, including both quantitative and qualitative measures that provide insight into whether the system is progressing toward more optimal multimodal performance.

- Travel time, indexed by mode
- VMT avoided through transit or other modes
- Bike ridership
- Use of carpool, van pool, or rideshare
- Percentage of riders who feel [travel time, on-time performance, etc.] has improved
- Interagency or interoperator coordination—for example:
    - Number of meetings or other interactions
    - Number or development of memorandums of understanding
    - Development or use of common strategies, response plans, etc.
    - Level of automation for common strategies or response plans
- Project team feedback, other stakeholder feedback, or both on how the deployment has optimized multimodal performance.

[11]This metric is used for transportation conformity analyses and for the CMAQ Total Emissions Reduction Performance Measure.

[12]Use U.S. Energy Information Administration to obtain Btu or kJ per gal of diesel or gasoline.

Improve Access to Transportation Alternatives

Accessibility, or access, can have multiple meanings. Accessibility is typically interpreted as the existence of physical access to goods, services, and destinations (i.e., transportation) or the ease of reaching goods, services, activities, and destinations or both. Access can be measured from the supply side (does the system provide access?) as well as the demand side (do users have access (or ease of access) to transportation alternatives?).

Table 12 presents a range of measures related to improved access to transportation alternatives. The selection of performance measures will depend on the technologies being deployed and what problem(s) they are trying to solve. A number of the measures are specific to transit; however, others may apply across a range of transportation alternatives, so the evaluation team may need to tailor the performance measure to their specific deployment.

Table 12. Performance measures for improved access to transportation alternatives.

Performance Measure Number	Performance Measures
1	Number of households within 1/4 mi of a public transit stop (or 1/2 mi of a transit station)
2	Ridership (transit, ride sharing, bicycle, etc., as appropriate)
3	Number of low-cost travel modes available in an area
4	Transportation travel cost as a percentage of income
5	Number of (new) bicycle share or carshare programs, or number of new partnerships or memorandum of understanding between transit agencies and transportation network companies (TNCs), or bike-sharing or other mobility-on-demand services
6	Number of new riders (people who have not previously used the mode)—either total over a period or per unit of time (transit, ride sharing, bicycle, etc.)
7	Percentage aware of different transportation options (or change in awareness) [survey or interview]
8	Percentage reporting [X mode] improved their [travel experience or commute] (survey or interview)
9	Percentage reporting it was very easy or somewhat easy to book or pay for a ride [survey or interview]
10	Percentage reporting it was very easy or somewhat easy to find the pickup location for the [vehicle or rideshare or bike share or shuttle] [survey or interview]
11	Percentage reporting the drop-off location (e.g., for bus or rideshare or shuttle) was very convenient or somewhat convenient to their final destination [survey or interview]
12	Percentage of riders who found the [transit or rideshare or bike share, etc.] service affordable [survey or interview]
13	Percentage of riders who found the [transit or rideshare or bikeshare, etc.] service accessible for all cognitive and physical abilities [survey or interview]

Increase Effectiveness of Providing Real-Time Integrated Multimodal Transportation Information to the Public for Making Informed Travel Decisions

Much research has been conducted on advanced traveler information systems (ATISs), yet, there is no standard set of performance measures that is used to measure the effectiveness of these information systems. Typically, research has relied on counting the number of users, surveying users, or both to understand the characteristics of their use (e.g., when, how often, and types of information sought), their satisfaction with the system, and the impacts of the ATIS on their travel behavior.

For projects that are providing the public with real-time integrated traffic, transit, and multimodal transportation information, the use of the ATIS should be measured for all platforms (apps, websites, kiosks, etc.). If possible, the types of information that users are accessing should be automatically recorded, along with other aspects of use, such as time of day and amount of time spent accessing the information. These data will provide useful insights; however, they will need to be supplemented with user surveys to understand the effectiveness of the ATIS. Table 13 provides suggested performance measures.

Table 13. Performance measures for effectiveness of real-time traveler information.

Performance Measure Number	Performance Measures
1	Percentage using advanced traveler information systems (ATIS)
2	Percentage of users who used the ATIS to plan a multimodal trip [survey or interview]
3	Percentage of ATIS users very satisfied or somewhat satisfied with the [accuracy or reliability] of the real-time traffic, transit, or multimodal information or Percentage very satisfied or somewhat satisfied with the accuracy or reliability of specific types of information, as appropriate: • Incident information. • Construction information. • Road weather condition information. • Transit arrival times. • Parking availability information. • Terminal turn times. [survey or interview]

Table 12. Performance Measures for Effectiveness of Providing Real-Time Integrated Traveler Information (continuation).

Performance Measure Number	Performance Measures
4	Percentage of ATIS users reporting that the real-time information has improved (select as appropriate): • Their overall travel experience. • Their commute. or Percentage of ATIS users who feel the real-time traffic, transit information, or both were useful [survey or interview] or Both
5	Percentage of ATIS users who made a change in travel either before or during their trip based on the real-time information provided: • Percentage who switched departure time. • Percentage who switched their route. • Percentage who canceled a trip. [survey or interview]
6	Percentage of users very satisfied or somewhat satisfied with: • Locations of kiosks. • Ease of using kiosks. [survey/interview]
7	Percentage of transit vehicle operators who are very satisfied or somewhat satisfied with real-time: • Rerouting information. • Special-event information. [survey or interview]

Reduce Costs and Improve Return on Investment

Cost savings may be measured in a variety of ways, and the measures depend on the technology being deployed. Cost savings may be measured directly in dollars; if measured in time (e.g., staff time), it can be converted to dollar savings. Return on investment can be measured through a benefit-cost analysis (see Chapter 4. Methods and Analytic Techniques for more information). Suggested performance measures are shown in Table 14.

Table 14. Performance measures for reduced costs and return on investment.

	Performance Measures
Performance Measure Number	**Agency**
1	Decreased operating expenses, such as decreased staff time for X activity (i.e., efficiency savings).
2	Decreased maintenance costs (e.g., due to improved asset management strategies)
3	**Transit agencies** may consider: • Decreased costs per passenger or per unit of time. • Increased fare revenues earned. • Increased fare revenues per total operating expenses (recovery ratio). • Vehicle revenue miles or hours.
Performance Measure Number	**Public**
4	Benefit-cost ratio or net present value

Other Benefits and Lessons Learned

As needed, ATTAIN grantees should develop additional PMs that measure anticipated benefits that are not captured in the PMs presented in this chapter. Measures of other benefits may be quantitative or qualitative. At a minimum, any surveys or interviews that are conducted should include an open-ended question that asks whether there are any other benefits of the deployment (e.g., in addition to the safety, mobility benefits, or both).

In addition, grantees should measure **lessons learned** from their deployments. While surveys may be used for this purpose, evaluation teams should conduct at least a few interviews with key project stakeholders to gather lessons-learned data. Interviews provide rich, qualitative data and enable the interviewer to probe for more detailed information.

Finally, for new and emerging technologies, certain additional measures may not be captured in the performance areas described in this section but may nonetheless be important to measure—for example, user experience, acceptance, or both.

Following are a few example PMs for AV technologies, listed separately for riders and onboard controllers or maintenance staff:

Riders:

- Assessment of ride comfort (jerkiness, acceleration)
- Comfort level with AV technology or unstaffed operation

- Recommendations for improvements

Onboard controllers or maintenance staff:

- Observations on passenger experiences or needs
- Issues or challenges with the technology
- Recommendations for improvement

Performance Measure References

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CHAPTER 4. METHODS AND ANALYTIC TECHNIQUES

This chapter has three sections: Benefit-Cost Analysis, Survey and Interview Methods, and Emissions and Energy Measurement.

Benefit-Cost Analysis

This section provides an overview of BCA and how this method might be applied to ATTAIN Program evaluations. The ATTAIN Program requires analysis of the "deployment and operational costs of the project compared to the benefits and savings the project provides."[1] While different methodologies might be considered for evaluations, the preferred method is BCA, as it provides a comprehensive accounting using a well-established analytical approach.

BCA is a systematic process by which the impacts of a project (or other action) are estimated and quantified through a comparison of the benefits from the project as they accrue both to direct users and to society as a whole—against project costs over a specified time period. Conducting BCA as part of a project evaluation serves three primary purposes:

- **Accountability:** BCA facilitates comparison and evaluation of diverse project outcomes by using a consistent measure.
- **Knowledge transfer:** A BCA provides useful insight and information on costs and benefits that other cities may use when considering similar projects.
- **Improved future analyses:** These analyses will help improve and aid in the calibration of the expected benefits and costs—particularly from innovative technologies—for future ex ante BCAs, which in turn will support well-informed decisionmaking on future transportation projects.

In outlining goals, objectives, and performance measures, grantees can address return on investment by incorporating BCA as the analytic method (see Table 3 in the Evaluation Overview chapter for an example). In cases in which grantees are deploying a range of different technologies and may not have sufficient resources to conduct separate BCAs for each technology, they can prioritize, focusing their BCAs on the technologies that are central to their overall deployment.

Completing the BCA will ordinarily be one of the final steps in project evaluation, as it requires synthesizing a variety of outcome measures from other elements of the evaluation, such as the impacts of the project on traffic flow and safety. Completion of the BCA allows for the inclusion of both up-to-date cost data and any expected operational or maintenance costs.

This section is intended to provide a brief overview of BCA. Additional detail and USDOT guidelines on BCA methodology in the context of discretionary grant programs may be found in *Benefit-Cost Analysis Guidance for Discretionary Grant Programs*. Updates are generally published annually, and grantees should reference the most recent version when designing and conducting BCAs.[2] In addition to insight into the methods for BCA, the guidance also provides

[1] 23 U.S.C. 503(c)(4)(F).

[2] Most recent BCA guidance is on the USDOT website https://www.transportation.gov/mission/office-secretary/office-policy/transportation-policy/benefit-cost-analysis-guidance.

values for use in monetizing several categories of benefits.[3] Nonetheless, many ATTAIN projects may have benefits or, in some cases, costs that are difficult to quantify or monetize. In these cases, grantees may find it useful to present the impacts in as much detail as possible—including quantifying them in the physical units they originally occur in—and to assess the benefits qualitatively. For example, it may be difficult to place a monetary value on improved transit service updates, but the BCA could describe the level of usage of the system in terms of users' accessing updates and provide qualitative information on how users value the information.

Goals of a High-Quality Benefit-Cost Analysis

A high-quality BCA should have the following characteristics:

- The analysis should be **comprehensive** and include all benefits and costs attributable to the project to the extent possible.
- The data and forecasts used should be **reliable**.
- The parameters used (e.g., monetization factors, discount rate, and analytical timeframe) should be **appropriate**.
- The project impacts should be compared with a **credible** baseline.
- The analysis should include an assessment of **uncertainty**, which may include sensitivity analysis around key parameters, data, or forecasts. Alternatively, the analysis may simply note areas of uncertainty.
- The analysis should be **transparent** and **replicable**, as demonstrated through a clear description of all assumptions, inputs, and modeling methods.

When reporting their BCA findings, ATTAIN grantees should clearly identify the assumptions used in the analysis, the estimation methods and data sources used, and any uncertainties remaining in the analysis (supported with sensitivity analysis results when feasible). Results should include:

- Benefits, ideally classified by primary-impact category (e.g., safety and mobility) and project element.
- Costs by each project element.
- Benefit-cost ratio.
- Net present value.

In cases in which the ATTAIN project consists of a number of distinct subprojects or elements, calculating the BCA results separately for each element is useful. For transparency, it is suggested that any documentation of the results include a

Useful BCA tools:

- California Department of Transportation's *Life-Cycle Benefit–Cost Analysis Model* **(Cal-B/C)**
- Federal Highway Administration's *Tools for Operations Benefit–Cost Analysis* **(TOPS-BC)**

[3]Local values based on sound empirical data or models may be used when available, except where noted.

copy of the completed BCA tool or spreadsheet used.[4]

When specialized models are used to calculate project impacts, providing fully transparent documentation may not be possible, but a summary of the modeling inputs and calculation methods can help improve the credibility of the BCA.

Defining Benefits

ATTAIN project evaluators will need to identify the relevant set of benefits to be included in the BCA. Some of the most common benefit categories for transportation projects are listed in table 15. Benefit estimation requires that benefits be *quantified* (e.g., person-hours of delay avoided and gallons of fuel saved) and then for those estimates to be *monetized* into dollar terms if they are not already. Monetization factors reflect the societal value of resources and can be based on market prices (such as retail fuel costs) where relevant. For nonmarket impacts that are more difficult to value, such as improved health and safety, USDOT has established recommended monetary values.

Table 15. Common benefit categories.

Benefit	Type	Goal	Measurement and Example Units
Safety	User benefit	Improve safety	Fatalities and injuries avoided[5] (counts)
Travel time savings	User benefit	Efficiency	Reduction in travel time (person-hours)
Vehicle operating cost (VOC)	User benefit	Reduced operating cost	Reduction in auto miles traveled[6] (vehicle miles)
Induced travel	User benefit	Increased consumer surplus for additional use or users in response to a higher level of service	Additional trips (count)
Amenity benefits	User benefit	Improve the quality of life for users of transit, pedestrian, and cycling facilities	Value of amenity per user trip (dollars)
Facility maintenance	Agency benefit	State of good repair and reduce maintenance and operating costs	Change in maintenance costs (dollars)

[4]Cal-B/C: https://dot.ca.gov/programs/transportation-planning/division-of-transportation-planning/data-analytics-services/transportation-economics.

TOPS-BC: https://ops.fhwa.dot.gov/plan4ops/topsbctool/.

[5]Reductions in property-damage-only accidents are often included with safety benefits, as they tend to rely on the same data sources and are affected by the same transportation improvements.

[6]Some facility improvements may reduce the per-mile VOCs. For example, paving a dirt road may reduce users' maintenance and tire replacement costs.

Table 14. Common benefit categories (continuation).

