Evaluation Methods and Techniques

Advanced Transportation and Congestion Management Technologies Deployment Program

December 2019

U.S. Department of Transportation
Federal Highway Administration

Foreword

The Federal Highway Administration (FHWA) Office of Operations is pleased to present this Evaluation Methods and Techniques in support of the Advanced Transportation Congestion Management Technologies Deployment (ATCMTD) Program. ATCMTD grant recipients must report the benefits (e.g., safety, mobility, environmental, etc.), costs, and effectiveness of their technology deployments, as well as lessons learned and recommendations for future deployment strategies. This document is designed to assist program grant recipients in fulfilling these reporting requirements. It offers an overview on 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 guidance on evaluating Adaptive Signal Control, Connected Vehicles and Automated Vehicles. We invite your comments so that we may consider them in future editions of the Evaluation Methods and Techniques.

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The Fixing America’s Surface Transportation Act or "FAST Act" established the Advanced Transportation Congestion Management Technologies Deployment (ATCMTD) Program to make competitive grants for the deployment of advanced transportation technologies. The legislation also mandates reporting requirements for the grantees, including data on the benefits (e.g., safety, mobility, environmental, etc.), costs, and effectiveness of the technology deployments, as well as lessons learned and recommendations for future deployment strategies. This Evaluation Methods and Techniques document is designed to assist grantees in designing and executing robust evaluations that fulfill their reporting requirements. It offers an overview on 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 guidance on evaluating Adaptive Signal Control, Connected Vehicles and Automated Vehicles. Finally, it seeks to provide grantees with a recommended set of performance measures that address the FAST Act reporting requirements.</td></tr>
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List of Acronyms

Acronym	Definition
ADS	Automated Driving System
ATCMTD	Advanced Transportation and Congestion Management Technologies Deployment
ASC	adaptive signal control
ASCT	adaptive signal control technology
ATIS	advanced traveler information system
ATSPM	automated traffic signal performance measure
AV	automated vehicle
BCA	benefit-cost analysis
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
DSRC	Dedicated Short-Range Communications
EMFAC	California Air Resources Board Emissions Factor Model
EPA	Environmental Protection Agency
FAST Act	Fixing America's Surface Transportation Act
FHWA	Federal Highway Administration
IRB	Institutional Review Board
ITS	intelligent transportation system
MAIS	Maximum Abbreviated Injury Scale
MPO	metropolitan planning organization
MOVES	Motor Vehicle Emission Simulator
NEPA	National Environmental Policy Act
ODD	operational design domain
PEMS	portable emissions monitoring systems
PII	personally identifiable information
PM	performance measure
ROI	return on investment
SIP	State Implementation Plan
TNC	transportation network company
TPM	Transportation Performance Management
TSP	transit signal priority

Acronym	Definition
TTR	travel time reliability
USDOT	U.S. Department of Transportation
U.S. EPA	U.S. Environmental Protection Agency
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VHT	vehicle hours traveled
VMT	vehicle miles travelled
VOC	vehicle operating cost
VOT	value of time

CHAPTER 1: INTRODUCTION

The Fixing America's Surface Transportation Act, Pub. L. 114-94, (FAST Act) established the Advanced Transportation Congestion Management Technologies Deployment (ATCMTD) Program to make competitive grants for the development of model deployment sites for large scale installation and operation of advanced transportation technologies.[1] The primary goals of these demonstrations are to improve safety, efficiency, system performance, and infrastructure return on investment. The FAST Act requires the Secretary of the U.S. Department of Transportation (USDOT) to request applications each fiscal year (2016 through 2020) and to award grants to at least five and not more than ten eligible entities. The legislation also mandates reporting requirements for the grantees, including Annual Reports that describe how the project costs compare to 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] **This Evaluation Methods and Techniques document is designed to assist grantees in designing and executing robust evaluations that enable them to fulfill the reporting requirements of 23 U.S.C. 503(c)(4)(F).**

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

This Evaluation Methods and Techniques document seeks to provide grantees with a recommended set of performance measures that address these reporting requirements. To the extent that grantees use the same or similar measures to assess deployment outcomes, it will be possible to synthesize findings across projects and obtain a better understanding of the impacts of their deployments across multiple technologies and sites.

HOW TO USE THIS DOCUMENT

The Evaluation Methods and Techniques document contains information on a range of topics. In order to better guide readers to the information that will be most useful to them, a brief description of each chapter and the target audience is provided below.

Evaluation Overview (Chapter 2): This chapter provides a framework for designing evaluations, based on evaluation best practices. An emphasis is placed on performance measurement and linking performance measures 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.

[1] FAST Act § 6004; 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).

Performance Measures (PM) (Chapter 3): This chapter is critical to both the project team and evaluation team members. It presents performance measures for each of the goal areas of the ATCMTD program, as described in 23 U.S.C. 503(c)(4)(F,G). Where available, particularly for the areas of safety, congestion/mobility, and environmental impacts, the PMs are drawn from USDOT guidance. While the list is not exhaustive and use of these specific PMs is not required, it is highly recommended that grantees utilize the PMs presented in this chapter to satisfy statutory reporting requirements. This will enable USDOT to more easily synthesize findings across project sites for the Program Level Report.

Methods and Analytics (Chapter 4): This chapter includes three key topics: **Benefit Cost Analysis (BCA)**; **Survey and Interview Methods,** and **Emissions and Energy Measurement.** These sub-chapters 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 sub-sections also includes a set of references for more detailed information.

- **BCA:** This analytic method is the recommended approach for comparing project benefits and costs. The sub-chapter is largely based on USDOT guidance and provides best practices in performing BCA.
- **Surveys and Interviews**: Best practice information is provided on range of survey related topics, including sampling, sample size, recruitment, and questionnaire design, among others.
- **Emissions and Energy Measurement**: This chapter 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 Best Practices (Chapter 5): This chapter outlines considerations and lessons learned with respect to evaluating specific technologies, namely: **Adaptive Signal Control**, **Connected Vehicle Technologies**, and **Automated Vehicle Technologies**. For projects that are deploying any of these technologies, the 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 sub-section 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

Evaluations can be used at different points in the project lifecycle. For example, some evaluations are conducted during implementation to assess whether a technology is operating as planned, while others are conducted post-implementation to assess the outcomes and impacts of a technology. Figure 1 shows where ATCMTD evaluation activities fit in the project lifecycle. During the pre-implementation phase, as the project design is underway, evaluation planning must also be conducted. The remainder of this chapter describes these key evaluation planning activities. During the implementation phase, as the technology is being tested and fully implemented, the data collection methods should also be tested and any baseline data collection should be completed (baseline data also may have been collected during pre-implementation). Once the technology has been implemented, post deployment data are collected for the duration of the evaluation period. Grantees should report interim as well as final evaluation/performance measurement findings in their Annual Reports (see Appendix B for Annual Report template).

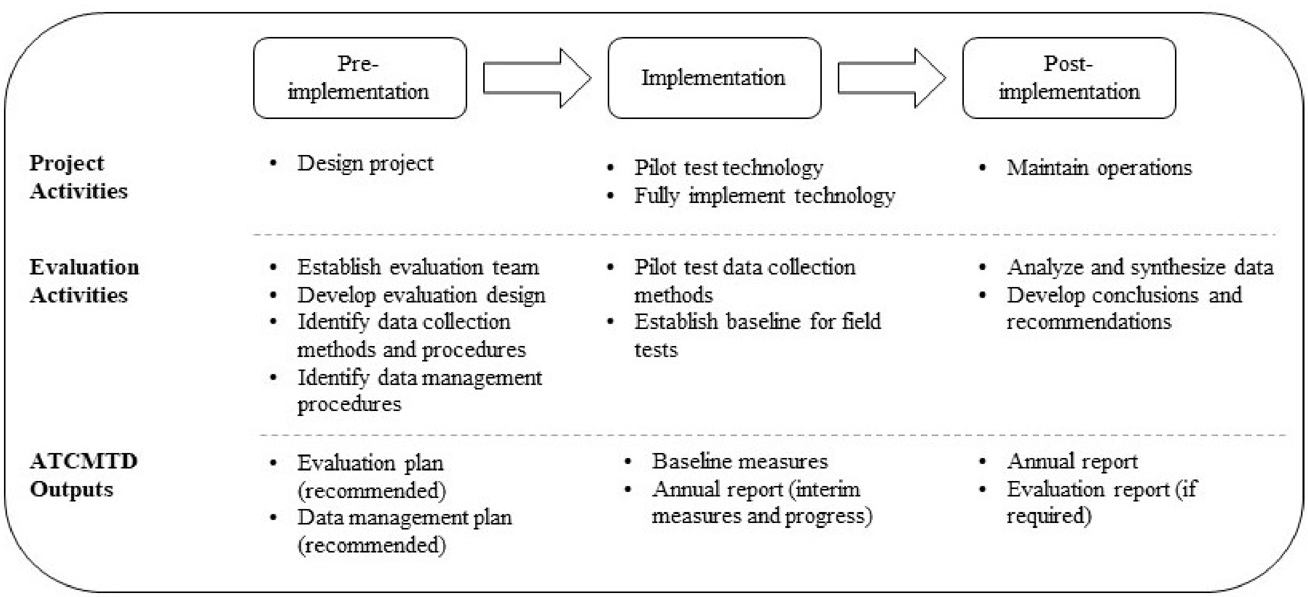

Figure 1. Graphic. Project Lifecycle

[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.

ATCMTD evaluations can largely be characterized as outcome evaluations. Outcome evaluations focus on whether a program or project has achieved its results-oriented objectives. However, the ATCMTD grantees should consider ways to measure interim progress toward their outcomes. Early measurement will inform interim improvements, as necessary, and also provide input into the required Annual Reports that document the benefits, costs, and effectiveness (among other measures) of the technologies being deployed.

Evaluations should be systematically planned and executed to ensure findings are credible and actionable. The remainder of this section describes this systematic approach to an evaluation. When planning evaluations, constraints that may impact the ability to conduct evaluation activities should be taken into account. 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. Evaluations can be conducted using an internal evaluation team, independent evaluators, or a mix of both. Evaluators should be brought on board as early as possible so that the design of the evaluation can occur as the deployment is being planned and the project generates sufficient data to support the evaluation. Given the reporting requirements in the FAST Act, it is recommended that an independent evaluator be used to design and manage ATCMTD evaluations.

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

Due to the complex nature of ATCMTD systems and technologies, evaluators should work closely with the ATCMTD project team.[2] 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 it's 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 ATCMTD 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 will be discussed in this chapter. Several templates are also included to assist grantees in structuring and documenting their evaluation and performance measurement plans.

[2] The "project team" refers to the team members involved in deploying the technology and may include staff from different organizations. The "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
	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/Objectives

Guiding an evaluation is an agreed upon set of project goals and objectives to drive the evaluation design. These goals and/or objectives 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 and share your understanding of the 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).

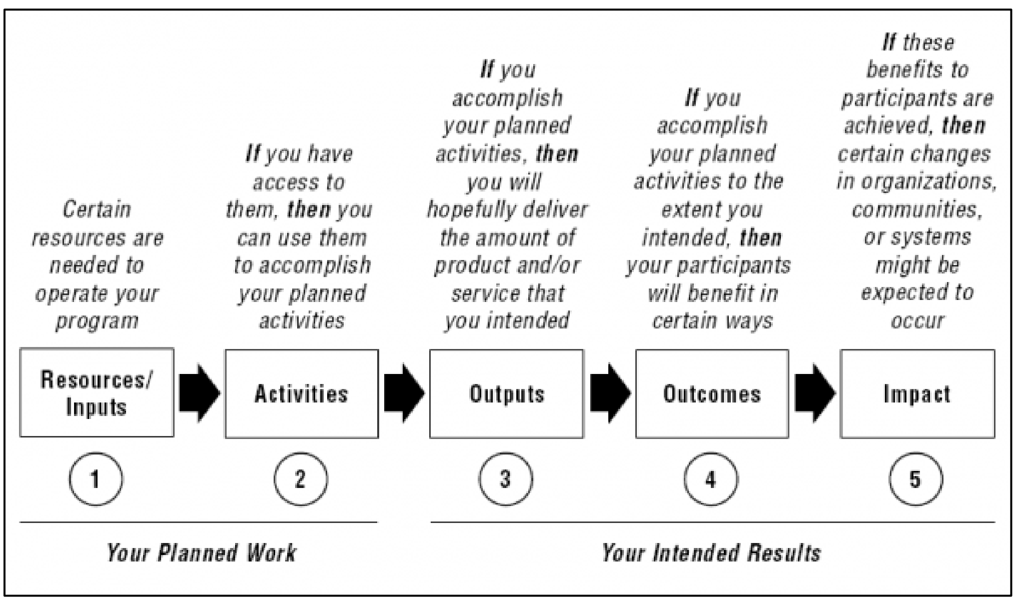

Figure 2. Graphic. Project or Program Logic Model[3]

[3] W. K. Kellogg Foundation (2004)

Additional detail on logic models can be found on the following link:
W.K. Kellogg Foundation: https://www.wkkf.org/resource-directory/resource/2006/02/wk-kellogg-foundation-logic-model-development-guide

ATCMTD project goals align with the priorities established in the FAST Act. These priorities relate to the use of advanced transportation technologies to improve safety, mobility, environment, system performance, and infrastructure return-on-investment.

Table 2 includes some of the priority goal areas listed in the FAST Act (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 should be considered in the development of project goals/objectives (see Chapter 3 for a set of recommended performance measures for each goal area).

Table 2. ATCMTD FAST Act Goals and Objectives.

Goal Area	Objective
Improve safety	• Reduce traffic related fatalities • Reduce traffic related injuries • Reduce traffic crashes
Reduce congestion/ Improve mobility	• Reduce traffic congestion • Reduce travel delay • Improve travel time, speeds or travel reliability
Reduce environmental impact	• Reduce transportation-related emissions
Optimize system performance	• Optimize multimodal system performance • Optimize system efficiency
Improve access to transportation alternatives	• Improve access to transportation alternatives
Improve effectiveness of real time integrated transportation information	• Provide the public with access to real-time integrated traffic, transit, and multimodal transportation information to make more informed travel decisions
Reduce costs/Improve return on investment (ROI)	• Provide cost savings to transportation agencies, businesses, and the traveling public • Demonstrate that benefits outweigh the costs
Share institutional or administrative benefits	• Develop Lessons Learned and Recommendations for future deployment strategies
Other benefits	• Provide other benefits to transportation users and the general public

Develop Evaluation Questions

Once goals and objectives have been established, specific research questions (or hypotheses) can be developed. These questions will be addressed through data collection, analysis, and interpretation. There should be at least one (and ideally several) evaluation questions in support of each goal. When designing evaluation questions, consider the following guidance:

- Design questions that are **specific** about the change in safety, system performance, agency efficiency, behavior, etc. that is expected as a result of the project activity.
- Avoid using polar questions (i.e., yes-no response).
- 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; improved travel time reliability, etc.). 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 how to organize evaluation goals, objectives and questions (a limited set of examples are included for descriptive purposes only).

Table 3. Template with Example Evaluation Goals, Objectives and Evaluation Questions.

Note: Examples are included for illustrative purposes only

Goal Area	Objective	Evaluation Question
Improve 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?
Reduce Congestion/Improve Mobility	Improve travel times	What impact did Adaptive Signal Control have on travel times along corridor Y?
Improve Effectiveness of Real-Time Integrated Transportation Information	Provide the public with access to real-time integrated traffic, transit, and multimodal transportation information to make more informed travel decisions	Did a majority of application users indicate that the travel time information helped improve their commute decision making?
Cost Savings and Improved Return on Investment	Provide cost savings to transportation agencies	What was the benefit-cost ratio of the adaptive signal control deployment?
Share Institutional Insights	Lesson Learned	What lessons learned did project managers identify to facilitate future successful deployments of CV?

Identify Performance Measures

As grantees develop their evaluation questions, it is important to begin identifying the performance measures or information that will address each evaluation question. The performance measures will be used to assess whether improvements and progress have been made on the safety, mobility, environmental, and other goal areas of the ATCMTD Program (as described in the Fast Act).

In developing performance measures:

- Determine if the information needed is qualitative or quantitative in nature.
- To the extent possible, select quantitative measures that can be monetized for use in benefit-cost analysis (see Chapter 4 on benefit-cost analysis for more information).
- Ensure that the data necessary for the measures can be collected (or otherwise acquired).

Chapter 3 provides additional guidance on performance measures, including recommended measures specific to fulfilling the requirements set forth in the FAST Act.

Develop Evaluation Design

While identifying the evaluation questions and performance measures, grantees should also be developing an appropriate evaluation design that describes how, within the constraints of time and cost, they will collect data that addresses 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 how the data will be collected. Evaluations of technology deployments often utilize a **before–after design**, whereby pre-deployment data (i.e., baseline data) is compared to 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 post-deployment period.

More robust designs, such as randomized experimental and quasi experimental designs, utilize 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 utilized 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, there may be multiple methods used 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. The same method may be used to address multiple evaluation questions. Vehicle field test data (e.g., CV data) may be used to inform both mobility and safety-related evaluation questions.

When developing data collection methods, thought should be given to 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, are available in the units required for the performance metric, etc.). Data elements will be either quantitative or qualitative, and can take many forms (e.g., speed data, crash data, survey responses, interview responses, etc.).

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/Method	Data Source	Data Collection Considerations
Field Test	• Roadside infrastructure (sensors, DSRC, etc.), • Vehicle probes (e.g., CV or AV data)	• Field test location/scope • Data collection period • Data elements to be collected, including unit of analysis • Data collection frequency/interval (hourly, daily, etc.) • Data requirements related to modeling or simulation (if applicable) • Data management (e.g., storage, quality control) • Data security (e.g., protecting privacy)
Surveys or Interviews[4]	• Survey responses • Interview responses	• Target population and sampling procedures • Participant recruitment/contact procedures • Expected sample size • Methods for encouraging survey response • Survey administration period • Key topics to be addressed in survey and/or interview guides
Internal Agency Data	• Information management systems • Operations data (e.g., response times, system downtime, maintenance data), website tracking, reports, documents, etc.	• Data collection period • Data elements to be collected, including unit of analysis • Frequency/interval (hourly, daily, etc.) • Accuracy/completeness of internal agency data

[4] See Chapter 4 on Survey and Interview Methods.

Data Limitations or Constraints

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

- Technology functionality problems,
- Low survey participation,
- Poor agency documentation, and
- 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 there are confounding factors that may impact 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 non-experimental design), it is particularly important to consider potential confounding factors that may be the cause of a change in the before-after data. Grantees should avoid attributing a change in outcomes to the technology deployment when in fact it is due to some other factor. Potential mitigation approaches should also be identified 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 or growth in jobs)
> - Changes in legislation

As grantees are thinking through the key components of their evaluation, including the evaluation questions, performance measures, data sources, data collection methodology, and data limitations, it is recommended that they document this information in the Evaluation Plan. The following template (see next page) is designed to provide grantees with a useful tool for summarizing this evaluation information.

Table 5. Example Methodology Template.

Note: Examples are included for illustrative purposes only

Evaluation Questions/Hypotheses	Performance Measure	Information Source/ Method	Data Element	Limitations/ Constraints
What proportion of drivers using CV application X rated the safety warnings as helpful?	Percent of respondents who feel safety warning was helpful	Survey	Survey response in post-survey	• Low response rate may be an issue
What impact did adaptive signal control have on travel times along Corridor Y?	Percent change in average travel times	Field test (vehicle probe data)	Pre-post comparison of vehicle probe data	• Weather, incidents may affect 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	• Incomplete data • Some impacts are difficult to quantify

For projects where data collection location, frequency, etc. may vary across the different technologies being deployed, it may be useful to document these data collection characteristics or procedures. See Table 6 below, which includes an example for illustrative purposes only.

Table 6. Template for Data Collection Procedures.

Data Element	Data Collection Frequency/ Interval	Location	Data Collection Period		Data Collection Responsible party
			Start	End	
Traffic Volumes	5 minutes	US 75 corridor	January 1, 2019 –	March 31, 2019	NJDOT

Develop Data Management Procedures

In most cases, grantees will be collecting significant amounts of data to support their evaluation and operations, and there are a number of data-related issues that need to be considered during evaluation planning. Management of data collected during the ATCMTD project may be documented in the Evaluation Plan but grantees are strongly encouraged to develop a separate data management plan (DMP) during the pre-implementation phase which describes how the project team will handle data both during and after the project. This DMP can be updated with more information as the project proceeds.

In planning for data management, grantees should consider how data will be captured, transferred, stored, and protected. The evaluation team will need to work closely with the project team to ensure that these protocols are put in place prior to the data collection period. Data management protocols include:

- Processes to log and transfer data to the evaluation team
- Data quality control procedures (e.g., data cleaning, etc.)
- Standards used for data and metadata format and content
- Plans for data storage/archiving
- Plans for data documentation (e.g., data dictionary)
- 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 FAST Act (for template, see Appendix B) and this should be reflected in their DMPs. Although not required, USDOT encourages grantees to make other relevant data available to the USDOT and the public to further advance the objectives of the ATCMTD program. For example, projects may provide the USDOT access to the underlying data used to determine the costs and benefits described in the report. The DMP should indicate whether project data contains confidential business information and personally identifiable information (PII), whether such data will be shared in a controlled access environment, or removed prior to providing public or USDOT access.

Additional voluntary guidance on creating DMPs can be found at the following link: 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 the evaluation data are going to be organized and analyzed. The analysis plan may be documented as a section of the Evaluation Plan, in the DMP, or a separate document.

The analyses must be structured to answer the questions about whether change occurred and whether these changes can be attributed 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 evaluation can be designed to produce the required data. For each of the evaluation questions, the evaluation plan should provide sufficient detail on how the data will be analyzed.

Since evaluation data may come from multiple sources, e.g., experimental design (field-tests), surveys, interviews, historical data, etc., different types of analyses may be used 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). Modeling or simulation also may be used as an analytic method.

EXECUTE THE EVALUATION PLAN

Executing the evaluation includes the collection of the data, the analysis of the data, and the development of findings.

Acquire or Collect Data

During data collection, the project team is capturing the data that have been identified in the evaluation plan. As detailed in previous sections, this may include system performance data, vehicle or infrastructure data, and survey responses, among other data elements.

Pilot Studies

Prior to the start of data collection, it is advisable to conduct a data collection pilot that tests the end-to-end data collection pipeline, particularly for new systems or tools (i.e., where there is no previously established data collection mechanism). For example, for Automated or Connected Vehicle 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/equipment, processing it, and transmitting it to where the evaluators will use it. Evaluators should be part of this feedback loop to make sure that the data are acceptable, including providing feedback on the format of sample data sets prior to the end-to-end test. In addition to a pilot study (that tests the data collection protocols), system acceptance testing should also be conducted, whereby the project team assesses whether or not the technology functions as designed.

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

During the data collection pilot, complete data documentation should be generated to accompany the data. This is a general best practice but particularly important if a third party evaluator will be conducting the evaluation, staff turnover may occur on the project, or data will be made available to others down the road). 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 was this data collected and why might someone want to use the data in this table).

Where possible, grantees should leverage insights from previous projects, including USDOT-funded intelligent transportation systems (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 can be found through the USDOT's ITS DataHub at https://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 is collected. For all deployments, however, the analyses must be structured to answer two questions:

1) Did the desired changes (i.e., in safety, mobility etc.) occur?
2) If changes occurred, were they the result 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 evaluation can be designed to produce the required data.

Develop Annual Report(s)

The FAST Act requires that grantees submit Annual Reports. This Evaluation Methods and Techniques document provides guidance on how to structure an evaluation that will produce the data needed to meet this reporting requirement. According to the FAST Act (23 U.S.C. 503(c)(4)(F)), *"For each eligible entity that receives a grant under this paragraph, not later than 1 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 efficiency and multimodal system performance."*

An Annual Report template has been designed to assist grantees in meeting their annual reporting requirement (see Appendix B). 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, among other information. 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. In order to collect information specified in the FAST Act, 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.

Evaluation References

Administration For Children and Families Office of Planning, Research and Evaluation . (2010). *The Program Manager's Guide to Evaluation Second Edition* . Washington D.C.

Barnard, Y. (2017). *D5.4 Updated Version of the FESTA Handbook.* Leeds, UK: FOT NET Data.

Dillman, D. A., Smith, J. D., & Christian, L. M. (2014). *Internet, Phone, Mail and Mixed-Mode, Fourth Edition.* Hoboken: John Wiley & Sons.

Gay, K., & Kniss, V. (2015). *Safety Pilot Model Deployment: Lessons Learned and Recommendations for Future Connected Vehicle Activities.* Washington, D.C.: Intelligent Transportation System Joint Program Office.

Groves, R. M., Fowler, Jr, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., & Tourangeau, R. (2009). *Survey Methodology, Second Edition.* Hoboken: John Wiley & Sons, Inc.

Marsden, P. V., & Wright, J. D. (2010). *Handbook of Survey Research, Second Edition.* Bingley: Emerald Group Publishing Limited.

Smith, S., & Razo, M. (2016). Using Traffic Microsimulation to Assess Deployment Strategies for the Connected Vehicle Safety Pilot. *Journal of Intennigent Transportation Systems*, 66-74.

W. K. Kellogg Foundation. (2004). *Logic model development guide*, (Figure 2. How to Read a Logic Model) Battle Creek, MI, obtained from: https://www.wkkf.org/resource-directory/resource/2006/02/wk-kellogg-foundation-logic-model-development-guide

CHAPTER 3: PERFORMANCE MEASURES

This chapter provides a set of recommended performance measures (PMs) to assist Advanced Transportation Congestion Management Technologies Deployment (ATCMTD) grantees in meeting the reporting requirements of the FAST (Fixing America's Surface Transportation) Act. 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, among other data (see Develop Annual Report for specific FAST Act 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 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; or
- Provided other benefits to transportation users and the general public.

The PMs presented below are intended to provide ATCMTD grantees a core set of measures. In developing the set of recommended PMs, several key criteria were utilized, to the extent possible. 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 benefit-cost analysis (BCA).

While the measures tend to be quantitative and outcome-based, measures that rely on qualitative data are also presented, as ATCMTD grantees will want to include performance measures that reflect a mix of both quantitative and qualitative data. In designing their evaluations, the ATCMTD grantees should start with the performance measures described below; however, the list is by no means exhaustive. Grantees may want to include additional performance measures that are tailored to their specific deployments and that provide insight on the safety, mobility, agency efficiency, and other impacts of their technology deployments. It should be noted that projects will not necessarily address all of 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.