Benefit	Type	Goal	Measurement and Example Units
Reduced emissions	Externality	Reduce negative health and environmental impacts from vehicle emissions	Kilograms per day by pollutant
Reduced noise and congestion	Externality	Reduce negative impacts from vehicle noise and vehicle congestion	Reduction in auto miles traveled (vehicle miles)

Monetizing project benefits is a key step in making benefits comparable across benefit categories, across time, and between different projects. Some project benefits will not be able to be monetized and will require a qualitative assessment of their benefit to users or society. A qualitative assessment may be due to:

- Lack of available data; for example, it may not be feasible to collect data on reduced TNC wait times resulting from curb demarcation of a TNC dropoff or pickup location at a transit station.
- Lack of established methodology for monetizing benefits; for example, a project may collect data on increased use of and satisfaction with a real-time transit application following an improvement, but the project team may not have an established or reasonable means of valuing the improved information available to users.

Guidelines for the use and valuation of common benefit categories may be found in *Benefit-Cost Analysis Guidance for Discretionary Grant Programs*. A summary of key benefits categories in the 2022 guidance is provided in the next section, but the benefits may change with each year's updated guidance.

- **Safety**: USDOT guidance provides monetized values for reductions in fatalities, injuries, and property-damage-only accidents. USDOT safety statistics generally use KABCO levels as follows, which measure observed injury severity at a crash scene:
    - K = A fatality resulting from a crash
    - A = Incapacitating injuries such as disabling or amputation
    - B = A few injuries such as nonincapacitating cuts and scrapes
    - C = Possible injury but on a lesser scale
    - O = No apparent injuries at the scene
- **Travel time savings**: USDOT guidance provides a recommended value of time estimates by purpose. When using these estimates, the analyst should multiply the value by the appropriate vehicle occupancy rates of 1.67 for passenger vehicles and 1.00 for commercial trucks. Additional vehicle occupancy rates for specific periods (i.e., weekend, peak, and off-peak travel) may be found in *Benefit-Cost Analysis Guidance for Discretionary Grant Programs*. Projects that are primarily intended to

improve congested peak-period travel should use the corresponding peak-period occupancy values. Local values may be used when available, and values for transit travel and wait times should be based on the most accurate available data applicable to the project.

- **VOC**: These costs comprise costs associated with operating the vehicle (fuel, maintenance, tires, depreciation, etc.) and exclude fixed costs. Additionally, VOC excludes transfers (e.g., State and Federal fuel excise taxes are not included in VOC). USDOT provides standard values, but local values may be substituted when available.

- **Reduced emissions**: Monetized values for emission reductions can be found in USDOT guidance. The recommended methodology for estimating emission reduction can be found in the section Emissions and Energy Measurement.

- **Amenity values**: USDOT's *Benefit-Cost Analysis Guidance for Discretionary Grant Programs* provides monetized values for various transportation facility amenities, including sidewalk expansion, various types of cycling paths, and improvements to transit facilities. These monetization values are typically applied either per use or per mile, meaning that they require an estimation of the total users of the facility. For values available per person-mile or per cycling-mile, USDOT recommends a cap per user for the total distance.

Defining Costs

The cost side of the BCA should include all costs that grantees expect to incur during the lifecycle of the project, as measured relative to the base case in which the project does not take place. Grantees should include costs irrespective of the entity by which they are paid. For cost elements with a lifespan beyond the analytical period of the BCA, grantees may calculate a residual asset value and should include the appropriately discounted residual value as a benefit when calculating the benefit–cost ratio.

Typical cost categories:

- Initial capital costs of development and installation
- Recurring operations and maintenance costs
- Recapitalization costs for replacement of equipment according to anticipated lifespans

General Principles

The next section discusses a number of general principles regarding BCAs.

Analysis Period

The analysis period would ideally correspond to the development and implementation period (including project construction) plus the expected service life of the facility or equipment being installed as part of the project. An analysis period of 20–30 years plus the development and the implementation period is typical for highway and transit construction projects. However, a shorter period, often as short as 7–10 years, may be more appropriate for projects that primarily involve ITS or other technologies, as this equipment generally has shorter service lives. Some ATTAIN projects may have innovative technologies for which well-established operational lifetimes do not exist, in which case the BCA should use the best available estimates, with sensitivity testing of alternative values.

When the project includes assets with differing lifespans, the BCA should include the costs of replacement of shorter lived assets during the analysis period. Conversely, assets with remaining useful life at the end of the analysis period can be assigned residual values in the final year.[7]

Adjust to real dollars:

- Use the Gross Domestic Product Deflator for converting past expenditures
- Do not adjust for expected inflation in future years

Inflation

The BCA should keep all monetary values in real rather than nominal terms, with the base year of the analysis period being a reasonable choice of reference point. In practice, any costs or values in earlier dollars should be adjusted to the base year. Likewise, for ex post BCA, grantees should adjust costs and benefits that are measured in nominal dollars so that the costs and benefits are in real (base year) dollars.

Discounting

Grantees should discount benefit and cost values that occur in different years of the BCA to adjust for the time value of money. ATTAIN projects should follow the guidance of the Office of Management and Budget's OMB Circular A-94, which recommends discounting future benefits and costs by using an annual real discount rate of 7 percent. The circular has additional detail on the rationale for discounting and the origins of the 7-percent figure. The exceptions are benefits from reduced carbon dioxide emissions, which grantees should discount at a rate of 3 percent per year.[8]

Double Counting and Transfers

Two common and related errors in the preparation of a BCA are double counting of benefits (i.e., two measurement methods are applied to a single source of economic benefit) and including the movement of money, which is a transfer rather than a change in economic value (e.g., tolls or transit fares are not included in BCAs, as these are transfers).

Choice of Base Case

The benefits and costs under evaluation in BCA are always relative to a baseline alternative. Under ex post analysis, the alternative will be the counterfactual no-build scenario, in which the current project did not occur. These no-build conditions are fundamentally unobservable and require thoughtful development of the expected conditions that would have occurred in the absence of the project. Depending on the nature of the project, the no-build case could include assumptions about:

- VMT growth.
- Travel times and speeds.
- Transit ridership.
- Changes in crash exposure and severity (e.g., due to exogenous changes to the vehicle fleet).

[7]Depreciation formulas can be found in USDOT guidance (see Methods and Analytic Techniques References). The residual value is at the end of the period of analysis and should be appropriately discounted.

[8]OMB Circular No. A-94 (1992): https://www.transportation.gov/regulations/omb-circular-94.

Before–after studies represent a common method for estimating the impact of a project relative to baseline conditions. However, concerns related to potential confounding factors or regression to the mean should be noted and, if possible, addressed using controls or additional modeling.

A control may be a useful tool in establishing a plausible no-build counterfactual. In ex post BCA, observing a control intersection, corridor, or region as applicable allows the analyst to account for confounding factors. Controls may include regional changes in travel patterns (e.g., a decrease in travel to the central business district of a city), larger macroeconomic trends (e.g., a recession leading to a decrease in VMT), or changes in vehicle safety (e.g., a trend toward safer cars' reducing the severity of accidents).

In addition to constructing a plausible no-build base case, grantees may add insight and value for future projects if the BCA includes analysis using a counterfactual baseline in which the conventional elements of the project *are* completed. In essence, grantees could conduct an analysis using a counterfactual baseline to identify the benefits that accrue from deploying innovative technology alone. For example, a project that expands bus service and installs transit signal priority (TSP) might be compared against an expansion of bus service without the TSP component. Grantees may conduct analysis of this nature in addition to the primary BCA, which uses a plausible no-build baseline.

Geographic Scope

The BCA should consider the expected geographic impact of the facility, as improvements may affect traveler route choice. A metropolitan planning organization travel demand model, if available, may provide some insight into the origin–destination patterns of travelers using the new facility.

Additionally, the geographic scope of the analysis should be sufficient to capture as many of the primary and secondary effects of the project as possible. Generally, grantees should consider expanding the geographic scope beyond the immediate deployment area (see example on adaptive signal control).

Example: Adaptive signal control

If deploying adaptive signal control at a set of intersections, mobility benefit calculations generally need to be made on the corridor as a whole, as travel time savings at those intersections could be offset (or enhanced) by other changes in the corridor.

Mode Shift and Induced Demand

Increased demand for transportation services following a level-of-service improvement can come from several sources, including mode shifts (e.g., commuters' switching from transit to cycling due to a new bike path); route changes (e.g., transit riders' switching from a parallel bus line to a new bus rapid transit line); or induced travel (e.g., an auto traveler making a recreational trip to a central business district that the traveler would not have made without the introduction of a new high-occupancy toll lane).

For travelers switching from one mode to another, the BCA considers the benefits derived from the new mode rather than the avoided costs of the prior mode. Induced travel within the same mode represents new trips that were not valued highly enough to be made under earlier conditions but were made following facility improvements. As such, the induced trips represent a smaller consumer surplus than that for other trips. In practice, BCAs use the **rule of one-half**, whereby benefits from induced demand are valued at half the level of benefits to existing users.[9]

In estimates of safety benefits associated with modal diversion of trips from highway modes, such as automobiles and trucks, to other passenger and freight modes, only a portion of these costs are external. These costs are largely internalized by individual users of the transportation system and should not be directly monetized. Only 10 percent of light-duty-vehicle crash costs and 17 percent of large-truck crash costs are assumed to be external and appropriate for monetization and inclusion in a BCA.[10]

Issues Specific to Advanced Transportation Technology and Innovation Project Benefit-Cost Analyses

The next section discusses issues specific to ATTAIN projects that are relevant to BCAs.

Value of Travel Time Information

ATISs can help travelers adjust their routes, departure times, travel modes, or other trip characteristics to avoid delays. In these cases, the benefits may be measured conventionally, such as through the changes in travel times and vehicle operational costs. However, prior research suggests that travelers also place a value on real-time information even when they do not make specific changes to their journeys in response to the information received. High-quality information can allow travelers to adjust future plans, notify others of their estimated arrival time, or even simply gain peace-of-mind benefits from knowing what to expect. The evaluation team should consider measuring a range of potential benefits (i.e., through surveys, interviews, or both) as part of the overall evaluation.

USDOT's *Benefit-Cost Analysis Guidance for Discretionary Grant Programs* provides values for real-time information displays within a transit facility or on a transit vehicle but no values for a real-time information application or website. The values provided for a transit facility and transit vehicle could be used as proxy values to estimate the benefit of a real-time information application, although these values are likely to undervalue the true benefit of having the information readily available on a user's phone.

If the nature of the project is such that the available values in the guidance cannot serve as reasonable proxies, then these benefits should be presented qualitatively in the BCA unless there are willingness-to-pay estimates that are supported by methodologically rigorous studies of consumer valuation. While it may not be possible to incorporate these measures directly into a BCA, the findings may support other areas of an evaluation.

Travel Time Reliability

It is widely recognized that transportation system users value the reliability of travel times in addition to valuing reductions in average travel time, and oftentimes, ITS projects, such as adaptive signal timing, are specifically designed to improve TTR rather than reduce overall travel time. However, there is no consensus method or established practice for quantifying this benefit, and USDOT has not established recommended monetary values. Changes in the

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[9]Most recent BCA guidance is on the USDOT website https://www.transportation.gov/mission/office-secretary/office-policy/transportation-policy/benefit-cost-analysis-guidance.

[10]See BCA guidance.

distribution of point-to-point travel times are sometimes presented as changes in the variance, standard deviation, or other metric. Using the idea of buffer time—that is, the difference between the mean travel time and a benchmark level used in travel planning, such as the 95th percentile—to approximate the impacts on travelers' decisionmaking may be reasonable. Given the range of approaches to measuring reliability impacts and the lack of standardized monetary values, the authors suggest that reliability benefits be included in the BCA as qualitative, nonmonetized values.

Option Value and Resiliency

Travelers and freight operators are generally better off when they have access to multiple means of travel and may place a value on these options even when the values are not used. For example, captive automobile commuters—those who do not have access to any alternative modes of transportation—have a more limited set of choices available to them than travelers with access to transit and ride-sharing services. Additionally, a larger set of transportation options can increase the resiliency of the transportation system by providing alternatives when a particular mode or route is disrupted. These benefits would generally be included qualitatively in the BCA due to the lack of well-established methods for valuing these impacts.

Survey and Interview Methods

This section outlines considerations and methods related to surveys and interviews. Based on the evaluation questions that are identified during evaluation planning (see Chapter 2. Evaluation Overview), the evaluation team determines whether surveys or interviews represent an appropriate method for collecting the necessary data. For technology deployments (e.g., ATIS and CV applications), grantees can use surveys or interviews to gather information from the users of the technology regarding users' experiences and satisfaction with the technology, as well as the impacts of the technology on travel behavior or attitudes. Surveys or interviews are also useful tools for gathering qualitative data from project team members or other stakeholders regarding the benefits, challenges, and lessons learned regarding the technology deployment. Ideally, survey or interview data complement other objective data that are collected from infrastructure or from the technology itself. However, for some evaluation questions, when no other data sources are available, surveys or interviews may provide the only source of data for a particular evaluation question.

For ATTAIN projects that involve surveys, interviews, or other qualitative methods, grantees should consult staff with expertise in the fields of survey and interview evaluation and survey and interview design and methods. In addition to surveys and interviews, other qualitative methods may be appropriate, such as focus groups or workshops. Table 16 describes these methods and provides considerations for using each.

Table 16. Summary of qualitative methods.

Method	Description	Considerations in Using the Method
Surveys	Use a systematic method to collect quantitative or qualitative measures or both of an individual's experiences, attitudes, behavior, etc.	• Enable the collection of individual-level data from a larger number of people. • Provide data on nonobservable traits such as users' characteristics, attitudes, experiences, or perceptions. • Use probability sampling to enable the generalization of findings from the sample to a larger population (see later section on sampling).
Interviews	Use a structured interview guide (typically with open-ended questions) to gain detailed insight into experiences, behaviors, attitudes, and opinions.	• Provide more indepth, detailed information (e.g., lessons learned). • Enable probing and followup, which can be useful if the topic is less well defined or if a deeper understanding of attitudes, behaviors, etc., is needed.
Focus groups or workshops	Use a group setting to collect qualitative feedback from multiple individuals.	• Enable the collection of information from multiple stakeholders at the same time. • Enable give-and-take among the participating individuals and may allow for participants to coalesce around certain ideas or conclusions.

The remainder of this section provides best practices on the following aspects of survey and interview development and administration:

- Target population
- Survey design
- Survey administration mode
- Sampling
- Recruitment
- Questionnaire design
- Response rates
- Privacy and PII
- Other considerations

Target Population
For technology deployments, the evaluation team will want to consider the population(s) who are affected by the technology or who can provide feedback on the technology, which may include multiple populations (see example to the right). The evaluation questions that have been developed will help define the target population. If possible, the team should collect different relevant populations' perspectives.

Example target population for transit CV application:
- **Bus drivers** (use or benefit from the technology)
- **Riders** (benefit from the technology)
- **Agency personnel or other project stakeholders** (experience in deploying and maintaining technology)

Survey Design
The evaluation questions that are identified during the evaluation-planning process will determine the appropriate design or approach for the surveys, interviews, or both. For example, if the evaluation questions revolve around users' experience and satisfaction with a technology, the survey should follow the deployment of the technology (a **postdeployment survey** only). However, if the evaluation questions involve a measure of change—perhaps understanding the change in users' behavior or attitudes as a result of using a particular technology—then the most robust design is a **pre–post or before–after design,** whereby the same questions are asked in both the pre- and postdeployment periods.

By conducting surveys in both the pre- (baseline) and postdeployment periods, a team can compare measurements over time. However, if a control group is not used,[11] tracking potential confounding factors (e.g., changes in the economy and construction) that may be the causes for a change in the measure rather than in the deployment may be important. The evaluation team may not be able to quantitatively measure the impacts of the confounding factors, but at a minimum, the confounding factors should be noted in any report of findings.

If pre–post surveys are being used, the grantee should consider **a panel design**, whereby the same individuals are surveyed in both the pre- and postdeployment periods. However, if resources do not allow for both pre- and postdeployment surveys, it is also possible to ask respondents (in a postdeployment survey only) whether they perceived changes in their attitudes, behaviors, etc., due to the technology. This method is not ideal, because it is more likely to lead to bias in the survey responses (i.e., problems with recall or positivity bias); but it offers an alternative option for grantees who are unable to conduct surveys in both the baseline and postdeployment periods.

Advantages to panel design (same individuals surveyed pre- and postdeployment):
- Individuals act as their own controls since an individual's key attributes will not change from the pre- to the postperiod.
- Can measure change at the individual level as well as in the aggregate.

Table 17 provides examples of survey design.

[11]With a control group, individuals who do not receive the treatment (e.g., are not exposed to the CV technology or the new traveler information application) are also surveyed before and after the deployment. Presumably, there are no changes in their attitudes, behaviors, etc., over time, which confirms that any change measured in the treatment group is due to the treatment.

Table 17. Survey design examples.

Example Evaluation Topics	Design
• Characteristics of technology use (e.g., frequency of use) • User satisfaction with different aspects of the technology • Attitudes about the technology	• Postdeployment survey
• Changes in attitudes or behaviors resulting from the use of technology	• Pre–post design (most robust) • Postdeployment survey only (i.e., retrospective questions on perceived changes)

Survey Administration

The nature of the specific project (including who is being surveyed) will influence and may even dictate the mode or method used for collecting the survey information. Surveys may be administered online, in person, by mail, or by telephone. Table 18 highlights each of these modes (mail and telephone are included for reference but are not likely to be used for ATTAIN projects).

Multiple modes may be used for the same survey effort either during different stages of the survey (recruitment versus survey method) or to reach different subpopulations, as appropriate. For example, for a technology being deployed at an intersection to improve pedestrian safety, an in-person intercept may be used for recruitment, and then respondents may be asked to complete the survey online. During the intercept, the interviewer would briefly explain the purpose of the project, obtain the respondent's agreement to participate, and collect the respondent's contact information.

Table 18. Survey administration modes.

Method	Considerations	Example Users
Online survey, including application based	• Participants should be able to complete at their convenience • The survey process should be streamlined (i.e., with skip patterns) • Response tends to be lower compared with in-person surveys, but with an engaged population, this may not be a concern • Developing a sample of eligible participants can be expensive if there is no readily available sampling frame • If a panel design is used, the team needs to assign respondents unique identifications to link responses across multiple surveys • Survey programming is required • Some populations (e.g., older people) may not have online access	• ATIS users • Connected-vehicle users
In person – Paper – Tablet	• Response rates are higher relative to other methods • If paper surveys are used, there is greater burden on respondents to follow directions, skip patterns, etc.; responses will need to be coded into a database • Tablets streamline the survey process but the team needs a sufficient number so respondents are not waiting to complete surveys • Tablets require survey programming	• Survey transit users onboard the bus • Survey truck operators at their fleet barn, rest stops
Mail	• This method requires mailing addresses • Response rates tend to be lower • This method requires followup contacts (e.g., reminder postcard) to increase response rates • No programming is required, but responses must be coded	• Residents who experience adaptive signal control improvements in a corridor (i.e., sample corridor addresses)
Telephone	• This method requires telephone numbers • Response rates are lower due to phone screening, such as caller ID • Phone system programming is required (computer-assisted telephone interview system)	

Sampling
As part of the survey design process, the evaluation team will need to develop the sampling frame from which the sample of respondents is drawn. For some technology deployments, it may be appropriate to survey all members of the population (i.e., no sampling). For example, if CV technology is being deployed in 60 fleet vehicles, the evaluation team may survey all drivers of the instrumented fleet vehicles. In other cases, such as the deployment of a publicly available ATIS, it is not feasible to survey all potential users, so a sample is drawn from the population. A list of users (a sampling frame) may be available (e.g., toll pass customers and transit pass riders), but in other cases, there is no available sampling frame, and the evaluation team will need to be creative in developing its sample. If a preexisting list or online panels are used, the evaluation should consider any biases or limitations to the list (e.g., accuracy and completeness).

Sampling frame versus sample:

- **Sampling frame:** The list or procedure that defines your population
- **Sample:** The individuals or units that are drawn from the sampling frame for inclusion in your survey and who may or may not choose to participate

In general, there are two key types of sampling: probability and nonprobability. With probability sampling, each individual has a known, nonzero probability of being randomly sampled, and the sample findings can be generalized to the larger population. With nonprobability samples, individuals are selected—rather than sampled—either for a reason due to the research (purposive) or because they are easy to access (convenience). While the findings cannot be generalized to the larger population, nonprobability samples can nonetheless yield useful insights.

Sample Size
The evaluation team will need to determine the appropriate sample size for the survey effort. For probability samples, the sample size is calculated using a standard formula that is based on several factors, including the population size, the desired confidence interval (margin of error), the confidence level, and the standard deviation in the responses. Sample size calculators, available online, can assist with this task. For example, sample size calculators demonstrate that a sample of 375 to 400 responses will generally be sufficient to enable the team to say with 95-percent confidence that the measured sample statistic is within 5 percent plus or minus of the true proportion in the overall population. If the teams needs greater precision in the survey estimates or if the team needs to analyze subsamples, the team will need to increase the sample size. For nonprobability samples, it is more difficult to determine sample sizes, but the evaluation team should determine the subgroups of interest and ensure a sufficient number of responses for each subgroup. Teams are encouraged to collect as many responses as their budgets allow; subgroups with fewer than 50 responses should be interpreted with extreme caution.

Recruitment
The recruitment procedures should be tailored to the study population and standardized so that the same protocols are being used across all respondents. A set of **screening criteria** should be developed to ensure that only qualified participants are selected. Common methods include in-person recruitment, phone recruitment, or online panel recruitment (e.g., online panels). The next section offers some suggestions for recruitment.

Recruitment Best Practices

Recruitment best practices include the following:

- **Keep the recruitment process simple** for respondents.
- **Be clear on any requirements for participation** (e.g., must have a valid driver's license) and ensure there is some mechanism for verifying that the potential respondent has met the requirements. A **screener questionnaire** may be needed to determine a person's eligibility to participate in the study. For example, if a team is deploying a technology along a corridor, the survey may need a screener question to identify drivers who traverse the corridor on a regular basis (e.g., at least 3 weekdays per week during peak hours).
- **Try to obtain a diverse or representative sample**, particularly with respect to demographics that may be related to a user's experience or satisfaction with the technology. For example, diversity by age and income can typically be important. If the screener questionnaire includes questions on age and income, you can monitor these characteristics of the sample during recruitment.
- **Overrecruit to allow for the fact that participants will drop out when setting recruitment targets for panel surveys** for any number of reasons that may or may not be related to the study. While it is difficult to estimate what the dropout rate will be (in part it depends on the nature and requirements of the survey), the team may assume that at least 20 to 30 percent of recruited participants may drop out at some point during the survey period.
- **Establish buy-in from the fleet manager** and provide the manager with scripts (e.g., that should accompany the survey invitation) and **encourage the manager to use the standardized protocols** developed for the evaluation. For certain populations, such as transit operators or truck drivers, recruitment may need to occur through fleet managers.

Questionnaire Design

Questionnaires should be designed to capture the specific performance measures and related data elements identified in grantees' evaluation plans, but they may also include additional questions that are needed for analysis purposes and do not explicitly measure a performance measure. For example, demographic questions or questions related to a respondent's typical use of a corridor may be needed to better interpret the survey responses and to provide context for understanding the key performance measures. If different populations are being surveyed**, questionnaires should be tailored to each population as needed** (i.e., according to the evaluation questions). For example, if surveying bus drivers and riders, there may be questions that are appropriate to one population and not the other. To the extent possible, however, the same or similar questions should be asked across survey populations.

Questionnaire Design Best Practices

Questionnaire design best practices include the following:

- Avoid questions that are biased or leading. An example of a biased question: To what extent do you agree that traffic congestion is a problem?
- Ask one question at a time; avoid double-barreled questions. An example of a double-barreled question: How satisfied or dissatisfied are you with the timing and quality of the traffic alerts?
- For scaled questions (e.g., level of agreement and extent of satisfaction):
    - Ensure the scales are balanced (e.g., same number of positive and negative points).
    - Be aware that maximum reliability is 5–7 points (neutral point is included if 5 or 7).
    - Label all points of the scale.
    - Use consistent language in your scales.
- Group similar questions together; think about the flow of questions.
- Use skip patterns as appropriate, so respondents can skip questions that are not relevant, or include a "Not applicable" response option if appropriate.
- For online as well as paper surveys, pay attention to how the questions are formatted. Proper formatting can make survey completion easier on the respondent and can reduce errors.
- Pretest your questionnaire to ensure respondents understand the questions, the response categories are complete, etc.

Response Rates

The evaluation team should use steps to maximize response rates. For probability samples, a high response rate enables the evaluation team to more confidently generalize from its sample to the larger population. If response rates are low, however, nonresponse error is a concern. Nonresponse error occurs when nonrespondents in the sample (e.g., people who were sampled but did not complete a survey) differ from respondents in ways that are germane to the survey topic; as a result, the sample findings are not representative of the population.

Methods for Improving Response Rates

Methods for improving response rates include the following:

- In any initial contact with potential or recruited participants, **explain the importance of the survey and how the resulting data will be used**; if respondents understand the value of the information, they may be more likely to participate.
- **Make the survey process as easy as possible** on the participant.
- **Use multiple reminder and followup contacts** to encourage survey completion.
- **Consider a small incentive** as a means of increasing participation, particularly for surveys that involve participation over a period of time (i.e., predeployment and postdeployment). Costs eligible for Federal reimbursement must be in accordance with the terms of the financial assistance award and the cost principles in 2 CFR Part 200.
    - Consider incentives that are appropriate to the target population. For example, if you are surveying transit users, you could provide a free 1-week transit pass.

For nonprobability samples, a high response rate may be similarly important to ensure that the findings reflect the attitudes, behaviors, etc., of the full pool of participants rather than a subset. Response rates should be included in any writeup of the findings, and if the response is low, the findings should be interpreted with caution.

Privacy and Personally Identifiable Information

For some survey designs, it may be necessary to collect PII from respondents, particularly if the evaluation team plans to survey respondents over time and needs to contact them (i.e., to send survey invitations, reminders, etc.). In such cases, the evaluation team needs to ensure that it protects the respondents' PII by keeping this information in a file separate from the survey responses. Anonymous identifications (IDs) can be assigned to each respondent to link responses across surveys and to track survey responses. When the survey has been completed, however, any files with PII should be destroyed. In addition, in any initial contacts with respondents, the evaluation team should briefly explain how it plans to protect the respondents' PII.

> **What is PII?**
> According to 2 CFR 200.1, PII is information that can be used to distinguish or trace an individual's identity either alone or when combined with other personal or identifying information that is linked or linkable to a specific individual.

For interviews, the evaluation team needs to consider what level of privacy is required in its reporting of the findings, and it needs to convey this information to the interviewees. For example, if external stakeholders are being interviewed, will they be identified by name or organization or some other grouping?

Institutional Review Board

For research involving human subjects, the evaluation team should obtain the approval of an institutional review board (IRB). For this process, the evaluation team will need to complete an application and will need to provide the IRB with all survey-related materials, including the questionnaire, any initial contact notifications, and reminder notifications. During the planning stages, the evaluation team should contact the IRB to confirm that IRB approval is required. If it is required, the evaluation team will need to build time into its schedule for an IRB review.

Other Considerations

Following are additional considerations regarding surveys and interviews:

- **Be sensitive to language barriers for non-English speakers**. The evaluation team's survey population may include people who do not speak or write English, and as a result, they may be less likely to complete the surveys due to language barriers. If any of the participants are non-English speakers, it may be important to be sensitive to how feedback will be gathered from this group. In geographies with large numbers of non-English speakers, the evaluation team will want to consider translating the questionnaire into one or more languages.
- **Provide respondents with a mechanism for providing ad hoc feedback on the technology**. In addition to collecting feedback via active methods such as surveys or interviews, ATTAIN grantees should consider providing a passive method such as a feedback form on its website portal. In this way, participants can share their thoughts and

feedback at any time. If such a feedback mechanism is offered, the evaluation team must ensure that respondents are aware of it.

Emissions and Energy Measurement

This section outlines methods and considerations related to quantifying emissions and energy for ATTAIN projects. Recent Executive Orders (EOs), including *Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis* (EO 13990, 2021) and *Tackling the Climate Crisis at Home and Abroad* (EO 14008, 2021), emphasize the importance of this goal area. For ATTAIN technology deployments in which emissions or energy savings are anticipated, deployers should seek to measure and report on these positive environmental benefits.