The remainder of this chapter presents performance measures for each of the key performance areas outlined in the FAST Act:

1. Improve Safety
2. Improve Mobility/Reduce Traffic Congestion
3. Reduce Environmental Impacts
4. Optimize Multimodal Performance
5. Improve Access to Transportation Alternatives
6. Effectiveness of providing real-time integrated multimodal transportation information to the public to make informed travel decisions
7. Cost Savings and Improved Return on Investment
8. Other Benefits/Lessons Learned

The references at the end of this chapter lists 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 a source of data to meet the grant performance measurement requirements.

IMPROVE SAFETY

Table 7 presents a number of safety-related performance measures, organized by mode of transportation. While they are generally prioritized within each mode, grantees must consider the measures that are most relevant to their specific deployments. That is, the selection of performance measures will depend on the technologies being deployed and what problem(s) they are trying to solve. Careful thought should be given to the specific type of safety benefits that are anticipated from the technology deployment.

Nearly all of 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 (pre-deployment) period and a post deployment period. The preferred type of measure is a rate, because it adjusts for the level of exposure; however, there may be cases where counts are the only data available (e.g., for bicycle or pedestrian measures).

FHWA adopted five safety-related performance measures as part of the TPM program. These include total counts for fatalities, serious injuries, and (as a separate category) fatalities and serious injuries to non-motorized road users, and rates per 100 million vehicle miles traveled (VMT) for fatalities and serious injuries. These categorizations are covered within the more detailed list of performance measures listed below. The Safety Performance Management Final

Rule also established methodological guidelines for reporting these measures, which grantees may find useful.[2]

Grantees should consider the use of multiple measures to understand the safety impacts of their technologies. In addition to crash records or field test data on crash precursors, survey data can provide a compliment (but not a substitute) to these other data sources, providing useful data on user (e.g., drivers, transit operators, etc.) experience or attitudes.

It is also important to 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, it is important to note that as geographic scope decreases, random variation tends to increase, and thus intersection or even corridor-level analysis can be highly variable 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**
-	**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 injuries
7	(Rate) Secondary crashes[3] per VMT
8	(Count) Number of secondary crashes
9	Crash precursors (e.g., Time to Collision; Hard Braking) Refer to the literature on the relationship between the precursor event and actual safety outcomes (e.g., number or severity of crash)
10	Percent of drivers who feel more safe (i.e. from crashes) while driving [along X corridor] [survey/interview]
11	Percent of drivers who indicate that [X warning/feature etc.] is very or somewhat helpful. [survey/interview]

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

[3] Secondary crashes refer to the number of additional crashes—starting from the time of detection of the primary incident—either within the incident scene or its queue, including the opposite direction, resulting from the original incident (Vasconez 2010).

-	Performance Measures
-	**Transit**
12	(Rate) Transit crashes per Vehicle Revenue Miles (or Passenger Miles Traveled) (PMT)
13	(Rate) Fatalities or injuries per Passenger Miles Traveled (PMT)
14	(Count) Number of transit passenger fatalities and/or injuries
15	Percent of transit vehicle operators who indicate that [X warning/feature etc.] is very or somewhat helpful [survey/interview]
-	**Non-motorized**
16	(Count) Number bicycle crashes, injuries and/or fatalities[4]
17	(Count) Number of pedestrian crashes, injuries and/or fatalities
18	Percent of bicyclists [or pedestrians] who feel more safe (i.e., from crashes) [crossing at X intersection/traveling along Y corridor] [survey/interview]

IMPROVE MOBILITY/REDUCE CONGESTION

This section highlights mobility and congestion related performance measures. The measures are organized by transportation mode, and are generally prioritized within mode. Grantees' selection of performance measures, however, will depend on the technologies being deployed and what problem(s) they are trying to solve. Careful thought should be given to the specific type of mobility benefits that are anticipated from the technology deployment.

Preferred measures include travel time, average speed and travel time reliability (TTR). While TTR is important to travelers, there is no consensus within USDOT on how to measure it, so this document does not recommend a specific measure. Standard deviation of travel time (or travel time index) is the most common method for measuring TTR, but variance or other measures may also be used. 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 ATCMTD mobility impacts (see 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

[4] Grantees may also consider the use of exposure-adjusted rates for pedestrian or bicyclist measures (e.g., change in bicycle crashes per 1000 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 post deployment periods.

Congestion Management and Air Quality Improvement (CMAQ) Program rule were incorporated. [5]

It is anticipated that grantees will be collecting the data to measure mobility/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 performance measures can be used at the intersection, corridor, or regional level, and it is important to consider geographic scope when developing performance measures. For technologies deployed at intersections, grantees should consider measuring impacts both at 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 taken into account. In cases where mobility impacts are anticipated to be greatest during peak hours, the performance measures should focus on those peak hours.

Table 8. Performance Measures for Improve Mobility/Reduce Congestion.

-	**Performance Measures**
-	**Vehicle**
1	Travel time: (Rate) Vehicle hours traveled (VHT) per vehicle miles traveled (VMT)
2	(Count) Average speed
3	(Rate) Travel Time Reliability 23 CFR 490.507: Percent of 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 (NPMRDS) is a potential data source for TTR, but grantees will need to assess the appropriateness of this data in meeting their evaluation needs.
4	Delay per trip (travel time) • (Rate) per vehicle or per person • (Count) average or total CMAQ Rule: Annual hours of peak hour excessive delay per capita (person-hours) *Note: Delay accounts for difference between actual and free-flow travel time*
5	(Rate) Vehicle volume/throughput (vehicles/hour)

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

-	**Performance Measures**
6	Percent 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/interview]
7	Percent of travelers who report that their travel experience along X corridor is (select appropriate measure): • Less congested • More reliable • Takes less time [survey/interview]
-	**Transit**
9	Average run time for transit *Note: Breaking data out by route can highlight particular locations with positive or negative impacts*
10	On-time performance (% trips)
11	Total passenger delay or average passenger delay
12	Completion Rate for transit service
13	Percent 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/interview]
14	Percent of transit vehicle operators who report that [travel time /travel time reliability/average speeds] has improved along the route [survey/interview]
15	Percent of transit vehicle operators who are very satisfied with [travel time/travel time reliability/average speed] along their route [survey/interview]
-	**Pedestrian/Bicycle/Rideshare**
16	Percent of pedestrian/riders who feel [travel time/on-time performance/etc.] has improved [survey/interview]

-	Performance Measures
17	Percent of riders who perceive that the rideshare time estimates are very accurate or somewhat accurate [survey/interview]
-	**Freight**[6]
18	Port Turn Time, including: • Reduced wait time (to enter terminal) • Reduced terminal time (time in terminal)
-	**Other**
19	Incident Clearance Time[7] (minutes)
20	23 CFR 490.707: Mode Share of Non-SOV modes (including telework)

For evaluations related to signalized control (including adaptive signal systems), specific performance measures which capture the ability of the control mechanism to respond to traffic and improve mobility should be considered.

Table 9. Additional Performance Measures Related to Signalized Control.

-	**Performance Measures**
-	**Volume and Capacity**
20	Saturation (by lane, approach, movement, or intersection)
21	Phase Termination Percent of terminations due to gap out, max out, etc.
22	Number of Stops
23	% Arrival on Green, % Arrival on Red
24	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). Through a pooled-fund effort, open-source software 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

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

[7] 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 (Vasconez 2010).

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

When evaluating environmental impacts, the Program Level Report objectives include reducing transportation-related emissions. Analysis should include applicable mobile-source emissions of regulated pollutants that are known to have adverse public health effects, namely ozone precursors—volatile organic compounds and nitrogen oxides—as well as carbon monoxide, and particulate matter (both PM10 and PM2.5) and the applicable precursors from transportation sources. Reductions in energy consumption and carbon dioxide equivalent could also be reported.

Chapter 4 provides information about models and tools that can be used for emissions and energy measurement. Additionally, the References section on Emissions and Energy Measurement provides links and useful resources.

Table 10. Performance Measures for Reduced Environmental Impacts.

-	Performance Measures
-	**Emissions**
1	Net Project Emissions in kilograms per day (kg/day)[8]
	Energy[9]
2	Energy Reduction in British Thermal Units (Btu)
3	Energy Reduction in Kilojoules (kJ)
4	Energy Reduction in gallons of fuel saved (gallons)

OPTIMIZE MULTIMODAL PERFORMANCE

Given the complex nature of our transportation systems, it is challenging to define and measure optimized multimodal performance. Below are a few suggested performance measures, including both quantitative and qualitative measures that provide insight on whether the system is progressing towards more optimal multimodal performance.

- Travel time, indexed by mode
- VMT avoided through transit or other modes
- Bike ridership
- Use of carpool/vanpool/rideshare
- Percent of riders who feel [travel time/on-time performance/etc.] has improved
- Inter-agency or inter-operator coordination – for example:
    - Number of meetings or other interactions;

[8] This metric is used for Transportation Conformity analyses and for the CMAQ Total Emissions Reduction Performance Measure.
[9] Use U.S. Energy Information Administration (EIA) to obtain Btu or kJ per gallon of diesel or gasoline.

- Number/development of Memorandums of Understandings
  - Development and/or use of common strategies, response plans, etc.
  - Level of automation for common strategies or response plans
- Project team and/or other stakeholder feedback on how the deployment has optimized multimodal performance

IMPROVE ACCESS TO TRANSPORTATION OPTIONS

Accessibility (or access) can have multiple meanings. While the FAST Act does not explicitly define what it means by access to transportation options, this is typically interpreted as the existence of physical access to goods, services and destinations (i.e. transportation) and/or the ease of reaching goods, services, activities and destinations. 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 options?).

The table on the following page presents a range of measures related to improved access to transportation options, as defined above. 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 options, so the evaluation team will need to tailor the performance measure to their specific deployment.

Table 11. Performance Measures for Improved Access to Transportation Options.

-	Performance Measures
1	Number of households within 1/4 mile of a public transit stop (or ½ mile of transit station)
2	Ridership (transit, ridesharing, bicycle, etc., as appropriate)
3	Number of (new) bicycle share/carshare programs OR Number of new partnerships/(memorandum of understanding)MOUs between transit agencies and transportation network companies (TNCs), bikesharing or other Mobility on Demand services
4	Number of *new* riders (people who have not previously used the mode) – either total over a period, or per unit of time (transit, ridesharing, bicycle, etc.)
5	Percent aware of different transportation options (or change in awareness) [survey/interview]
6	Percent reporting [X mode] improved their [travel experience/commute] [survey/interview]
7	Percent reporting it was very easy or somewhat easy to book/pay a ride [survey/interview]
8	Percent reporting it was very easy or somewhat easy to find the pick-up location for the [vehicle/rideshare/bicycle share/shuttle] [survey/interview]
9	Percent reporting the drop-off location (e.g., for bus/rideshare/shuttle) was very convenient or somewhat convenient to their final destination [survey/interview]
10	Percent of riders who found the [transit/rideshare/bikeshare, etc.] service affordable [survey/interview]

EFFECTIVENESS OF PROVIDING REAL-TIME INTEGRATED TRANSPORTATION INFORMATION TO THE PUBLIC TO MAKE INFORMED TRAVEL DECISIONS

While there has been quite a bit of research conducted on advanced traveler information systems (ATIS), 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 and/or surveying users to understand the characteristics of their use (e.g., when, how often, types of information sought, etc.), 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, use of the ATIS should be measured for all platforms (apps, website, kiosk, 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. The table below provides suggested performance measures.

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

-	Performance Measures
1	Percent using ATIS
2	Percent of users who used the ATIS to plan a multimodal trip [survey/interview]
3	Percent of ATIS users very satisfied or somewhat satisfied with the [accuracy OR reliability] of the real-time traffic, transit, and/or multimodal information. OR Percent very 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/interview]
4	Percent of ATIS users reporting that the real-time information has improved (select as appropriate): • Their overall travel experience • Their commute AND/OR Percent of ATIS users who feel the real-time traffic and/or transit information was useful [survey/interview]
5	Percent of ATIS users who made a change in travel (either before or during their trip) based on the real-time information provided • Percent who switched departure time • Percent who switched their route • Percent who cancelled a trip [survey/interview]
6	Percent of users very satisfied or somewhat satisfied with: • Location of kiosks • Ease of using the kiosk [survey/interview]
7	Percent of transit vehicle operators who are very satisfied or somewhat satisfied with the real-time information • Re-routing information

-	Performance Measures
	• Special event [survey/interview]

COST SAVINGS AND IMPROVED RETURN ON INVESTMENT

Cost savings may be measured in a variety of ways and the measures depend on the technology being deployed. This 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 for more information).

Table 13. Performance Measures for Cost Savings and Return on Investment.

-	Performance Measures
-	**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
-	**Public**
4	Benefit-Cost Ratio or Net Present Value

OTHER BENEFITS/LESSONS LEARNED

As needed, ATCMTD 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 in nature. At a minimum, any surveys or interviews that are conducted should include an open-ended question that asks if there are "any other benefits" of the deployment (e.g., in addition to the safety and/or mobility benefits).

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

Finally, for new and emerging technologies, there may be additional measures that are not captured in the performance areas described above, but that are nonetheless important to measure – for example, user experience and/or acceptance.