Fuel consumption, as well as criteria pollutant and greenhouse gas impacts, can be quantified by using the following methods:

- Direct measurement using portable emissions measurement systems (PEMSs) and real-time fuel flow sensors
- Mobile-source emissions inventory models such as the U.S. Environmental Protection Agency's (EPA's) MOtor Vehicle Emission Simulator (MOVES), the California Air Resources Board's (CARB's) Emission Factor (EMFAC) model, or other tools such as the FHWA CMAQ Emissions Calculator Toolkit.

To quantify any emissions or energy impacts associated with a project, a net difference in inventories must be taken between the baseline conditions (i.e., conditions before project deployment) and the deployment conditions (i.e., after deployment).

To ensure equitable deployment of future highway projects, environmental and economic justice should be taken into consideration when analyzing emission and energy impacts, such as in the Oregon DOT's recent peer review of its environmental assessment conducted for the I–5 Rose Quarter Improvement Project in Portland, OR. The original interstate highway construction in the 1960s divided the historically Black Rose Quarter neighborhood, and the improvement project has proposed highway caps to reconnect portions of the neighborhood and emission reduction strategies. The peer review panel attempted to consider restorative justice in its project evaluation. Restorative justice tries to consider any past harmful environmental and economic damage done to underserved and underrepresented communities when developing new projects.

Another resource on equity is the Greenlining Institute's clean mobility equity playbook. This report provides an equity evaluation methodology based on lessons learned from a review of California's clean mobility equity programs. Best practices and recommendations are included, as well as detailed information—in the form of case studies—on California's clean mobility equity programs.

Directly measuring emissions and fuel consumption is a time- and cost-intensive process, so ITS projects may not conduct direct emissions or fuel measurements. The alternative is to quantify fuel consumption, criteria pollutants, and greenhouse gas emission benefits through some form of modeling. For the best emissions- and energy-modeling estimates, incorporating local fleet and activity data is suggested.

On-Road Emissions Models and Tools

Federal and State governments developed a number of models and tools to evaluate onroad emission and fuel reduction benefits. This section describes three relevant emissions models and tools: MOVES, CARB's EMFAC model, and the CMAQ Emissions Calculator Toolkit.

Motor Vehicle Emission Simulator

EPA's MOVES is a state-of-the-science emission modeling system that estimates emissions for mobile sources at the national, county, and project levels. EPA provides MOVES technical documentation, user guides, manuals, and training for developing State Implementation Plans, transportation conformity, and hotspot analysis.

Emission Factors

The EMFAC emissions model is developed and used by CARB to assess emissions from onroad vehicles—including cars, trucks, and buses—in California. EMFAC can also be used to estimate fuel consumption. Similarly, CARB supplies technical documentation, handbooks, and user guides for using EMFAC in various applications.

Congestion Mitigation and Air Quality Emissions Calculator Toolkit

FHWA has developed a series of tools to provide technical support and resources for the CMAQ Program. FHWA has undertaken the initiative of developing a series of spreadsheet-based tools to facilitate the calculation of representative emission benefits for regulated pollutants, including carbon monoxide, nitrogen oxides, particulate matter with diameters of 2.5 and 10 microns or less (PM2.5 and PM10, respectively), and volatile organic compounds, as well as for fuel consumption and carbon dioxide equivalent.

The CMAQ Toolkit recently introduced a series of tools to evaluate different vehicle-to-infrastructure (V2I) technologies. Even if the CMAQ tools themselves cannot be used, some ITS deployers and evaluators may find the methodologies used in the toolkit useful in evaluating emissions and fuel consumption impacts for their proposed projects. Each tool has associated documentation that details the methodology and MOVES modeling run specifications.

Methods of Evaluation

Vehicle emissions—including greenhouse gas and criteria pollutant emissions—and fuel consumption, like many other traffic parameters, can be either directly measured or modeled using the most accurate input data available. Assessing emissions and fuel consumption depends highly on the project and its intended outcomes. Decision criteria for whether to measure or model should include time, cost, and quality or precision needed. Direct measurements can be expensive and time-consuming but can yield superior quality—and less uncertainty—compared with modeling. However, emissions and fuel-use modeling should be sufficient for most if not all ITS projects. It is recommended to note there are different degrees of modeling. Not all projects will require high-precision modeling with extensive local fleet and activity input data. Some projects may simply need to quantify a decrease in VMT or operating hours. An analysis of emissions and fuel consumption determines the quantitative impact of the project. To ensure these impacts are distributed equitably, consider the socioeconomic status and racial makeup of affected communities.

The next sections describe direct measurement and modeling in more detail. For flexibility, a measurement approach and two tiers of modeling—simple and advanced— are explained in more detail.

Direct Measurement Evaluation

This approach will require emissions that are monitored using PEMSs and direct the monitoring of fuel consumption. An example of a project that would use this approach would be a V2I communications project in which emissions and fuel consumption would be measured without the V2I technology implemented (i.e., baseline scenario or no-build scenario) and then be compared with measured emissions and fuel consumption with the V2I technology implemented (i.e., project scenario or build scenario). A more specific case could involve traffic signal prioritization of a transit bus. A transit bus would transmit its approach to a traffic signal at an intersection, and the light cycle would be adjusted to allow the transit bus priority. This V2I project would reduce the red-light time, which would reduce the overall idling time of the transit bus.

Emissions Inventory Evaluation—Simple

A simple emissions inventory approach for evaluating ITS projects would be similar to what is currently done for evaluating some CMAQ projects. For this approach, the ITS deployer or evaluator can determine whether any of the currently available CMAQ tools could be used to evaluate emissions benefits. New CMAQ tools for V2I projects—including adaptive traffic control systems (ATCSs), electronic open-road tolling, and travel advisories—have been published recently.[12] If the CMAQ tools are not sufficient for evaluating the ITS project, then composite emission rates aggregated by pollutant and fuel consumption rates (i.e., representing the national fleet) can be obtained by conducting a national-scale MOVES run to assist with the evaluation.

An example of a simple emissions inventory evaluation would be a project that results in a VMT reduction. Composite emissions rates on a mass-of-pollutant-emitted-per-mile basis (i.e., usually in grams per mile or kilograms per mile) can be multiplied by the expected VMT reduction to obtain the overall estimated emissions benefit.

Emissions Inventory Evaluation—Advanced

An advanced emissions inventory approach would either use CV telematics data, conduct traffic microsimulation modeling, or both to develop detailed drive schedules or operating mode distributions as an input for MOVES or EMFAC. Users could then estimate the potential benefits by finding the difference in emissions and fuel consumption inventories between the baseline and project deployment scenarios.

Examples of ITS projects using an advanced emissions inventory approach would include technology deployments such as cooperative adaptive cruise control (CACC), in which the second-by-second changes to the vehicle trajectories are known. CACC deployments are likely to result in improved traffic flow and less braking, which would lead to subsequent emission reductions and fuel savings. The following documents (see Methods and Analytic Techniques

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[12] See: https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/?_gl=1*1q96uwq*_ga*MjYyMDAwOTc5LjE3MDk2NDM5NDg.*_ga_VW1SFWJKBB*MTcwOTkxMTI2Ny4xLjAuMTcwOTkxMTI3NC4wLjAuMA.

References at the end of this chapter) showcase projects that have used advanced approaches to determine driving-behavior changes at a high frequency for estimating the benefits of CVs and automated vehicles:

- *A Framework for Evaluating Energy and Emissions Impacts of Connected and Automated Vehicles Through Traffic Microsimulations*.
- *Applications for the Environment: Real-Time Information Synthesis: Eco-Signal Operations Modeling Report*.
- *Benefits Estimation Model for Automated Vehicle Operations: Phase 2 Final Report*.
- *Estimating Emission Benefits of Electronic Open-Road Tolling Conversion Projects*.
- *Meta-Analysis of Adaptive Cruise Control Applications: Operational and Environmental Benefits*.
- *Performance Comparisons of Cooperative and Adaptive Cruise Control Testing*.

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CHAPTER 5. TECHNOLOGY-SPECIFIC INFORMATION

This chapter presents methods and lessons learned with respect to evaluating Adaptive Signal Control, Connected Vehicles, and Automated Vehicles.

Adaptive Signal Control

Adaptive-signal-control technologies (ASCTs) increase the flexibility of signalized control systems to meet changing traffic demand on key arterial corridors. A wide variety of systems that alter traffic signal timing dynamically by sensing traffic conditions in realtime have been developed. These systems have widely varying capabilities and methods for allocating green time between movements. The specific algorithms and methodologies that ASCT systems use are not examined in this chapter. Instead, this chapter focuses on the analysis techniques, performance measures, datasets, and tools needed to analyze the impacts of an adaptive signal system.

Key areas that should be considered are:

- **Analysis approaches**: What type of approach is right for testing the ASCT? Will the system be evaluated in a real-world setting, or will a simulation model be used to evaluate performance?
- **Data collection**: What types of data can or should be collected? Which datasets are required to support desired performance measures?

Analysis Approaches

The two broad categories for testing ASCT systems are real-world field studies and simulation assessments. In implementation settings, the adaptive signal system is installed and tested against actual traffic, with all the variations and idiosyncrasies that occur in demand from day to day. Such implementations necessarily give the best information about how well the system functions in a given corridor, but disentangling the impact of the signal system from other changes in conditions is more difficult because no perfect control scenario can be used for comparison. Instead, a reasonably large sample of data must be collected to capture and account for variation.

> **Analysis approaches**
> **Field study:**
> - Real-world implementation using before–after or on–off data.
> - **Simulation study** High-resolution traffic modeling.

Alternatively, simulation studies offer a platform for testing an ASCT system by using a control-experiment setup. The same demand pattern can be modeled for both the adaptive system and one or several other control systems. Demand can also be varied stochastically—but in a managed and replicable way by using known random distributions. Simulation also has the advantage of being a controlled environment that does not produce actual negative impacts if a system or methodology leads to dramatically worse outcomes than expected. Since all vehicles are tracked and modeled individually, simulations allow for highly detailed performance measures to be created, some of which would be infeasible to collect in a real-world implementation, such as trip-level performance measures for every vehicle in the simulation.

However, simulations are only representations of how the ASCT system will work. The random variations inherent in actual demand are hard to fully model, so performance, once the system is implemented, may differ from modeled results. Furthermore, simulation studies require the underlying simulation to be validated against existing conditions. Otherwise, any results generated by the simulation might be unreliable. Calibration and validation of simulation models are not standardized processes in traffic simulation and have numerous pitfalls that need to be considered. As noted, including the appropriate level of variation in a simulation model is difficult, and overcalibration is a significant concern. Models that have been tuned too tightly to match a small set of data will not produce realistic results when used to forecast the impact of an experimental treatment.

Within real-world implementation studies, several experimental approaches have been used in previous research. Ideally, a control-experiment approach would be taken—as in a simulation—but this approach is not possible. The exact same demand is never repeated from one day to the next because daily routines are not perfectly static and need to change from day to day. Instead, some alternating approach must be taken. Two general approaches have been used in previous studies: before versus after and off versus on.

Before–after studies collect data samples under both baseline and experimental conditions, usually before and following the implementation of the new system. Some before–after studies add further complexity by breaking up postimplementation data into multiple cohorts to examine both immediate and long-term impacts. Before–after studies[1] are common throughout transportation engineering. Critical concerns for such studies are data collection and ensuring that sufficiently large samples have been captured to provide meaningful analysis.

Alternatively, **on–off studies** alternate back and forth between the old and new systems being considered. Such studies seek to approximate a control-experiment study more closely under the assumption that the traffic patterns are related to each other on a day-to-day, week-to-week, or month-to-month basis much more closely than on a year-to-year basis. Such a study may activate the new ASCT system on alternating weeks and compare those samples against one another with little or no modification, since the first and second weeks of any given month are likely to be quite similar—excluding holidays, which can be easily filtered out. The primary disadvantage of the on–off approach is the inability to detect long-term changes due to the treatment. Drivers exposed to alternating traffic control systems may become highly conservative and allocate significant extra time for their journeys to accommodate the uncertainty the study produces. If a before–after approach had been taken instead, those same drivers might have converged to a more stable, less conservative pattern after an acclimation period of several weeks. Thus, an on–off approach may provide more statistically accurate results comparing the two or more systems under current conditions but may not be able to account for changes to those conditions that the treatment causes.

Table 19 summarizes the advantages, disadvantages, and considerations for each of the study approaches.

[1]See references: Fontaine, M. D., J. Ma, and J. Hu., *Evaluation of the Virginia Department of Transportation Adaptive Signal Control Technology Pilot Project*; Sharma, A., N. Hawkins, S. Knickerbocker, S. Poddar, and J. Shaw, *Performance-Based Operations Assessment of Adaptive Control Implementation in Des Moines, Iowa*; and Day, C. M., D. M. Bullock, H. Li, S. M. Remias, A. M. Hainen, R. S. Freije, A. L. Stevens, J. R. Sturdevant, and T. M. Brennan, *Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach*.

Table 19. Advantages and disadvantages of study approaches.

Study Approach	Advantages	Disadvantages	Considerations
Simulation control experiment	• This approach allows for direct control-experiment analysis • Easy-to-implement alternative plans optimize control algorithms • There are no real-world impacts if negative outcomes are found	• This approach makes it difficult to account for variations in traffic demand and unusual circumstances • Overcalibration or poor calibration can lead to unrealistic results	• Thorough and multifaceted calibration and validation should be done to ensure that the underlying model is applicable
Field studies: before–after	• These studies allow traffic patterns to stabilize over time in the new system • These studies do not create confusion due to switching back and forth between control schemes	• Any external significant changes from before to after must be accounted for • Travel changes from before to after must be accounted for	• Ensure sufficient data collection, especially for pretreatment conditions, which are harder or impossible to get more of after the fact
Field studies: on–off	• This approach allows for direct comparison of treatment and nontreatment options • This study makes it easier to ensure that sufficient data are collected for each scenario by simply rerunning whichever scenario needs more	• This approach does not allow the evaluator to examine long-term changes in the system due to the adaptive signal control technology	• Consider the impact of frequent changes to the control system on driver behavior

Data Collection

To support holistic analyses of ASCT systems, high-quality data should be collected. As detailed in the next section, a wide variety of performance measures have been used to explore the impacts of ASCTs. As a result, a wide variety of data sources have been used to support and produce those performance measures. Within traffic operations, data collection generally follows three patterns: fixed-sensor data, floating vehicle probe data, and trajectory data.

> **Traffic operations data collection:**
> - **Fixed sensor**: Volumes and queues collected using inductive loop detectors, cameras, or radar sensors.
> - **Floating vehicle probe**: Travel times, speeds, stops, etc., based on uniquely identified vehicles (instrumented research vehicles, commercial fleets, or Wi-Fi/Bluetooth®-tracked private vehicles).
> - **Trajectory data**: High-resolution vehicle traces, usually produced by a simulation model.

Fixed sensors—typically, inductive loop sensors that are embedded in the pavement—provide spot measurements and are the main data sources used by ASCT systems to sense the presence of vehicles at intersections. Radar-based or camera-based sensor options are also commonly used. Arrays of fixed sensors provide volumes and, possibly, speeds directly, and some simple modeling techniques can estimate speeds, queue lengths for individual approaches or lanes, and traffic movements through each study intersection. Fixed sensors are located close to the intersections they relate to, with advanced queue detectors sometimes placed several hundred feet upstream in any given direction. Thus, fixed sensors are unable to provide any information—other than, perhaps, average speed or travel time—for the segments between intersections. This lack of coverage can be a significant hurdle if driveways or access points are located between intersections where significant traffic enters and exits roadways in locations where the sensors cannot account for them.

Notable variation can occur, even within fixed-sensor systems. Some intersections feature independent detection on every approach lane, while others aggregate data by movement. The level of aggregation may vary depending on whether the approach is the major or minor road. Many turning lanes feature upstream queue detectors, although some through lanes and right-turn lanes also have such advanced detection to monitor queuing activity. More rarely, exit detectors are placed on the outgoing legs of the intersection to capture departures from the intersection. These exit detectors can be extremely valuable for determining accurate turning movements and looking for spillback queue issues in highly saturated or closely spaced intersection systems.

The data from the signal control system itself can also be considered a fixed sensor. Modern signal controllers have mechanisms for producing log files that detail the actuations and control decisions that the algorithm selects. Incorporating controller information into analysis is necessary to identify how platoons of vehicles are interacting with signal phasing. Data from **probe vehicles**, unlike fixed sensors, have wider geographic flexibility and can cover interstitial areas between intersections. Vehicles with built-in Global Positioning System (GPS) devices—or drivers using GPS-based applications on smartphones or dedicated navigation tools—can produce sample measures of traffic conditions along the roadway as they travel. Individual vehicles can also be traced using Wi-Fi or Bluetooth® communications. Dedicated instrumented roadway vehicles often use radar, light detection and ranging (LiDAR), or camera technologies to observe conditions around the vehicle for a more complete assessment of traffic behavior.

Floating probe vehicle data provide more continuous samples across an entire study segment—especially for areas with significant traffic from which to potentially sample. However, the additional options and resolution provided by probe vehicle data may need to be purchased. For example, commercial aggregation firms collect and sell data, or sensors can be purchased and attached to vehicles or installed in managed fleets to collect data internally.

To gain a complete picture of driving behavior in a corridor, **full trajectories** can be collected. Unlike the data options noted earlier, full trajectory data are not sampling specific locations or a subset of vehicles. Instead, every vehicle's full path, including location, speed, and surrounding conditions, is measured. Some real-world options exist for collecting full trajectories (helicopter or drone-based photography, for example), but only small samples are generally possible due to cost. Trajectories are, however, produced automatically by simulation models. Within the modeling environment, every vehicle is updated at extremely high resolution (usually once every 1/10 of a second), and any vehicle-specific or environmental factors can be calculated and stored for later analysis. This provides the most flexibility in terms of analysis and allows for highly sophisticated performance measures. Table 20 indicates the types of measures that are produced or can be modeled or estimated by each data collection technique (also see table 9 in the Performance Measures chapter for performance measures related to signalized control).

Table 20. Data collection techniques.

Measures	Fixed	Floating Probe	Trajectory
Volume	Yes	No	Yes
Queues	Maybe[1]	Yes	Yes
Speed and travel time	Maybe[2]	Yes	Yes
Delay	Estimated	Estimated	Yes
Stops	Estimated	Yes	Yes
Arrivals	Estimated	Yes	Yes
Progression	No	Yes	Yes

[1]If upstream queue detectors are present.
[2]If radar- or camera-based speed measurements are used.

Other data types are also necessary for the holistic analysis of adaptive signal systems. Staying within operations, multimodal data can provide a more complete picture of total delay and movements through a signalized corridor. Bicycle detectors, information from transit systems, or measurements of pedestrian activity can be critical for exploring total multimodal person delay occurring at each intersection in a study area rather than limiting the analysis to vehicle delay.

Signalized control plays a significant role in safety and the number of traffic incidents that occur within a corridor. Crash reports form the basis for understanding where crashes occur and what, if any, role traffic signals may have played in each event. Collecting those for before–after or on–off studies is critical to incorporating safety aspects into analysis.

A significant concern regarding data collection is the sample size. Regardless of the type of data collected and the technology used to collect them, sufficient data must be collected to ensure that any analysis provides an accurate assessment of the performance of the adaptive signal system. The concerns herein are not particular to adaptive signals; generally accepted practices regarding data significance should be used.

When considering overall performance within a benefit-cost–type framework, several distinct costs arise for adaptive signal systems. Typical costs of implementing and maintaining the physical hardware are present, as with other treatments. However, adaptive signal systems are highly software dependent and thus generally require licenses from vendors to use the products and get updates and support as the algorithms of the ASCT systems are improved. Additionally, using such software requires an investment in workforce training so that operating engineers have the requisite expertise to use the system, make modifications over time, and troubleshoot issues. Collecting the necessary data to consider these costs can be important to evaluating ASCT systems.

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Connected Vehicles

Connected vehicles (CVs) are motor vehicles that communicate with equipped infrastructure, other equipped vehicles, other road users (e.g., pedestrians and bicyclists), or all of them by using vehicle-to-everything communications. CV technologies implement various applications that are designed to enhance vehicle safety, improve traffic mobility, and reduce the environmental impacts of transportation. The following subsections present best practices that relate specifically to evaluating the performance and impact of CV applications before and post CV deployment.

Predeployment Planning

The first set of best practices focuses on evaluation planning, experimental design, CV exposure tracking, and readiness of CV applications.

Deployment Scope and CV Exposure

Prior to deploying CV technology, it may be important to understand whether the deployment will generate the amount of data required to be able to statistically evaluate the impacts of the CV applications being deployed. The number of CVs and the number of equipped infrastructure locations in the deployment, as well as the exposure of these CVs (i.e., interactions among CVs and between CVs and equipped infrastructure), directly affect the amount of data being collected for the evaluation. The required deployment size and CV exposure will depend on the goals of the evaluation and selected experimental design, which can be estimated using a power analysis.

In a deployment of autonomous vehicle technologies that function without receiving any data from other vehicles or the infrastructure, calculating the exposure to various types of traffic events based on the location of the deployment, the demographics and travel patterns of the drivers, and the expected driving mileage is fairly straightforward. However, exposure in a CV deployment depends on a CV being within close proximity of another CV or connected infrastructure. The recommended way to estimate how frequently this exposure will occur is to run traffic simulations based on the planned deployment levels using real-world traffic data from the deployment site.

For strategic recruitment, select drivers who:

- Take the same roadway during the morning commute
- Routinely pass through a specific intersection or location of interest
- Are most likely to experience hazardous driving conditions

Simulations should consider the following:

- Demographics of the drivers being recruited.
- Vehicle types (e.g., passenger cars, taxis, trucks, and transit buses).
- Travel patterns of the drivers being recruited.
- Types of applications being deployed on the site.

The results of the traffic simulation model will provide an estimate of how frequently CVs will interact with one another and with the equipped infrastructure in different types of driving scenarios (e.g., vehicle following, lane change, and intersection crossing) in the deployment environment. These results will also enable the deployer to understand the impacts of changing different variables to optimize the experimental design (e.g., adding more vehicles and changing the recruitment strategy) (Barnard 2017; Smith and Razo 2016).

If running a traffic simulation is not possible, the team should try to be intentional about how to maximize CV interactions in the deployment. One way to be intentional is through the recruitment of drivers and vehicle fleets to participate in deployments of CV. Also, the rarer the types of events that the CV application is trying to address, the larger the deployment will need to be to collect a viable sample size of these events.

Experimental Design

To assess the real-world impact of new applications, the deployment of these applications typically involves before and after periods. The before period is dedicated to collecting baseline data without application assistance, during which the applications operate in the background but do not provide any information for drivers. In the after period, the applications become fully active and issue messages to drivers to collect treatment data with application assistance. To isolate the effects of confounding factors specific to a deployment site and duration, incorporating a control group of drivers or vehicles that operate without application assistance in both the before and after periods might be helpful. In this case, the evaluation will compare the driving performance between the control group and the treatment group that experiences a before period without and an after period with application assistance.

Why use anonymous vehicle IDs:

- To identify vehicles that are not working properly, transmitting bad data, or not getting sufficient exposure
- To make before–after comparisons of individual vehicles

Large individual differences between drivers exist. Thus, in evaluations of how humans interact with technologies, the most robust experimental design considers a within-subject statistical analysis. This analysis compares drivers with only themselves both without (before) and with (after) the assistance of vehicle technologies. This analysis also allows the evaluation to focus on a specific driver's changes in behavior and performance rather than average changes across a group.

To conduct a within-subject's evaluation:

- Assign an individual vehicle to a single participant.
- Instruct participants not to let anyone else drive the vehicle during the deployment.

Of course, in the case that CV technology is being deployed on vehicle fleets or on participants' personal vehicles, this type of evaluation may not be possible. As an alternative, marking the data when an individual participant is driving a vehicle so that the data can still be parsed by drivers is helpful.

Tracking Vehicles Using Anonymous IDs

In a CV deployment, basic safety messages (BSMs) are used to communicate a vehicle's location and other vehicle information (e.g., brake pedal press and turn signal use) to other vehicles. In some deployments, these BSMs are anonymized so that individual vehicles cannot be identified.

However, in any deployment of CV technology that is being used for research and evaluation, creating an anonymized vehicle identifier can be important.

Vehicle identifiers are necessary to pinpoint those CVs that are having problems with their applications or not being driven for a relatively long period of time, so that corrective action can be taken. In addition, vehicle identifiers allow a comparison of a specific vehicle both before and after the CV technology is deployed. This comparison of specific vehicles enables the team to account for the variability between vehicles. If the evaluator does not have the ability to track specific vehicles throughout the two deployment periods, the evaluation will need to combine the data from all vehicles, making it much less likely that an effect will be observed.

Impact of Invisible (Not Connected) Vehicles

One of the greatest challenges of evaluating a CV deployment in a real-world environment is that not all the vehicles in that environment will be equipped with CV technology. This means that CV applications will become active only in the presence of other CVs or connected infrastructure, and CVs will not be able to see all the surrounding not-connected vehicles (non-CVs) in the environment. This presents a number of challenges to conducting CV evaluations that can vary based on which CV applications are being deployed, the deployment rate at the site (percentage of equipped vehicles), and the goals for the evaluation.

When assessing the impact of CV technology, the evaluation team should carefully consider how the combination of CVs and non-CVs may affect the project's unique deployment and evaluation. Some application performance metrics for CV deployments may not represent the actual driving scenario if a non-CV absent in the data is really present in the driving scenario. For example, metrics showing how far from the crosswalk a CV has stopped after responding to a pedestrian in a signalized crosswalk may not be accurate if a non-CV is between the CV and the crosswalk. The CV driver may be responding to the lead non-CV slowing ahead and not to the pedestrian or the application alert, and there will be no way to determine the cause of slowing from the data. One way to mitigate this problem is to install additional sensors on CVs or the infrastructure to collect data on the presence of surrounding vehicles and other road users and to validate the CV data against the data from these sensors (this tactic will be discussed further in the section Use of Other (i.e., Non-CV System) Data.

Other considerations due to invisible vehicles are as follows:

- Users (e.g., drivers and pedestrians) would not be able to create a mental model of how the application works because it would not work all the time. Users generally have no way of knowing which other vehicles or infrastructure in the environment are equipped or are not equipped, so they will not be able to develop an expectation of when the application will or will not be able to support them.
- Often in transportation research, performance metrics are normalized by exposure (i.e., VMT or VHT). These normalization metrics become irrelevant with CV evaluations because their applications do not work unless the CV interacts with another CV or the equipped infrastructure. For these metrics to be useful, the data collection strategy must provide insight into exactly when the application was active (interacting) and when it was not compared with the entirety of the users' experience.

Application Performance Testing/Validation

Objective data (data from non-CV sources or data from controlled experiments) on the performance of the application before the deployment are needed to evaluate a CV application in a deployment and properly interpret its evaluation results. Each CV environment is unique, and the performance of a certain application is likely to vary based on the environment in which it is deployed. Impacts of a deployed application are highly dependent on how well the application is working (e.g., true and false alert rates for a safety application). Without this context, interpreting the results of the impact analysis might not be possible.

System performance data:

- Rate of false system activations
- Rate of missed activations
- Frequency of different types of system errors

Ideally, the capability of a CV application should be carefully tested and validated before the deployment to characterize its performance and operational boundaries. In situations in which validation before deployment is not possible, collecting data to support application validation during the deployment so it can be measured in hindsight and factored into the impact evaluation results may be important.

Postdeployment

The second set of best practices deals with the postdeployment of CV technology at the deployment site, including the before and after data collection periods. These best practices pertain to tracking the interactions of CVs, application performance, and data collection and management.

Expected Versus Actual Connected-Vehicle Interactions

Once a deployment location, size, and recruitment strategy have been identified and a traffic simulation model has been used to estimate the CV interactions, tracking the actual vehicle-to-vehicle (V2V) and V2I interactions observed during the demonstration will be helpful. This exercise is helpful for validating the interaction model and ensuring that the expected number of interactions is being met. For a lower-than-expected CV application engagement, understanding the interactions that the site is generating helps identify the circumstances of the application outputs (e.g., are the CV applications just not activated, or are they not getting any opportunities to activate because interactions are lower than expected?).