A few example PMs for automated vehicle technologies are provided below (separately for riders and onboard controllers or maintenance staff):

Riders:

- Assessment of ride comfort (jerkiness, acceleration)
- Comfort level with AV technology and/or unstaffed operation
- Recommendations for improvements

Onboard controllers or Maintenance staff:

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

Performance Measure References

Beaulieu, M. et al. (2014). *WSDOT's Handbook for Corridor Capacity Evaluation*, Olympia, WA: Washington State Department of Transportation, obtained from: http://wsdot.wa.gov/publications/fulltext/graynotebook/CCR14_methodology.pdf

Easley, R. et al. (2017). *Freight Performance Measure Primer*, Report No. FHWA-HOP-16-089 Washington, D.C., obtained from: https://ops.fhwa.dot.gov/publications/fhwahop16089/index.htm

Federal Highway Administration. (2017). *National Performance Management Measures to Assess System Performance, Freight Movement, and CMAQ Program*, Washington, D.C., obtained from: https://www.federalregister.gov/documents/2017/01/18/2017-00681/national-performance-management-measures-assessing-performance-of-the-national-highway-system

Federal Highway Administration. (2019). *Transportation Performance Management,* obtained from: https://www.fhwa.dot.gov/tpm/, last accessed March 2019.

Krugler, P. et al. (2006). *Performance Measurement Tool Box and Reporting System for Research Programs and Projects,* College Station, TX: National Cooperative Highway Research Program obtained from: http://www.trb.org/Publications/Blurbs/159957.aspx

National Cooperative Highway Research Program. (2008). *Cost-Effective Performance Measures for Travel Time Delay, Variation, and Reliability,* Washington, D.C., obtained from: http://nap.edu/14167

National Transportation Operations Coalition. (2005). *Performance Measurement Initiative, Final Report,* Washington, D.C., obtained from: https://transportationops.org/publications/performance-measurement-initiative-final-report

Research and Technology Coordinating Committee. (2012). *Identifying Potential Performance Measures for FHWA RD&T,* Washington, D.C., obtained from: https://www.nap.edu/read/22816/chapter/3

Shaheen, S., Cohen, A., Yelchuru, B. Sarkhili, S. (2017). *Mobility on Demand Operational Concept Report*, Report No. FHWA-JPO-18-611, Washington, D.C., obtained from: http://innovativemobility.org/wp-content/uploads/Mobility-on-Demand-Operational-Concept-Report-2017.pdf

Smith, S., Bellone, J., Bransfield, S., Ingles, A., Noel, G., Reed, E., & Yanagisawa, M. (2015). *Benefits Estimation Framework for Automated Vehicle Operations,* Report No. FHWA-JPO-16-229, Cambridge, MA, obtained from: https://rosap.ntl.bts.gov/view/dot/4298

Taylor, R. (2010). *Penn DOT ITS Evaluations and Activities Final Report,* Report No. FHWA-PA-2010-001-060908, Camp Hill, PA, obtained from: http://www.dot7.state.pa.us/BPR_PDF_FILES/Documents/Research/Complete%20Projects/Planning/ITS%20Evaluations%20and%20Activities.pdf

Vasconez, K. (2010). *Traffic Incident Management (TIM) Performance Measurement Knowledge Management System,* Report No. FHWA-HOP-10-011, Washington, D.C., obtained from: https://ops.fhwa.dot.gov/publications/fhwahop10011/tim_kms.pdf

CHAPTER 4: METHODS AND ANALYTIC TECHNIQUES

This chapter includes three sections: benefit-cost analysis (BCA), Survey and Interview Methods, and Emissions and Energy Measurement.

BENEFIT-COST ANALYSIS

This section provides an overview of BCA and how it might be applied to ATCMTD evaluations. The ATCMTD program requires analysis of "deployment and operational costs of the project compared to the benefits and savings the project provides." Although different methodologies might be used for measuring these impacts, the preferred method is BCA because it provides a comprehensive accounting using a well-established analytical approach.

BCA is systematic process by which the impacts of a project (or other action) are estimated and quantified through a comparison of the benefits from a 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 allows diverse project outcomes to be compared and evaluated using a consistent measure.
- **Knowledge Transfer**. A BCA provides useful insight and information on costs and benefits that may be used by other cities considering similar projects.
- **Improved Future Analyses**. These analyses will help improve and aid calibration of the expected benefits and costs, particularly from innovative technologies, for future ex ante BCAs. This in turn will support well informed decision-making 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 where grantees are deploying a range of different technologies and may not have sufficient resources to conduct separate BCA analyses for each technology, they can prioritize, focusing their BCA on the technology (ies) 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 impacts of the project on traffic flow and safety. This also allows for up-to-date cost data to be included in the analysis, including 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 (within the context of discretionary grant programs) may be found in the "Benefit-Cost Analysis Guidance for Discretionary Grant Programs" (2018). Updates are generally published annually, and the most recent version should be referenced when designing and conducting BCA analysis. In addition to insight into the methods for BCA analysis, the guidance also provides values for use in monetizing several categories of benefits.[1] Nonetheless, many ATCMTD projects may have benefits (or in some cases, costs) that are difficult to quantify or monetize. In these cases, it is useful to present the impacts in as much detail as possible and 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 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, analytical timeframe) should be **appropriate**.
- The project impacts should be compared to a **credible** baseline.
- The analysis should include an assessment of **uncertainty**. This 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, ATCMTD 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 broken down by major impact category (e.g. safety, mobility) and project element
- Costs by major project element
- Benefit-cost ratio
- Net present value

In cases where the ATCMTD project consists of a number of distinct sub-projects or elements, it is useful to calculate the BCA results separately for each. In the interest of transparency, it is strongly recommended that any documentation of the results include a copy of the completed BCA tool or spreadsheet used.[2]

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)**

[1] Local values based on sound empirical data or models may be used where available, except where noted.
[2] Cal-B/C: http://www.dot.ca.gov/hq/tpp/offices/eab/LCBC_Analysis_Model.html
TOPS-BC: https://ops.fhwa.dot.gov/plan4ops/topsbctool/

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

Defining Benefits

ATCMTD 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 the table below. Benefit estimation requires that benefits be *quantified* (e.g., person-hours of delay avoided, 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 non-market impacts that are more difficult to value, such as improved health and safety, USDOT has established recommended monetary values.

Table 14. Common Benefit Categories.

Benefit	Type	Goal	Measurement and Example Units
Safety	User Benefit	Improve safety	Fatalities and injuries avoided[3] (counts)
Travel Time Savings	User Benefit	Efficiency	Reduction in travel time (person-hours)
Vehicle Operating Cost	User Benefit	Reduced operating cost	Reduction in auto miles traveled[4] (vehicle-miles)
Induced Travel	User Benefit	Increased consumer surplus for additional use/users in response to higher level of service (LOS)	Additional trips (count)
Facility Maintenance	Agency Benefit	State of good repair / Reduce maintenance and operating costs	Change in maintenance costs (dollars)
Reduced Emissions	Externality	Reduce negative health and environment impacts from vehicle emissions	Kilograms per day (kg/day) by pollutant

[3] Reductions in property damage only accidents are often included with safety benefits, as they tend to rely on the same data sources and are impacted by the same transportation improvements.
[4] Some facility improvements may reduce the per mile vehicle operating costs. For example, paving a dirt road may reduce maintenance and tire replacement costs for users.

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:

- A lack of available data – for example, it may not by feasible to collect data on reduced transportation network company (TNC) wait times resulting from curb demarcation of a TNC drop off/pick up location at a transit station.
- No established methodology for monetizing benefits – for example, a project may collect data on increased use of and satisfaction with a real-time transit app 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 use and valuation of common benefit categories may be found in the "Benefit-Cost Analysis Guidance for Discretionary Grant Programs" (2018). A summary of key benefits categories is provided below. See Appendix C for USDOT values used in monetizing these categories of benefits.

- **Safety:** USDOT guidance provides monetized values for reductions in fatalities, injuries, and property damage only accidents. USDOT safety statistics generally utilize KABCO levels, which measure the observed injury severity at the crash scene. Maximum Abbreviated Injury Scale (MAIS) coded values may be found in the Discretionary Grant Program Guidance. MAIS categorizes injuries along a six-point scale from Minor to Not Survivable. Either scale may be used as long as the values are applied consistently.

- **Travel Time Savings:** USDOT guidance provides recommended value of time estimates by purpose. When using these estimates, the analyst should multiply the value by the appropriate vehicle occupancy rate (1.39 for passenger vehicles and 1.00 for commercial trucks). Local values may be used where available, and values for transit travel and wait times should be based on the most accurate available data applicable to the project.

- **Vehicle Operating Cost** (VOC): These costs are comprised of costs associated with operating the vehicle (fuel, maintenance, maintenance, 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 where available.

- **Reduced Emissions**: Monetized values for emission reductions can be found in Table 23 of Appendix C. The recommended methodology for estimating emission reduction may be found in the section on Emissions and Energy Measurement.

Defining Costs

The cost side of the BCA should include all costs that are expected to be incurred over the lifecycle of the project, as measured relative to the base case in which the project does not take place. Costs should be included irrespective of the entity by whom they are paid. For cost elements with a lifespan beyond the analytical period of the BCA, a residual asset value may be calculated as an offset to costs.

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

Below are 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 implementation period is typical for highway and transit projects. However, a shorter period may be appropriate for projects involving ITS or other technologies, as this equipment generally has shorter service lives. Some ATCMTD 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 costs for 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 a residual value in the final year.[5]

Inflation

It is recommended that the BCA 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, this means any costs or values in earlier dollars should be adjusted to the base year. Likewise, for ex-post BCA analysis, costs and benefits that are measured in nominal dollars should be adjusted so that they are in real (base year) dollars.

Adjust to Real Dollars

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

Discounting

Benefit and cost values that occur in different years of the BCA should be discounted to adjust for the time value of money. ATCMTD projects should follow the guidance of OMB Circular A-

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

94, which recommends discounting future benefits and costs using an annual real discount rate of seven percent. The Circular has additional detail on the rationale for discounting and the origins of the seven percent figure.

Double Counting and Transfers

Two common and related errors when preparing a BCA are double counting benefits (i.e., two measurement methods are applied to a single source of economic benefit) and including 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 an 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 which 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/speeds
- Transit ridership
- Changes in crash exposure and severity (e.g., due to exogenous changes to the vehicle fleet)

Before/after studies are 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 control for confounding factors. This 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 towards safer cars reducing the severity of accidents).

In addition to constructing a plausible "no-build" base case, it 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, this may be used to identify the benefits which 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. Analysis of this nature should be conducted in addition to the primary BCA which uses a plausible "no-build" baseline.

Geographic Scope

The BCA analysis should consider the expected geographic impact of the facility, as improvements may affect traveler route choice. An MPO travel demand model, if available, may provide some insight into the origin-destination patterns of travelers using the new facility.

> ***Example: Adaptive Signal Control***
> If deploying ASC 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.

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. This generally results in expanding the geographic scope beyond the immediate deployment area (see example on adaptive signal control).

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 would not have been made without the introduction of a new high occupancy toll lane).

For travelers switching from one mode to another, the BCA analysis 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, they represent a smaller consumer surplus than that for other trips. In practice, BCAs use the **rule of one half,** in which benefits from induced demand are valued at half the level of benefits to existing users.

Issues Specific to ATCMTD Project BCAs

Below are some issues specific to ATCMTD projects that are relevant to BCAs.

Value of Travel Time Information

Advanced traveler information systems can help travelers adjust their routes, departure time, travel mode, or other trip characteristics to avoid delays. In these cases, the benefits may be measured conventionally, such as through the change in travel time 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 provide “peace of mind” benefits from knowing what to expect. There are a range of potential benefits that the evaluation team will want to measure (i.e., through surveys and/or interviews) as part of the overall evaluation. 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 reliability of travel times in addition to valuing reductions in average 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 distribution of point-to-point travel times are sometimes presented as a change in the variance, standard deviation, or other metric. It can also be reasonable to use the idea of "buffer time" – i.e., 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 traveler decision-making. Given the range of approaches to measuring reliability impacts and the lack of standardized monetary values, it is recommended that reliability benefits be included in the BCA as a qualitative, non-monetized value.

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 they 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 ridesharing services. Additionally, a larger set of transportation options can increase resiliency of the transportation system by providing alternative 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), the evaluation team determines if surveys or interviews are an appropriate method for collecting the necessary data. For technology deployments (e.g., ATIS, CV applications, etc.), surveys or interviews can be used to gather information from the users of the technology regarding their experiences and satisfaction with the technology, as well as impacts of the technology on travel behavior or attitudes. Surveys or interviews are also a useful tool for gathering qualitative data from project team members or other stakeholders regarding the benefits, challenges, and lessons learned of the technology deployment. Ideally, survey or interview data provide a complement to other objective data that are collected from infrastructure or from the technology itself. However, for some evaluation questions, where no other data sources are available, surveys or interviews may provide the only source of data for a particular evaluation question.

For ATCMTD projects that involve surveys, interviews, or other qualitative methods, it is highly recommended that grantees utilize staff with expertise in the field of evaluation and survey/interview design and methods. In addition to surveys and interviews, other qualitative methods may be appropriate, such as focus groups or workshops. Table 15 describes these methods and provides considerations in using each.

Table 15. Summary of Qualitative Methods.