Data about actual CV interactions experienced during the deployment can also be valuable to the evaluation. In a traditional deployment, some evaluation metrics are normalized by driving miles or time to indicate exposure to a certain stimulus (e.g., number of warnings per mile driven). In a CV deployment, overall driving miles are not relevant because the CV application is active only in the presence of other CVs or equipped infrastructure. As a result, the number of V2V or V2I interactions can serve as a surrogate measure for exposure to qualify the frequency with which an event occurs.

If interactions cannot be quantified and tracked in realtime during the deployment, it is suggested to calculate interactions post hoc so that this metric can be considered in the evaluation activities.

Monitoring Connected-Vehicle Applications in the Deployment

Once CVs are deployed, it is recommended to monitor these CVs to keep track of how frequently they have CV interactions and how often the applications are triggered. CVs with very few interactions or application activations (i.e., alerts from a safety application) relative to other CVs may have device or application health issues or may not be driving in the deployment area enough to generate sufficient data. Additionally, CVs receiving an unexpectedly large number of application activations relative to other CVs may have an issue with high false-activation rates. Monitoring and replacing problematic or low-interaction devices during the deployment can improve the evaluation results by ensuring that the largest possible number of usable data are collected for the evaluation.

Connected-Vehicle Application Logic

Once CVs are deployed—particularly if thorough performance validation testing and application tuning were not completed before the deployment—it may be tempting to adjust the applications to fix problems or reduce the frequency of false alerts. If one of the goals of the deployment is to conduct a rigorous evaluation, making changes once the official deployment period has started is not advisable, since doing so will compromise the integrity of the evaluation. One exception would be a situation involving any risk to driver safety; such cases must be addressed immediately. Another exception would be a quick fix to an application early in the deployment to avoid unnecessary effort to evaluate an application with unacceptable performance.

If it is likely that the team will want to adjust the applications after they have been deployed, the team should build a tuning period into the experimental design and mark the data from the different phases accordingly so that the evaluator can account for changes made to the system during the deployment.

Use of Other (i.e., Non-CV Application) Data

CVs generate a considerable number of data; however, the data generated by the application will likely not be sufficient to accommodate all the evaluation goals. Most likely, additional data collection (e.g., external sensors on either the vehicles or the roadway, as well as supporting data from external sources, such as weather data) will be required. The evaluation data being collected as part of the deployment should be determined in the predeployment planning phase by assessing the evaluation goals, objectives, and associated measures of performance and effectiveness rather than just relying on data that the CVs and their applications will produce.

Validating Performance of Connected-Vehicle Applications

It is necessary to the evaluation to have a full understanding of the performance of the CV applications in the actual deployed environment; that is, did the CV applications function per design intent? If thorough pilot tests and performance tests were not conducted before the start of the deployment, data to support an application accuracy analysis should be collected as part of the deployment. If the technology did not have the desired impacts, application performance data may help explain the lack of results.

Data Organization and Indexing

Data collected as part of the deployment should be organized and indexed in a way that suits the experimental design being used in the site evaluation. This organization may not be inherent in the standard CV data that the applications produce and therefore may need to be added or postprocessed. For example, as discussed in the section Tracking Vehicles Using Anonymous

IDs, including vehicle identifiers with the data helps the evaluators identify an individual driver or vehicle across different test periods. Additionally, all data should be indexed in a way that makes it easy to identify the data from different test groups that the evaluator is interested in (e.g., control–treatment, before–after, and equipped–unequipped).

Connected-Vehicle References

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Automated Vehicles
This section discusses additional considerations for evaluating projects that include AVs.[2] Automation can be used in a broad variety of applications and may be used to support a variety of transportation and societal goals. The considerations in the next section are thus quite broad; specific project objectives should inform the evaluation design. Projects focused primarily on testing the technical performance of an automation technology may differ significantly from those focused on user acceptance of automation or those in which the use of automation is ancillary to another objective (e.g., congestion reduction).

Technological Maturity
Automation technologies encompass both mature, production-advanced driver assistance systems and automated driving systems (ADSs), which range from early research and development to onroad testing. Deployers should have a clear understanding of the capabilities and limitations of the system to be used in the pilot and design the evaluation plan accordingly. For projects that include less mature technologies, considering scenarios in which the technology does not perform as intended may be helpful. How can the evaluation produce useful information for the sponsoring agency if the technology cannot perform key functions as originally envisioned?

Representativeness of Pilot System
Systems demonstrated in pilots may differ in critical aspects from those that would ultimately be deployed or commercialized. For example, the base vehicle may differ in important ways from a permanent system (e.g., size, operating speeds, capacity, fit, and finish), or a system intended to be unstaffed in a permanent operation may be staffed with an onboard attendant or safety driver during a pilot. The service area or route may also be different from what would be expected for a mature system (e.g., parking lots, dedicated tracks, or low-speed, low-traffic roads rather than high-speed, high-traffic, complex environments). These differences should be considered in the design of technical performance and user acceptance metrics.

Is the technical performance of a prototype technology relevant for future investment decisions? In some cases, it may not be necessary to do an indepth analysis of specific metrics, such as emissions or reliability, if the results cannot be used meaningfully to support future decisions. For example, if the pilot uses a production passenger van that has been upfit with automation technology but the future vision requires a battery electric bus, a detailed analysis of emissions may not be meaningful for the project's objective.

Rapidly Evolving Technologies
Automation technologies are rapidly evolving. Many systems deployed in a pilot test or demonstration are being continuously refined and updated, such that their fundamental capabilities could significantly differ by project conclusion. This situation is intensified for a project with a long lead time or planning stage. For public-sector projects that use grant funding, it can easily be 2 or 3 years from the time the application is submitted to the time a deployer is able to start conducting any physical testing. This additional time can be challenging to account for in planning an evaluation. If the technology is not held constant or "frozen" during the course

[2]This section discusses projects that include at least one SAE International (SAE) Level 1 or higher application. See SAE Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles J3016_201806, https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic.

of the project, understanding the meaning of results over time might be difficult. Are changes in desired metrics due to increasing user acclimation to the technology, for example, or due to changes in the technology itself?

For most technology demonstrations, the vendor is required to "freeze" the technology for the duration of the demonstration; however, for technologies such as AV, freezing the technology may not always be desirable. First, there could be safety implications. As ADS developers learn more about the performance of the hardware or software in real-world settings, they are constantly making improvements to support safe operations. Failure to incorporate these improvements could lead to unsafe operations. Second, given the rapid pace of change in this industry, evaluation results that are based on a previous generation of automation technology may be somewhat less valuable for knowledge sharing with other potential deployers. The evaluation team will need to consider these factors against the need for reliable evaluation data.

Human Factors and User Acceptance

Automation is very new to most host communities and users. Strong favorability ratings or, conversely, concerns may be heavily affected by the novelty of the technology and not merely its performance. Potential users may be unable to forecast accurately the extent to which they would use a system that is still immature and wholly novel to them. Some efforts have been made to understand the relationship between usage intention to actual future use, but this is an area where further research is needed. Questions about willingness to ride a hypothetical future service should be carefully framed, especially if the pilot differs in any meaningful way from the service described.

Many applications are intended for eventual operation without a driver or operator on board the vehicle. However, due to both current technological limitations and State or local requirements, most demonstrations today are still staffed by a driver or attendant. The presence of a human staffer on board, even if the staffer is not actively driving the vehicle, is likely to significantly influence perceptions by those who interact with the vehicle and the system. The staffer's very presence can create a sense of security, and even brief personal interactions can affect overall impressions. While there have been creative approaches to address this problem, it is difficult overall to mimic the experience of an unstaffed system while still having a staff person on board.[3] Evaluation design should take this into consideration.

Identifying relevant human factors metrics will depend on the project objective. For projects with AV systems at SAE International (SAE) Levels 1–3, when driver supervision is required for some part of the driving task, the evaluation may include metrics related to the human driver's interaction with the automation, such as driver disengagement, fatigue, or mode confusion. Level 3 systems (and Level 4 systems moving in and out of their operational design domain (ODD)) may also include driver reengagement. Human factors evaluation of projects at SAE Levels 4 and 5 may focus on user acceptance, wherein the user could be defined as the passenger or relevant agency staffer (maintenance worker, control center staffer, etc.). Other human factors metrics that may be relevant include the evaluation of the human–machine interface and usability for passengers with mobility, sensory, or cognitive impairments.

[3]For example, some shuttle pilots have had an incognito attendant pose as a fellow passenger.

Institutional Issues and Internal Capacity Building

The transportation industry is at an early stage regarding the adoption of automation. Very few public-sector agencies have any experience with these technologies. A benefit of early engagement with new technology is the ability of an organization to identify institutional issues and build organizational capacity.

Federal, State, and local requirements may not be clearly understood at the project outset—particularly if they involve applying existing policies to new automation scenarios—or may change during the project. Even for locations with clear, AV-specific requirements in place, there are many unknowns. Procurement processes or labor issues could delay or even prevent projects. Identifying these issues by implementing a demonstration can help an organization determine local policy positions and appropriate mitigations to achieve goals.

Similarly, some agency staff might have a learning curve in understanding what these technologies can and cannot do today and what they might do in the future. Agencies may need to change their operations and maintenance models due to automation and may need to define new ways of partnering with the private sector, as there are many new entrants to the transportation industry, and accepted norms may no longer apply.

If the deployment's goals include identifying institutional issues and internal capacity building, the evaluation design should consider how to meaningfully incorporate these elements.

Confounding Factors

Demonstrations and pilots often introduce multiple new features, services, and operational conditions simultaneously. Clearly distinguishing between impacts related to the use of driving automation and other aspects of the project can be critical for a successful evaluation.

Identifying Critical Stakeholders

Stakeholders should be identified early to inform the evaluation design. Introducing automation into motor vehicles may change the dynamic between existing stakeholders and could highlight the need to engage more closely with certain groups. For example, given the role of States in licensing drivers, departments of motor vehicles have begun to engage with their State DOT counterparts in new ways, as States question what it means for the ADS to be the vehicle operator. Automation is often coupled with other new mobility technologies such as application-based reservations and electronic fare payment. A passenger system may be intended to improve mobility, but some populations may have digital, banking, or accessibility barriers, particularly for service concepts that are unstaffed.

Relationships With Private-Sector Partners

Automation research, development, and commercialization are extremely competitive industries. Transportation agencies may find that their relationships with private-sector partners are somewhat different from those with traditional transportation applications. The sector is also very fluid, with new companies forming and dissolving quickly and key staff moving between companies relatively frequently.

Private-sector partners may have serious concerns about sharing or publicizing information that would be included in a standard government-sponsored evaluation, such as information about system performance and user acceptance. This concern can extend to the choice of metrics and survey design. Some firms may also be unfamiliar with the details of industry reporting standards, such as National Transit Database definitions. It is therefore critical to define evaluation requirements and the necessary data clearly in the earliest stages of planning.

Negotiation over the characterization of performance and user experience may also be required. To assess desired metrics, data access is critical. Some vehicle and system data may be wholly within the control of the private-sector partner in the absence of other contractual arrangements. Others can be measured externally—for example, by the use of infrastructure-based cameras. The evaluation plan should consider the next-best alternatives if the desired data cannot be obtained.

Data Analysis and Management

The quantity of data collected by an AV is generally enormous.[4] Project teams could be easily overwhelmed by available data in terms of both data storage and analysis, and even data transfer may exceed available bandwidth. While it is generally helpful to identify core data elements early on and disregard superfluous data, during the course of the evaluation, new areas of interest may come to light. Each deployment team will need to consider the preferred balance between manageability and the ability to explore previously unidentified questions.

To aid evaluation, deployers should have a clear plan for which data elements will automatically be logged by the on-vehicle technology versus what will need to be collected manually. Since these systems will be running for an extended period, identifying triggers for capturing data may be valuable. For example, an unplanned intervention by a safety driver could be a trigger to capture safety-relevant data from an ADS. Similarly, the data plan should address the potential need for the installation of an onboard or infrastructure-based camera, a data acquisition system, etc., and consider the appropriate balance between more and less frequent data updates.

Evaluators should consider that the types of data that are useful for assessing the automation technology will generally differ from those used to assess the service more holistically. For example, passenger boardings by stop may be a key metric for the overall performance of a transit pilot that uses automation, but this information would be only contextual data for an evaluation that is focused on the technical performance of the technology.

Infrastructure

Deployers may be interested in studying the interaction between AVs and roadway infrastructure. Automation technologies being developed today generally do not rely on infrastructure elements for operation, but there are a few notable exceptions. For example, some systems include V2I elements such as signal-phase-and-timing data to facilitate intersection movements and turning. The evaluation of these elements would be similar to other V2I evaluations but could expand to observing the performance of the AV in making left-hand turns.

When developing ADS, it is recommended to consider the need to maintain roadways and land markings in good condition. Some projects may wish to include pavement conditions as part of the data collected. Less mature ADSs may require the addition of infrastructure elements (e.g., bollards) to assist in localization or be challenged by changes to the environment, such as the

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[4]However, some vehicle systems, such as event data recorders (EDRs), store only limited data and may be event driven, so if more extensive data are needed, additional data acquisition systems may be needed.

appearance of snowbanks after a storm. Understanding the capabilities of the system being tested will help deployers identify appropriate baseline data and metrics. The next section lists key types of data to consider, including an evaluation of a project involving AVs; some data may not be applicable, depending on the applications deployed.

Operational Design Domain

- Describe the specific conditions under which an ADS or feature is intended to function.
- Identify roadway and roadside features important for operations within the ODD.
- Describe the data that will be used to verify whether the AV is properly operating within its ODD.
- Describe metrics and indicators that quantify the level of safety within the ODD.

Vehicle Operational Data

- Identify data that will be collected in crash, near-miss, malfunction, and degradation situations (e.g., LiDAR, radar, EDR, or some other type of data acquisition system).
- Identify what data are collected and whether the information is documented when crash mitigation technologies are triggered.
- Describe the information to be collected in circumstances in which the AV goes back to the minimal risk condition or fallback situation. Describe how disengagement events will be recorded and stored and distinguish between planned and unplanned disengagements. Describe how the instruments used for data collection onboard the vehicle will be documented and maintained over time (i.e., AV maintenance, sensor calibrations, and equipment check documentation).
- Describe which curbside or infrastructure elements will be recorded and documented at the locations where pickups and dropoffs will occur.
- Describe fuel efficiency, power draw related to onboard computing, or battery performance data of interest and how they will be collected and shared.

Data Processing

- Describe how any AV sensor data will be processed.
- Describe how the AV software updates will be documented and the data output for that information.
- Describe the data output of the simulation, test track, or on-road test or all of them that will affirm the effectiveness of the solution(s) to respond to the research questions.

Perceived Safety

- Describe the process for collecting data on the experience of those who interact with the AVs.
- Describe the process for collecting data on the cybersecurity and privacy concerns of those who interact with the AVs.

AV References

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APPENDIX A: EVALUATION PLAN TEMPLATE

The purpose of this template is to assist grantees in developing their evaluation plans for the Advanced Transportation Technologies and Innovative Mobility Deployment program, also known as the Advanced Transportation Technology and Innovation (ATTAIN) program. The contents of this template do not have the force and effect of law and are not meant to bind the public in any way.

This template is a tool for summarizing key evaluation-related information at a high level. Evaluation plans should address all of the questions provided in this template, but this document should not be completed as a form. Grantees are expected to produce a formatted report.

For additional guidance, please see the Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) program's *Evaluation Methods and Techniques* document at https://ops.fhwa.dot.gov/publications/fhwahop19053/fhwahop19053.pdf.

If you have any questions about this template, please contact Margaret Petrella, social scientist, at the Volpe National Transportation Systems Center, at margaret.petrella@dot.gov.

This template has six parts:

- Part 1 of 6: Introduction and Project Overview.
- Part 2 of 6: Project Goals, Objectives, and Evaluation Questions.
- Part 3 of 6: Performance Measures.
- Part 4 of 6: Evaluation Methodology.
- Part 5 of 6: Data Collection Procedures and Data Management.
- Part 6 of 6: Wrap-Up.

SAMPLE

PART 1 of 6: INTRODUCTION AND PROJECT OVERVIEW

The title page and/or introduction should include:

- Project Title
- Grant Award Recipient
- Fiscal Year of the Award as Stated in the Award Agreement
- Organization(s) Preparing the Evaluation Plan

1. Provide a description of your current project, including:

    - The technologies being deployed
    - The geographic area[1]
    - The intended beneficiaries
    - What constitutes end-of-project successes
    - Any other information that may be relevant

2. Briefly describe the purpose of this project. What need or problem was identified, and why were the deployments in this project selected to provide the solution? Does the project have unique challenges? Were other strategies considered? Is a historical context relevant to this project? Are there related projects?

3. Summarize the project evaluation process and include a list of the project stakeholders (project team, collaborators, evaluation team) and their roles and responsibilities, particularly with respect to data collection and completion of the evaluation. In addition, provide a deployment and evaluation schedule in terms of months and years, with project milestones.

    Schedule elements should include but are not limited to:

    - Data collection for the baseline; and
    - Piloting or testing; and
    - Project deployment; and
    - Data collection following deployment; and
    - Analysis and reporting

[1]Maps, diagrams, and photos are helpful.

PART 2 of 6: PROJECT GOALS, OBJECTIVES, AND EVALUATION QUESTIONS

1. Provide a description of the relevant use case(s) for your current project.[2] Each use case should describe:

   - The expected location and scope of the deployment (e.g., intersection, corridor, and regional); and
   - A list of the relevant technologies for each use case; and
   - A description of how individuals will interact with a technology or group of technologies (i.e., the affected individuals) to achieve a specific goal or set of goals

Example Use Case
Use case 1 deploys integrated corridor management strategies on State Route Alpha from milepost 1 to milepost 2 to reroute drivers following an incident and improve travel time during peak congestion so as to improve safety and reduce travel times, respectively. The two key technologies being deployed are intersection movement count technology to adjust traffic signal timing in realtime and traffic signal priority technology for local buses, with the goal of improving TTR.

2. Based on the aforementioned use cases, is any historical data currently available that could be used to inform project goals, performance measures, or performance targets? Provide a high-level summary of the data and how those data have informed the evaluation plan.

[2]Visual aids such as diagrams or photos are helpful.

SAMPLE

3. Complete the following table regarding current project goal areas, objectives, and evaluation questions. If your project has multiple use cases, complete this table separately for each use case.

   For each goal area that is applicable to the project use case, provide a list of the specific objectives and related evaluation questions. The objective should clearly indicate the expected direction of change or level (e.g., reduce travel speeds or achieve a minimum of 85-percent detection rate). Develop at least one evaluation question for each objective; multiple specific evaluation questions are better than a few general ones.
   Project goals should be connected to the goals stated in Section 13006 of the Infrastructure Investment and Jobs Act (IIJA) (Pub. L. No. 117-58, also known as the "Bipartisan Infrastructure Law" (BIL)). The list of goals is provided at the end of this document. Output-based goals may be used to supplement outcome-based goals, but they generally address technical performance or intermediate targets that serve as indicators for outcomes.

SAMPLE

Use Case 1: _________

Goal Area	Objectives	Evaluation Questions
Example row: Improved mobility	Improve travel time reliability in the corridor during different operational scenarios (e.g., peak hours and incidents)	To what extent has travel time reliability improved in the integrated corridor management corridor during different operational scenarios?
Improved safety		
Improved mobility		
Reduced environmental impacts		
Effectiveness of realtime transportation information		
Improved access to transportation alternatives		
Reduced costs		
Economic benefits		
Improved network performance		
Other goals (Please specify):		

SAMPLE

PART 3 of 6: PERFORMANCE MEASURES

1. For each evaluation question provided previously, organized by use case, list one or more performance measures.[1] Ensure measures are sufficiently detailed. This organization should link the performance measures to current project goals.
   When selecting performance measures, consider the unit of analysis (metric) needed for your analysis. For projects that aim to affect user experience, consider supplementing quantitative metrics with survey data. For metrics that depend on the level of exposure, such as crashes, consider using rates rather than frequencies.

Example
Use Case 1: Integrated Corridor Management (ICM)

Goal	Evaluation Questions	Performance Measures
Effectiveness of real-time transportation information	What proportion of drivers rated the routing information as helpful?	• The proportion of drivers who rated the routing information as helpful
Improved mobility	Did ICM deployment improve travel time reliability through the corridor?	• Average travel time through the corridor • Average peak travel time through the corridor • Average travel time through the corridor between an incident and an hour after the incident has been cleared
Improved mobility	Did technology service providers' technologies on the corridor improve bus travel times?	• Travel time of buses traveling in the corridor

2. Have performance targets been set for any of the performance measures? If so, list the targets by measure and briefly describe how the target was developed.

[1]For additional information on performance measures, please see the ATCMTD *Evaluation Methods and Techniques* document at https://ops.fhwa.dot.gov/publications/fhwahop19053/fhwahop19053.pdf.

SAMPLE

PART 4 of 6: EVALUATION METHODOLOGY

1. Describe the method(s) the current project will use to address each evaluation question (likely a mix of quantitative and qualitative methods), and if your project includes multiple use cases or technologies, be clear about how each will be evaluated if methods differ. List project data sources and key modeling tools (if relevant) for each performance measure. Ensure the evaluation design enables the measurement of the proposed performance measures (i.e., the specific data elements that are required).
   The description should include the experimental design, as appropriate (e.g., before-and-after and treatment-and-control).[42] For a time series, the description should include how many observations will compose your comparison groups. (Will the baseline and postdeployment periods include data points from multiple years or quarters?) If relevant, discuss the control group or untreated comparison corridor.

   Describe any potential confounding factors, limitations, or risks associated with the method or the data elements. Include strategies to mitigate these concerns.

Example:
Use Case 1: Integrated Corridor Management (ICM)

Evaluation Questions	Performance Measures	Source or Method	Experimental Design	Limitations or Constraints
To what extent has the ICM deployment reduced traffic crash rates at intersections through the project corridor?	Traffic crash rates at intersections through the project corridor	Public safety data on crashes	A comparison of 2 years of baseline data with one year of postdeployment data	A low crash rate in the baseline, before deployment, would make a reduction in crash rates difficult to measure

2. Describe all assumptions made in the evaluation. If any of the analyses in the evaluation rely heavily on assumptions, do sensitivity tests exist that could be conducted to bolster results?
3. Will the evaluation address equity? If so, describe the methodology.

[42] A treatment-and-control design would compare the performance of the project corridor with a similar but unaffected corridor.

SAMPLE

PART 5 of 6: DATA COLLECTION PROCEDURES AND DATA MANAGEMENT

1. Describe how the data will be collected for the baseline and following deployment, including any plans for a pilot.
   Summarize plans for data management (e.g., data logging and transmission to the evaluation team if applicable; data storage; data access and privacy protection; data fusion if applicable; and data quality checks). Note, for existing systems, less detail may be needed.

   For surveys, the description should include the general method of recruitment, the sample size, and potential survey topics. For field studies, the description should include the location, data collection frequency, and data collection period.

2. Provide a brief overview of how, throughout the duration of the project, the project team will collect challenges, lessons learned, and suggestions for future deployers.

SAMPLE

PART 6 of 6: WRAP-UP

Do you expect to update this evaluation plan? At what point in the project timeline do you expect to be able to revise this evaluation plan?

1. Provide a table with any relevant technical terms or abbreviations and their definitions.

Goals Derived from the Selection Criteria and Reporting Requirements in the BIL

Outcome-related goals:

- **Improved safety**: Reduction in the number and severity of traffic crashes and an increase in driver, passenger, and pedestrian safety
- **Improved mobility**: Improve the mobility of people and goods (e.g., congestion, travel time reliability)
- **Reduced environmental impacts**: Protect the environment and deliver environmental benefits that alleviate congestion and streamline traffic flow (e.g., emissions, fuel use)
- **Effectiveness of realtime transportation information**: Collect, disseminate, and use real-time traffic, work zone, weather, transit, paratransit, parking, and other transportation-related information to improve mobility, reduce congestion, and provide for more efficient, accessible, and integrated transportation and transportation services
- **Improved access to transportation alternatives**
- **Reduced costs**: Reduce costs and improve return on investments, including through optimization of existing transportation capacity
- **Economic benefits**: Deliver economic benefits by reducing delays, improving system performance, and providing for the efficient and reliable movement of goods and services

Output-based goals:

- **Improved network performance**: Measure and improve the operational performance of the applicable transportation network (including optimized multimodal system performance)
- **Extended asset life**: Improve the durability and extend the life of transportation infrastructure
- **Enhanced monitoring of assets**: Monitor transportation assets to improve infrastructure management, reduce maintenance costs, prioritize investment decisions, and ensure a state of good repair
- **Incentivized travelers to share or shift trips**: Incentivize travelers to share trips during periods in which travel demand exceeds system capacity; or to shift trips to periods in which travel demand does not exceed system capacity

Other goals stated in BIL:

- **Facilitated account-based payments**: Facilitate account-based payments for transportation access and services and integrate payment systems across modes
- **Accelerated the deployment of connected- and autonomous-vehicle technologies**: Accelerate the deployment of vehicle-to-vehicle, vehicle-to-infrastructure, vehicle-to-pedestrian, autonomous vehicles, and other technologies

APPENDIX B: ANNUAL REPORT TEMPLATE

The purpose of this template is to assist grantees in preparing uniform Annual Reports for the Advanced Transportation Technologies and Innovative Mobility Deployment program, also known as the Advanced Transportation Technology and Innovation (ATTAIN) program. This template, while not required, is highly recommended, as the Federal Highway Administration intends to use the information from the grantees' Annual Reports to prepare the required Program Level Reports on the effectiveness of the grant recipients in meeting their projected deployment plans.

Reporting Requirement

23 U.S.C. 503(c)(4)(F) says, "For each eligible entity that receives a grant under this paragraph, not later than one year after the entity receives the grant, and each year thereafter, the entity shall submit a report to the Secretary that describes—

i. deployment and operational costs of the project compared to the benefits and savings the project provides; and
ii. how the project has met the original expectations projected in the deployment plan submitted with the application, such as—
    I. data on how the project has helped reduce traffic crashes, congestion, costs, and other benefits of the deployed systems;
    II. data on the effect of measuring and improving transportation system performance through the deployment of advanced technologies;
    III. the effectiveness of providing real-time integrated traffic, transit, and multimodal transportation information to the public to make informed travel decisions; and
    IV. lessons learned and recommendations for future deployment strategies to optimize transportation mobility, efficiency, multimodal system performance, and payment system performance."

As data collection nears completion, please consult your evaluation plan and the final report template for guidance on summarizing the evaluation.

This template has three parts:

- Part 1 of 3: Introduction and Overview
- Part 2 of 3: Evaluation/Research Activities and Findings
- Part 3 of 3: Wrap-up

SAMPLE

PART 1 of 3: INTRODUCTION AND OVERVIEW

Project Title:
Grant Award Recipient:
Annual Report Period *[insert date range]*:
Prepared by *[name, agency, and title]*:

Note: Responses to questions 1–7 should reflect the **current** project scope and goals. If there have been no changes in project scope or goals since the previous Annual Report, responses to questions 1–7 should be the same as in the previous Annual Report. Responses to questions 8 and 9 should be updated with each Annual Report.

1. **Please provide a *high-level* description of your current project, including intended beneficiaries.** *(Please limit to approximately 350 words or less.)*

2. **Please note any prior approved deviations (provide date approved) or changes in scope from the original proposal. These may include changes due to project-driven outcomes or unforeseen performance challenges such as unforeseen legal or administrative constraints, difficulty obtaining necessary resources or support, or executive decisions to alter course.**

3. **Do you consider any aspects of your project cutting-edge, noteworthy, or innovative? If yes, please describe**.