Method	Description	Considerations in Using the Method
Surveys	Utilizes a systematic method to collect quantitative and/or qualitative measures of an individual's experiences, attitudes, behavior, etc.	• Enables the collection of individual level data from a larger number of people • Provides data on non-observable traits such as users' characteristics, attitudes, experiences, or perceptions • If probability sampling is used – enables the generalization of findings from the sample to a larger population (See section on sampling below).
Interviews	Utilizes a structured interview guide (typically with open-ended questions) to gain detailed insight on experiences, behavior, attitudes, and opinions.	• Provides more in-depth, detailed information (e.g., lessons learned). • Enables probing and follow-up, which can be useful if the topic is less well defined or if a deeper understanding of attitudes, behavior, etc. is needed.
Focus Groups or Workshops	Utilizes a group setting to collect qualitative feedback from multiple individuals	• Enables the collection of information from multiple stakeholders at the same time • Enables "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/interview development and administration:

- Target population
- Survey design
- Survey administration mode
- Sampling
- Recruitment
- Questionnaire design
- Response Rates
- Privacy and personally identifiable Information
- Other Considerations

Target Population

For technology deployments, the evaluation team will want to consider the population(s) who are impacted by the technology or who can provide feedback on the technology; this 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 perspectives of different relevant populations should be collected.

Example Target Population for Transit CV Application

- **Bus drivers** (use/benefit from the technology)
- **Riders** (benefit from the technology)
- **Agency personnel/other project stakeholders** (experience 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 and/or interviews. For example, if the evaluation questions revolve around users' experience and satisfaction with a technology, your survey should be conducted following deployment of the technology (a **post-deployment 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, the most robust design is a **pre-post or before-after design,** whereby the same questions are asked in both the pre-and post-deployment periods.

By conducting surveys in both the pre (baseline) and post deployment periods, it is possible to compare measurements over time. However, if a control group is not used[6], it becomes important to track potential confounding factors (e.g., changes in the economy, construction, etc.) which may be the cause for a change in the measure (rather than the deployment). 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.

Advantages to Panel Design (same individuals surveyed pre-and post):

- Individual acts as his/her own control, since key attributes of the individual will not change from the pre-to post period.
- Can measure change at the individual level as well as in the aggregate.

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 post-deployment periods.

However, if resources do not allow for both a pre-and post-deployment survey, it is also possible to ask respondents (in a post deployment survey only) if they perceived a change in their attitudes, behavior, 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, positivity bias), but it offers an

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

alternate option for grantees who are not able to conduct surveys in both the baseline and the post deployment periods.

Table 16. 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	Post-Deployment Survey
• Changes in attitudes, behavior resulting from use of the technology	• Pre-Post Design (most robust) • Post-Deployment 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) that is used to collect the survey information. Surveys may be administered online, in-person, by mail or by telephone. Table 17 highlights each of these modes (mail and telephone are included for reference, but are not likely to be used for ATCMTD projects).

Multiple modes may be used for the same survey effort – either during different stages of the survey (recruitment vs. survey method) or to reach different sub-populations, 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 their contact information.

Table 17. Survey Administration Modes.

Method	Considerations	Example Uses
Online survey **(including app-based)**	• Convenient; participants can complete at their convenience • Streamlines survey process (i.e., with skip patterns) • Response tends to be lower compared to 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, need to assign respondents unique IDs to link responses across multiple surveys • Survey programming required • Some populations (e.g., seniors) may not have online access	• Advanced traveler information system users • Connected vehicle users
In-person **- paper** **- tablet**	• Response rates are higher, relative to other methods • If paper surveys are used: greater burden on respondents to follow directions, skip patterns, etc.; Reponses will need to be coded into a database. • Tablets streamline the survey process, but need a sufficient number so respondents are not waiting to complete survey • Tablets require survey programming	• Survey transit users onboard the bus • Survey truck operators at their fleet barn, rest stops
Mail	• Requires mailing addresses • Response rates tend to be lower • Requires follow-up contacts (e.g., reminder postcard) to increase response rates • No programming required, but responses must be coded	• Adaptive signal control improvements in a corridor (i.e., sample corridor addresses)
Telephone	• Requires telephone numbers • Response rates are lower, due to phone screening, caller ID • Phone system programming required (Computer Aided 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, Transit Pass Riders, etc.); 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 pre-existing list or online panels are used, the evaluation should consider any biases or limitations to the list (e.g., accuracy, completeness).

> ***Sampling Frame vs. 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 (who may or may not choose to participate)

In general, there are two key types of sampling: probability and non-probability. With probability sampling, each individual has a known, non-zero probability of being randomly sampled, and the sample findings can be generalized to the larger population. With non-probability 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, non-probability 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 of deviation in the responses. As a rule of thumb, a sample of 375 to 400 responses will generally be sufficient to enable you to say with 95% confidence that your sample statistic (the estimate from your survey) is within 5% (plus or minus) of the true proportion in the overall population. If greater precision in the survey estimates is needed or if there is a need to analyze sub-samples, the sample size will need to be increased. For non-probability samples, it is more difficult to determine sample sizes, but the evaluation team should determine the subgroups of interest and ensure that there are a sufficient number of responses for each subgroup. Teams are encouraged to collect as many responses as their budget allows; sub-groups with less 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). On the following page is some guidance for recruitment.

Recruitment Best Practices

- ***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 technology is being deployed along a corridor, you may need a screener question to identify drivers who traverse the corridor on a regular basis (e.g., at least three 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 is typically important. If your screener questionnaire includes questions on age and income, you can monitor these characteristics of the sample during recruitment.*

- ***For panel surveys, when setting recruitment targets, over-recruit to allow for the fact that participants will drop out,*** *for any number of reasons (which 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), it is reasonable to assume that at least 20% to 30% of recruited participants may dropout at some point during the survey period.*

- *For certain populations, such as transit operators or truck drivers, recruitment may need to occur through fleet managers. If this is the case,* ***establish buy-in from the fleet manag****er and provide them with scripts (e.g., that should accompany the survey invitation) and* ***encourage them to use the standardized protocols*** *developed for the evaluation.*

Questionnaire Design

Questionnaires should be designed to capture the specific performance measures and related data elements identified in your 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 in order to better interpret the survey responses and to provide context for understanding the key performance measures. If different populations are being surveyed**, tailor**

the questionnaires 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
(Including but not limited to):

- *Avoid questions that are biased or leading.*
  - *Example biased question: To what extent do you agree that traffic congestion is a major 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, extent of satisfaction, etc.):*
  - *Ensure the scales are balanced (e.g., same number of positive and negative points).*
  - *Be aware that maximum reliability is 5 to 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 applicable.*
- *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.*
- *Pre-test your questionnaire to ensure respondents understand the questions, the response categories are complete, etc.*

Response Rates

The evaluation team should utilize steps to maximize response rates. For probability samples, a high response rate enables the evaluation team to more confidently generalize from their sample to the larger population. If response rates are low, however, non-response error is a concern. Non-response error occurs when non-respondents 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.

For non-probability samples, a high response rate is similarly important to ensuring that the findings reflect the attitudes, behavior, etc. of the full pool of participants (rather than a subset). Response rates should be included in any write-up of the findings, and if the response is low, the findings should be interpreted with caution.

Methods for Improving Response Rates

- *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/follow-up 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., pre-deployment and post deployment.)*
  - *Consider incentives that are appropriate to the target population. For example, if you are surveying transit users, you could provide a free one week transit pass.*

Privacy and Personally Identifiable Information

For some survey designs, it may be necessary to collect personally identifiable information (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 separate file from the survey responses. Anonymous IDs can be assigned to each respondent to link responses across surveys and to track survey response. 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?

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 notification, reminder notifications, etc. 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

Below are a few additional considerations regarding surveys and interviews:

- **Be sensitive to language barriers for non-English speakers.** Your survey population may include people who do not speak and/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 is important to be sensitive to how feedback will be gathered from this group. In geographies with a large number 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, ATCMTD 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 ESTIMATES

This section outlines methods and considerations related to quantifying emissions and energy for ATCMTD projects. Emissions and fuel consumption impacts can be quantified either by: 1) direct measurement using portable emissions monitoring systems (PEMS) and real-time fuel flow meters, 2) by using mobile-source emissions models such as the United States Environmental Protection Agency's (USEPA) Motor Vehicle Emission Simulator (MOVES) or the California Air Resources Board's (CARB) Emission Factors (EMFAC) model; or other tools such as the FHWA Congestion Mitigation and Air Quality (CMAQ) Emissions Calculator Toolkit. To quantify any emissions or energy impacts associated with a project, a net difference in emissions and fuel consumption must be taken between the baseline conditions (i.e., conditions before project deployment) and the deployment conditions (i.e., after deployment).

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

On-Road Emissions Models and Tools

There are a number of models and tools developed by federal and State governments to evaluate on-road emission and fuel reduction benefits. This section describes three relevant emissions models and tools including MOVES, CARB's EMFAC Model, and the CMAQ Emissions Calculator Toolkit.

MOVES

USEPA's MOVES is a state-of-the-science emission modeling system that estimates emissions for mobile sources at the national, county, and project level. USEPA provides MOVES technical documentation, user guides, manuals, and training for developing SIPs, transportation conformity, and hot-spot analysis.

EMFAC

The EMFAC emissions model is developed and used by CARB to assess emissions from on-road 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.

CMAQ 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. These tools do not currently estimate fuel consumption benefits.

Even if the CMAQ tools themselves cannot be used, some ATCMTD grantees may find the methodologies utilized 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 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 are expensive and time-consuming but can yield superior quality—and less uncertainty—to modeling. However, emissions and fuel use modeling should be sufficient for most if not all ATCMTD projects. It is important 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 vehicle miles travelled (VMT) or operating hours. The following sections describe direct measurement and modeling in more detail. For flexibility, there is a measurement approach and two tiers of modeling—simple and advanced—explained in more detail below.

Direct Measurement Evaluation

This approach will require emissions that are monitored using Portable Emissions Monitoring Systems (PEMS) and direct the monitoring of fuel consumption. An example of a project that would utilize this approach would be a vehicle-to-infrastructure (V2I) communications project where emissions and fuel consumption would be measured without the V2I technology implemented (i.e., baseline scenario or no-build scenario) and then be compared to 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 ATCMTD projects would be similar to what is currently done for evaluating some CMAQ projects. For this approach, the ATCMTD project can determine if any of the currently available CMAQ tools could be utilized to evaluate emissions benefits. If the CMAQ tools are not sufficient for evaluating the ATCMTD 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/mile or kilograms/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 utilize either collected vehicle telematics data and/or conduct traffic microsimulation modeling 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 ATCMTD projects utilizing an advanced emissions inventory approach would include technology deployments such as cooperative adaptive cruise control (CACC) where 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 References at the end of this chapter) showcase projects that have utilized advanced approaches to determine driving behavior changes at a high frequency for estimating benefits of connected and automated vehicles:

- Benefits Estimation Model for Automated Vehicle Operations Phase 2 Final Report

- A Framework for Evaluating Energy and Emissions Impacts of Connected and Automated Vehicles Through Traffic Microsimulations
- Meta-Analysis of Adaptive Cruise Control Applications: Operational and Environmental Benefits
- Comparing Performance of Cooperative and Adaptive Cruise Control Field Tests,
- Applications for the Environment: Real-Time Information Synthesis- eco-signal operations modeling report.

Methods and Analytic Techniques References

BCA References

Bai, Y. & Kattan, L. (2014). *Modeling Riders′ Behavioral Responses to Real-Time Information at Light Rail Transit Stations,* Calgary, Alberta: Transportation Research Board, obtained from: https://www.researchgate.net/publication/279284285_Modeling_Riders'_Behavioral_Responses_to_Real-Time_Information_at_Light_Rail_Transit_Stations

Office of Management and Budget. (1992). *OMB Circular No. A-94: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, Washington, D.C., obtained from: https://www.transportation.gov/regulations/omb-circular-94

Office of Management and Budget. (2003). *OMB Circular No. A-4: Regulatory Analysis*, Washington, D.C., obtained from: https://www.transportation.gov/regulations/omb-circular-no-4-0

Song, D., He, X. & Peeta, S. (2014). *Field Deployment to Quantify the Value of Real-time Information by Integrating Driver Routing Decisions and Route Assignment Strategies*, NEXTRANS Project No. 058PY03, West Lafayette, IN, obtained from: https://www.purdue.edu/discoverypark/nextrans/assets/pdfs/058PY03%20Final%20Report.pdf

Transportation Economics Committee, Transportation Research Board. (no date). *Transportation Benefit-Cost Analysis,* Washington, D.C., obtained from: http://bca.transportationeconomics.org/

USDOT Office of the Secretary. (2018). *Benefit-Cost Analysis Guidance for Discretionary Grant Programs*, Washington, D.C., obtained from: https://www.transportation.gov/office-policy/transportation-policy/benefit-cost-analysis-guidance

Victoria Transport Policy Institute. (2016). *Transportation Cost and Benefit Analysis. Techniques, Estimates and Implications*, Victoria, BC, obtained from: http://www.vtpi.org/tca/, last accessed November 9, 2018.

Survey and Interview Methods References

Administration For Children and Families Office of Planning, Research and Evaluation . (2010). *The Program Manager's Guide to Evaluation Second Edition* . Washington D.C.

Barnard, Y. (2017). *D5.4 Updated Version of the FESTA Handbook.* Leeds, UK: FOT NET Data.

Dillman, D. A., Smith, J. D., & Christian, L. M. (2014). *Internet, Phone, Mail and Mixed-Mode, Fourth Edition.* Hoboken: John Wiley & Sons.

Gay, K., & Kniss, V. (2015). *Safety Pilot Model Deployment: Lessons Learned and Recommendations for Future Connected Vehicle Activities.* Washington, D.C.: Intelligent Transportation System Joint Program Office.

Groves, R. M., Fowler, Jr, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., & Tourangeau, R. (2009). *Survey Methodology, Second Edition.* Hoboken: John Wiley & Sons, Inc.

Marsden, P. V., & Wright, J. D. (2010). *Handbook of Survey Research, Second Edition.* Bingley: Emerald Group Publishing Limited.

Smith, S., & Razo, M. (2016). Using Traffic Microsimulation to Assess Deployment Strategies for the Connected Vehicle Safety Pilot. *Journal of Intennigent Transportation Systems*, 66-74.

Emissions and Energy Measurement References

California Air Research Board. (2018). *Mobile Source Emissions Inventory — Categories*, Sacramento, CA, obtained from: https://www.arb.ca.gov/msei/categories.htm#emfac2014.

Federal Highway Administration, Office of Planning, Environment, & Realty. (2018). *CMAQ Emissions Calculator Toolkit*, Washington, D.C., obtained from: https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/.

Eilbert, A., Berg, I., & Smith, S. (2019). *Meta-Analysis of Adaptive Cruise Control Applications: Operational and Environmental Benefits,* Report No. FHWA-JPO-18-743, Cambridge, MA, obtained from: https://rosap.ntl.bts.gov/view/dot/41929.

Eilbert, A., Chouinard, A.M., Tiernan, T. & Smith, S. (2019). *Comparing Performance of Cooperative and Adaptive Cruise Control Field Tests,* Orlando, FL: 2019 Automated Vehicle Symposium, obtained from: file:///C:/Users/Andrew.Eilbert/Downloads/BreakoutReport-Session18(Part1).pdf

Eilbert, A., Jackson, L., Noel, G. & Smith, S. (2018). *A Framework for Evaluating Energy and Emissions of Connected and Automated Vehicles Through Traffic Microsimulations,* Washington, D.C.: Transportation Research Board 97th Annual Meeting, obtained from: http://amonline.trb.org/2017trb-1.3983622/t010-1.3999179/513-1.3999401/18-06134-1.3999419/18-06134-1.3999420?qr=1.

Smith, S. et al. (2018). *Benefits Estimation Model for Automated Vehicle Operations: Phase 2 FinalReport,* Report No. FHWA-JPO-18-636, Cambridge, MA, obtained from: https://rosap.ntl.bts.gov/view/dot/34458.

United States Environmental Protection Agency. (MOVES2014b). *MOVES and Other Mobile Source Emissions Models*, Washington, D.C., obtained from: https://www.epa.gov/moves, last accessed: September 23, 2019.

Yelchuru et al. (2014). *AERIS—Applications for the Environment: Real-time Information Synthesis, Eco-Signal Operations Modeling Report*, Report No. FHWA-JPO-14-185, Washington, D.C.: Intelligent Transportation Systems Joint Program Office, obtained from: https://rosap.ntl.bts.gov/view/dot/3537.

Yelchuru et al. (2015). *AERIS—Applications for the Environment: Low Emissions Zones Operational Scenario Modeling Report*, Report No. FHWA-JPO-14-187, Washington, D.C.: Intelligent Transportation Systems Joint Program Office, obtained from: https://rosap.ntl.bts.gov/view/dot/3538.

CHAPTER 5: TECHNOLOGY–SPECIFIC GUIDANCE

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

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 have been developed which alter traffic signal timing dynamically by sensing traffic conditions in real time. These systems have widely varying capabilities and methods for allocating green time between movements. The specific algorithms and methodologies used by ASCT systems will not be examined in this chapter. Instead, this chapter focuses on the analysis techniques, performance measures, data sets, and tools needed to analyze the impacts of an adaptive signal system.

Key areas which must be considered include:

- **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 data sets 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 variation and idiosyncrasies which 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 in order to capture and account for variation.

Alternatively, simulation studies offer a platform for testing an ASCT system using a control-experiment setup. The exact 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 using known random distributions. Simulation further has the advantage of being a controlled environment which doesn't 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

> ***Analysis Approaches***
>
> **Field Study**
> Real-world implementation using before-after or on-off data.
>
> **Simulation Study**
> High-resolution traffic modeling.

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. Further, simulation studies require the underlying simulation to be validated against existing conditions. Otherwise, any results generated by the simulation cannot be trusted. Calibration and validation of simulation models is not a standardized process in traffic simulation, and has numerous pitfalls which need to be considered. As noted, including the appropriate level of variation in a simulation model is difficult, and over-calibration is a significant concern. Models which 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 is not possible. The exact same demand is never repeated from one day to the next because daily routines are not perfectly static and needs 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 prior to and following implementation of the new system. Some before-after studies add further complexity by breaking up post-implementation data into multiple cohorts, creating before-after-long after study setups in order to examine both immediate and long-term changes in traffic patterns. Before-after studies are common throughout transportation engineering. The critical concern for such studies is 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 more closely approximate a control-experiment study 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 week 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 produced by the study. If a before-after approach had been taken instead, those same drivers may 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 caused by the treatment.

The following table summarizes the advantages, disadvantages, and considerations for each of the study approaches.

Table 18. Advantages and Disadvantages of Study Approaches.

Study Approach	Advantages	Disadvantages	Considerations
Simulation Control-Experiment	• Direct control-experiment analysis • Easy to implement alternative plans, optimize control algorithms • No real-world impacts if negative outcomes are found	• Difficult to account for variation in traffic demand and unusual circumstances • Over-calibration or poor calibration can lead to unrealistic results	• Thorough and multi-faceted calibration and validation should be done to ensure that the underlying model is applicable
Field Studies: Before-After	• Allows traffic patterns to "stabilize" over time in the new system • Doesn't create confusion due to switching back and forth between control schemes	• Any external major 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 pre-treatment condition (harder/impossible to get more of after-the-fact)
Field Studies: On-Off	• Direct comparison of treatment and non-treatment options • Easier to ensure that sufficient data are collected for each scenario (simply rerun whichever needs more)	• Not able to examine long-term changes in the system due to the ASCT	• 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 must be collected. As will be 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.

Fixed sensors, typically inductive loop sensors which are embedded in the pavement, provide spot-measurements and are the main data source 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 closely 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 can be a significant hurdle if there are driveways or access points between intersections where significant traffic enters and exits the roadway in locations where the sensors cannot account for them.

Even within fixed-sensor systems, there can be notable variation. 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- 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 which detail the actuations and control decisions which 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 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 employ radar, Lidar, or camera technologies to observe conditions around the vehicle for a more complete assessment of traffic behavior. Floating probe vehicle data provides 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 come with a price tag. 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.

Traffic Ops 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.

To gain a complete picture of driving behavior in a corridor, **full trajectories** can be collected. Unlike the data options noted above, 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 $1/10^{th}$ 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 opens the door to highly sophisticated performance measures. Table 19 indicates the types of measures which are produced or can be modeled or estimated by each data collection technique (also see Table 9 in the Performance Measures Chapter for PMs related to signalized control).

Table 19. Data Collection Techniques.

Measures	Fixed	Floating Probe	Trajectory
Volume	Yes	No	Yes
Queues	Maybe[1]	Yes	Yes
Speed/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 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 analysis to vehicle-delay.

Signalized control plays a significant role in safety and the number of traffic incidents which 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 sample size. Regardless of the type of data which is collected and the technology used to collect it, sufficient data must be collected to ensure that any analysis provides an accurate assessment of the performance of the adaptive signal system. The concerns here are not particular to adaptive signals; generally accepted practices regarding data significance should be used.

When looking at overall performance within a cost-benefit type framework, several distinct costs arise for adaptive signal systems. Typical costs for 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 the vendor in order to use the product and get updates and support as the algorithms of the ASCT system 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 is important to evaluating ASCT systems.

ASC References

Atkins North America. (2016). *Automated Traffic Signal Performance Measures Component Details*, Atlanta, GA, obtained from: https://atspm.cflsmartroads.com/ATSPM/Images/ATSPM_Component_Details.pdf

Benekohal, R., Garshasebi, B., Liu, X., & Jeon, H. (2018). *Evaluation of Adaptive Signal Control technology – Volume 2: Comparison of Base Conditions to First Year After Implementation*, Report no: FHWA-ICT-18-005, Urbana-Champaign, IL, obtained from: https://www.ideals.illinois.edu/bitstream/handle/2142/99873/FHWA-ICT-18-005.pdf?sequence=2&isAllowed=y

Day, C. et al. (2014). *Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach,* West Lafayette, Indiana: Purdue University, obtained from: https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1002&context=jtrpaffdocs

Fontaine, M., Ma, J., & Hu, J. (2015). *Evaluation of the Virginia Department of Transportation Adaptive Signal Control Technology Pilot Project*, Report No: VCTIR 15-R24, Charlottesville, VA: Virginia Department of Transportation, obtained from: http://www.virginiadot.org/vtrc/main/online_reports/pdf/15-r24.pdf

Sharma, A., Hawkins, N., Knickerbocker, S., Poddar, S. & Shaw, J. (2018). *Performance-Based Operations Assessment of Adaptive Control Implementation in Des Moines, Iowa*, Ames, Iowa: Iowa State University

Stevanovic, A. (2010*). NCHRP Synthesis 403: Adaptive Traffic Control Systems: Domestic and Foreign State of Practice*, Washington, D.C.: National Cooperative Highway Research Program, obtained from: https://www.nap.edu/read/14364/chapter/1

Stevanovic, A. & Radivojevic. (2017). *Framework for Quantitative Annual Evaluation of Traffic Signal Systems*, Report no: TRB No 2619, pp. 20-35, Washington, D.C., obtained from: http://dx.doi.org/10.3141/2619-03

Taylor, M. & Mackey, J. (2018). *Automated Traffic Signal Performance Measures*, Presentation, Utah Department of Transportation Annual Conference

Utah Department of Transportation. *Automated Traffic Signal Performance Measures*, obtained from: https://udottraffic.utah.gov/ATSPM/

CONNECTED VEHICLE

Connected vehicles (CVs) are vehicles that communicate with equipped infrastructure and other connected vehicles while on the roadway. Often, connected vehicles use Dedicated Short Range Communication (DSRC), a two way, low latency, 5.9 GHz communication channel that is reserved for transportation purposes. However connected vehicles can use other communication channels, such as a cellular network. Connected vehicle technologies have a number of different applications, including improving vehicle safety, improving mobility, and reducing the environmental impacts of transportation. The following subsections contain best practices that relate specifically to evaluating the performance of connected vehicle technologies.

Evaluation Planning

The first set of best practices relate specifically to evaluation planning and experimental design.

Use of Traffic Simulation Models

Prior to deploying technology, it's important to understand whether or not the deployment will generate the amount of exposure required to be able to evaluate the impacts of the technology being deployed. The required exposure will depend on the goals of the evaluation and the experimental design being used, and can be estimated using a power analysis.

In a traditional deployment with vehicle-based technologies, it's fairly straightforward to calculate exposure to various types of events based on the location of the demonstration, the demographics of the drivers, and the expected driving mileage. In a CV deployment, however, exposure is based on a CV being within close proximity of another CV or connected infrastructure. The best way to estimate how frequently this will occur is to run traffic simulations based on the planned deployment levels using real-world traffic data from the deployment site.

Simulations should take into account the following:

- Demographics of the drivers being recruited
- Vehicle types (e.g., passenger cars, taxis, trucks, transit buses)
- Travel patterns of the drivers being recruited
- The types of applications that are being deployed in the site

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

Strategic Use of Recruitment

For example, select drivers who:

- Take the same freeway during the morning commute
- Routinely pass through a specific intersection
- Are most likely to experience hazardous weather conditions on the road.

In the case that running traffic simulation is not possible, it is still helpful to think strategically about how to maximize CV interactions in the environment. One way to do this is through the recruitment strategy. Also, important to keep in mind is that the rarer the types of events that the CV system is trying to address, the larger the deployment will need to be to collect a viable sample size of these events.

Within-Subject Experimental Design

There are large individual differences between individual drivers, so in evaluations of how humans interact with in-vehicle technologies, the most robust experimental design is a within-subjects design. This design compares each driver only to themselves both with, and without the vehicle technologies. This allows the evaluation to focus on a specific driver's changes in behavior and performance, rather than average changes across a population.

To conduct a within-subject's evaluation:

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

Of course, in the case that connected vehicle technology is being deployed on fleet vehicles or into participant's personal vehicles, this may not be possible. As an alternative, it is helpful to mark in the data when an individual participant is driving a vehicle so that the data can still be parsed by drivers.

Tracking Vehicles Using Anonymous IDs

In a CV deployment using DSRC technology, basic safety messages (BSMs) are used to communicate a vehicle's location and vehicle kinematics to other vehicles. In a true deployment, these BSMs are anonymized so that individual vehicles can't be identified. However, in any deployment of CV technology that is being used for research and evaluation, it is important to create an anonymized vehicle identifier.

First, vehicle identifiers can detect vehicles that are having problems, so that corrective action can be taken. Second, vehicle identifiers allow a comparison of a specific vehicle both before and after the CV technology is deployed. If the evaluator does not have the ability to track specific vehicles throughout the different phases of the deployment, the evaluation will need to combine the data from all vehicles, making it much less likely that an effect will be observed.