SAMPLE

4. **Please indicate which ATTAIN-targeted technologies your project covers, and briefly describe the technologies in a few sentences.** *(Check all that apply and briefly describe.)*

☐ Advanced traveler information systems (e.g., real-time information)

Please describe:

☐ Advanced transportation management technologies

Please describe:

☐ Advanced transportation technologies to improve emergency evacuation and response by Federal, State, and local authorities

Please describe:

☐ Infrastructure maintenance, monitoring, and condition assessment

Please describe:

☐ Advanced public transportation systems

Please describe:

☐ Transportation system performance monitoring, data collection, analysis, and dissemination (e.g., artificial intelligence, machine learning, advanced analytics)

Please describe:

☐ Advanced safety systems—including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian communication—and associated technologies that would enable V2V or V2I communication, including cellular or other technology

Please describe:

☐ Advanced safety systems, including autonomous vehicle development or deployment

Please describe:

☐ Integration of intelligent transportation systems using smart grid or similar energy distribution and charging systems

Please describe:

☐ Electronic pricing, toll collection, and payment systems

Please describe:

[List continues on next page.]

4. **Please indicate which ATTAIN-targeted technologies your project covers, and briefly describe the technologies in a few sentences.** *(Check all that apply and briefly describe.)* **(continuation)**

SAMPLE

☐ Integrated corridor management systems

Please describe:

☐ Advanced parking reservation or variable-pricing systems

Please describe:

☐ Technology that enhances high-occupancy-vehicle toll lanes, cordon pricing, or congestion pricing

Please describe:

☐ Integration of transportation service payment systems

Please describe:

☐ Advanced mobility, access, and on-demand transportation service technologies such as dynamic ride-sharing and other shared-use mobility applications and information systems to support human services for older people, people with disabilities, or disenfranchised individuals

Please describe:

☐ Retrofitting dedicated short-range communications technology deployed as part of an existing pilot program to cellular vehicle-to-everything technology, subject to the condition that the retrofitted technology operate only within the existing spectrum allocations for connected vehicle systems

Please describe:

☐ Other: ____

Please describe:

SAMPLE

5. Please provide a high-level description of the relevant use case(s) for your project. Each use case may include one or more technologies that are designed to solve the same problem (or set of problems). The use case description should include the relevant technologies being deployed, the goals of the deployment, and how the goals will be achieved. In addition, the population who will be affected by the technologies (or group of technologies) should be described (e.g., pedestrians, bicyclists, and commercial vehicle drivers). Please describe as many use cases as relevant.

Example Use Case: **Integrated Corridor Management (ICM)**
In the ICM use case, ICM strategies are being deployed to reroute drivers following an incident, with the goal of reducing travel times and improving safety. Improved traveler information will be provided to drivers on the highway, informing them of incidents and providing information on alternate routes. Two key technologies are being deployed on the arterial in the corridor to improve capacity: intersection movement count technology to adjust traffic signal timing in realtime and traffic signal priority technology for local buses. Rerouting drivers following an incident will divert traffic from locations with higher risks of secondary crashes and thus improve safety. Expanding capacity on the arterial in the corridor through improved signal timing and signal priority for buses will relieve congestion and improve travel time reliability both during peak periods generally and following an incident.

Use Case 1. *[insert name]*

Use Case 2. *[insert name]*

Etc. (Add more Use Cases, if applicable)

SAMPLE

6. What are your project's goals? (*Check all that apply.)*
Note: For each goal identified, you will be asked in part 2 of 3 to map your project's performance measures and findings to date.

Outcome-Related Goals

☐ Improved safety
☐ Improved mobility
☐ Reduced environmental impacts
☐ Effectiveness of realtime transportation information
☐ Reduced costs
☐ Improved access to transportation alternatives
☐ Economic benefits
☐ Other goals and benefits (Please describe): ____

Output-Based Goals

☐ Improved network performance (optimized multimodal system performance)
☐ Extended asset life
☐ Enhanced monitoring of assets
☐ Incentivized travelers to share or shift trips
☐ Other goals and benefits (Please describe): ____

Other Goals Stated in the Bipartisan Infrastructure Law

☐ Facilitated account-based payments
☐ Accelerated the deployment of connected and autonomous vehicle technologies

7. Please indicate which service models or modes your project(s) is(are) designed to address. *(Check all that apply.)*

☐ Passenger vehicle
☐ Pedestrian or bicycle
☐ Transit
☐ Freight
☐ Mobility on demand
☐ Other (Please describe): __________________

SAMPLE

8. **Have any of the answers to questions 1–7 changed since the previous Annual Report?**

☐ Yes
☐ No
☐ This is the first Annual Report.

9. **What is the current status of your project, and what activities are you currently engaged in?** *(For each use case, check all that apply.)*
Note: If your project has multiple use cases or technologies that are at different stages, list the key use cases in the first column, and check the boxes for each column accordingly. Add more rows as necessary.

Key Project Use Cases	**Project Status/Activities**
Use Case 1: *[insert name]*	☐ Planning/Design ☐ Concept of Operations Development ☐ Technology/Equipment Procurement ☐ Baseline Data Collection or Analysis ☐ Piloting/Testing/Partial Deployment ☐ Installation/Implementation for Full Deployment ☐ Completed Deployment ☐ Evaluation (Postdeployment Data Collection or Analysis) ☐ Project Completed in Full
Use Case 2: *[insert name]*	☐ Planning/Design ☐ Concept of Operations Development ☐ Technology/Equipment Procurement ☐ Baseline Data Collection or Analysis ☐ Piloting/Testing/Partial Deployment ☐ Installation/Implementation for Full Deployment ☐ Completed Deployment

SAMPLE

	☐ Evaluation (Postdeployment Data Collection or Analysis) ☐ Project Completed in Full
Use Case 3: *[insert name]*	☐ Planning/Design ☐ Concept of Operations Development ☐ Technology/Equipment Procurement ☐ Baseline Data Collection or Analysis ☐ Piloting/Testing/Partial Deployment ☐ Installation/Implementation for Full Deployment ☐ Completed Deployment ☐ Evaluation (Postdeployment Data Collection or Analysis) ☐ Project Completed in Full

Note: Please add new rows for additional use cases as needed.

SAMPLE

PART 2 of 3: EVALUATION/RESEARCH ACTIVITIES AND FINDINGS

1. **Please complete the following table regarding your evaluation activities. For each goal area that is applicable to your project—and for each use case that addresses each goal—provide a list of the performance measures and a status update on your research activities. The update should include the status of baseline data collection, if applicable, and any challenges or data limitations. If performance measurement is complete, please briefly describe the findings.**

Goal Area	Performance Measures: Quantitative and Qualitative	Research Update (e.g., baseline data collection, challenges, milestones achieved, and findings including data that support any findings)
Example row: Improved safety	Use Case: **CV/Pedestrian Mobile App** 1. Rate of pedestrian/bicycle crashes 2. Rate of near-miss pedestrian/bicycle crashes 3. Satisfaction rating from a user survey Use Case: **V2I Curve Speed Warning System** 1. Change in speed before/after the warning activated 2. Rate at which the warning was perceived as helpful from the driver survey	Baseline data collection is underway – we are acquiring crash data and analyzing video data for near misses. The App is being tested and refined. We anticipate the start of the evaluation in approximately 5 to 6 months.
Improved safety	Use Case: *[insert name]* 1. 2. 3. Use Case: *[insert name]* 1. 2. 3. Etc.	
[List continues on next page.]		
Improved mobility	Use Case: *[insert name]* 1. 2.	

SAMPLE

Goal Area	Performance Measures: Quantitative and Qualitative	Research Update (e.g., baseline data collection, challenges, milestones achieved, and findings including data that support any findings)
	3. Etc.	
Reduced environmental impacts	Use Case: *[insert name]* 1. 2. 3. Etc.	
Effectiveness of realtime transportation information	Use Case: *[insert name]* 1. 2. 3. Etc.	
Improved access to transportation alternatives	Use Case: *[insert name]* 1. 2. 3. Etc.	
Reduced costs	Use Case: *[insert name]* 1. 2. 3. Etc.	
[List continues on next page.]		
Economic benefits	Use Case: *[insert name]* 1. 2. 3. Etc.	

SAMPLE

Goal Area	Performance Measures: Quantitative and Qualitative	Research Update (e.g., baseline data collection, challenges, milestones achieved, and findings including data that support any findings)
Improved network performance	Use Case: *[insert name]* 1. 2. 3. Etc.	
Other goals (Please describe):	Use case: *[insert name]* 1. 2. 3. Etc.	
Other goals (Please describe):	Use case: *[insert name]* 1. 2. 3. Etc.	
Other goals *[ADD IF NEEDED]* (Please describe):	Use case: *[insert name]* 1. 2. 3. Etc.	

SAMPLE

PART 3 of 3: WRAP-UP

1. **In your view, how is the project doing with respect to meeting original expectations (i.e., as stated in the project proposal)?**
2. **How do deployment and operational costs of the project compare with the benefits and savings the project provides; that is, can you provide an objective benefit-cost analysis or alternative subjective comparison?**
3. **Challenges may arise throughout the project development, deployment, and operational phases. Grantees have faced challenges related to procurement, stakeholder coordination, regulatory requirements, technology, and evaluation, among others.** **Please complete the following table regarding challenges and lessons learned from your deployment since your previous Annual Report. To the best of your ability, provide a description of specific challenges, lessons learned from the experience, and recommendations, if any, for future deployers. The lessons learned should include recommendations for future deployment strategies to optimize transportation mobility, efficiency, multimodal system performance, and payment system performance.** *(Add more rows as necessary.)*

SAMPLE

The challenges listed in the following table should be limited to those faced in the past year—whether new, continuing, or recurring.

Challenge	Description of the Challenge	Lessons Learned from the Challenge and/or Recommendations for Future Deployers	
Example row	The procurement process has taken longer than initially anticipated	The request for proposal and equipment procurement process can lead to project delays. Try to reduce the total number of contracts issued, and include a system integration team as early as possible in the process.	
a.			
b.			
c.			

4. Do you have other recommendations that are not related to challenges?
5. Do you have any final comments or feedback?

APPENDIX C: FINAL REPORT TEMPLATE

The contents of this template do not have the force and effect of law and are not meant to bind the States or the public in any way. This template is intended only to provide a high-level guide for what ATTAIN grantees should include in their Final Reports based on existing requirements under the law or agency policies. All reporting requirements for each ATTAIN funding recipient are established separately in each ATTAIN grant award agreement. If you have any questions about your reporting requirements, please contact the agreement officer. If you have questions about the content of this template, please contact Margaret Petrella (margaret.petrella@dot.gov), U.S. Department of Transportation (DOT), Volpe Center.

1. Project Summary

- Description of the project, including the technologies being deployed; these technologies may be organized as "use cases" if that provides a helpful framework:
  - Include project location(s) and initial (baseline) conditions the project is trying to address, providing context for the purpose of the project.
- Project Scope
  - Describe any changes in scope from the original award, highlighting any key goal areas or performance measures that were no longer being addressed as a result of the change in scope.
- Project Timeline

2. Performance Metrics, Evaluation Methods, and Data Sources

- Description of project goals the project covers that align with Section 13006 of the Infrastructure Investment and Jobs Act (IIJA) (Pub. L. No. 117-58, also known as the "Bipartisan Infrastructure Law" (BIL)) including *(NOTE: this description should focus on goals that were measured in the evaluation)*:
  - Improved safety
  - Reduced congestion and/or improved mobility (e.g., travel time reliability)
  - Reduced environmental impacts (e.g., emissions or energy)
  - Improved system performance or optimized multimodal system performance
  - Enhanced access to transportation options
  - Effectiveness of providing integrated real-time transportation information to the public to make informed travel decisions
  - Reduced costs
  - Institutional or administrative benefits (e.g., increased inter-agency coordination)
  - Other benefits
- This section should include a brief description of how the deployed technologies were expected to meet their stated goals.
- Description of performance metrics that shows how they are aligned with project goals (described in Section 13006 of the IIJA (BIL) and evaluation questions/hypotheses (include performance measure targets, if applicable). *Please note this list is not exhaustive, and grantees may use other performance metrics tailored to their projects:*
  - Reduced traffic-related fatalities and injuries
  - Reduced traffic congestion and improved travel time reliability
  - Reduced transportation-related emissions
  - Optimized multimodal system performance
  - Improved access to transportation alternatives

- Provided the public with access to real-time integrated traffic, transit, and multimodal transportation information to make informed travel decisions
  - Provided cost savings to transportation agencies, businesses, and the traveling public
  - Provided other benefits to transportation users and the general public
- Evaluation design and method(s) that are being used to address each performance measure:
  - Data sources
  - Data collection time period
  - Any challenges with data sources or data collection that may have impacted the evaluation (alternatively, these challenges could be discussed in Section 3 with Evaluation findings)
- For example, if surveys are used, include information on the target population, how they were sampled or recruited, how the survey was administered, the response rate, and the types of questions that were asked (include the questionnaire in an appendix).

Note: Grantees can use a table to summarize this information. See table 1 in the appendix for an example. The table should be accompanied by text that provides more details.

3. Evaluation Results

- Detailed evaluation results (quantitative and qualitative) organized by goal area or use cases:
  - Describe any data limitations, including external factors that may have impacted the evaluation findings

4. Lessons Learned, Recommendations, and Conclusions

- Key Takeaways, including:
  - The overall effectiveness of the grantee in meeting their deployment plans
  - Deployment and operational costs of the project compared to the benefits and savings the project provides
- Project lessons learned
- Recommendations for future deployers regarding strategies to optimize transportation efficiency and multimodal system performance

Appendix

Table 1 provides an example of the type of information that grantees may want to summarize using a table format. A more detailed write-up should accompany any tables.

Table 1: Performance Measurement Summary Table

Goal Area	Performance Measure	Data Method	Data Source	Data Collection Time Period	Sample Size (if applicable)
Safety	Percent of respondents who feel safety warning was helpful	Survey	Survey response in post-survey	3 months postdeployment	N=288
Safety	Number of fatalities	Quantitative data comparison	Fatality Analysis Reporting System (FARS) data	1 year of baseline data and 1 year of postdeployment data	
Reduced congestion and/or improved mobility	Percent change in average travel times	Field test (vehicle probe data)	Pre-post comparison of vehicle probe data	1 year of baseline data and 1 year of postdeployment data	
Reduced environmental impacts	Reduction in GHG emissions	Environmental modeling	Environmental model emission estimates	1 year of baseline data and 1 year of postdeployment data	
Cost savings and return on investment	Net present value	Benefit-cost analysis	Monetized estimates of project impacts	1 year of baseline data and 1 year of postdeployment data	
[ADD]	[ADD]	[ADD]	[ADD]	[ADD]	

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