Why Use Anonymous Vehicle IDs

1. To identify vehicles that are:
    - Not working properly
    - Transmitting bad data
    - Not getting sufficient exposure
2. To make before-after comparisons of individual vehicles
    - Design accounts for variability between vehicles
    - Design most likely to measure an effect, if it exists

The 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 of the vehicles in that environment will be equipped with connected vehicle technology.

This means that the technology will only become active in the presence of other DSRC-equipped vehicles or infrastructure, and equipped vehicles will not be able to "see" all the other unequipped vehicles 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 in the site (% of equipped vehicles), and the goals for the evaluation.

When conducting a CV demonstration, the evaluation team should carefully think through how the combination of equipped and unequipped vehicles may impact their unique deployment and evaluation. Some vehicle performance metrics for CV demonstrations may not represent the actual driving scenario if an unequipped vehicle that is not represented in the data is present in the driving scenario. For example, metrics showing how far from the crosswalk a vehicle stopped after detecting a pedestrian in a signalized crosswalk may not be accurate if there is an unequipped lead vehicle between the CV and the crosswalk. The driver may be responding to the lead vehicle slowing in front of them and not to the pedestrian or the warning, and there will be no way to determine this from the data. One way to mitigate this problem is to install additional sensors to collect data on the presence of surrounding vehicles and to validate the CV data against the data from these sensors (this will be discussed further in the section, Use of Other (i.e., Non-CV System) Data).

Other considerations due to "invisible vehicles" are described below.

- Users of the system (e.g., drivers, pedestrians) won't be able to create a mental model of how the system works because it won't work all the time. Users generally have no way of knowing which other vehicles or infrastructure in the environment are equipped or unequipped, so they won't be able to develop an expectation of when the system will be able to support them and when it won't.

- Often in transportation research, performance metrics are normalized by things like miles or hours of driving. These normalization metrics become irrelevant with CV evaluations because the system is not activated all of the time. In order for these metrics to be useful, the data collection strategy must provide insight into exactly when the system was active (interacting) and when it was not compared to the entirety of the users' experience.

System Performance Testing/Validation

To be able to evaluate a demonstration and properly interpret the results of the evaluation on a CV system, it is critical to have objective data (data from non-CV sources or data from controlled experiments) on the performance of the system prior to the demonstration. Each CV environment is unique, and the performance of a certain application is likely to vary based on the environment where it is deployed. Impacts of a deployed system are highly dependent on how well the applications are working, and without this context it will not be possible to interpret the results of the impact analysis.

> ***System Performance Data***
>
> - Rate of false system activations
> - Rate of missed activations
> - Frequency of different types of system errors

Ideally, system performance should be carefully tested and known prior to the start of the formal deployment. In situations where this is not possible, it is important to collect data that can support system and application validation during the deployment so it can be measured in hindsight and factored into the impact evaluation results.

Data Collection

The following set of best practices pertain to data collection and management.

Expected Versus Actual 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, it is helpful to track the actual vehicle-to-vehicle (V2V) and V2I interactions observed during the demonstration. First, this exercise is helpful for validating the interaction model and ensuring that the expected number of interactions is being met. In the case that there is a lower than expected CV system engagement, understanding the interactions that the site is generating is important to understanding the cause of the system 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?).

Second, data about actual interactions experienced during the demonstration can be very valuable to the evaluation. In a traditional demonstration, some evaluation metrics are normalized by driving miles or driving time to indicate exposure to a certain stimulus (e.g., number of warnings per mile driven). In a CV demonstration, overall driving miles are not relevant because the CV system is only active in the presence of other connected vehicles or 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 real-time during the demonstration, it is recommended to calculate interactions post-hoc so that this metric can be considered in the evaluation activities.

Monitoring CV Systems/Applications in the Field

Once CV equipped vehicles are in the field, it is recommended to monitor the vehicles to keep track of how frequently they are having CV interactions and how frequently the applications are engaging. Devices that are getting very few interactions or system alerts (relative to other study vehicles) may have system health issues, or may not be driving in the study area enough to generate sufficient data. Additionally, vehicles that are receiving a very large number of system alerts (relative to other study vehicles) may have an issue that is causing false alerts. Monitoring and replacing problematic or low interaction devices during the demonstration can improve the evaluation results by ensuring that the largest possible amount of valuable data are collected for the evaluation.

CV Application Logic

Once vehicles are deployed in a CV environment (particularly if thorough performance validation testing and application tuning were not completed prior to the demonstration) it may be tempting to make adjustments to the applications to fix problems or reduce the frequency of false alerts. If one of the goals of the study is to conduct a rigorous evaluation, it's not advised to make changes once the official experimental design period has started, since doing so will compromise the integrity of the evaluation. An exception would be a situation where there is any risk to driver safety; such cases must be addressed immediately.

If it is expected that the team will want to adjust the applications after they've been in the field, it is advised to 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 demonstration.

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

CVs generate a considerable amount of data, however the data generated by the system will likely not be sufficient to accommodate all of 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 data being collected as part of the deployment should be determined by assessing the evaluation goals, objectives, and associated performance metrics, rather than just relying on data that the system will produce.

Validating the System Performance of the CV Applications

As previously mentioned, it is critical to the evaluation to have an understanding of the performance of the CV system and applications in the actual deployed environment; that is, did the CV applications function as they were designed to function? If thorough pilot tests/system performance tests are not conducted prior to the start of the experimental design, data to support a system accuracy analysis should be collected as part of the deployment. If the technology does not result in the desired impacts, this may be due to a system performance issue, but without measuring system performance, it will not be possible to determine if this was a factor.

Data Organization and Indexing

Data collected as part of the demonstration 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 system produces, and therefore may need to be added or post-processed. For example, as discussed in the section, Tracking Vehicles Using Anonymous Ids, it is helpful to include vehicle identifiers with the data so that the evaluators can identify an individual subject or vehicle across different test phases. 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, equipped/unequipped).

CV References

Barnard, Y. (2017). *D5.4 Updated Version of the FESTA Handbook.* Leeds, UK: FOT NET Data. Last accessed: December 31, 2018

Bezzina, D., & Sayer, J. (2015). *Safety Pilot Model Deployment: Test Conductor Team Report*, Report No. DOT-HS-812-171, Washington, D.C.: National Highway Traffic Safety Administration, obtained from: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/812171-safetypilotmodeldeploydeltestcondrtmrep.pdf

Gay, K., & Kniss, V. (2015). *Safety Pilot Model Deployment: Lessons Learned and Recommendations for Future Connected Vehicle Activities*, Washington, D.C.: Intelligent Transportation Systems Joint Program Office, obtained from: https://rosap.ntl.bts.gov/view/dot/4361

Pecheux, K., Kennedy, J. & Strathman, J. (2015). *Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists*, Report No. 0084, Washington, D.C.: Federal Transit Administration, obtained from: https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0084.pdf

Administration For Children and Families Office of Planning, Research and Evaluation . (2010). *The Program Manager's Guide to Evaluation Second Edition* . Washington D.C.

Barnard, Y. (2017). *D5.4 Updated Version of the FESTA Handbook.* Leeds, UK: FOT NET Data.

Dillman, D. A., Smith, J. D., & Christian, L. M. (2014). *Internet, Phone, Mail and Mixed-Mode, Fourth Edition.* Hoboken: John Wiley & Sons.

Gay, K., & Kniss, V. (2015). *Safety Pilot Model Deployment: Lessons Learned and Recommendations for Future Connected Vehicle Activities.* Washington, D.C.: Intelligent Transportation System Joint Program Office.

Groves, R. M., Fowler, Jr, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., & Tourangeau, R. (2009). *Survey Methodology, Second Edition.* Hoboken: John Wiley & Sons, Inc.

Marsden, P. V., & Wright, J. D. (2010). *Handbook of Survey Research, Second Edition.* Bingley: Emerald Group Publishing Limited.

Smith, S., & Razo, M. (2016). Using Traffic Microsimulation to Assess Deployment Strategies for the Connected Vehicle Safety Pilot. *Journal of Intennigent Transportation Systems*, 66-74.

AUTOMATED VEHICLE

This section discusses considerations for evaluating projects that include automated vehicles (AVs). [1] Automation can be used in a broad variety of applications and may be used to support a variety of transportation and societal goals. Systems demonstrated in pilots may differ in critical aspects to those which would ultimately be deployed or commercialized. This should be taken into consideration when designing technical performance and user acceptance metrics. The following section provides considerations for evaluation design of projects including AVs.

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. This can be challenging to account for in planning an evaluation. If the technology is not held constant, or "frozen" during the course of the project, it may be difficult to understand the meaning of results over time. 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, this may not always be desirable. First, there could be safety implications. As Automated Driving System (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 the 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 impacted 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 of usage intention to actual future use, but this is an area where further research is needed.

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

[1] This section discusses projects which include at least one 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.

staffer on board, even if he or she is not actively driving the vehicle, is likely to significantly influence the perception of those who interact with the vehicle and the system. While there have been creative approaches to address this problem[2], it is difficult on the whole to mimic the experience of an unstaffed system while still having a staff person on board. Evaluation design should take this into consideration.

For projects with AV systems at SAE Levels 1-3, where driver supervision is required for some part of the driving task, the evaluation should include metrics regarding driver engagement, fatigue, and other human factors issues such as mode confusion. An additional area for Level 3 systems is driver re-engagement.

Institutional Issues and Internal Capacity Building

The transportation industry is at an early stage with regard to 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 for an organization to identify institutional issues and to build organizational capacity.

Federal, State, and local requirements may not be clearly understood at project outset, or they may change during the course of 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 through implementation of a demonstration can help an organization determine local policy positions and appropriate mitigations to achieve goals.

Similarly, there is a learning curve for agency staff in understanding what these technologies can and cannot do today, and what they might do in the future. Agencies may also 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 identification of institutional issues and internal capacity building, the evaluation design should consider how to meaningfully incorporate these elements.

Identifying Critical Stakeholders

Introducing automation into motor vehicles may change the dynamic between existing stakeholders, and could elevate the importance of those previously less closely involved. 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 grapple with the question of what it means for the ADS to be the vehicle operator. These types of stakeholders should be identified early on so that impacts on them can be measured.

[2] For example, a "Wizard of Oz" car may have an operator in the back seat using a specially-designed control system, while passengers ride in the front, thereby approximating the experience of driverless operation.

Relationships with Private Sector Partners

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

Private sector partners may have serious concerns about sharing or publicizing information which 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. 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.

In order 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 externally measured, for example by use of infrastructure-based cameras. The evaluation plan should consider next-best alternatives if the desired data cannot be obtained.

Data Analysis and Management

The quantity of data collected by an automated vehicle is enormous. Project teams could be easily overwhelmed by available data, in terms of both data storage and analysis. 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 will need to consider the preferred balance between manageability and the ability to explore previously unidentified questions. Below are 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 (ODD)

- 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., Light Detection and Ranging, radar, Event Data Recorder 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 where the AV goes back to the minimal risk condition or fallback situation. Describe how disengagement events will be recorded and stored. Describe how the instruments used for data onboard the vehicle will be documented and maintained over time (i.e., AV maintenance, sensor calibrations and equipment check documentation).
- Describe which curbside/infrastructure elements will be recorded and documented at the locations where pick-up and drop-off will occur.

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, and/or on-road test that will affirm the effectiveness of the solution(s) to respond to the research questions.

Perceived Safety

- Describe the process for collecting the experience of those who interact with the AVs.

AV References

Campbell, J. L., Brown, J. L., Graving, J. S., Richard, C. M., Lichty, M. G., Bacon, L. P., … & Sanquist, T. (2018). *Human Factors Design Guidance For Level 2 And Level 3 Automated Driving Concepts,* Report No. DOT-HS-812-555, Washington, D.C.: National Highway Traffic Safety Administration, obtained from: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13494_812555_l2l3automationhfguidance.pdf

S. Nordhoff, J. de Winter, R. Madigan, N. Merat, B. van Arem & R. Happee. (2018). *User acceptance of automated shuttles in Berlin-Schöneberg: A questionnaire study*, Transportation Research Part F*,* vol. 58, pp. 843-854, Washington, D.C., obtained from: https://www.sciencedirect.com/science/article/abs/pii/S1369847817305478

Smith et al. (2018). *Benefits Estimation Model for Automated Vehicle Operations: Phase II Final Report*. Report No: FHWA-JPO-18-636, Washington, D.C.: Intelligent Transportation Systems Joint Program Office

Thorn, Eric, Kimmel, Shawn, & Chaka, Michelle (2018). *A Framework for Automated Driving SystemTestable Cases and Scenarios*, Report No. DOT HS 812 623, Washington, D.C.: National Highway Traffic Safety Administration, obtained from: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13882-automateddrivingsystems_092618_v1a_tag.pdf

Zmud, Johanna & Sener, Ipek. (2017). *Towards an Understanding of the Travel Behavior Impact of Autonomous Vehicles,* Washington, D.C.: Transportation Research Procedia 25 (2017) 2500–2519, obtained from https://www.sciencedirect.com/science/article/pii/S2352146517305884

APPENDIX A: EVALUATION PLAN CHECKLIST

This checklist is designed to assist ATCMTD grantees in developing their Evaluation Plans. Example templates that grantees can include in their Evaluation Plans are also provided. The templates are a tool for summarizing key evaluation-related information at a high level; the Evaluation Plans should include more detailed descriptions of measures, methods, and procedures.

If you have any questions about the checklist, please contact Margaret Petrella (Social Scientist, The Volpe Center) at Margaret.Petrella@dot.gov.

Evaluation Plan Topic
Project Overview • *Describe the project and highlight the technologies being deployed* • *List the project stakeholders (project team, partners, evaluation team) and describe roles and responsibilities, particularly with respect to completing the evaluation* • *Summarize what constitutes end-of-project successes* • *Provide a deployment and evaluation schedule in terms of months and years; include project milestones*
Evaluation Goals/Objectives and Evaluation Questions[1] (see Table 1 below) • *Describe project evaluation goals and/or objectives and associated evaluation questions* • *Develop at least one evaluation question for each goal or objective; multiple specific, evaluation questions are better than a few general ones*
Performance Measures (PMs) (see Table 2) • *Identify one or more performance measure(s) for* ***each*** *evaluation question* • *Ensure (describe how) you are meeting the performance measures prescribed in the FAST Act* • *Develop system performance measures that measure whether the technology is functioning as intended (i.e. to verify the functionality of the technology).* • *Ensure (describe how) your PMs are measurable within the scope of the evaluation. If targets are described, ensure they are appropriate* • *Think about the unit of analysis (metric) needed for your analysis* • *Describe the data sources for each PM (include existing data sources as well as primary data collection). If your agency is uncertain about the data sources or elements, indicate what data you would need to measure the PMs and note that updates to the plan will include more details on "X".*

Evaluation Methodology (see Table 2 below)
• *Describe the method(s) that will be used to address each evaluation question (likely a mix of quantitative and qualitative methods)*
    o *Describe the experimental design, as appropriate (before-after; treatment-control)*
    o *Describe potential confounding factors*
• *Ensure the evaluation design enables the measurement of the proposed PMs; identify the specific data elements that are required*
• *Describe any limitations or risks associated with the method or the data elements*
• *If multiple technologies are deployed, be clear how the different technologies will be evaluated*

Data Collection Procedures and Data Management
• *Describe how the data will be collected, including any plans for a pilot*
    o *For example, for surveys, plan should include: general method of recruitment; sample size; potential survey topics*
    o *For field studies, plan should include: location, data collection frequency, data collection period*

[1] Evaluation questions may take the form of hypotheses.

Evaluation Plan Topic
• *Address 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), data quality checks, etc.) [note: for existing systems, less detail may be needed]*

Table 20: Example TEMPLATE for Evaluation Goals, Objectives, and Evaluation Questions

Goal Area	Objective	Evaluation Question
Improve Safety	Reduce Traffic crashes	To what extent has Connected Vehicle (CV) application X reduced traffic crashes along corridor X?
		What proportion of drivers using CV application X rated the safety warnings as helpful?
Reduce Congestion/Improve Mobility	Improve travel times	What impact did adaptive signal control have on travel times along corridor Y?
Improve Effectiveness of Real-Time Integrated Transportation Information	Provide the public with access to real-time integrated traffic, transit, and multimodal transportation information to make more informed travel decisions	Did a majority of application users indicate that the travel time information helped improve their commute decision making?
Cost Savings and Improved Return on Investment	Provide cost savings to transportation agencies	What was the benefit-cost ratio of the adaptive signal control deployment?
Share Institutional Insights	Lesson Learned	What lessons learned did project managers identify to facilitate future successful deployments of CV?
[ADD]	[ADD]	[ADD]

Note: Examples are included for illustrative purposes only. Additionally, there may be multiple performance measures per Evaluation question

Table 21: Example TEMPLATE for Evaluation Performance Measures and Methodology

Evaluation Questions/Hypotheses	Performance Measure	Information Source/ Method	Data Element	Limitations/ Constraints
What proportion of drivers using CV application X rated the safety warnings as helpful?	% of respondents who feel safety warning was helpful	Survey	Survey response in post-survey	• Low response rate may be an issue
What impact did adaptive signal control have on travel times along corridor Y?	% change in average travel times	Field test (vehicle probe data)	Pre-post comparison of vehicle probe data	• Weather, incidents may affect 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	• Incomplete data • Some impacts are difficult to quantify
[ADD]	[ADD]	[ADD]	[ADD]	• [ADD]

Note: Examples are included for illustrative purposes only. Additionally, there may be multiple performance measures per Evaluation question

APPENDIX B: ANNUAL REPORT TEMPLATE

The purpose of this template is to assist grantees in preparing uniform annual reports. This template, while not required, is highly recommended, as the Federal Highway Administration intends to use the information from the grantees' annual reports in the required annual report on the effectiveness of the ATCMTD grant recipients in meeting their projected deployment plans.

Reporting Requirement:

23 U.S.C. 503(c)(4)(F) says *"That for each eligible entity that receives a grant under this paragraph, not later than 1 year after the entity receives the grant, and every 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 efficiency and multimodal system performance."*

This template has 4 parts:

- **Part 1 of 4 Introduction and Overview**
- **Part 2 of 4 Evaluation / Research Activities**
- **Part 3 of 4: Findings**
- **Part 4 of 4: Wrap up**

PART 1 of 4: 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 through 3 should reflect ***current*** *project scope and goals. If there have been no changes in project scope or goals (since the last Annual Report), responses to questions 1 through 3 should be the same as the previous Annual Report.* 1. **Please provide a *high-level* description of your project, including intended beneficiaries. (Please limit to approximately 350 words or less.) *Note: in Part 4 of 4, Q 1, you will be asked to note any major deviations or changes in scope due to either project-driven outcomes or other unforeseen challenges.***

Project Title:

2. **Please indicate which ATCMTD-targeted technologies your project covers** *(Check all that apply)***.**

☐ Advanced traveler information systems

☐ Advanced transportation management technologies

☐ Infrastructure maintenance, monitoring, and condition assessment

☐ Advanced public transportation systems

☐ Transportation system performance (monitoring) data collection, analysis and dissemination

☐ Advanced safety systems, including vehicle-to-vehicle and vehicle-to-infrastructure communication, autonomous vehicle development or deployment, and associated technologies that would enable V2V or V2I, including cellular or other technology

☐ Integration of intelligent transportation systems using Smart Grid or similar energy distribution and charging systems

☐ Electronic pricing and payment systems

☐ Advanced mobility and access technologies, such as dynamic ridesharing and information systems to support human services for elderly, disabled, or disenfranchised individuals.

☐ Other (Describe)

____

3. **What are your project's goals?** (*Check all that apply.)* Note: For each goal identified, you will be asked in Part 2 and Part 3 to map your project's "Performance Measures" and "Findings" to date, respectively.

☐ Improved safety

☐ Reduced congestion and/or improved mobility (e.g., travel time reliability)

☐ Reduced environmental impacts (e.g., emissions and /or energy)

☐ Improved system performance/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 (please specify:____)

☐ Other goals (Please specify:____)

PART 2 of 4: EVALUATION/RESEARCH ACTIVITIES

Please complete the following table regarding your evaluation activities. For each goal area that is applicable to your project, provide the performance measures (PMs) 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 research is completed, please indicate that here in Part 2, but please reserve "Findings" for Part 3.

Goal Area	**Performance Measures - Quantitative and Qualitative (if multiple technologies apply, please note the different technologies)**	**Research Update (e.g., baseline data collection, challenges, milestones achieved, etc.)**
Improved Safety (e.g., reduced crashes)	1. 2. 3. Etc.	
Reduced Congestion/Improved mobility (e.g., travel time reliability)	1. 2. 3. Etc.	
Reduced environmental impacts	1. 2. 3. Etc.	
Improved System performance (including optimized multimodal system performance)	1. 2. 3. Etc.	
Enhanced Access to Transportation Alternatives	1. 2. 3. Etc.	
Effectiveness of providing integrated real-time transportation information to the public to make Informed travel decisions	1. 2. 3. Etc.	

Goal Area	Performance Measures - Quantitative and Qualitative (if multiple technologies apply, please note the different technologies)	Research Update (e.g., baseline data collection, challenges, milestones achieved, etc.)
Reduced costs	1. 2. 3. Etc.	

PART 2 of 4: EVALUATION/RESEARCH ACTIVITIES, CONTINUED

Goal Area	**Performance Measures - Quantitative and Qualitative (if multiple technologies apply, please note the different technologies)**	**Research Update (e.g., baseline data collection, challenges, milestones achieved, etc.)**
Institutional or administrative benefits	1. 2. 3. Etc.	
Other benefits: Please specify:		
Other benefits: Please specify:		
Other goals [ADD IF NEEDED] Please specify:		

PART 3 of 4: FINDINGS

For each applicable goal area, please describe the impacts of your project based on findings from the performance measures. If data collection is still underway (i.e., findings are not yet available), indicate "In Progress" in the Findings column. Please use the "Notes/ Considerations" column to include any other relevant information regarding the evaluation. Note: the numbering for the Findings should correspond to the numbering used for Performance Measures in Part 2.

Goal Area	Findings (tied to performance measures; also include any anecdotal evidence)	Notes/Considerations
Improved Safety (e.g., reduced crashes)	1. 2. 3. Etc.	
Reduced Congestion/Improved mobility (e.g., travel time reliability)	1. 2. 3. Etc.	
Reduced environmental impacts	1. 2. 3. Etc.	
Improved System performance (including optimized multimodal system performance)	1. 2. 3. Etc.	
Enhanced Access to Transportation Alternatives	1. 2. 3. Etc.	

PART 3 of 4: FINDINGS, CONTINUED

Goal Area	**Findings (tied to performance measures; also include any anecdotal evidence)**	**Notes/Considerations**
Effectiveness of providing integrated real-time transportation information to the public to make informed decisions	1. 2. 3. Etc.	
Reduced costs	1. 2. 3. Etc.	
Institutional and/or administrative benefits	1. 2. 3. Etc.	
Other benefits: Please specify:	1. 2. 3. Etc.	
Other benefits: Please specify:	1. 2. 3. Etc.	
Other goals [ADD IF NEEDED] Please specify:	1. 2. 3. Etc.	

PART 4 of 4: 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)? Note here any *major* deviations or changes in scope from the original proposal due to either project-driven outcomes or other unforeseen challenges; e.g., unavailability of presumed data, unforeseen legal or administrative constraints, unexpected stumbling blocks, obvious delays, time-consuming tasks, or executive decisions to alter course.
2. Are there any aspects of your project that you consider cutting edge, noteworthy, or innovative? If yes, please describe.
3. How do deployment and operational costs of the project compare to the benefits and savings the project provides; i.e., can you provide an objective Benefit Cost analysis (BCA) or alternate subjective comparison?
4. What are lessons learned-to-date from your deployment, specifically regarding future deployment strategies to optimize transportation efficiency and multimodal system performance? Please note lessons learned with respect to challenges in technology deployment (e.g., technical, institutional, etc.), research (e.g., performance measurement), or other lessons learned.
5. What recommendations can you provide regarding future deployment strategies in this/these area(s)?
6. Do you have any final comments or feedback?

APPENDIX C: VALUES FOR BENEFIT COST ANALYSIS[1]

Table 22. Value of Reduced Fatalities and Injuries.

KABCO Level	Monetized Value (2017 U.S. $ per incident)
K – Killed	$9,600,000
A – Incapacitating	$459,100
B – Non-Incapacitating	$125,000
C – Possible Injury	$63,900
O – No Injury	$3,200
U – Injured (Severity Unknown)	$174,000
Unknown if Injured (only accident count reported)	$132,200
Property Damage only (per vehicle)	$4,300

Table 23. Value of Travel Time Savings.

Category	Purpose	Hourly Value (2017 U.S. $ per person-hour)
In-Vehicle Travel	Personal	$14.80
In-Vehicle Travel	Business[2]	$26.50
In-Vehicle Travel	All-Purpose[3]	$16.10
Out-of-Vehicle time	Walk access, waiting, and transfer time	$28.40
Commercial Vehicle Operators	Truck Drivers	$28.60
Commercial Vehicle Operators	Bus Drivers	$30.00
Commercial Vehicle Operators	Transit Rail Operators	$48.90
Commercial Vehicle Operators	Locomotive Engineers	$44.90

Table 24. Vehicle Operating Costs.

Vehicle Type	Value per Mile (2017 U.S. $ per mile)
Light Duty Vehicles	$0.39
Commercial Trucks	$0.90

[1] The values shown in Table 22 through Table 26 are taken from Office of the Secretary, U.S. Department of Transportation. (2018). *Benefit-Cost Analysis Guidance for Discretionary Grant Programs*. Obtained from: https://www.transportation.gov/BUILDgrants/additional-guidance

[2] This does not include commuting, which is valued as personal travel.

[3] Based on typical local surface travel distributions (88.2% personal, 11.8% business). A local distribution may be used where available.

Table 25. Damage Costs for Pollutant Emissions.

Emission Type	Value per Short Ton (2017 U.S. $ per short-ton)
Volatile Organic Compounds (VOCs)	$2,000
Nitrogen Oxides (NOx)	$8,300
Particulate Matter ($PM_{2.5}$)	$377,800
Sulfur Dioxide (SO_2)	$48,900

Table 26. Social Cost of Carbon.

Year	Value per Metric Ton (2017 U.S. $ per metric-ton)
2017	$1
2020	$1
2025	$1
2030	$1
2035	$2
2040	$2
2045	$2
2050	$2

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